GEOLOGY AS APPLIED TO LAND-USE MANAGEMENT ON CUMBERLAND ISLAND, GEORGIA

by

William H. McLemore, Charles T. Swann,

Perry B. Wigley, Mary C. Turlington,

Vernon J. Henry , Gregory J. Nash, J. Martinez,

Robert E. Carver, John T. Thurmond

Prepared for the

United States Department of Interior

as part of Contract No. CX5000-8-1563

DEPARTMENT OF NATURAL RESOURCES
Joe D. Tanner, Commissioner

ENVIRONMENTAL PROTECTION DIVISION
J. Leonard Ledbetter, Director

GEORGIA GEOLOGIC SURVEY
William H. McLemore, State Geologist

Atlanta

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APPENDICES

1-0 AN INTRODUCTION TO THE CUMBERLAND ISLAND PROJECT

Cumberland Island is the largest and southernmost of Georgia's barrier islands. The majority of Cumberland Island is owned by the National Park Service and operated as a National Seashore under Public Law 92-536, passed on October 23, 1972 (National Park Service, 1977).

The acquisition of Cumberland Island was initiated and widely supported by public outcry to save Cumberland Island from commercial exploitation and preserve the island in its natural state. In support of these concerns, the National Park Service has undertaken extensive planning in order to protect the natural environment and simultaneously allow public use. This planning brought to light the fact that very little detailed data concerning present geologic processes and basic hydrologic and geologic resources were available for Cumberland Island. Therefore, on September 28, 1978, the Georgia Geologic Survey agreed, on a contractual basis, to conduct investigations on Cumberland Island to produce these basic data needed for the prudent planning and use of the National Seashore.

To meet these ends, the Georgia Geologic Survey has undertaken an extensive subsurface testing program and other on-site investigations. A synthesis of existing geologic, hydrologic, remote sensing, and other pertinent information has been provided as an aid in planning. The Georgia Geologic Survey has drilled 19 stratigraphic test/water monitor wells on Cumberland Island with a cumulative total of 2155 ft. (657 m) drilled. This included a deep stratigraphic test/monitor well into the Principal Artesian Aquifer. Seismic data offshore from Cumberland Island also has been obtained to aid stratigraphic correlations. As a result of these test wells and seismic records, "in use" as well as potential aquifers on Cumberland Island have been identified. A number of remote sensing studies have resulted in new and more detailed geologic, landform-natural vegetation, land use and geologic hazards maps.

The Survey's intent is to present useful and accurate information to those people planning the future of Cumberland Island National Seashore. Therefore, the scope of study is directed more to applied geology rather than the theoretical aspects. In realization that the primary users of this report will probably not be intimately acquainted with geologic nomenclature, the wording has been simplified as much as possible. It is the Survey's belief that a broader and more concise understanding for the users of this report is worth the expense in style.

As part of the Georgia Geologic Survey's evaluation of Cumberland Island, great emphasis was placed on evaluating the subsurface stratigraphy of the island. In other words, we were attempting to obtain a good understanding of the geometry of the various sand, clay, and calcareous strata that underlie the site. Such knowledge is extremely important in assessing the potential impacts of septic disposal, ground-water availability, salt-water infiltration and so forth. And, while the bulk of the text is written in rather general terms, more precise technical back-up is provided in appendices.

Drilling procedures, descriptions of cores and cuttings, a list of microfossils, as well as informative photographs also are provided in the appendices.

2-0 GEOGRAPHY OF CUMBERLAND ISLAND AND THE SURROUNDING REGION

2-1 Regional geographic setting

Cumberland Island is part of a chain of barrier islands that extends along much of the Atlantic coast of the United States. These barrier islands are well developed along the entire Georgia coast. In Georgia they are commonly referred to as the "Sea Islands" or as the "Golden Isles". The islands vary in size from that of Cumberland Island, the largest in Georgia, to several islands that are barely above the high tide mark.

Jekyll Island lies north of Cumberland Island with St. Andrew Sound between the two. Amelia Island, to the south of Cumberland Island, is separated from Cumberland Island by Cumberland Sound. There are three rivers that flow into the salt marshes landward of Cumberland Island and the Atlantic Intracoastal Waterway west of Cumberland Island. These rivers are the Satilla River entering near the north end of Cumberland, the Crooked River entering near the midpoint of the island, and the St. Marys River entering near the south end of Cumberland Island. All of these rivers are tidally influenced and salt marshes extend several miles inland along their courses. The Crooked River is almost entirely a tidal river and rapidly diminishes in size above the tidal range.

Cumberland Island is a portion of Camden County, which is bordered on the north by Glynn County, on the west by Brantley and Charlton counties and on the south by Nassau County (Florida). The St. Marys River forms the Georgia-Florida boundary.

Woodbine, Kingsland and St. Marys are the major population centers in Camden County. St. Marys is located on the mainland in the extreme southeast portion of Camden County on the banks of the St. Marys River. Kingsland, a smaller town, is located west and further inland from St. Marys. Fernandina Beach, Florida, is located on Amelia Island, just across Cumberland Sound from Cumberland Island. Cumberland Island is located between two major coastal cities: Brunswick, to the

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2-2 Geography of Cumberland Island

There are no roads or highways connecting Cumberland Island with the mainland; therefore all transportation to and from the island must be made by boat or airplane. The National Park Service has two major landing points on the west side of Cumberland Island; Dungeness Wharf and Sea Camp Wharf. Plum Orchard Wharf is also a landing point but is not extensively used by the National Park Service. These landing points and some private ones are connected to the rest of the island via the main road, which is also referred to as Grand Avenue. The only landing strip is suitable for light aircraft only.

The major population concentrations on Cumberland Island are at High Point, Squaw Town, Little Greyfield and Dungeness. High Point is situated on the northern end of the island on private lands, and the majority of the buildings are private dwellings. Squaw Town and Little Greyfield are located in the middle portion of the island. These areas consist almost exclusively of private dwellings on National Park Service land. Many of these dwellings are being removed when they become unoccupied. Dungeness is located on the southern end of Cumberland Island and is comprised of private dwellings as well as a number of National Park Service buildings, including historic sites such as the Carriage House, the Captain's House and the Dungeness ruins.

Greyfield, Stafford and Plum Orchard are the three mansions still intact on the island. Greyfield, which is privately owned, is presently operated as a luxury hotel. Stafford, also privately owned, is unoccupied at the present, although the surrounding buildings are used. Plum Orchard is owned by the National Park Service and will be restored as a national historic site. It is presently being used as a first aid station for the northern camp sites.

Cumberland Island also has a number of inland marshes. The majority of these marshes are freshwater and support lush vegetation. Some of the marshes, such as Whitney Lake, Willow Pond and portions of the Sweetwater Complex, are open ponds. The ponds and marshes occur naturally west of stabilized sand dunes. The dunes act as dams, which block the eastward flow of surface waters.

Salt marshes are also a significant part of Cumberland Island and are attached to the western edge of the island. The salt marshes generally are not specifically named except for the Raccoon Keys Salt Marsh on the south end of the island. There are also two inland salt marshes connected with the Atlantic Intracoastal Waterway by tidal creeks. Figure 2-1 illustrates the major geographic features of Cumberland Island.

2-3 Climate

The regional climate is generally characterized by short, mild winters and warm, humid summers. The Atlantic Ocean has a moderating effect on the coastal weather, producing cooler summers and warmer winters.

Cumberland Island is subject to violent storms, such as tropical storms and hurricanes. There is a special threat to the barrier island because of the effects of torrential rains, high winds and surge tides produced by these storms. The Cumberland Island area, however, does not appear to be as susceptible to hurricanes as some other portions of the Atlantic and Gulf coast. Since 1881, only nine very destructive hurricanes have passed in the immediate area of Cumberland Island (N.P.S. 1977).

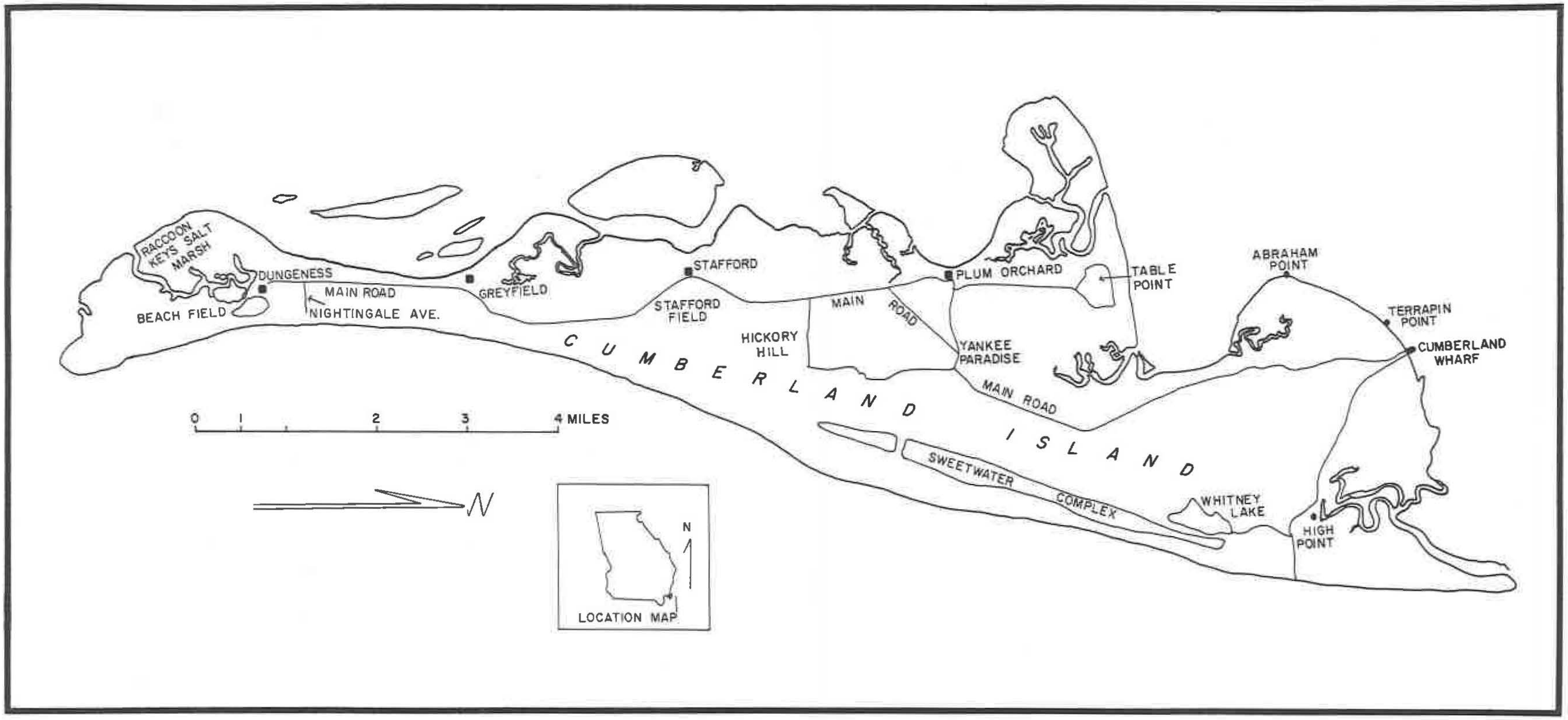


Figure 2–1. Major geographic features of Cumberland Island, Georgia.

3-0 GENERAL GEOLOGY OF THE CUMBERLAND ISLAND REGION

3-1 Introduction *

Cumberland Island is located in the portion of the Coastal Plain which contains the youngest sediments in Georgia. These sediments represent modern and ancient barrier islands and related environments, which have moved eastward in response to a falling sea level since early Pleistocene time (Table 3-1, Figure 3-1, and Plate 1). Only Holocene and Pleistocene aged sediments are exposed at the surface of the island.

The Pliocene series is represented in the subsurface on Cumberland Island by a sandy equivalent to the Duplin Formation. These sands were deposited under marine conditions when the shoreline was inland from the present coast. The sands are stratigraphically below clays of the basal Pleistocene and above calcareous sediments of Miocene age.

The Miocene series comprises two formations; a lower Hawthorne Formation that consists predominantly of sands and clays with minor carbonate beds and an upper Charlton Formation that consists predominantly of carbonates with minor sands and clays. These sediments underlie the Pliocene sediments and, in turn, overlie the Ocala Group.

The Ocala Group is composed of limestones of upper Eocene age in unconformable contact with the suprajacent Miocene series. No Oligocene sediments have been recognized on Cumberland Island or in the southeastern area of Georgia. According to the Florida Bureau of Geology, the Ocala Group is divided into three formations: the lower Inglis, the Williston, and the upper Crystal River Formations. Stratigraphic test well CI-01, drilled on Cumberland Island by the Georgia Geologic Survey, established the presence of the Crystal River Formation, but did not penetrate through the formation.

* A detailed description of the stratigraphy of the Cumberland Island area is provided in Appendix A.

3-2 Holocene-Pleistocene Geology

The Holocene deposits on Cumberland Island consist primarily of fine-grained sands situated along the eastern edge of the island and clays of the salt marshes on the western edge (Plate 1). This pattern is typical of barrier islands of the Georgia coast. The Holocene deposits of the eastern side of the island represent dune, interdune deflation areas and beach environments. Fresh water ponds and marshes, which are receiving sediments, are scattered over the island. These marshes are exceptionally well developed west of the dunes. Here the dunes act as dams impounding the eastward drainage which results in marshes and ponds. Other fresh water marshes occupy slight depressions in the land surface and appear to be receiving modern sedimentation.

The salt marshes typically are located on the western edge of the island although there are some tidally influenced marshes in the island interior. Both the salt and interior marshes are characterized by clay and silt size grains with interbedded, fine-to very fine-grained quartz sands.

The Holocene age deposits are easily distinguished from the upper Pleistocene Satilla Formation in that the Satilla Formation lacks significant clay units. The Holocene sands also may be differentiated from the Pleistocene sands by the presence of a soil profile and the absence of calcareous shell debris in the Satilla Formation.

The Pleistocene sediments of the Georgia coast also are situated in "terraces" which parallel the present coast. These "terraces" were first noted by William Bartram in his excursions through coastal Georgia and were subsequently described in the account of his travels published in 1791. Each "terrace" is composed of a barrier island and its related marsh or lagoon deposits landward of the barrier. The marsh deposits lie within a given range of elevations which differ for each barrier-marsh complex (Table 3-1). The older "terraces" occupy positions of higher elevation than the younger ones. This results in a series of "steps" or "terraces" which terminate at the present coast. Table 3-1 is a synopsis of the elevations of the Pleistocene shorelines recognized in Georgia.

Table 3-1 - Recognized Shorelines of the Lower Georgia Coastal Plain

SHORELINE	ELEVATIONS ABOVE MSL	AGE
Present day or Holocene coast	0	Holocene
Silver Bluff	Approximately 4½ ft (1.4 m)	Late Pleistocene
Princess Anne	Approximately 13 ft (4.0 m)	Late Pleistocene
Pamlico	Approximately 24½ ft (7.5 m)	Pleistocene
Talbot	39 - 46 ft. (12-14 m)	Pleistocene
Penholoway	69 - 75½ ft. (21-23 m)	Pleistocene
Wilcomico	95 - 102 ft. (29-31 m)	Early Pleistocene

(Adapted from Hails and Hoyt, 1969)

These obvious topographic features have led to each shoreline and its associated environments being assigned a formal lithostratigraphic name which corresponds to the name of the shoreline. For example, the Wilcomico barrier/marsh complex is referred to as the Wilcomico Formation. The mapping of these formations is based largely on elevation. Theoretically, each barrier/marsh complex represents a stabilization of the shoreline followed by a regression and transgression which stabilizes at a lower elevation than the previous barrier/marsh complex.

Two lithologic units in the Pleistocene sediments are recognizable in drill holes on Cumberland Island. The upper unit is a barrier island facies consisting of a sand composed of predominantly fine-grained quartz; whereas the lower unit is a back barrier facies composed of silts and clays. The upper sand unit is assigned to the Silver Bluff shoreline deposits. The lower, fine-grained terrestrial unit has not been assigned to any shoreline or formation. This unit suggests a restricted marine environment such as a modern-day salt marsh.

A review of existing literature that relates to the Pleistocene sediments of the Cumberland Island region reveals that the upper sand unit present throughout Cumberland Island fits the stratigraphic position and lithologic description of the Satilla Formation described in Veatch and Stephenson (1911). Therefore, the Satilla Formation is adopted as the name of the upper sand unit of Pleistocene age on Cumberland Island. The name is applied as described in Veatch and Stephenson (1911) on Cumberland Island with the exception of the river deposits which are omitted (Plate 1). The type sections for this formation are located on the Satilla River only a few kilometers from Cumberland Island on the mainland. Preliminary results of ongoing research suggest that the term Satilla Formation "may be useful in a regional scale, and is presently being considered for adoption and use by the Georgia Geologic Survey" (Paul Huddlestun, oral commun., 1980).

The lower unit of fine-grained terrestrial sediments that is present on Cumberland Island has not been named. This unit also appears to be a mappable unit on Cumberland Island and on the mainland in southeast Georgia. Both the Satilla Formation and the lower fine-grained terrestrial sediments unit are detailed in the Neogene Stratigraphy section (refer to Appendix A) of this report.

3-3 Pliocene series

The Pliocene series is represented on Cumberland Island by one lithostratigraphic unit equivalent to the Duplin Formation. The Duplin equivalent is not exposed to the surface on Cumberland Island, but is represented in the subsurface by a marine sand which fines upward. In southeastern Georgia, the Pliocene series is covered by Pleistocene sediments. There are few exposures of these sediments at the surface, as the Pliocene shoreline appears to have about the same location as the highest Pleistocene terraces (Paul Huddlestun, oral commun., 1980). The Pliocene sediments on Cumberland Island are described in more detail in the Neogene Stratigraphy section of this report.

3-4 Miocene series

The Miocene series in the southeast Georgia region consists of two units. The upper, calcareous unit is the equivalent of the Charlton Formation and the lower clastic and carbonate sediments comprise the Hawthorn Formation. The Tampa Limestone, which is the basal Miocene unit in east Florida, is not present in southeastern Georgia. In well CI-01 (GGS 3426) the Miocene sediments had a total thickness of 320 ft (97.5 m). The Charlton Formation is 210 ft(64 m) in CI-01 with the Hawthorn Formation making up the remainder of the series. The most recent study of the Miocene sediments was made by Watson (1979), but the main emphasis in his paper was groundwater. An isopachous map produced by Watson showed the Miocene sediments to be between 400 ft (120 m) and 500 ft (150 m) thick in the Cumberland Island area. The test drilling on Cumberland Island has shown that Watson's figures for the thickness of the Miocene are too high and should be revised downward closer to the 320 ft (97.5 m) of sediments encountered in CI-01.

3-5 Upper Eocene sediments

The sediments of late Eocene age are represented in the southeastern Georgia region as the Ocala Group. The Ocala Group consists of a thick sequence of limestones which lie unconformably on the middle Eocene Claiborne Group. The Florida Bureau of Geology recognizes the following formations in ascending order; the Inglis Formation, the Williston Formation, and the Crystal River Formation. Cumberland Island well CI-01 penetrated 113 ft. (34.4 m) of the Crystal River Formation. The lithology of the Crystal River Formation encountered in CI-01 is not typical of the formation. Rather, the formation consists of a fossiliferous (bryzoan-rich), white limestone. This bryzoan facies, nevertheless, is considered to be a member of the Crystal River Formation as yet unnamed (Paul Huddlestun, oral commun., 1980).

Figure 3-2 is a structure contour map of the top of the Ocala Group in the Cumberland Island region.

3-6 Structural geology

Several faults have been proposed north of Cumberland Island in Glynn County (refer to Figure 3-3). These faults are considered to be potential pathways whereby salty ground waters have contaminated portions of the Principal Artesian Aquifer in the vicinity of Brunswick. They are discussed in greater detail in groundwater geology section of this report.

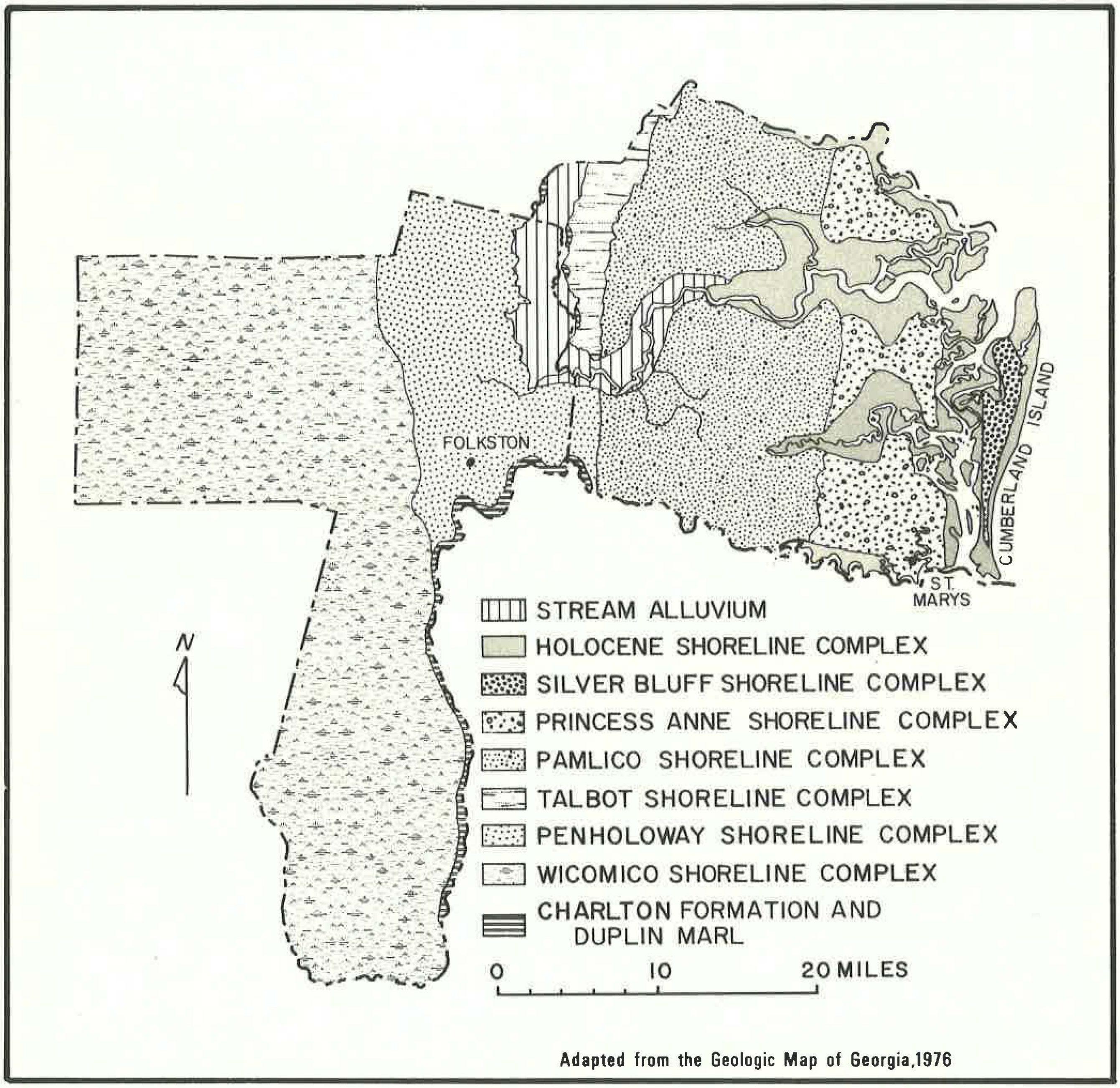


Figure 3–1. Regional geology of southeast Georgia.

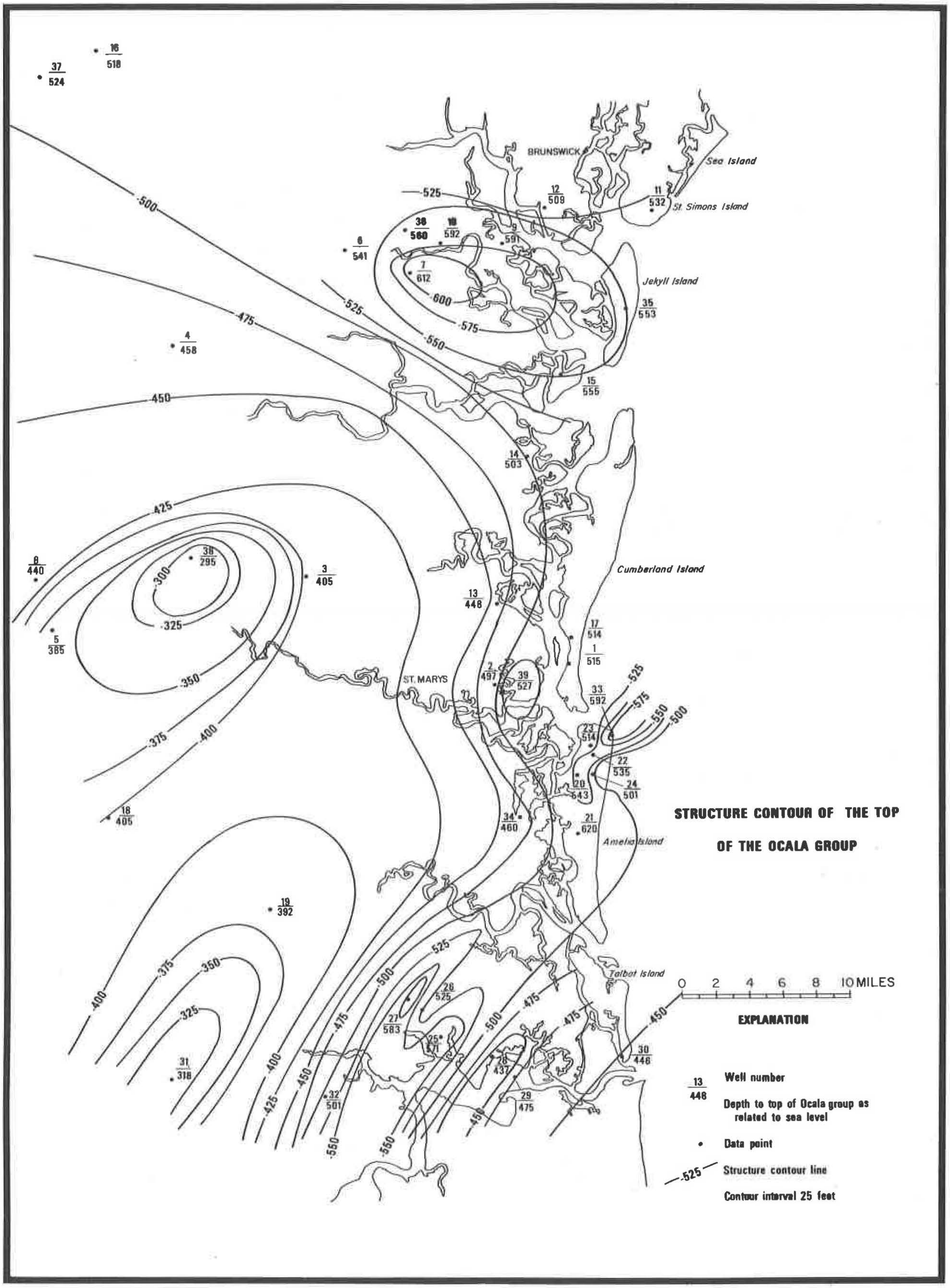


Figure 3–2. Structure contour of the top of the Ocala Group.

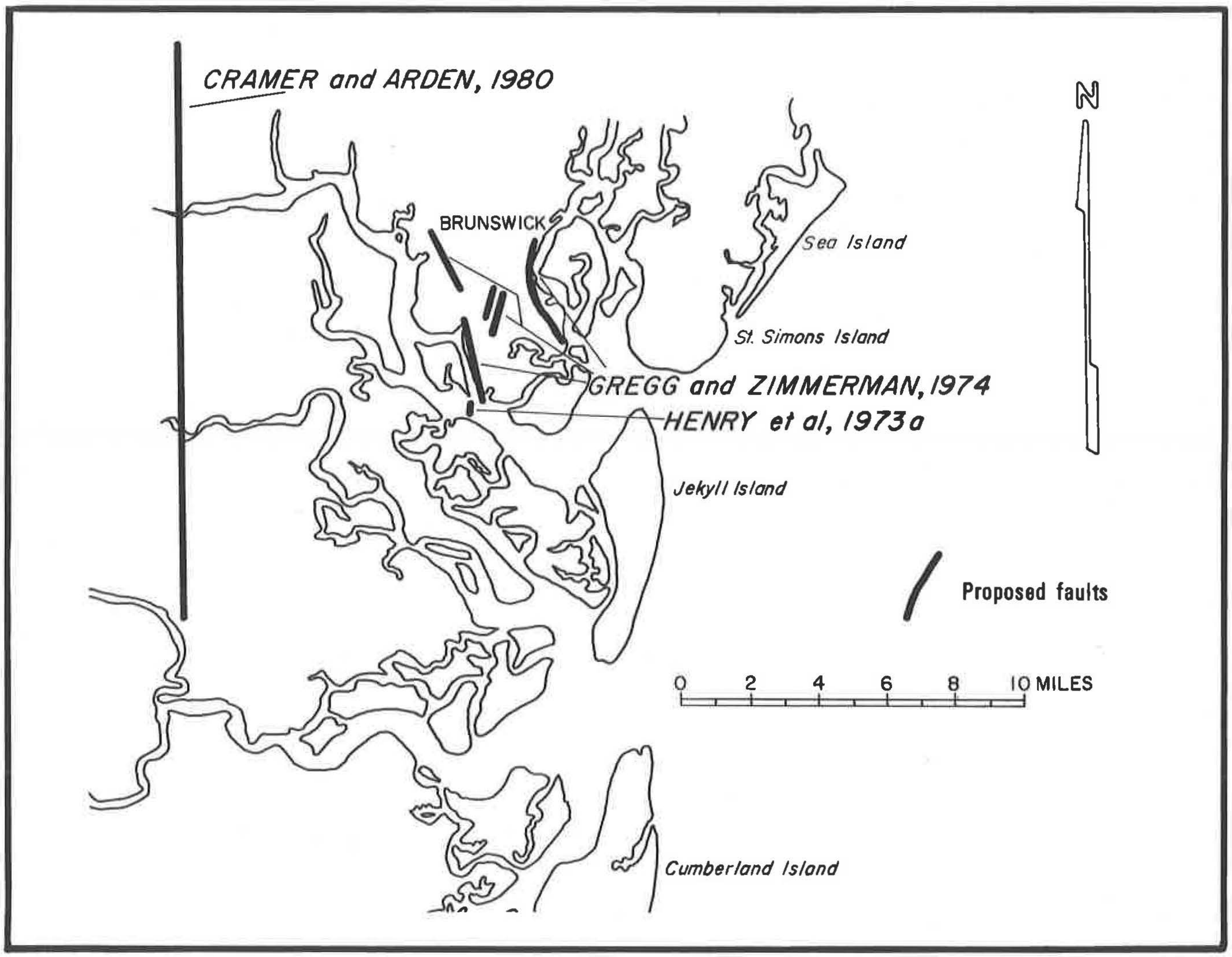


Figure 3–3. Geologic structure proposed in the Cumberland Island region.

4-0 STRATIGRAPHY

4-1 Introduction

Cumberland Island is made of and underlain by layers of sand, clay, silt and limestone which are known to range in age from Miocene to Holocene. The purpose of this section is to present a concise description of the stratigraphic units. Much information on the stratigraphy was obtained from the boreholes (refer to Figure 4-1). For more concise and detailed description of the stratigraphy, the reader is referred to Appendix A.

4-2 Quaternary deposits

4-2-1 Holocene (Recent) deposits:

Holocene or recent sediments include those deposited from 25,000 years ago to the present. The oceanward side of Cumberland Island began forming about 5000 years before present (B.P.) when a marked lowering of sea level allowed the formation of a Holocene barrier-island system somewhat seaward of its present location (Henry and others, 1973). As a result of subsequent island retreat, this Holocene barrier system became welded onto the pre-existing Pleistocene Silver Bluff barrier island. Thus Cumberland Island is a composite of relatively recent Holocene and older Pleistocene barrier island complexes (Plate 2).

4-2-2 Pleistocene deposits:

Deposits of Pleistocene age are predominantly composed of sand, clayey sand, and sandy clay consisting of a barrier island facies as well as a back barrier facies (refer to Section 3-2). The barrier island facies is characterized by fine, clean sand (refer to Figure 4-9) whereas the back barrier environment is represented by a more clayey facies (Figs. 4-2 through 4-7).

Macrofossils are uncommon in the Pleistocene deposits, except for abundant plant remains in the upper part of the barrier island facies and a few shells. Ophiomorpha nodosa (Fig. 4-8), the fossil burrow of the shrimp Callianassa major, is also found.

4-3 Pliocene and Miocene deposits

These epochs are represented by the Pliocene age Duplin Formation which directly overlies the Miocene Charlton Formation.

The Duplin Formation is middle Pliocene in age and consists of yellowish-brown to greenish-gray, fine-grained sand in the upper part and pale green sand in the lower part. The Duplin includes clay and clayey sand interbeds, some of which are cross-bedded. The Duplin fossils include clams, oysters, scallops, sea snails and abundant microfossils. The general distribution and thickness of the Duplin on Cumberland Island is shown on Figures 4-2 through 4-7, which are based on well logs. In addition, Figures 4-10 through 4-15 which are based on seismic studies, show the distribution of the middle Pliocene (and presumably the Duplin). The abundance of marine fossils indicates that the Duplin sediments probably were deposited in shallow marine conditions.

The Charlton Formation of middle Miocene age is a well cemented limestone. Because of its hardness, drilling was stopped at the top of the Charlton. The borings which did penetrate the Charlton showed a yellowish-gray, hard, sandy, phosphatic limestone that locally contains chert. In places the Charlton contains enough fossils to be called coquina (beach rock). Fossil impressions of sea snails occur commonly in the Charlton. The Charlton is identified on the seismic profiles (Figs. 4-10 through 4-15) as the middle Miocene. The Charlton was deposited in a shallow marine environment.

4-4 Summary

Sediments on and beneath Cumberland Island consist of sand, mud and limestone deposited in both marine and non-marine environments. The Pleistocene and Holocene deposits show evidence of deposition in a barrier island complex which includes dune and salt marsh deposits. The older deposits, because of their fossil content, are interpreted as being shallow marine.

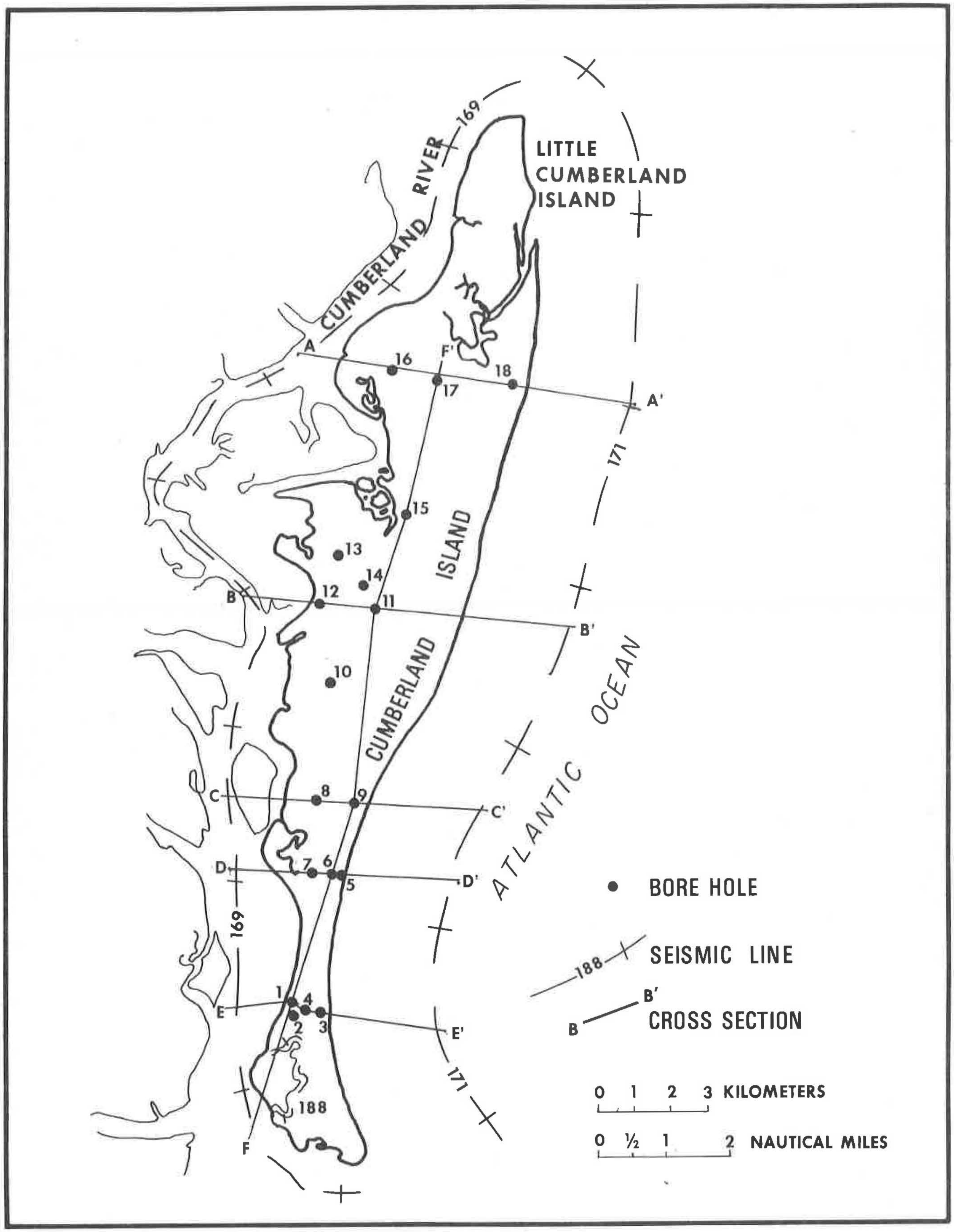
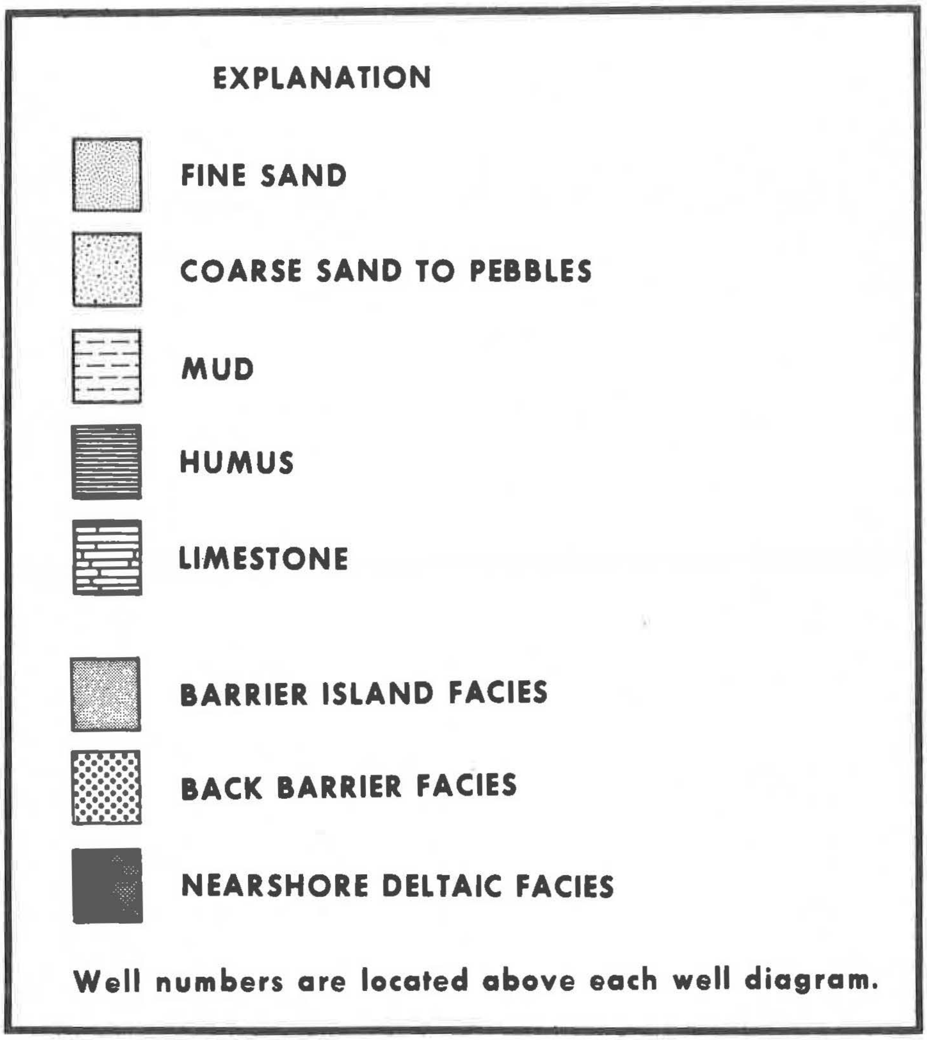


Figure 4—1. Bore hole, seismic line, and cross section locations, Cumberland Island, Georgia.



Explanation for figures 4–2 through 4–7.

These figures are presented in metric units to more closely fit with seismic interpretations.

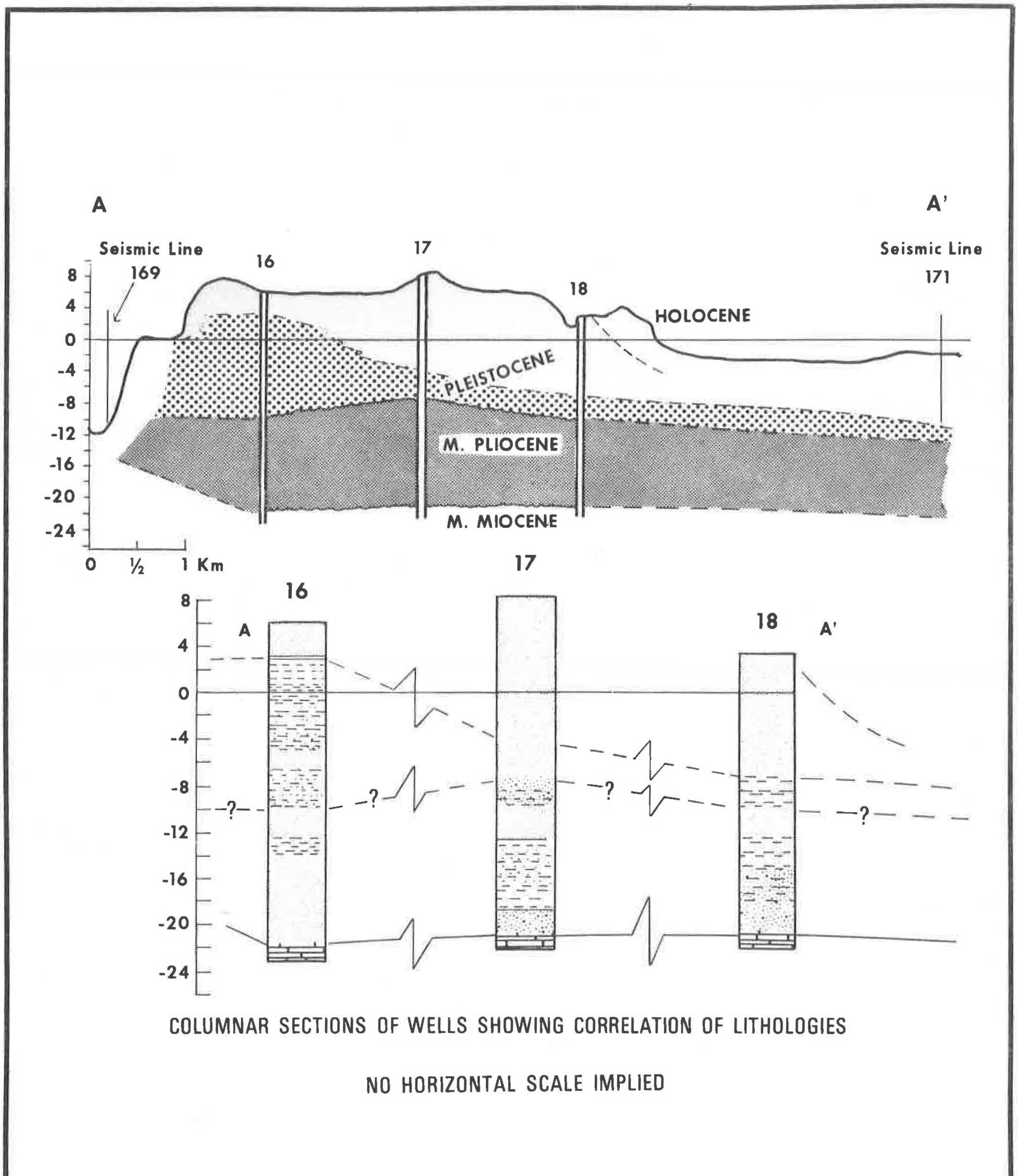


Figure 4–2. Geologic cross section A-A′.

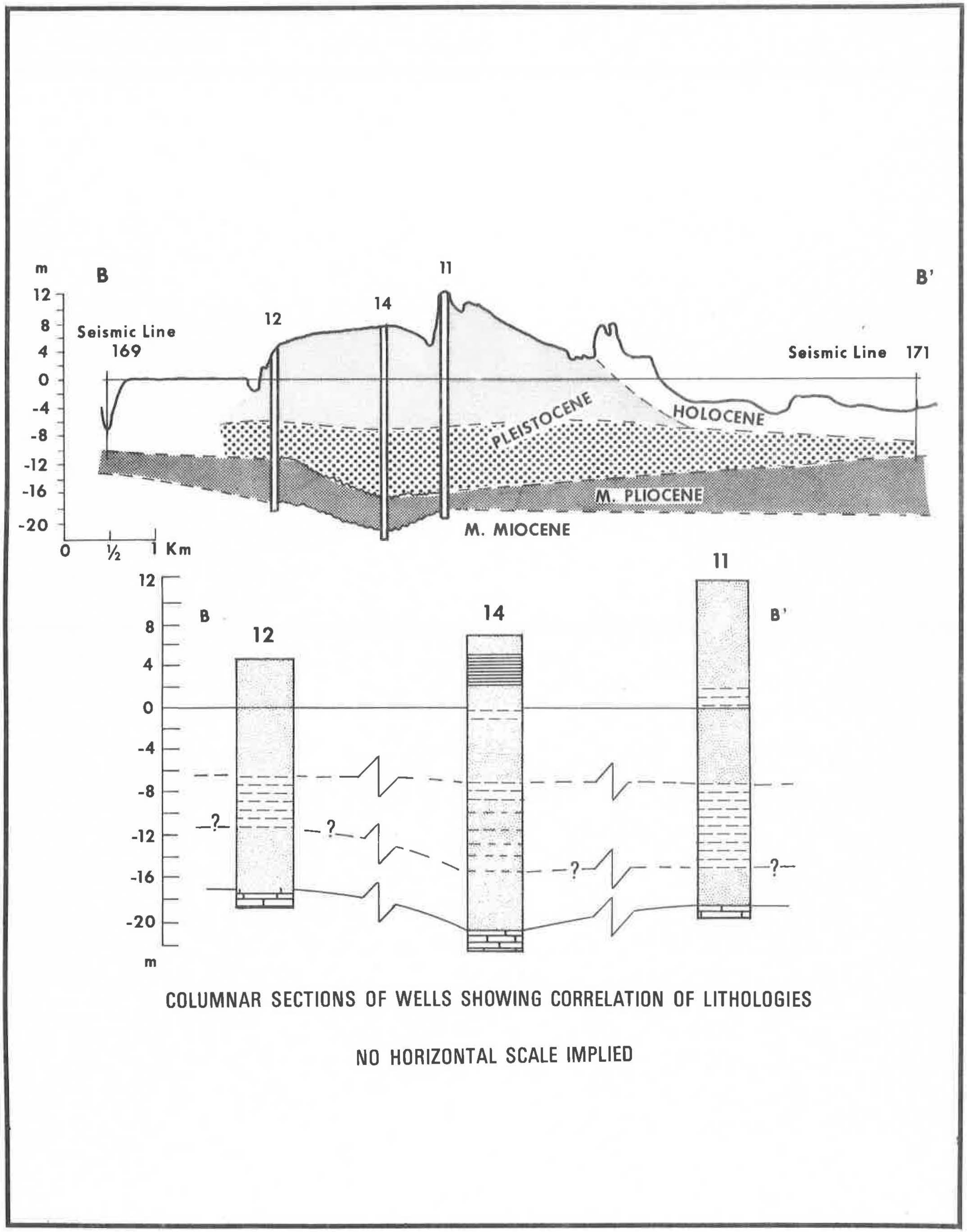
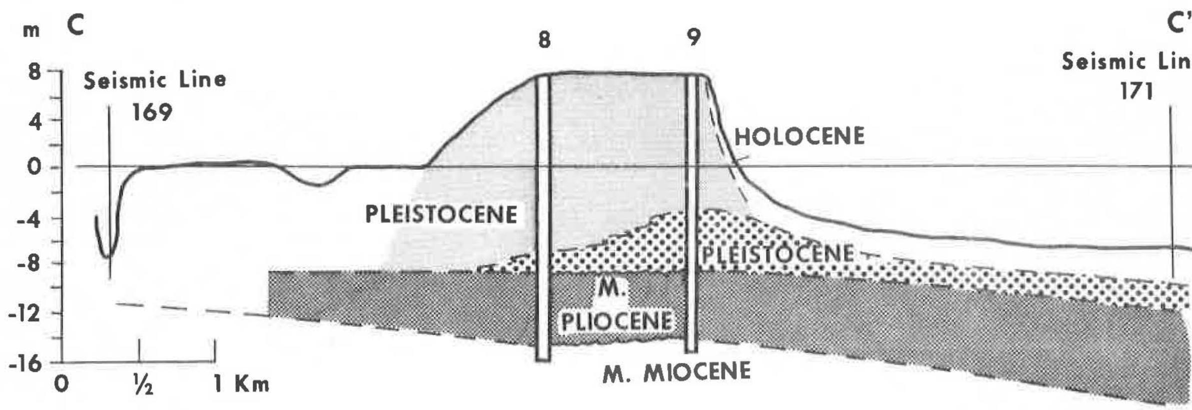
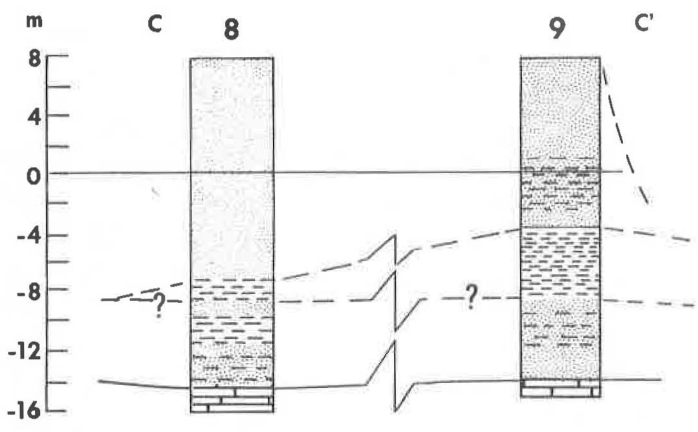


Figure 4–3. Geologic cross section B-B′.

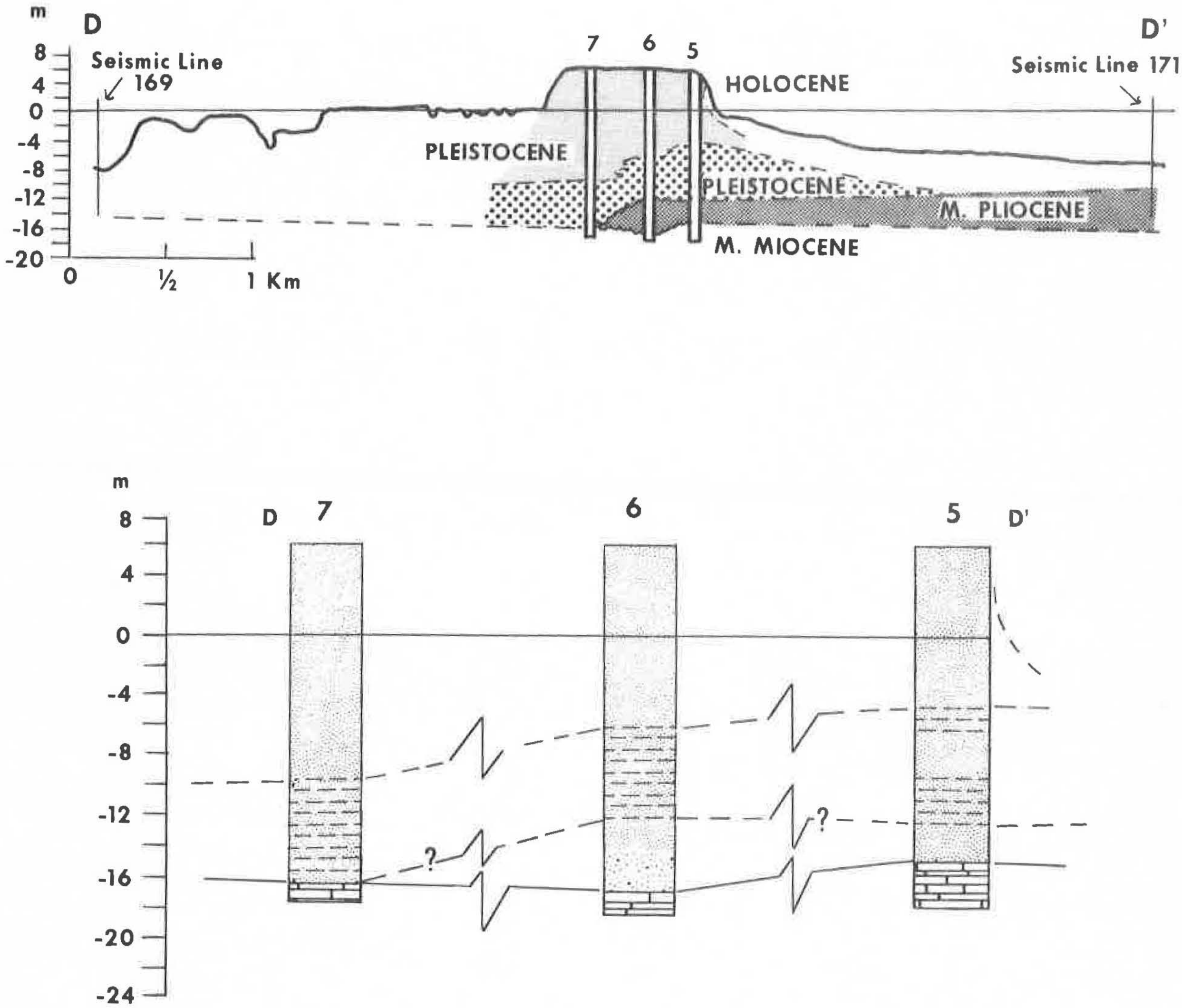




COLUMNAR SECTIONS OF WELLS SHOWING CORRELATION OF LITHOLOGIES

NO HORIZONTAL SCALE IMPLIED

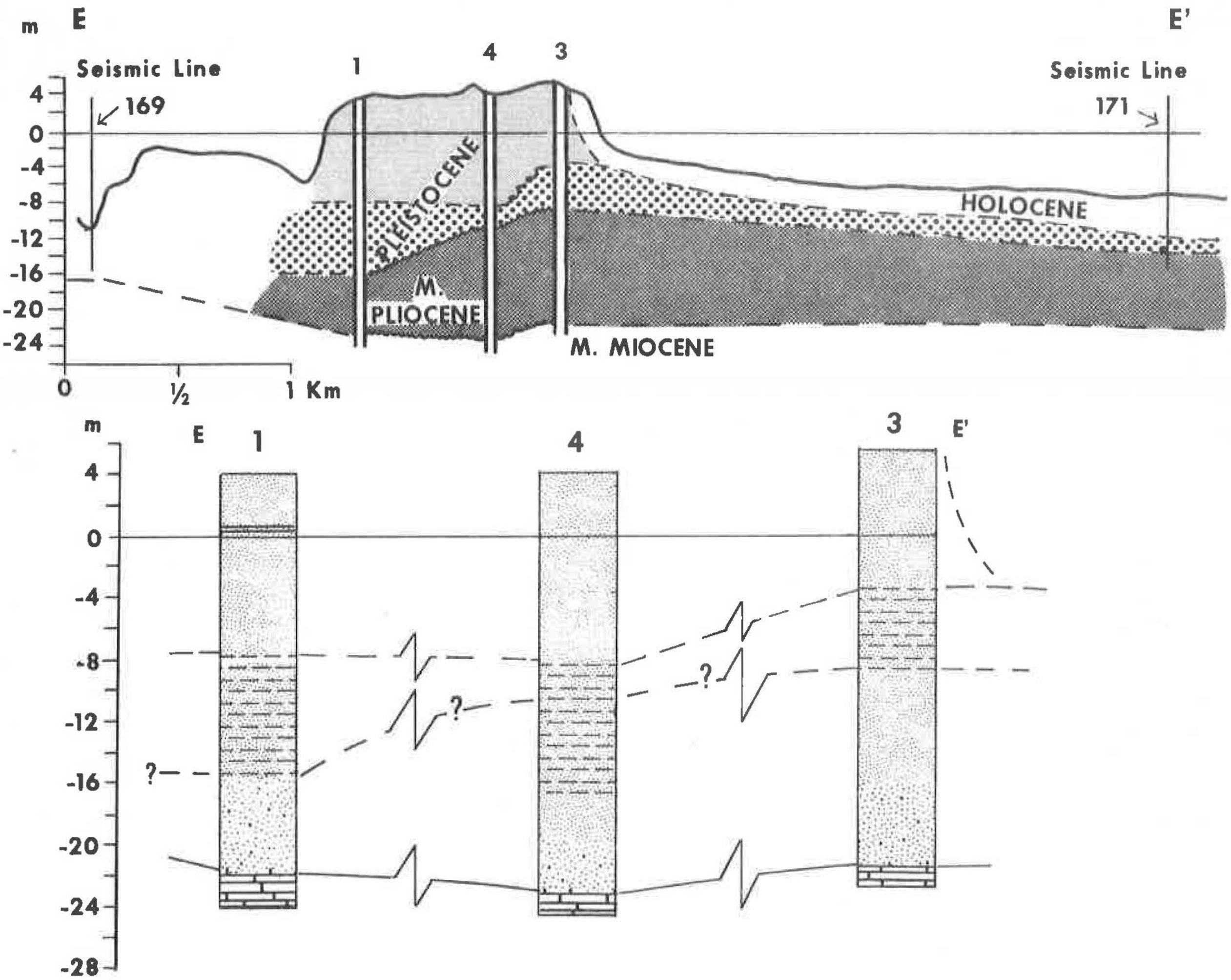
Figure 4–4. Geologic cross section C-C′.



COLUMNAR SECTIONS OF WELLS SHOWING CORRELATION OF LITHOLOGIES

NO HORIZONTAL SCALE IMPLIED

Figure 4–5. Geologic cross section D-D′.



COLUMNAR SECTIONS OF WELLS SHOWING CORRELATION OF LITHOLOGIES

NO HORIZONTAL SCALE IMPLIED

Figure 4–6. Geologic cross section E-E′.

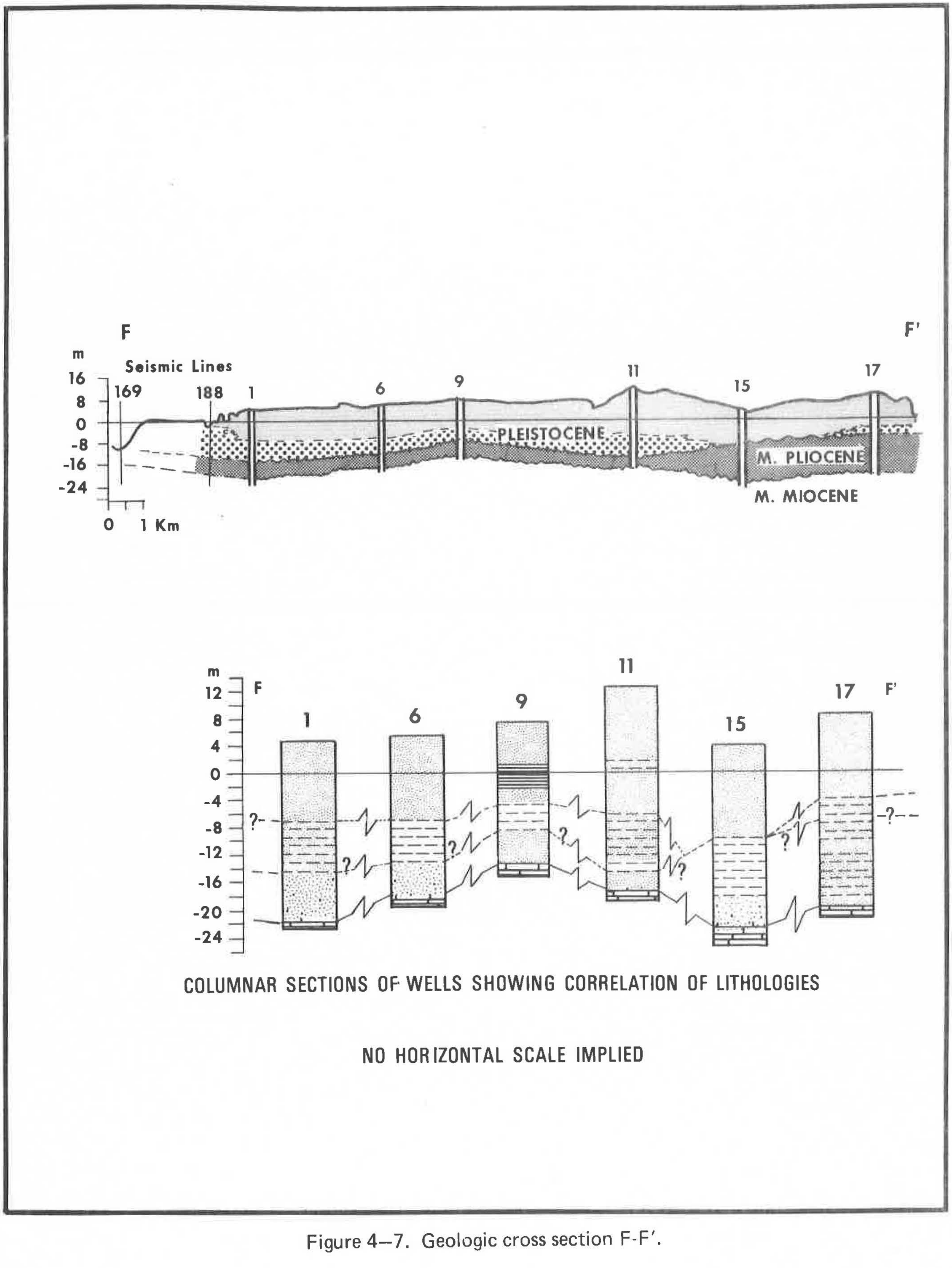


Figure 4–7. Geologic cross section F-F′.

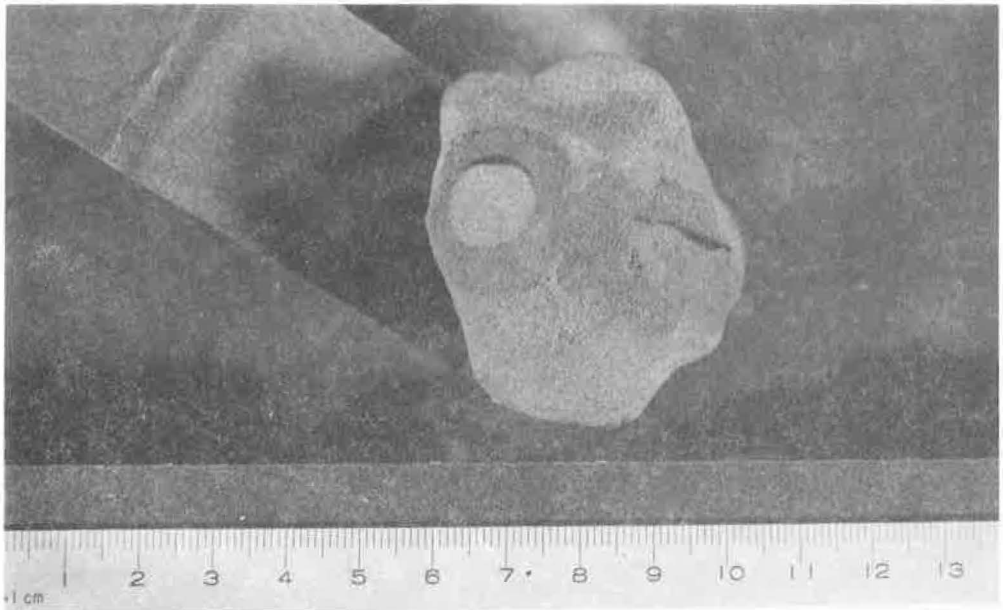


Figure 4–8. Ophiomorpha nodosa burrow in boring 3 at 7 m below surface, illustrating well-preserved wall structure. Note smooth mud in the interior surface of burrow.

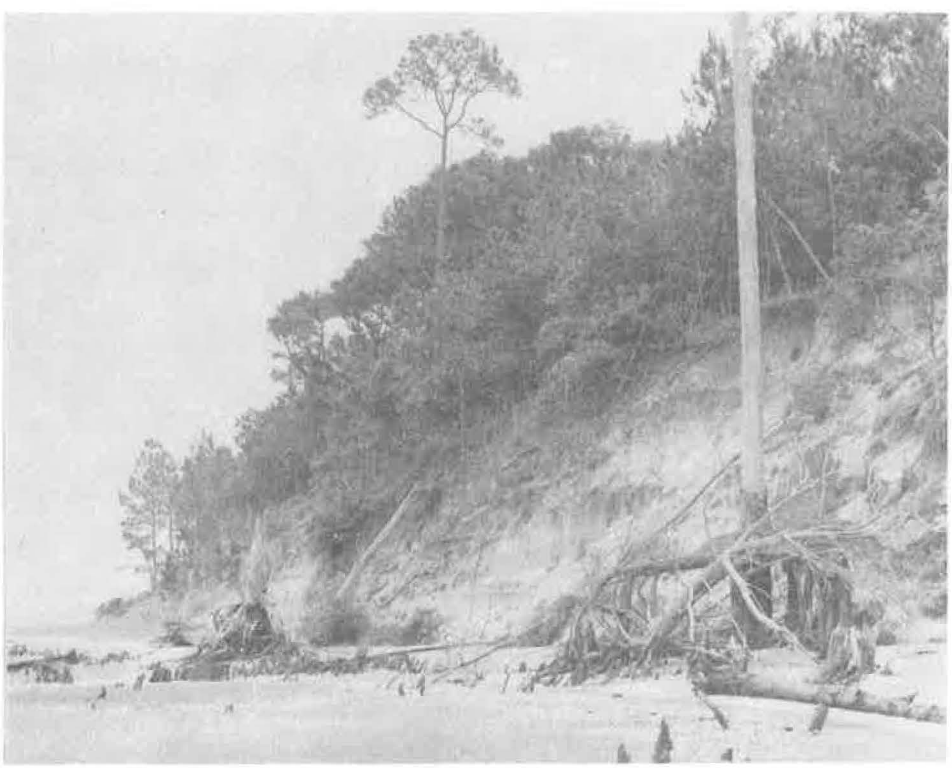


Figure 4–9. Cumberland Island Wharf outcrop. Pleistocene barrier island deposits (foreshore facies) on 12 m high erosional scarp.

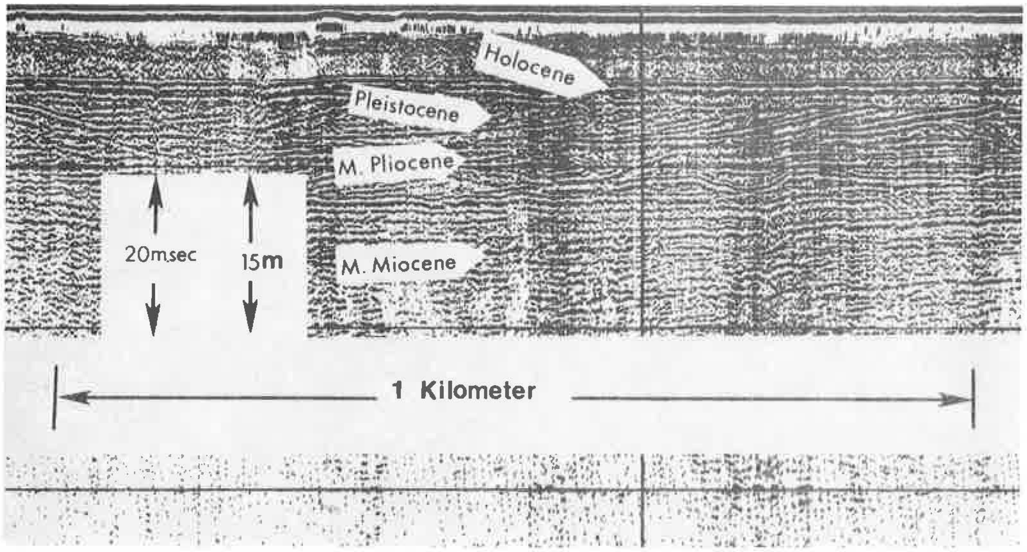


Figure 4—10. Seismic profile in Cumberland River, 2 km south of Cumberland Wharf, showing thin Holocene deposits unconformably overlying sediments of Pleistocene crossbedded deposits. The latter overlie middle Pliocene sediments. A horizontal unconformity defines the boundary between Pliocene sediments and the limestone (middle Miocene).

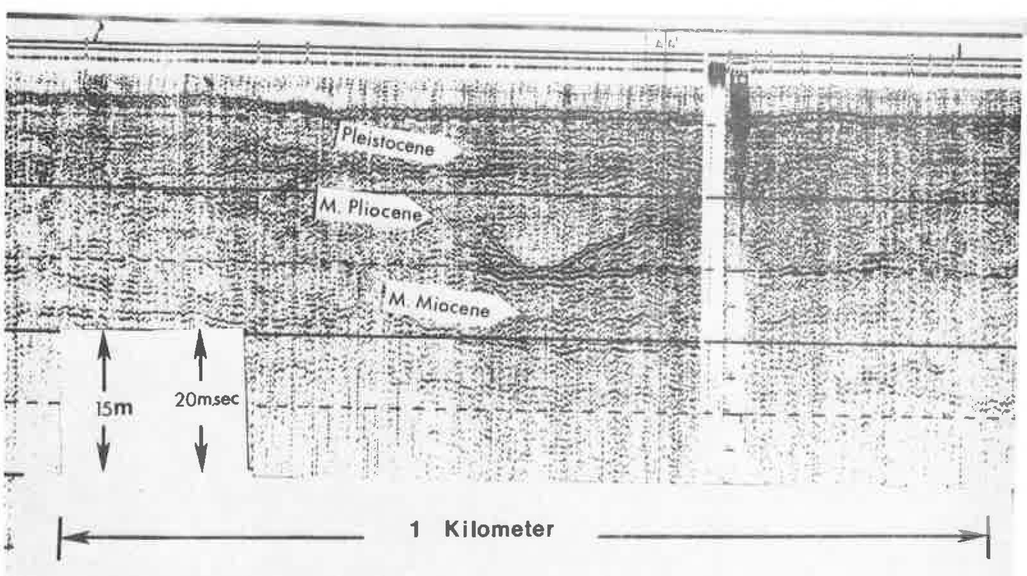


Figure 4—11. Seismic profile; intersection of seismic line 171 with cross section A-A′, showing large channel cut with fill of probably Pleistocene age. The channel is cut into middle Pliocene deposits with the channel bottom on the top of Miocene sediments.

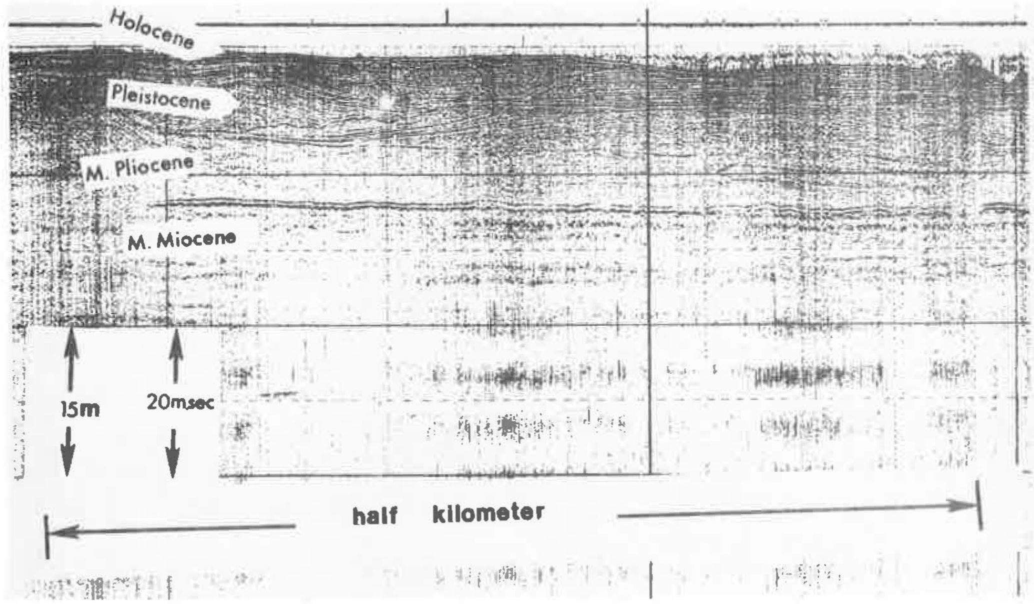


Figure 4–12. Seismic profile in Beach Creek (seismic line 188), 1 km southeast of Dungeness, showing Holocene channel deposits unconformably overlying bedded sediments of back barrier facies of Pleistocene age. A strong reflector defines the boundary between the middle Miocene and middle Pliocene sediments.

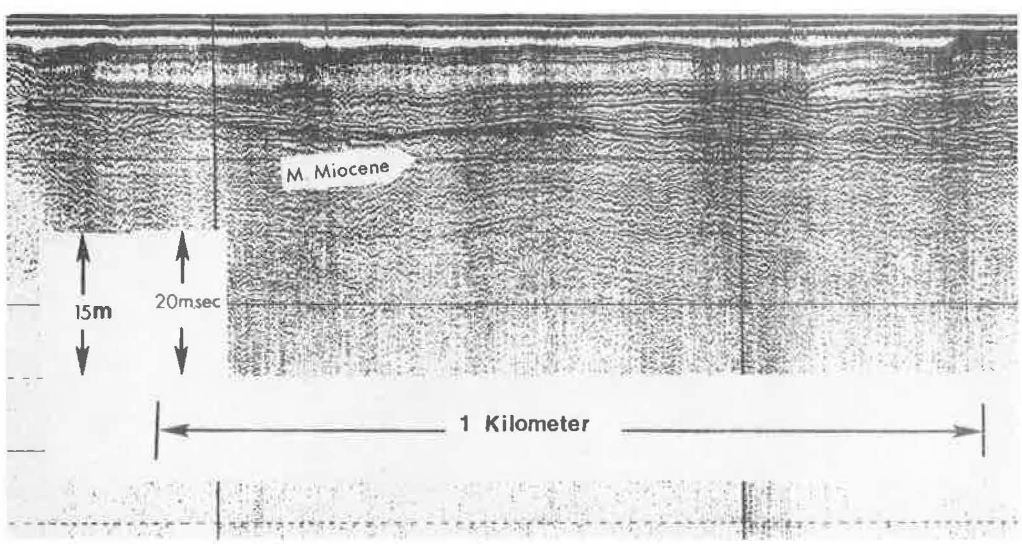


Figure 4–13. Seismic profile in Cumberland River (seismic line 169), in front of Stafford Island. Reworked sediments of Pliocene-Holocene age directly overlie the middle Miocene Charlton limestone.

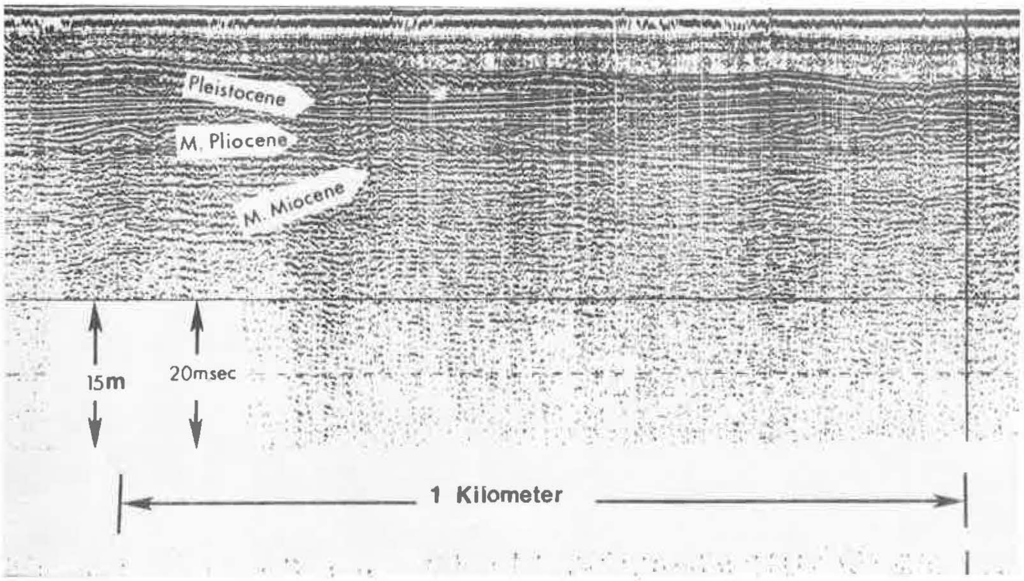


Figure 4–14. Seismic profile in Cumberland River (seismic line 169), 5 km south of Cumberland Wharf, showing flat-lying beds of Pleistocene unconformably overlying a thin sequence of Pliocene sediments. The latter overlie the erosional surface of the middle Miocene.

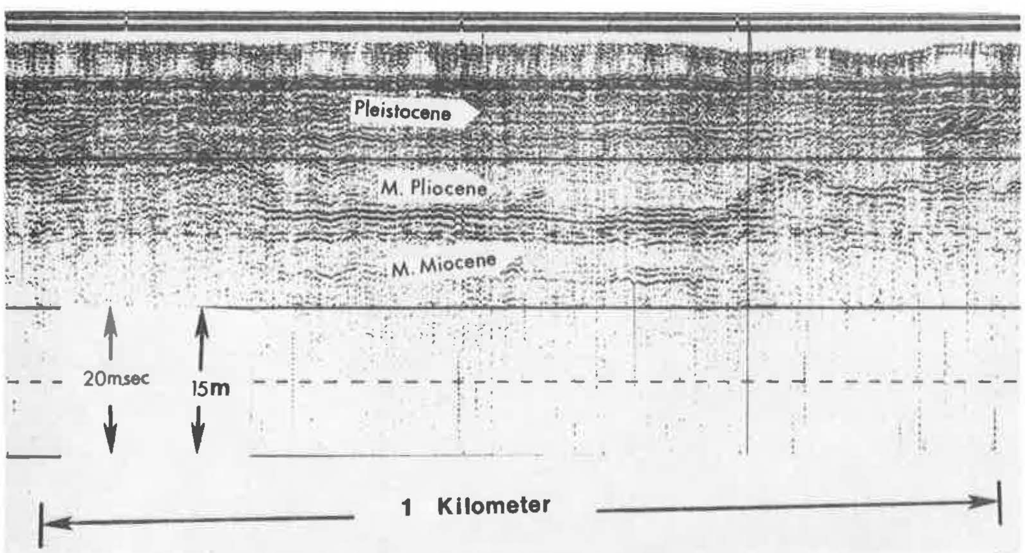


Figure 4–15. Seismic profile in southern end of the seismic line 171, showing karst. Quaternary deposit overlies coarse material of the Duplin Formation (middle Pliocene). The latter deposits overlie an irregular surface developed by karstification on the limestone (middle Miocene).

5-0 HYDROGEOLOGY OF CUMBERLAND ISLAND

5-1 Introduction

After acquisition of large portions of Cumberland Island by the National Park Service, it became apparent there essentially was no hydrogeologic data available. In response to this need, the Georgia Geologic Survey conducted a geologic and ground-water survey of the island. Such a survey provides the basic data on which planning decisions can be made. The ground-water survey also has resulted in several recommendations listed in Section 12.

This study is not a detailed examination of the ground-water systems on Cumberland Island, but rather a general discussion of the most important aspects of them. In this regard, the Georgia Geologic Survey inventoried a majority of the existing water wells on National Park Service property, constructed a deep well into the Principal Artesian Aquifer, constructed 17 shallow wells to monitor the unconfined water table, lithologically logged one private well, and examined shallow seismic data for the area surrounding Cumberland Island.

5-2 Previous work on the hydrogeology of Cumberland Island

The most prolific aquifer on Cumberland Island is the Principal Artesian Aquifer, also known as the Floridan Aquifer. The Principal Artesian Aquifer has attracted much attention because of the large water withdrawals along the Atlantic coast of Georgia and Florida. These withdrawals have resulted in significant changes in the potentiometric surface of the aquifer, resulting in an increased potential for salt water encroachment. Governmental and public concern over changes in the potentiometric surface have resulted in publication of voluminous regional (but not specific to Cumberland Island) works by the United States Geological Survey, the Georgia Geologic Survey, the Florida Water Management Districts, the

the Florida Bureau of Geology and private industry.

The first study that specifically mentioned wells on Cumberland Island was by McCallie (1898). Warren (1944), in a study of the Principal Artesian Aquifer along the entire Georgia Coast, measured heads on a number of wells on Cumberland Island and in the St. Marys area. A regional study by Stringfield (1966) dealt with many aspects of the Principal Artesian Aquifer including the chemistry and its implications on water quality. Krause and Gregg (1972) documented changes in the potentiometric surface of the Principal Artesian Aquifer from 1880 to 1971. Johnson and others (1980) published a regional map of the estimated original potentiometric surface of the Principal Artesian Aquifer.

The shallow aquifers of Miocene to Holocene age have had little study. The latest studies are by Watson (1979), who conducted a regional analysis of the shallow aquifers of the coastal area of Georgia, and Beck (1979), whose paper is a discussion of the use of ponds for irrigation and the hydrologic similarities between the ponds and large-diameter wells. Frazee and McClaugherty (1979) of the St. John's Water Management District (Florida) published a comprehensive paper that deals with the major ground water systems in the St. Johns Water Management District, including the shallow aquifers. Portions of their work were conducted across the St. Marys River from Cumberland Island; therefore, the data probably can be applied to Cumberland Island.

5-3 Well inventory of Cumberland Island

An inventory (Table 5-1) of existing wells on Cumberland Island has resulted in the documentation of 48 wells located largely on National Park Service property. The inventory was concentrated on National Park Service properties and included only the most accessible private wells; therefore, 48 wells in considered to be a conservative figure. Figure 5-1 is a location map of the wells inventoried.

The inventory resulted in the location of 15 larger-diameter wells that are believed to tap the Principal Artesian Aquifer. The remainder of the wells are from two to three inches (about 5-8 cm) in diameter and withdraw water from shallower aquifers.

5-4 Well construction techniques used on Cumberland Island

There are three types of well construction used on Cumberland Island; "driven wells", "rock wells", and "deep wells". The modes of construction correlate with well use and depth. Well construction methods used in the unconsolidated sands and clays of the Pleistocene and Pliocene age sediments result in Type 1, usually referred to as "driven wells". These wells are used by the National Park Service in several campgrounds, where only small amounts of water are required. The Type 1 wells are constructed by driving a slotted drive point and casing into the sediments with a hammer mounted on a drill rig. This type of well is restricted to use in soft sediments near the surface and is seldom more than 90 feet (27 m) in depth because of the hard dolostone of the Charlton Formation, which cannot be penetrated by the drive point.

Wells constructed by the second type of well construction are commonly referred to as "rock wells". The Type 2 wells are of intermediate depth and typically are used for domestic purposes on Cumberland Island. Standard rotary drilling methodology is used to open a well bore from the surface through the calcareous sediments of the Charlton Formation. The well is then cased from the top of the calcareous sediments to the surface, with open hole construction through the calcareous sediments. Through use of compressed air or water pressure a reservoir is opened in the underlying calcareous sands.

Wells made by the third type of well construction are commonly referred to as "deep wells". The Type 3 wells obtain water from the Principal Artesian Aquifer. Standard rotary or cable tool methodology is used to open a well bore from the surface to the top of the Principal Artesian Aquifer. This is then cased internally and drilling is continued inside the casing. The portion of the well below the casing is left open to the aquifer. In the majority of the wells on Cumberland Island, the potentiometric surface of the Principal Artesian Aquifer is above the land surface; therefore, these wells flow at the surface without pumping.

5-5 Characteristics of the Principal Artesian Aquifer

The Principal Artesian Aquifer consists of hydrologically connected limestone from middle Eocene to Miocene in age. This aquifer is the most viable source of fresh water on the island.

The earliest recorded well drilled into the Principal Artesian Aquifer on Cumberland Island was constructed in 1887 (McCallie, 1898). This well had a head of 67 ft (20.4 m) above mean sea level and was estimated to flow at a rate of 800,000 gallons (3,000,000 liters) per day (McCallie, 1898).

Because of the large amounts of water used by the coastal industries, there has been significant decline in the potentiometric surface of the Principal Artesian Aquifer (Krause and Gregg, 1972). These changes are largely the result of water withdrawal. Cones of depression surrounding Brunswick and the St. Marys-Fernandina Beach area are of primary concern on Cumberland Island. The southern half of the island is influenced by the St. Marys-Fernandina Beach cone of depression. Figure 5-2 is a map of the potentiometric surface of the Principal Artesian Aquifer at Cumberland Island, based on September 1980 measurements. The map indicates a lowering of the potentiometric surface towards Fernandina Beach. There are no water level measurements for the extreme northern portion of Cumberland Island, but this area may be influenced by pumping in the Brunswick area. Figure 5-3 is a potentiometric map of the Brunswick-Fernandina Beach area (Mitchell, 1980) which was adapted for use in this report. This map suggests that the lowering of the potentiometric surface, illustrated in figure 5-2, is a result of pumpage in the St. Marys-Fernandina Beach area.

Salt water intrusion also has been a problem in the Principal Artesian Aquifer in Brunswick, as well as Fernandina Beach, Florida. Studies by Wait and Gregg (1973), Gregg and Zimmerman (1974), and Harden and Associates (1979) address the geohydrology of salt water intrusion. These studies indicate that deep zones in the aquifer contain salty connate water under relatively high heads (i.e. high hydrostatic pressures). As a result of the higher heads, saline waters will move up well bores and contaminate the water of the Ocala Group. The remedial measure for this problem has been to terminate wells above these zones of high chloride water. On Cumberland Island, it is recommended that wells drilled into the Ocala Group not exceed 1000 ft (about 300 m) in depth to prevent possible contamination of the aquifer.

The water analyses from wells using the Principal Artesian Aquifer on Cumberland Island indicate the water is hard to very hard, but meets the chemical standards for general use as well as drinking water (Table 5-2). Table 5-3 is a synopsis of water analyses taken from the Principal Artesian Aquifer on Cumberland Island. The values in Table 5-3 represent the arithmetic mean of all samples.

The average chloride (Cl) concentration is 37.25 ppm. This is well below the maximum limit of 250 ppm; therefore, no salt water intrusion into the aquifer is indicated. Fluorides (F) have an average concentration of 0.7 ppm on Cumberland Island. Fluoride concentrations between 0.7 ppm and 1.2 ppm are generally considered ideal to help reduce the incidence of tooth decay in young children and 1.5 ppm is considered the maximum allowable concentration. On Cumberland Island a concentration of 0.7 ppm appears to be characteristic of the water from the Principal Artesian Aquifer. The average concentration of $CaCO_3$ is 328.0 ppm. Water with a $CaCO_3$ concentration of more than 200 ppm is considered very hard water. This high concentration of carbonates may cause scale to form in boilers and water heaters and may also result in the "liming up" of water pipes.

Total dissolved solids include all material in solution in the water. The total dissolved solids in the water of the Principal Artesian Aquifer averaged 463.5 ppm on Cumberland Island. Generally, total dissolved solids should not exceed 500 ppm although concentrations up to 1000 ppm can be used if no other supplies are available, but concentrations over 1000 ppm are considered unacceptable.

Table 5-3 also includes a number of other chemical components, all of which are within acceptable limits. For more detailed information on those chemical components the reader is referred to Hem (1970), Sonderegger and others (1978) and the Rules for Safe Drinking Water published by the Georgia Environmental Protection Division.

Sediments overlying the Principal Artesian Aquifer in the vicinity of Cumberland Island are from 400 to 600 feet thick (120-180 m) and consist of clays and sandy clays with lens-shaped bodies of sand, gravel, and thin carbonate layers. These shallow sediments have been largely ignored as potential aquifer because of the proximity to the highly productive Principal Artesian Aquifer. Wells tapping the shallow aquifers require screening and filter packing, and consequently are more expensive to construct per foot of depth. Shallower wells can also be expected to produce less water per foot of depth than wells tapping the Principal Artesian Aquifer. Nevertheless, a water user requiring perhaps 200 gallons (750 liters) of water per minute or less may find a better cost-benefit ratio from a shallow well.

Water quality (Table 5-4) in the shallow aquifers is comparable to or better than water quality in the Principal Artesian Aquifer (Watson, 1979). Contamination of unconfined surface aquifers can be a problem, particularly in populated areas. Properly cased shallow wells completed in Pliocene-Miocene sediments are protected from surface contamination by clay interlayered with the water-bearing sands and carbonates.

5-7 General ground-water flow characteristics at Cumberland Island

Figure 5-5 is an idealized cross-section from St. Marys to Cumberland Island, summarizing the relationship of the various water-bearing units and direction of water movement. The most important aspect of this figure is that it clearly points out that the unconfined and Pliocene-Miocene aquifers are somewhat susceptible to contamination. Also in some estuaries, saline surface water may enter the Pliocene-Miocene aquifer system. If this is the case, then the Park Service should not consider constructing wells in these two aquifers; rather, the Miocene Sand Aquifer or the Principal Artesian Aquifer should be utilized.

TABLE 5-1
WELL INVENTORY OF CUMBERLAND ISLAND

Map No.	Name	Diameter	Use
001	Carriage House	4 inches	none
002	Dungeness #1	4 inches	none
003	Grange #1	4 inches	domestic
004	Grange #2	2 inches	domestic
005	NPS #1	2 inches	domestic
006	NPS #2	2 inches	domestic
007	Capt. Middleton	3 inches	domestic
008	NPS-Brickhill	2 inches	camp use
009	NPS-Stafford	2 inches	camp use
010	Dungeness #2	4 inches	none
011	NPS-barracks	2 inches	domestic
012	-	2 inches	domestic
013	-	2 inches	none
014	Greyfield #1	3 inches	domestic
015	Greyfield #2	8 inches	domestic
016	-	4 inches	none
017	-	2 inches	domestic
018	-	2 inches	domestic
019	-	2 inches	domestic
020	-	3 x 2 inches	domestic
021	-	3 inches	none
022	-	3 inches	domestic
023	-	2 inches	domestic
024	-	2 inches	domestic
025	-	2 inches	domestic
026	-	2 inches	domestic
027	-	4 inches	domestic
028	-	2 inches	none-capped
029	Dungeness Garden Well	4 inches	domestic
030	NPS-Superintendent Well	2 inches	domestic
031	-	4 inches	domestic
032	-	4 inches	domestic
033	-	2 inches	domestic
034	Stafford	6 inches	livestock
035	-	2 inches	none-capped
036	Greyfield Tower	3 inches	none
037	NPS #3	2 inches	none-capped
038	NPS #4	2 inches	domestic
039	NPS #5	2 inches	domestic

Table 5-1
WELL INVENTORY OF CUMBERLAND ISLAND
(Continued)

Map No.	Name	Diameter	Use
040	NPS #6	2 inches	domestic
041	NPS #7	2 inches	domestic
042	-	2 inches	domestic
043	-	2 inches	none
044	NPS #8	2 inches	domestic
045	-	2 inches	domestic
046	Plum Orchard #1	4 inches	domestic
047	Yankee Paradise	4 inches	camp use
048	Beach Well	*	none

* casing rusted beneath ground level

Table 5-2

MAXIMUM CONTAMINANT LEVELS FOR DRINKING WATER
(ppm)

Inorganic

Primary		Secondary	
Arsenic	0.05	Chlorine (Cl)	250.0
Barium	1.00	Copper (Cu)	1.0
Cadmium	0.01	Iron (Fe)	0.30
Chromium	0.05	Manganese (Mn)	0.05
Lead	0.05	Sulfate (SO_4)	250
Mercury	0.002	Zinc (Zn)	5
Nitrate (as N)	10.00	Total Dissolved Solids	500
Selenium	0.01		
Silver	0.05		

Organic Chemicals

Chlorinated Hydrocarbons:

Endrin	0.0002
Lindane	0.004
Methoxychlor	0.01
Toxaphene	0.005

Chlorophenoxys:

2,4-D	0.1
2,4,5-TP	0.01

Source: Rules for Safe Drinking Water, Georgia Environmental Protection Division

TABLE 5-3

ANALYSES OF WATER FROM THE PRINCIPAL ARTESIAN AQUIFER ON CUMBERLAND ISLAND, GEORGIA

Silica (SiO_2)	28 ppm	Fluoride (F)	.70 ppm
Iron (Fe)	0.16 ppm	Nitrate (NO_3)	-0-
Manganese (Mn)	-0-	Phosphate (PO_4)	-0-
Calcium (Ca)	66.25 ppm	Sulfide (S)	20.66 ppm
Magnesium (Mg)	39.50 ppm	Bicarbonate (HCO_3)	192.75 ppm
Sodium (Na)	24.00 ppm	Alkalinity as $CaCO_3$	158.25 ppm
Potassium (K)	3.00 ppm	Hardness as $CaCO_3$	328.00 ppm
Sulfate (SO_4)	165.50 ppm	Dissolved Solids	463.50 ppm
Chloride (Cl)	37.25 ppm	pH	7.47

Above values represent the mean value of all samples.

TABLE 5-4
ANALYSES OF WATER FROM THE PLIOCENE - MIOCENE AQUIFER

Silica (SiO_2)	20.3	ppm	Flouride (F)	.16	ppm
Iron (Fe)	.24	ppm	Nitrate (NO_3)	-0-	
Manganese (Mn)	-0-		Phosphate (PO_4)	-0-	
Calcium (Ca)	54.3	ppm	Sulfide (S)	15.3	ppm
Magnesium (Mg)	8.0	ppm	Bicarbonate (HCO_3)	170.6	ppm
Sodium (Na)	22.0	ppm	Alkalinity as $CaCO_3$	140.0	ppm
Potassium (K)	1.9	ppm	Hardness as $CaCO_3$	168.6	ppm
Sulfate (SO_4)	6.5	ppm	Dissolved Solids	322.2	ppm
Chloride (Cl)	50.0	ppm	pH	7.65	ppm

Above values represent the mean value of all samples.

6.0 LANDFORMS AND NATURAL VEGETATION

6-1 Introduction

Cumberland Island is typical of the Georgia barrier islands as are the landforms and the vegetation that cover it. An excellent study of the vegetation on Cumberland Island was published by Hillestad and others (1975) under contract with the National Park Service. This report dealt mainly with the ecology of Cumberland Island, but included geologic considerations which were adapted from previous works. Vegetation and natural environments on Cumberland Island were briefly mentioned in a regional study by Wharton (1978); also a brief study of the landforms on Cumberland Island was published by Henry (1973) under contract with the National Park Service. Roberts (1975), in an investigation of the geologic evolution of the south end of Cumberland Island, correlated vegetation with present landforms. The detailed study by Hillestad and others (1975) can hardly be improved upon; therefore, this study is a review of the vegetation and a more accurate analysis of landforms. Plate 2 is a landform and natural vegetation map produced from aerial photography as well as ground survey.

6-2 Beach

A beach is defined as a land area which lies within the normal tidal range. Beaches can be composed of a number of sediments ranging in size from clay size particles to whole oyster valves. The most prominent beaches on Cumberland Island are situated on the eastern side of the island. The fine-grained quartz sand beaches are as much as 300 ft (90 m) wide on the south end of Cumberland Island. The sands contain significant amounts of dark, heavy minerals which make them a darker color than the purer quartz sand beaches of the Gulf Coast. The longshore drift is north to south and therefore transports the beach sands in a southerly direction. This is evident from the rapid growth of the south end of Cumberland Island after completion of the jetty. The jetty acts as a sediment trap and causes accretion north of it; the jetty has resulted in the addition of approximately .62 $mi.^2$ (1.61 km^2) of land to Cumberland Island since 1881 (Roberts, 1975). This phenomenon was discussed by Roberts (1975) as well as by Nash (1977). There is little to no vegetation growing on the beaches on the eastern side of the island.

There are two types of beaches on the western side of the island. Beaches which border the Pleistocene portion of the island are narrow sand beaches that commonly contain appreciable amounts of clay. The sand on these beaches is largely derived from the erosion of the island itself. The clay and organic material are derived from suspended material in the waters west of the island. The most common plants on these beaches are _Salicornia sp._ and _Spartina sp._ These plants commonly appear to have reestablished themselves after being eroded from the marsh. The second type of beach is composed of the imbricated valves of the common oyster _Crassostrea virginica_. These beaches are not extensive and occur only where significant oyster populations exist. The oyster shell beaches are most common in the vicinity of the salt marsh although they are found in isolated patches along the entire length of the western side of the island. _Salicornia sp._ and _Spartina sp._ are both common on the oyster shell beaches. _Salicornia sp._ seems to be especially compatible with this environment. All beaches on the western side of the island are narrow and are too small to plot on the landforms map (Plate 2).

6-3 Salt marshes

The salt marshes on Cumberland Island are located on the western side of the island, adjoining the higher Pleistocene portion of the island. These marshes are separated from other salt marshes by the Intracoastal Waterway and Cumberland River, although they are very similar in vegetation as well as topography.

The marshes on Cumberland Island, as well as the other marshes, can be divided into high marshes and low marshes. Both of these divisions are represented as a single unit on Plate 2. The low marshes, as the name implies, are topographically lower and commonly have a clay and silt substrate. The most common plant is *Spartina alterniflora*. The high marshes are topographically higher and are composed of a coarser sandier substrate. On Cumberland Island the high marshes have a fine-to medium-grained, argillaceous sand substrate. This sand is derived from the Pleistocene core of the island, the dunes of the Holocene portion, or from spoil banks placed in the salt marsh. The major plants that vegetate the marsh are listed below:

Distichlis spicata	*Salicornia virginica*
Iva frustescens	*Spartina alterniflora*
Juniperus virginiana	*Spartina patens*
Juncus sp.	

6-4 Foredunes

The foredunes on Cumberland Island are located directly behind the beaches and extend westward to the edge of the interdune meadow. These dunes vary in size from 1.5 ft (0.5 m) to 3 ft (1 m) high to well-developed dunes 6 or more feet (2 m) high. They are composed of fine-grained, crossbedded, quartz sand with dark, heavy minerals. Because the dunes are located just back of the beach, they are subject to erosion from storms; therefore, these dunes are variable in size and shape and subject to cyclical changes. As a general rule, foredunes are eroded during the winter months because of storms and rebuilt during the summer months.

Plants on the foredunes are tolerant to an environment that includes salt spray, wind, drought, sand abrasion, burial, and occasional flooding by salt water during storms. The major plants found in this environment are listed below:

Croton punctatus	Pasaalum vaginatum
Hydrocotyle bonariensis	Sabatia stellaris
Lippia nodiflora	Uniola paniculata
Myrica cerifera	Yucca gloriosa

6-5 Interdune meadow

The interdune meadow is a flat to broadly basin-shaped area located between the foredunes and the back or rear dunes. This landform originates from zones of deflation which have subsequently become stabilized by vegetation. Because deflation areas and interdune meadows are related, they have been mapped as one unit on Plate 2. Active deflation areas commonly have a shell pavement developed to some extent on the surface, although it becomes less noticeable after vegetation begins to stabilize the area. Interdune meadows received sedimentation from windblown sand that originates from the foredunes and the beach as well as from occasional wash-over associated with storms. It should be noted that sedimentation takes places in these areas only where there is a vegetative cover.

The interdune meadow is protected from salt spray more than the beach or foredunes; therefore, a greater number of plants can survive in this environment. Hillestad and others (1975) divided the interdune meadows on Cumberland Island into several communities, each of which represents a different set of environmental conditions. The major plants found on this landform are listed below:

Andropogon virginicus	Hydrocotyle bonariensis
Chenchrus echinatus	Iva imbricata
Dichromena colorata	Myrica cerifera
Eremochla ophiuroides	Spartina patens
Eupaterium capillifolium	Yucca gloriosa

6-6 Back dunes (rear dunes) and other active dunes

The back dunes on Cumberland Island form a very prominent sand ridge, which extends almost the length of the island and is as much as 45 ft. (14 m) in height. This landform is composed of crossbedded, fine-grained quartz sand with dark, heavy minerals. Where erosion has exposed the interior of these dunes, pronounced crossbedding can be seen where the dark, heavy minerals mark the cross laminations. The dunes are formed from the prevailing easterly winds and thus migrate in a westward direction.

The vegetation over which the dune is migrating affects many aspects of the dune, including morphology and migration rate. The rate of dune migration is considerably higher where there is sparse or low vegetation. For example, the rates of migration in the Raccoon Keys Salt Marsh and the Beach Fields are higher than in areas where the dune must migrate over the oak-palmetto interior forest. The vegetation over which dunes migrate also influences the shape of the dune. As the dunes migrate over heavy vegetation, the leeward side of the dune steepens and the dune gains height.

The dunes have little vegetative cover to stabilize the sands. The major plants found in the back dune environment are listed below:

Croton punctatus	*Oenothera humifus*	*Uniola panticulata*
Myrica cerifera	*Yucca gloriosa*	

6-7 Stabilized and partially stabilized dunes

This landform represents dunes that have been partially or completely stabilized by vegetation. Excellent examples of this landform are located in the Sweetwater Complex (Fig. 2-1) and near Whitney Lake. The stabilized dunes in the Sweetwater Complex have impeded the natural drainage systems, and shallow ponds and marshes have formed at their base. These dunes have a different plant cover from those stabilized without the marshes at their base; therefore, the plant cover is variable in this landform and specific taxa will not be named. In general, the vegetative cover varies from plants described in the back dune environment to that of the oak-palmetto forests.

6-8 Inland marshes

The inland marshes on Cumberland Island can be divided into two major groups. The most common inland marsh on Cumberland Island is the freshwater marsh. These marshes form in depressions or where the natural drainge systems have been impeded. Johnson Pond is an excellent example of an inland marsh that occupies a closed depression in the land surface. Whitney Lake and the Sweetwater Complex are examples of inland ponds and marshes that have formed where sand dunes have impounded natural drainges. None of these marshes are influenced by salt water or tidal action.

These marshes contain a large number of plant taxa. The more common plants are listed below. This includes marsh, aquatic and semiaquatic plants.

Axolla coaoliniana	*Panicum hemitomon*
Cephalanthus occidentalis	*Pontderia cordata*
Cladium jamaicense	*Pontedria laceolata*
Limnobium spongia	*Sabatia stellaris*
Magnolia virginiana	*Similax auriculata*
Nelumbo luten	*Spartina bakeri*
Nymphoides aquatica	*Typha latifolia*
Nyssa sylvatica	*Ultricularia sp.*

The second type of inland marsh is a variant of the salt marsh described in 6-3 above and includes those inland marshes influenced by the saline waters of the Intracoastal Waterway and Cumberland River. Because these marshes are connected to the estuarine waters, the water level is influenced by tidal action.

The influx of salt water also influences the salinity of the marsh, but not uniformly. At high tide the salinity of the water where the estuary enters into the marsh is nearly the same as that in Cumberland Sound, but salinity appears to decrease away from the point of entry. At low tide, the waters running out of the marshes have a decreased salinity, but it is doubtful if the water ever becomes truly fresh water before the tide again floods the marshes. The salinity of water exiting the inland salt marshes at low tide is 6.5 parts per thousand, whereas the salinity of the surrounding unconfined water table is 0.5 parts per thousand as determined from adjacent monitor wells.

The vegetation of the inland salt marshes is essentially the same as that of the high salt marsh (refer to Section 6-3). In this study, the areas of decreasing salt water influence could not be mapped; therefore, the entire marsh was mapped as salt marsh on Plate 2. The substrate is black to dark gray organic clays and silts.

6-9 Interior forests

The interior forest is the largest landform mapped. This division covers the flat to rolling sands of the Pleistocene portion of the island. Hillestad and others (1975) divided the forests into several communities, which are considered one unit in this study. This division contain extensive flora. The plants listed below are the more common plants and by no means are a complete listing.

Cercis canadensis	Quercus laevis
Ilex vomitoria	Quercus nigra
Luniperus silicicola	Quercus virginiana
Lyonia ferruginea	Sabal palmetto
Nyssa sylvatica	Sassafras albidem
Pinus palustric	Serenoa repens
Pinus taeda	Vaccinium arboreum

7-0 LAND USE ON CUMBERLAND ISLAND *

7-1 Introduction

Present land use on Cumberland Island is shown on Plate 3. In the compliation of this map, it was discovered that land uses would commonly fit into more than one class. In such cases the category which was most useful in planning was chosen.

7-2 Marginal marine lands

These lands include salt marshes and beaches. The marginal marine lands are used largely for recreational purposes; the salt marshes also serve as a nutrient source for marine life important to the local seafood industry.

7-3 Agricultural lands

These lands are presently used or were used in the past as agricultural lands. There are no row crops presently being grown on Cumberland Island, although this activity was significant in the past. The present agricultural uses include pastures for livestock, hay production and pine plantations. Among the abandoned agricultural lands are those used for rice and row crops, as well as tree crops such as olives and tung nuts.

7-4 Residential lands

These areas include all residential areas in private as well as governmental ownership. Some of the private dwellings have been removed by the National Park Service since completion of the map; therefore, there may be some inaccuracies. The areas owned by the National Park Service and intended for public use have been mapped as a separate unit.

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* The reader is referred to Plate 3. Reference to the plate shows the locations of various classes of lands. Also, the land use map was prepared prior to the extensive forest fires in the summer of 1981.

7-5 Recreational lands

This class of land use overlaps many of the other classes. The recreational areas of Plate 3 are primarily used for recreation. These areas include the interior forests and the sand dune complex, as well as inland marshes and natural areas. Developed campsites are included in recreational areas although there is presently only one.

7-6 Miscellaneous lands

Airstrips also are indicated on Plate 3. Only one of those (near Stafford) is still used.

8-0 HISTORICAL CHANGES IN THE MEAN HIGH WATER SHORELINE AND NEARSHORE BATHYMETRY OF CUMBERLAND ISLAND *

8-1 History of shoreline changes, 1843-1979, general description

Cumberland Island is the largest of the Georgia coastal islands. It is nearly 19 miles (30 km) long and has an area of roughly 60 mi^2 (160 km^2) of which nearly two thirds are above spring tide. Net erosion and accretion for the periods 1843 to 1974 are shown in Figure 8-1. The curves depicting cumulative changes and rates are illustrated in Figures 8-2 and 8-3. Figures 8-4 shows the changes in the mean highwater (M.H.W.) shoreline for the northern part of the island for the period 1869 to 1965. Figure 8-5 shows the changes in the M.H.W. shoreline in the central part of the island from 1871 to 1962 and Figure 8-6 shows the changes in the M.H.W. shoreline in the southern part of the island for the period 1873 to 1971. Figure 8-7 shows the various positions of the M.H.W. shoreline during the period 1857 to 1979; Figure 8-8 summarizes net accretion and erosion along the shoreline over that 122-year period.

Little Cumberland Island is separated from the main body of the island by marsh and a small, but active, tidal inlet, which for the purposes of this section will be considered collectively with the main island mass. Broad sandy beaches flank the ocean and inlet margins, merging into extensive but discontinuous dune systems of over 65 ft (20 m) relief that extend inland for approximately 0.6 mi (1 km). Except for the St. Marys Entrance jetties on the south end of the island, no man-made beach structures are present.

8-2 Northern segment

The northwestern tip of Cumberland Island has averaged 5 ft (1.5 m)/yr. erosion over the past 100 years. In the vicinity of transect C3 (Figure 8-4) net

* Sections 8-2 through 8-10 are rather technical and need not be read for an overall understanding of how shoreline changes may effect the management of Cumberland Island.

erosion for the 46-year period between 1871 and 1917 was followed by oscillations of accretion and erosion, resulting in a slight net gain for the 103 year period between 1871 and 1974. For the same period, oscillations also were superimposed on the accretional trend of the northeastern tip where a maximum advance of 1260 ft (384 m) adjacent to transect C5 (Fig. 8-4) resulted in a net gain of over 0.08 mi^2 (0.2 km^2). Reversals of the erosion and accretion rates illustrate the highly changeable nature of the section of shoreline from transect C6 south to Christmas Creek inlet. Negligible net change has occurred in the vicinity of transect C7, although north of this point erosion has been predominant. South of transect C7 the shoreline has prograded 1400 ft (430 m), largely as the result of the formation of a tidal delta by Christmas Creek. Since 1885 accretion has been predominant along the Little Cumberland Island shoreline, although appreciable erosion (approximately 10 ft/yr (3 m/yr)) occurred in the area adjacent to transect C6. The section between transects C3 and C9 (Fig. 8-4) was significantly eroded by Hurricane Dora; however, cumulative curves shown in Figure 8-2 indicate only a slight net effect relative to long-term rates of shoreline change.

8-3 Central segment

In the Long Point area (Fig. 8-4), accretion of approximately 0.4 mi^2 (1 km^2) has occurred since 1869, over 70 percent of which occurred prior to 1924. The section of beach extending approximately 2.5 mi (4 km) south and 1 mi (1.5 km) north of transect C11 (Fig. 8-1) averaged over 160 ft (50 m) of erosion prior to 1924. Since that time the trend has reversed to one of gradual accretion. Along this section of coast, relatively high and stable dunes are situated behind a wide plain of unstable and partially stable dunes.

The unstable area approximately corresponds to the zone of beach recovery since 1924. The southern half of the island has a gently curving arcuate shoreline along the northern section of which southeastern progradation has occurred, resulting in a gain of approximately 0.3 mi^2 (0.8 km^2) since 1971. At transect C12 (Figures 8-1 and 8-4) accretion amounted to approximately 22 ft (6.6 m)/yr. The 1871 shoreline in this area closely corresponds to a line of relatively high and unstable dunes that are migrating over a forested area. Further south, at transect C13 (Fig. 8-1) the shore has been accreting since 1924. Approximately 330 ft (100 m) of shoreline that had been eroded prior to 1917 had recovered by 1958; this recovery continued until 1974; between 1974 and 1979, however, significant shoreline retreat has occurred. A comparison of 1962, 1964, and 1965 U.S. Geological Survey aerial photographs shows that the entire central segment of shoreline was eroded during Hurricane Dora in 1964 but had rapidly recovered by 1965.

8-4 Southern segment

The shoreline of the southern segment of Cumberland Island has been significantly influenced by the emplacement of large jetties, extending 2.5 mi (4.1 km) and 1.5 mi (2.4 km) seaward from the southern end of Cumberland Island and the northern end of Amelia Island, respectively. Prior to the initiation of their construction in 1881, the southeastern end of Cumberland was rapidly eroding. Early reports by the U.S. Army Corps of Engineers (1865 and 1879) described the St. Marys Entrance as having increased in width by 1590 ft (484 m) from 1843 to 1857 and an additional 213 ft (65 m) by 1879. Maximum rate of shoreline loss was 220,000 ft^2 (0.02 km^2)/yr along the inlet throat (between transect C16 (Fig. 8-6) and Beach Creek) on Cumberland from 1943 to 1957; shoreline loss had decreased to 75,000 ft^2 (0.007 km^2)/yr from 1857 to 1876. Simultaneous shoaling and shifting of the main channel prompted the Corps of Engineers to initiate jetty construction at the entrance channel in 1881.

Figure 8-3 shows the reversal of this erosional trend following the emplacement of the jetties. The southernmost end of Cumberland Island stabilized and the southeastern segment of the island rapidly accreted. Shoreline advance was greatest at the inlet throat where there was a maximum gain of 1.1 mi (1.75 km) along transect C18 (Fig. 8-6) since 1876 at a rate of 60 ft (18 m)/yr. Accretion decreased to the north away from the influence of the jetties. During the period 1888 to 1902, the rate of accretion slowed, possibly reflecting the passage of the severe hurricane of 1898. The now extinct meander of Beach Creek (Fig. 8-6) was cut through to the ocean during this hurricane. This cut separated the island into two parts before a dike was constructed, re-establishing the shoreline. After the dike was constructed, the beach in that area rapidly accreted and the meander was abandoned by the main flow of Beach Creek. Narrow, discontinuous lines of partially stable dunes now approximate the positions of the 1898 and 1917 shorelines which are separated by larger stabilized dune areas. Nearly 0.8 mi^2 (2 km^2) of land have been added to the southern end of Cumberland Island since the emplacement of the jetties. Between 1852 and 1974 the southern end of the island accreted, although net loss occurred in the vicinity of transect C15 (Fig. 8-1). Low-lying areas of the highly accretional southern end were typified by free sand or poorly vegetated low foredunes, which were easily inundated by the high water levels associated with Hurricane Dora. Maximum shoreline recession of approximately 650 ft (200 m) occurred at transect C15 (Fig. 8-3) during this minor hurricane.

8-5 Historical bathymetric changes in the ebb-tidal deltas and shoal areas

8-5-1 General statement:

A comparison of hydrographic smooth sheets for St. Andrew and St. Marys inlets has provided evidence concerning the historical changes in the position, size, and configuration of the channels and associated shoals. These dynamic environments exert extensive control over the adjacent barrier shorelines. For example, navigational improvements at both St. Simons Sound and St. Marys Entrance exert a strong influence on bathymetric changes in those areas.

8-5-2 St. Andrew Sound:

Transect locations and ebb-tidal delta configurations are shown in Figure 8-9. Bathymetric profiles at each transect are given in Figures 8-10 and 8-11. Volume changes were calculated for the period 1869-71 to 1924. No other complete bathymetric surveys of the St. Andrew ebb-tidal delta were made after 1924.

St. Andrew Sound separates Jekyll Island from Cumberland Island and is over 2.5 mi (4 km) wide at its narrowest point. The sound is the largest on the Georgia coast and connects the ocean with the Satilla, Little Satilla, and Cumberland Rivers and Jointer and Jekyll Creeks. Maximum depths in the inlet throat area are approximately 90 ft (27 m). An extensive system of marginal and distal shoals borders the northern margin of the entrance channel, which continues 7.5 mi (12 km) seaward of the inlet in a gently-curving arc to a point 3.7 mi (6 km) off Long Point on Cumberland Island.

For the 55-year period 1869 to 1924, losses in sediment volume below the 1969 M.H.W. shoreline are estimated to be 2.3×10^8 ft^3 ($6.4 \times 10^6 m^3$) and shoreline accretion seaward of the 1969 M.H.W. shoreline was $1.1 \times 10^9 ft^3$ ($30.4 \times 10^6 m^3$). Rates of erosion were higher in the entrance channel, which deepened and lengthened seaward. Although no completed survey of the ebb-tidal delta has been done to date, a recent survey (1976) by the U.S. Coast and Geodetic Survey of the north marginal shoals area shows a general increase in the shoal volume along the periphery of the northern-marginal and distal shoals. This survey modified only portions of the original 1924 survey.

The three major sound channels shown in transect 5 (Fig. 8-10) merge at the inlet throat. Cross-sections of the northern and middle channels have been reduced in area, largely by accretion along their margins from 1869 to 1935. At transect 6 (Fig. 8-10), major sound channels have merged to form two main channels of which the south channel is considerably larger and acts as the primary drainageway for the sound (Howard, 1971). The south channel has eroded the margins of the centrally located shoal area from 1869 to 1935 and has migrated up to 1300 ft (400 m) to the south at a depth of 50 ft (15 m), resulting in an increase in its cross-sectional area.

Although southerly migration of the main channel is not evident on transects 7 and 8 (Fig. 8-10), minor southward migration occurred along the entire length of the entrance channel seaward of the inlet from 1869 to 1924. A funnel-shaped channel, similar in area and running parallel to the main channel, forms the northern boundary of the northern-marginal shoals (Fig. 8-10). This channel, first discernible at the 23 ft (7 m) depth, becomes more conspicuous as it narrows and shoals landward. It eventually transects the marginal shoals off the south end of Jekyll Island and connects with the main channel at the inlet throat. Similar features are present at most Georgia inlets but are not as well developed as the St. Andrew Sound entrance.

Transects 7 and 8 cross both the main channels and the funnel channel and show the general deepening and migration of the funnel channel to the south. Because no shoaling occurred on the north side of the funnel channel, a general widening resulted from 1869 to 1924. During the same period, the funnel channel also deepened and extended landward. A comparison of the 1924 survey with modifications from the 1976 survey indicates that there has been little change in the position of the main channel or the funnel channel. However, there has been a shoaling of the funnel channel and an extension of the distal shoals to the south. The extension of the distal shoals effectively increases the length of the main channel by more than 0.6 mi (1 km) before crossing the shoal system.

Marginal shoals along the northern boundary of the main channel have shallowed and migrated south following the trend of the channel. Contemporaneous erosion of their northern flanks, due to the southward migration of the funnel channel, resulted in a net loss in sediment volume primarily below the 6 ft (1.8 m) isobath. The northern shoals were an essentially stable area, although their east-west trend became highly segmented by an increase in the number and size of channels similar to those described by Oertel (1975) as "spill-over channels". A comparison of the 1924 survey with the modified 1976 survey shows that two of these channels, which trend northeast, have deepened and cut through the northern marginal shoal system connecting the main channel with the funnel channel. South of the main channel, shoals inside the 18 ft (5.5 m) isobath have deepened nearly uniformly as shown on transect 9 (Fig. 8-11).

8-5-3 St. Marys Entrance:

The St. Marys Entrance is bordered by Cumberland Island to the north and Amelia Island to the south. Two large jetties extend 2.5 mi (4.1) km and 1.5 mi (2.4 km) seaward from the southern end of Cumberland Island and the northern end of Amelia Island, respectively. Tidal flow is confined within the jetties where a depth of about 33 ft (10 m) is maintained by dredging. Maximum depths at the inlet throat are approximately 70 ft (21 m). The inlet carries tidal flow between Cumberland Sound and the Amelia River, which drain marsh areas behind Cumberland and Amelia Islands, and the ocean. The inlet also receives tidal and freshwater flow from the St. Marys River, whose principal drainage originates in the Okeefenokee Swamp. The inlet configurations at St. Marys Entrance before construction of the jetties in 1876 and the present configuration are shown in Figure 8-12.

Construction of the jetties at St. Marys Entrance was initiated in 1881 with the laying of the foundation for the north jetty (U.S. Army Corps of Engineers, 1902). At that time, five groins were constructed along the shoreline adjacent to Fort Clinch to retard shoreline erosion. The initial proposal called for twin jetties, the outer end of each jetty to be constructed at a height of half tide and the shore ends to M.L.W. By 1883 it was evident that the jetties needed to be raised to a higher level in response to current-scouring near the shore of Cumberland Island. This scour resulted from the persistence of a flood-oriented funnel channel near the base of Cumberland Island (Fig. 8-12). Erosion persisted also in the vicinity of Fort Clinch and two additional groins were constructed. Approximately 330 ft (100 m) of accretion had occurred at the base of the south jetty by 1886.

As work proceeded on the jetties, a southward migration of the northern-marginal shoals, upon which the northern jetty was being constructed, caused shoaling of the project channel to such an extent as to require the opening of a gap in the south jetty (i.e. Amelia Island jetty) along the line of the old main channel to accomodate navigation. To prevent further encroachment of the shoals, the north jetty was extended and raised (U.S. Army Corps of Engineers, 1891). As this work progressed, a new channel began to form inside and adjacent to the north jetty which extended into the shoals. By 1899, flow through the gap in the south jetty was reduced and dredging operations began the removal of shoal material obstructing the jetty entrance seaward of the gap. Lengthening of the north jetty and dredging of the channel shoals permitted closing of the south jetty gap. With the jetties completed, the tidal current flow and the development of a more efficient ebb flow caused the scouring of the channel and the further removal of shoal material (U.S. Corps of Engineers, 1902).

As previously mentioned, the major hurricane of October 1898 cut through the beach on the south end of Cumberland Island, connecting the ocean with Beach Creek (Fig. 8-6). This breach in the shoreline rapidly widened and deepened, probably in response to flood tidal and littoral flow now restricted by the north jetty. To close the breach, a pile and stone dike 1.3 mi (2.1 km) long was constructed in 1904 from the shore end of the jetty and tied to the northwest high ground. Work on the jetties was completed at this time, although between 1905 and 1913 considerable jetty maintenance work was carried out.

In 1927 the north jetty was raised to 12 in (35 cm) above the M.H.W. and the south jetty was raised to 2 in (6 cm) below M.H.W. The channel has been subject to periodic maintenance dredging with disposal areas offshore, in tidal creeks and in deep areas of the inlet throat since 1903. The channel was realigned to a position within the natural channel near the south jetty in 1956 survey. The U.S. Army Corps of Engineers (1961) estimated an annual rate of shoaling of 4.0 x $10^6 ft^3$ (11.4 x $10^4 m^3$). Records of the entrance channel dredging (U.S. Army Corps of Engineers, 1961) show that between 1903 and 1956 a total of 9.2 x $10^7 ft^3$ (2.6 x $10^6 m^3$) has been dredged from the St. Marys Entrance. Dredged channels of the Atlantic Intracoastal Waterway, to the north and south of Cumberland Sound, extend to the deep gorge of the main channel.

The ebb delta configuration prior to the construction of the jetties is shown in Figure 8-12. The main channel extended 1.7 mi (2.8 km) seaward of the inlet to a point of bifurcation in 23 ft (7 m) of water. Large, arcuate, marginal shoals bordered the channel on the north; and distal shoals extended around the delta front to the south. The northern channel crossed the distal shoals almost 1.2 mi (2 km) north of the south channel (Fig. 8-12). Although the southern channel was longer and deeper, the northern channel followed a more direct course which continued west from the main channel and crossed the distal shoals with a minimum depth of 10 ft (3 m). At the point of bifurcation, the south channel hooked to the southeast and continued along the inner margin of the shoals before attenuating into distal shoals with a minimum depth of 10 ft (3 m). Both channels were approximately symmetrical in cross-section as was the main channel seaward of the inlet.

Surveys of 1843, 1856, and 1876 show the rapid migration of both channels to the south. From 1843 to 1876 the south channel lengthened and began to parallel the trend of the Amelia Island shoreline. The lengthening was forced by a southern migration of the distal shoal system and resulted in a decrease in flow efficiency for the south channel. A simultaneous migration of the north channel during this period was coupled with an increase in flow capacity as it cut into the distal shoals and extended seaward. Between 1856 and 1876 the ebb-tidal delta volume increased 1.8 x $10^8 ft^3$ (5.1 x $10^6 m^3$), primarily due to enlargement of the distal shoal system and shoaling in the south channel. During this same period a new north channel was formed further to the north, which may have been subsequent to the abandonment of the old south channel; or, the new north channel also may have formed after the two older channels had migrated to the south and shoaled to such an extent as to require a more direct route to the sea for efficient ebb flow. The new north channel probably would have then begun to migrate to the south and continued the cyclic pattern of channel migration and abandonment.

8-6 Discussion - net shoreline changes

Considering the total ocean shorelines of the barrier islands from St. Simons Island to Little Talbot Island, there has been minor net accretion amounting to approximately 1.5 mi^2 (4 km^2) since the mid-nineteenth century. The estimated volumetric increase along the shoreline was based on the empirical relationship that a gain of one square foot (930 cm^2) of area along the shoreline is equivalent to a volumetric gain of one cubic yard (0.8 m^3) of sediment (U.S. Army Corps of Engineers, 1966). By this relationship approximately 1.1 x $10^9 ft^3$ (32 x $10^6 m^3$) of sediment has been added to the ocean shoreline between the mid-nineteenth century and 1974. Although limited bathymetric evidence does not allow a direct comparison of volume change per time period, the shoreline gains approximate the net volume loss between the 18 ft (5.5 m) depth contour and the mid-nineteenth century M.H.W. shoreline. These data indicate that sediment input roughly equaled sediment loss within the nearshore zone.

Accretion above the M.H.W. shoreline has been dominant along the lower Georgia coast; however, when comparing linear distances along the coast, erosional shorelines approximately equal depositional shorelines (Fig. 8-13). This disparity results from the intensified accretion in a relatively small area adjacent to the St. Marys Entrance jetties, where over 80 percent of the total accretion above the M.H.W. shoreline has occurred. If the erosional and accretional trends in the vicinity of St. Marys Entrance had not been altered by jetty construction, a net erosion of roughly .035 mi^2 (0.09 km^2) would have resulted. This estimate of net erosion is likely to be high because rate-of-change curves indicate a slowing of rates of erosion on the south end of Cumberland Island prior to the emplacement of the jetties.

Shoreline segments experiencing greatest net change and greatest rates of change are the northern and southern thirds of the island and along inlet margins. Maximum rates of accretion occurred on the south end of Cumberland Island south of transect C13 (Fig. 8-1) where almost 640,000 ft^3 (18,000 m^3) of sediment per year were deposited for the period 1876 to 1974. However, a recent increase in the rate of erosion has occurred in the south-central portion of Cumberland Island in an area historically characterized by relatively minor shoreline oscillations. Comparing Fig. 8-1 with Figures 8-7 and 8-8 at the approximate location on transect C13, almost 700 ft (200 m) of retreat has occurred between 1974 and 1979. This figure may be somewhat misleading as the 1979 measurement was based on aerial photos taken the day after Hurricane David (September 4, 1979). Significant net erosion also has occurred along small isolated sections of Little Cumberland Island.

8-7 Relations of shoreline change to coastal processes

While it is possible to evaluate coastal stability within the study area based on a qualitative knowledge of the sediment transport characteristics and long-term coastal changes, a more accurate evaluation of coastal stability would require quantitative knowledge of the supply of energy and sediment budget. However, sufficient field data to evaluate these factors does not exist. Quantification of the sediment budget would be highly speculatory in nature, and although mathematical formulas have been derived for sediment transport model studies, problems with scale restrict the field use of such formulas to the relatively simple situations.

Sediment sources and sinks must be considered in terms of the potential transporting agents such as wind, waves, tidal and non-tidal currents, and the inter-relationship of these agents which necessitates their consideration as a system. When the supply and loss of material are equal and constant, the shoreline will eventually attain stability. However, the two principal sources of energy, tides and wave action, are continually changing, which causes the shoreline to be in a state of dynamic equilibrium. That is, even given a constant supply and loss of material, the shoreline will never appear stable within a short time reference of months or years. The shallow shoreface will be continually approaching equilibrium with respect to wave and tidal energy. Sea-level rise short-term trends can also be erratic. For this reason, erosional and accretional trends only can be assessed over periods of decades or perhaps even centuries.

8-8 Natural causes of erosion and accretion - sea level rise

A theoretical model for sea-level rise as a cause of shoreline erosion was introduced by Bruun (1962) and favorably evaluated by Schwartz (1967, 1968) from model and field studies. This theory demonstrates how dynamic equilibrium is maintained during sea level rise along relatively straight shorelines where the sediment budget is in longshore quantitative equilibrium. The effective maintenance of equilibrium varies with sediment, wave, current and slope characteristics. Gentle slopes give rise to a phase-difference between "action", or sea-level rise, and "reaction", or shoreline erosion and offshore deposition (Bruun, 1962). However, dominance of tidal inlets on sedimentary processes, a gently sloping nearshore zone, and paucity of severe storms and hurricanes over the past few decades may have obscured this process in the study area.

The influence of the nodal tidal cycle, combined with sea-level rise, may have caused significant variations in the vertical positions of M.H.W. and M.L.W. shorelines that could have resulted in erroneous estimates of sediment volume in transport, particularly when survey dates fall at different points of the 18.6 year lunar cycle. Of particular significance is the increase in the elevation of the

M.L.W. shoreline caused by a rise in sea level, because offshore delta and shoal volumes were based on the position of M.L.W. As an example, the area encompassed by the volume change survey at St. Andrew Sound was over 40 mi^2 (100 km^2). Within this area a sea-level rise of approximately 4.3 in (11 cm) (Hicks, 1973) from 1929 to 1971 would effectively reduce delta shoal volume by roughly 4.0 x $10^8 ft^3$ (11 x $10^6 m^3$). Although a sea-level rise of this magnitude falls easily within the limits of error when comparing old hydrographic surveys, the effect would be a positive change in volume estimates, possibly as much as 100 percent. Adjusting for known sea-level rise and assuming a constant tidal range for the period 1924 to 1954, volume loss estimates would decrease by 14 percent for St. Marys Entrance. The original volume change estimates, however, may still be considered a net loss in sediment volume because a rise in sea level essentially reduces these shoal areas by submerging them.

8-9 Hydraulic and sedimentary processes at inlets

The most readily observable changes during the period covered by this study were southerly channel migrations in the outer portions of the ebb-tidal deltas, where littoral currents become relatively stronger with respect to tidal currents. Because the Coriolis Force can be considered negligible (Bruun and Gerritsen, 1960), wave energy must be the primary force in accomplishing such migrations in the outer ebb-tidal delta. Wave energy also counteracts the seaward movement of sediments by ebb-tidal flow. The dominant influence of relatively high energy waves from the northeast on delta configuration increases away from the axis of the main channel. This effect is augmented and reflected from north to south by: 1) increased rates of channel migration, 2) the decrease in tidal prisms and corresponding decrease in the dominance of tidal currents over littoral currents seaward of the inlet throat, and 3) the lesser refraction of waves approaching from the northeast resulting from the alignment of the shoreline, nearshore bathymetry and the bottom gradient.

Channel migration is a cyclic process in the outer reaches of the ebb-tidal deltas. Both the rate of channel migration and the length of the channel affected are a function of wave and tidal energy, although the process is somewhat modified by the initial direction of the ebb-tidal jet. One complete cycle is on the order of decades for St. Marys Entrance and 100 to 150 years for St. Andrews Sound.

It is evident that a southward migration of the outer main ebb-tidal channel eventually results in a reduction of channel flow efficiency. This is seen at St. Marys Entrance where southward channel migration results from the southward development of distal shoals along the outer margin of the channel. The southward growth and development of distal shoals indicates the on-going process of by-passing. At some point in time, this southward shoal development restricts ebb flow efficiency to such an extent that a new channel is formed to re-establish a more direct and efficient ebb-tidal exit. The new channel is located to the north of the old channel and its formation is probably initiated during periods of higher tides. Initially, the channel is relatively small and shares the volume of water jetted seaward during ebb tide. However, the high efficiency of the new channel eventually results in an increase of its flow capacity while simultaneous shoaling occurs in the old channel. As sediment by-passing is established by wave action, the development of distal shoals begins to force the southward migration of the new channel.

Wave refraction plays a significant role in the accumulation of sand at ebb-tidal deltas. Waves approaching approximately normal to the shoreline are refracted by the delta shoal system and the resulting littoral drift is directed toward the shoreline on both sides of the inlet. Because there is a dominant direction of wave energy from the northeast, offsets develop on the downdrift or southern sides of the inlets (O'Brien, 1969). This process results from the development of an energy shadow south of the ebb-tidal delta in which material carried by the shoreward component of littoral transport is deposited. Such offsets are clearly evident at St. Marys Entrance and St. Andrew Sound.

Erosional and depositional trends at the northernmost parts of the island are indicative of the relationship between sedimentary transport characteristics in these areas and the hydraulics of associated inlet systems. At the north end of Cumberland, net littoral transport to the north results from the sheltering effects of the ebb-tidal deltas which restrict the approach of waves from the northeast. Lower energy southeast waves produce northward littoral movement in concert with flood tidal flow.

A centrally located shoal system such as Stafford Shoal off Cumberland Island (Fig. 8-14) may also be related to the influence of tidal hydraulics. Similar features are present along most Georgia barrier islands. The central location of these shoals between inlets suggests a possible formation in response to an energy minimum with respect to tidal flow. During flood tide, tidal currents converge on the inlets from both sides, resulting in an area of relatively slack water near the center of an island. Although tidal flow near the sea flood-tide convergence is probably incapable of inducing significant bedload sediment movement, such currents may be capable of imparting movement to sediment suspended by shoaling waves.

Transect C12 (Fig. 8-5) is at the southern extreme of Stafford Shoal on Cumberland Island, where a net sediment transport to the south has resulted in the development of a prograding foreland and the accretion of 2.3×10^{8} ft^{3} (6.6×10^{6} m^{3}) of sediment inside the present trend of the M.H.W. shoreline between 1871 and 1974. However, the outer portion of Stafford Shoal is strongly skewed to the north indicating that, while alongshore littoral processes clearly impart a net southward drift, the more constant tidal influence may be more important offshore.

Upon approaching the south ends of the islands, the dominant southward littoral drift becomes intensified during flood tidal flow. As on the north ends of the island, however, accretion is limited by the proximity of the inlet throat to the associated channels and sediment supply. The positions of flood-dominated funnel channels have considerable control over sedimentary transport characteristics at the south ends of the islands. During the period from 1843 to 1976, prior to the construction of the jetties at St. Marys Entrance, an apparently flood-dominated funnel channel crossed the northern marginal shoals near the south end of Cumberland Island (Fig. 8-12). This channel migrated to the northwest and caused the erosion on the south end of the island for that period. Construction of the north jetty eventually terminated tidal flow through this channel. However, the erosion on the south end of Cumberland Island during that period may not have continued if the flood channel was subject to cyclic migrations.

The transfer of sand past inlets and the accumulation of sand at inlet-associated shoals and deltas are of extreme importance to an understanding of the sediment budget and related shoreline movement in the study area. Although by-passing actively occurs at these inlets, increases in delta and shoal volumes suggest that these areas still function as vast sediment sinks for material in littoral transport and have not yet attained a balance between the sedimentary and hydraulic characteristics of the inlet and ambient wave forces. This may result primarily from changes in sea level.

Brunn and Gerritsen (1960) and Brunn (1962) quantitatively analyzed the important relationship of littoral drift and tidal flow to inlet stability. However, sufficient field data do not yet exist in the study area to determine by-passing stability, locational stability, or cross-sectional stability in the study area. The ratio of "tidal prism" to "mean annual net amount of littoral drift" provides a relative measure of inlet stability (Brunn and Gerritsen, 1960). Accordingly, there is a decrease in stability to the south in the study area. Inlet stability also varies with changes in the tidal prism, minimum cross-sectional area of the inlet and sediment supply. These changes may be brought about by: the filling of estuarine storage areas; the trapping of river sediment; the landward transport of suspended and fine sediment; sea level changes; lateral and vertical marsh expansion; sediment compaction, subsidence or uplift; and man-made alterations such as the construction of dams in mainland rivers, the dredging of sounds and intracoastal waterways, shoreline construction, the dredging of entrance channels, or the construction of jetties. Although the relative importance of each of these is difficult to assess, man-made alterations of both St. Marys Entrance and St. Simons Sound are clearly the controlling factors in these areas.

At St. Marys Entrance, erosion of the inlet margins and shoaling of the inlet occurred prior to the construction of the jetties. The natural process primarily involved a change in inlet morphology and hydraulics rather than changes in cross-sectional areas of the inlet throat or the tidal prism and may have resulted from: 1) a rapidly increased rate of littoral drift due to the severe hurricanes of the late 1800's and subsequent shoaling of the inlet, 2) the deepening and lengthening of existing channels, or 3) the formation of additional channels. All of the above possibilities would account for the redistribution of tidal flow rather than a change in the tidal prism.

8-10 Severe storms and hurricanes

Severe storms and hurricanes may cause significant modification of the coastal zone and inner shelf within relatively short periods of time. These high energy events may also be of greater significance in the geologic record than the predominant lower energy conditions. Equilibrium adjustments in nearshore and inlet areas may be largely accomplished by high energy events. The intensity, duration, and frequency of severe storms significantly determines the rate of shoreline response to a rise in sea level, growth and development of dunes, shoaling, migration of inlet channels, and the response of nearshore areas to man-made alterations of the sediment budget.

Beaches are subject to cyclic changes related primarily to transient meteorologic conditions. Johnson (1949) found that deepwater wave steepness (H_0/L_0) was an important factor determining whether a nearshore profile was aggradational or erosional. Numerous field and model studies (Shepard, 1950; Saville, 1957; Iwagaki and Noda, 1963; Johnson and Eagleson, 1966; Hayes, 1971; Sonu and Van Beek, 1971; Dean, 1973, and others) have shown the relationship of wave steepness to the development of either a summer/normal or winter/storm profile. Recent coverage of this subject by Dean (1973, 1976) demonstrated the importance of additional factors in onshore-offshore transport, including the fall velocity of sand particles, the breaking wave height, and wind drift currents. Generally, the formation of a winter or storm beach following mild summer conditions involves the removal of sand from the upper beach, which often results in the formation of a scarp at the foot of the dune line. The seaward movement of this eroded material causes a reduction in the slope of the shoreface profile. In conjunction with the offshore transport of sand, a seaward shift in the breaker zone results in the formation of an offshore bar. A return to gentle summer wave conditions generally causes a reversal of these processes. Onshore transport of the material stored in the bar is commonly accomplished by the landward migration of ridge and runnel systems which eventually weld onto the beach face and reestablish the summer profile (Johnson, 1949; Saville, 1957; Dean, 1976).

Generally, low wave energy levels in the study area indicate that shoreface profiles should undergo equilibrium adjustments within a relatively shallow nearshore zone. A rise in sea level may cause a sediment deficit to exist seaward of that portion of the profile in which equilibrium is maintained with respect to relatively low energy waves. Tidal flow in conjunction with oscillatory wave motion may also move sediment at depths greater than those to which the shoreface profile can rapidly adjust. Under these conditions, offshore transport during a severe storm or hurricane would supply material to the undernourished portion of the profile and reestablish equilibrium to depth only modified by rare high-energy conditions.

Ebb-tidal deltas would significantly modify the effects of a severe storm. Although such modifications would greatly depend on the stage of the tidal cycle with respect to the duration and peak intensity of the storm, the delta would probably buffer adjacent shorelines. A portion of the incident wave energy would be dissipated on the shoal systems. Also, the shoal system would supply sediment to undernourished nearshore areas because of an increased rate of littoral drift, possibly intensified by increased flood tidal flow. These factors would further reduce incident wave energy and associated offshore transport.

Shoreline accretion in the study area is reflected in development of parallel beach/dune ridge complexes, a process that begins with an excess of sand in the nearshore zone. In many cases, this excess may result from the lateral movement of large volumes of sand during severe storms. As the shoreface profile attains equilibrium, the sediment excess is deposited in the form of low sand ridges. Once established above M.H.W., beach ridges may be altered by eolian processes or perhaps partially or completely eroded by storm surge. The ultimate heightening or deflation of a beach/dune ridge will depend principally on climatic conditions, the development of stabilizing vegetation and the supply of material to the shoreline. High ridges may result from the destruction of the lower ridges and foredune complexes by a severe storm. Major high dune lines on several of the islands correspond to late 19th century shoreline positions and probably reflect significant devegetation by the several hurricanes of that period, particularly the storm of 1898 (Figs. 8-5, and 8-6).

8-11 Man's influence in the coastal zone

Barrier island shorelines and inlets in the study area are considered to be in a state of dynamic equilibrium with the nearshore sand prism. Because there exists a delicate balance of opposing forces which control this equilibrium, any man-made alteration of the coastal zone will commonly be reflected in a modification of sediment transport characteristics. Jetty construction, dredging operations, the destruction of dunes and attempts to stabilize the shoreline by the construction of seawalls and groins have all affected shoreline stability within the study area.

The construction of jetties at St. Marys Entrance was proposed to eliminate the problems of shoaling and shifting navigation channels. Side effects to jetty construction are: 1) a drastic alteration of the ebb-tidal deltal system, 2) initially intensified accretion immediately adjacent to the jetties, 3) the probable elimination of by-passing, and 4) the development of a vast sediment sink seaward of the jetties. The apparent intensification of erosional trends along the shoreline of Amelia Island may also be influenced by the construction of the jetties.

Although tidal flow is essentially confined within the jetties, a portion of both the ebb and flood flow passes over and through the jetties. This process, evident from a cursory examination of aerial and LANDSAT satellite photographs, is particularly important. Much of the sediment in littoral transport that is transported over and through the jetties is subsequently carried seaward with ebb-tidal flow. Although sediment that has passed through the jetties may have contributed to substantial accretion on the south end of Cumberland Island at transect C18 and C19 (Fig. 8-6) and on the north end of Amelia Island, most of the sediment has been deposited seaward of the jetties and lost to the littoral system. The extensive shoal area, developed seaward of the jetties and which exhibits only minor southward movement, is far from approaching the dimensions necessary to re-establish sediment transport under normal wave conditions.

8-12 Destruction of dunes

Despite a longstanding recognition of the importance of coastal dunes by both scientific and public sectors, much of the dune system on St. Simons, Jekyll and Amelia Islands has been destroyed. The resulting accelerated erosion has prompted the construction of groins and seawalls on St. Simons, Jekyll and Amelia Islands. Such structures are only temporarily effective and not only reduce the recreational value of the shoreline, but often increase the long-term problem of shoreline recession. By destroying the flexibility of the beach, these structures must withstand the full force of storm waves, and this commonly results in an increase in the erosion of sediment from in front of them. This eventually results in their collapse, as has been the case along the south end of St. Simons Island and central areas of Jekyll Island. Furthermore, along sections of shoreline protected by seawalls, there is less material available for the development of a storm profile. Adjacent, unstabilized sections of shoreline undergo accelerated erosion to fill this deficit. As is usually the case, the construction of a groin or section of seawall precipitates the construction of another such structure downdrift.

Much of the dune system on Cumberland Island has been altered by the early introduction of large grazing animals, primarily hogs and horses. Overgrazing has resulted in the formation of large migrating dunes and deflation areas. An 1870 topographic survey shows extensive dunes already established along the northern half of Cumberland Island. A 1956 survey, however, depicts eroding forests bordering the south central shoreline, a condition similar to that seen on the northern end of Jekyll Island today.

A comparison of 1977 and 1956 topographic surveys shows a general widening of the dune system along most of the island. These high migrating dunes not only destroy additional inland vegetation but also function as a vast sediment sink.

The dune system along the central and south central sections of the islands increased in size and height to where 50 to 65 ft (15 to 20 m) high dunes migrate over meadows, ponds, and forests, (see Fig. 8-15). Expanses of active and inactive deflation areas front the seaward side of the migrating dunes.

Apparently, overgrazing of low areas on Cumberland Island increased their susceptibility to wind deflation and storm attack, which eventually flattened any ridges which may have formed. Areas once similar in appearance to deflation zones on Cumberland Island correlate with large scale erosional losses on north central Jekyll and Amelia Islands for the period 1856 to 1871 and on southern Amelia

Island for the period 1871 to 1924. Overgrazing may have contributed significantly to the initiation of such losses; the erosion, in turn, probably was enhanced by severe storms or hurricanes.

The National Park Service has constructed enclosures in some deflation areas on Cumberland Island. These fenced-off areas prevented grazing by free ranging animals and, within a one-year period, there were significant increases in vegetation within the enclosures.

8-13 Summary and conclusions

During the 131-year period between 1843 and 1974, the shoreline and nearshore zone from St. Simons Island, Georgia, to Little Talbot Island, Florida, have experienced significant changes in position and volume, respectively (Fig. 8-13). In terms of net change, accretion has been slightly dominant during the period of study with progradation occurring along approximately 60 percent of the shoreline. Within the past two decades, however, over 50 percent of the shorelines in the study area have undergone net erosion.

Shoreline areas experiencing greatest net change and greatest rates of change are the northern and southern thirds of the islands and along the sound margins. Induced by the construction of the St. Marys Entrance jetties, maximum rates of accretion occurred on the south end of Cumberland Island where approximately 640,000 ft^3 (18,000 m^3) of sediment per year were deposited during the period 1876 to 1974. Also, the highest rate of shoreline advance, 60 ft (18 m) per year, occurred within this area. The highest long-term rate of shoreline retreat, 43 ft (13 m) per year, was located on the north end of Amelia Island during the period 1871 to 1924. Cumberland Island also experienced shoreline losses though probably never this high. Although the above rates are maxima for the study area, changes of this magnitude are not unexpected in the immediate vicinity of inlets. Shoreline changes are intimately associated with migrating ebb-tidal delta channels and shoals and alterations of the hydrologic regime related to maintenance of navigational channels.

The shoreline sections adjacent to tidal inlets, therefore, are the most undesirable locations for development.

Ironically, most of the current sites of problem erosion are located in the historically stable central areas of the islands. Although recent erosional trends on Jekyll and Amelia Islands contradict earlier periods of stability, it should be noted that these areas have been heavily influenced by man in the past several decades. Both islands are located south of navigation projects (i.e. St. Simons Sound and St. Marys Entrance). Net rates of erosion and accretion along central island areas rarely amount to more than $\pm$ 3 ft (1 m) per year when calculated over a 100-year period. Nevertheless, an unusually high number of seasonal northeasterly storms or the passage of a hurricane, however, may cause 60 to 100 ft (20 to 30 m) of erosion in less than one year's time or in a single event.

For example, based on aerial photos taken the day after the passage of Hurricane David, the position of the high water shoreline along the southern bight of Cumberland Island (between C12 and C14 in Figure 8-1) was between 500 and 700 ft (150-200 m) inland from the 1974 shoreline as shown on Fig. 8-7. Because the position of the high water shoreline immediately preceding the hurricane was not known, the actual extent of retreat could not be determined. Nevertheless, relative to historical rates of movement, including the effect of Hurricane Dora (See Figures 8-2 and 8-3), it is concluded that most of this erosion can be attributed to Hurricane David. In areas free of shore protection structures, severe storm erosion is usually followed by beach accretion and low foredune development caused by the more prevalent day-to-day conditions of waves and tides, which tend to deposit material along the coast.

Referring to Figures 8-1, 8-3, 8-7, and 8-8, the shoreline segments at C10 and between C12 and C14 will continue to show the greatest change. The changes in the vicinity of C10 are directly related to the inlet dynamics associated with Christmas Creek and probably will not result in any significant net changes. However, net shoreline trends of a more critical extent in all likelihood will continue in the bight between C12 and C14. Furthermore, the island behind this segment is narrow and relatively low, while water depths seaward of the segments are deeper than elsewhere along the island front. These conditions make this portion of the island extremely vulnerable for washover and/or breakthrough by major hurricanes; of particular concern in this regard is the narrowest part of the island in the Beach Creek area, the site of an earlier breakthrough by the 1898 hurricane (Fig. 8-6). Although the highwater shoreline along the central portion of the island shows little net change since 1871, the backshore areas are subject to severe flooding due to the lowered topography following dune migration away from the beach front.

Despite the critical conditions described above, no engineering structures or other protective devices are recommended at this time. Grazing of dune areas should cease and all vehicular and foot traffic should be closely managed, with dune crossover structures provided at all designated beach access points. Should continued erosion threaten to break through the Beach Creek area, consideration should be given to the effect such breaching would have on the maintenance and operation of the jetty and navigation channel.

Finally, over 23 miles (37 km) of navigation channel, with a controlling depth in excess of 42 ft (13 m) and a bottom width of 400-600 ft (120-180 m), is proposed for the King Bay Submarine Support Base. This project will significantly increase the disequilibrium in sediment source and sink already caused by the St. Marys Entrance Project and the Atlantic Intracoastal Waterway. To what extent this project will adversely effect the ocean and estuarine shoreline of Cumberland Island can only be speculated; however, it is possible that at least the estuarine shoreline adjacent to St. Marys Sound would undergo increased erosion.

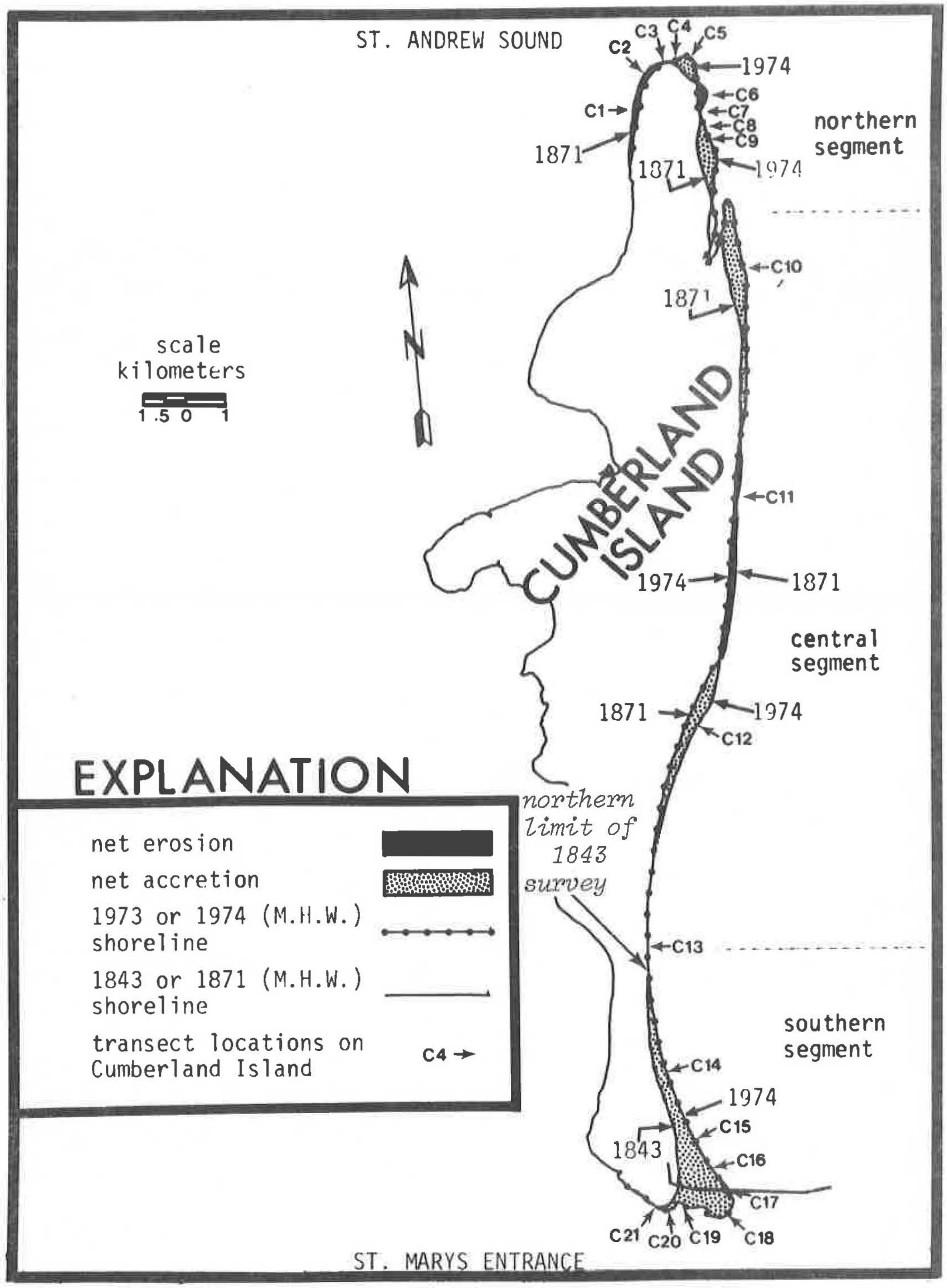

Figure 8–1. Net shoreline changes on Cumberland Island, Georgia, 1843 to 1974.

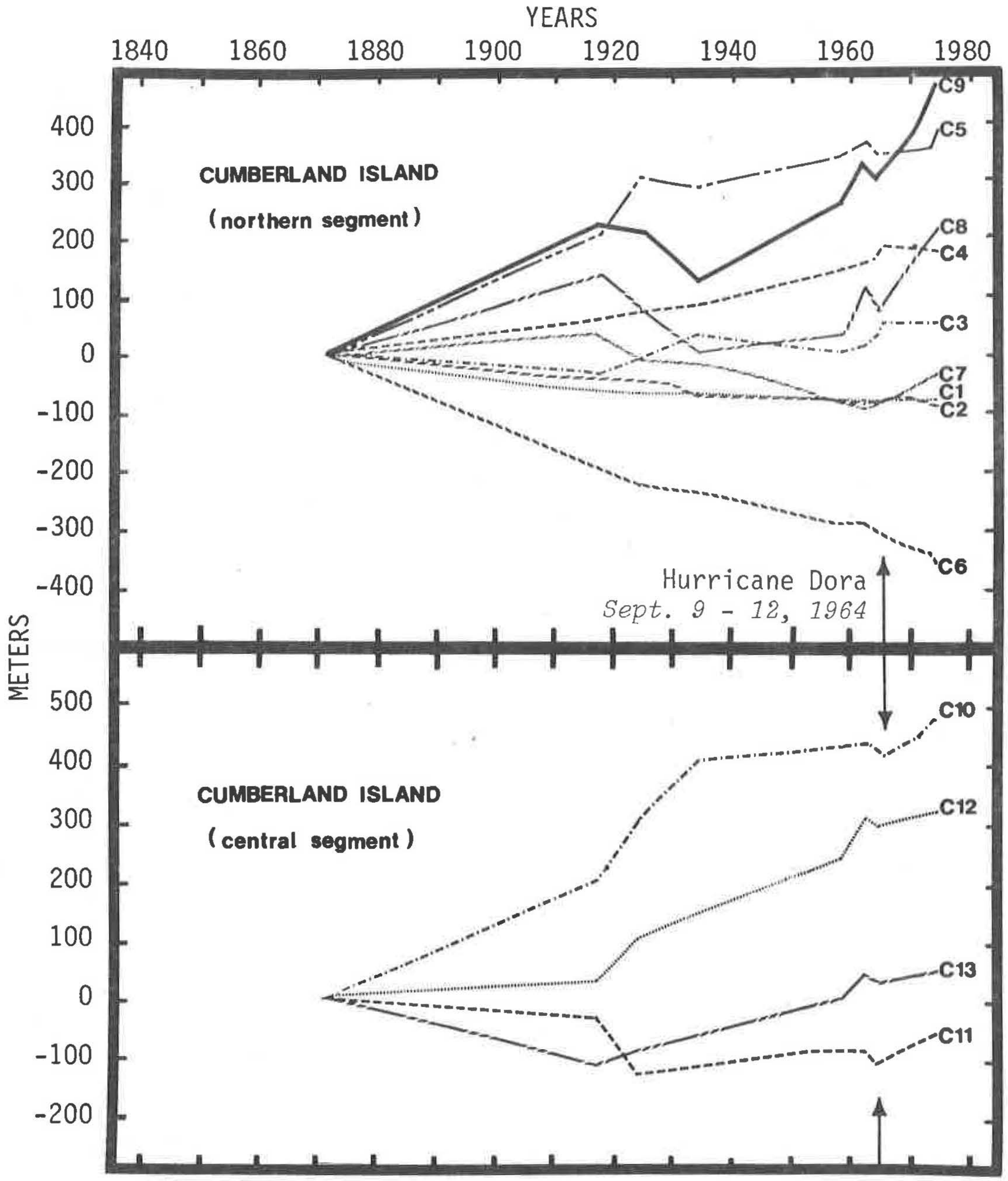

Figure 8—2. Cumulative changes in the M.H.W. shoreline of Cumberland Island, Georgia between 1871 and 1974. C1 through C13 refer to transect locations on Cumberland Island shown in figure 8—1.

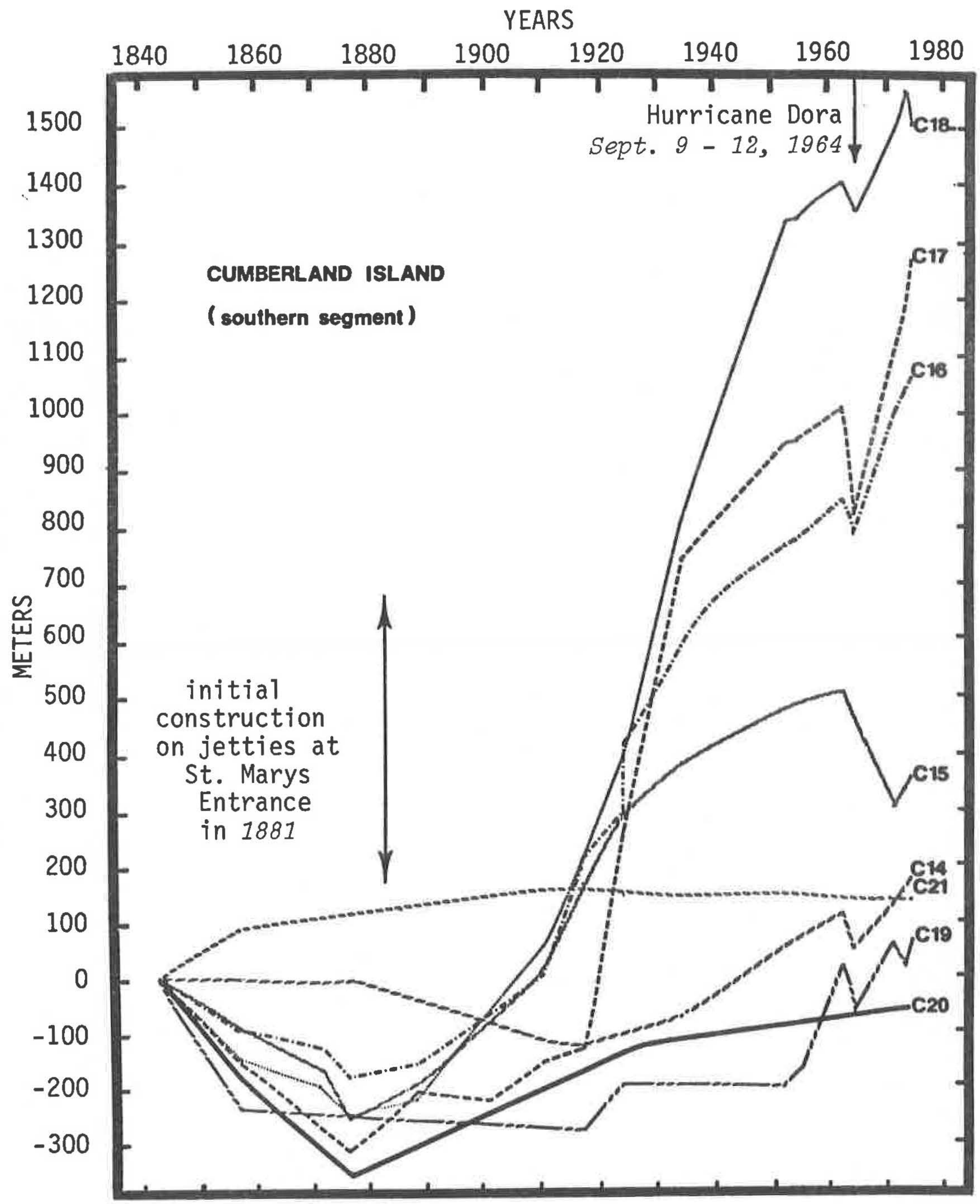

Figure 8–3. Cumulative changes in the M.H.W. shoreline on the south end of Cumberland Island, Georgia between 1843 and 1974. C14 through C21 refer to transect locations on Cumberland Island shown in figure 8–1.

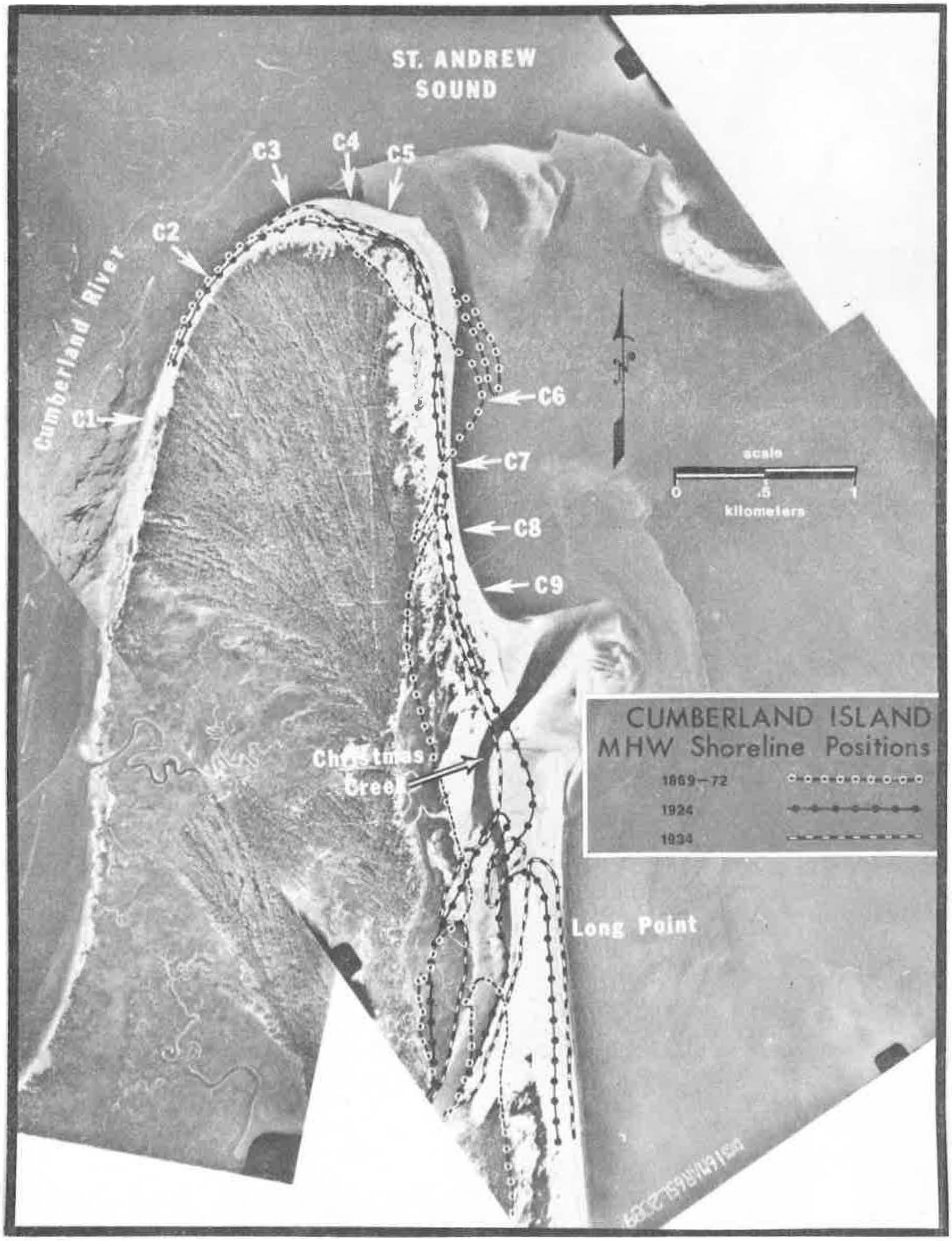

Figure 8–4. M.H.W. shoreline changes in the north end of Cumberland Island, Georgia. C1 through C9 refer to transect locations. U.S. C&GS aerial photograph taken in 1965.

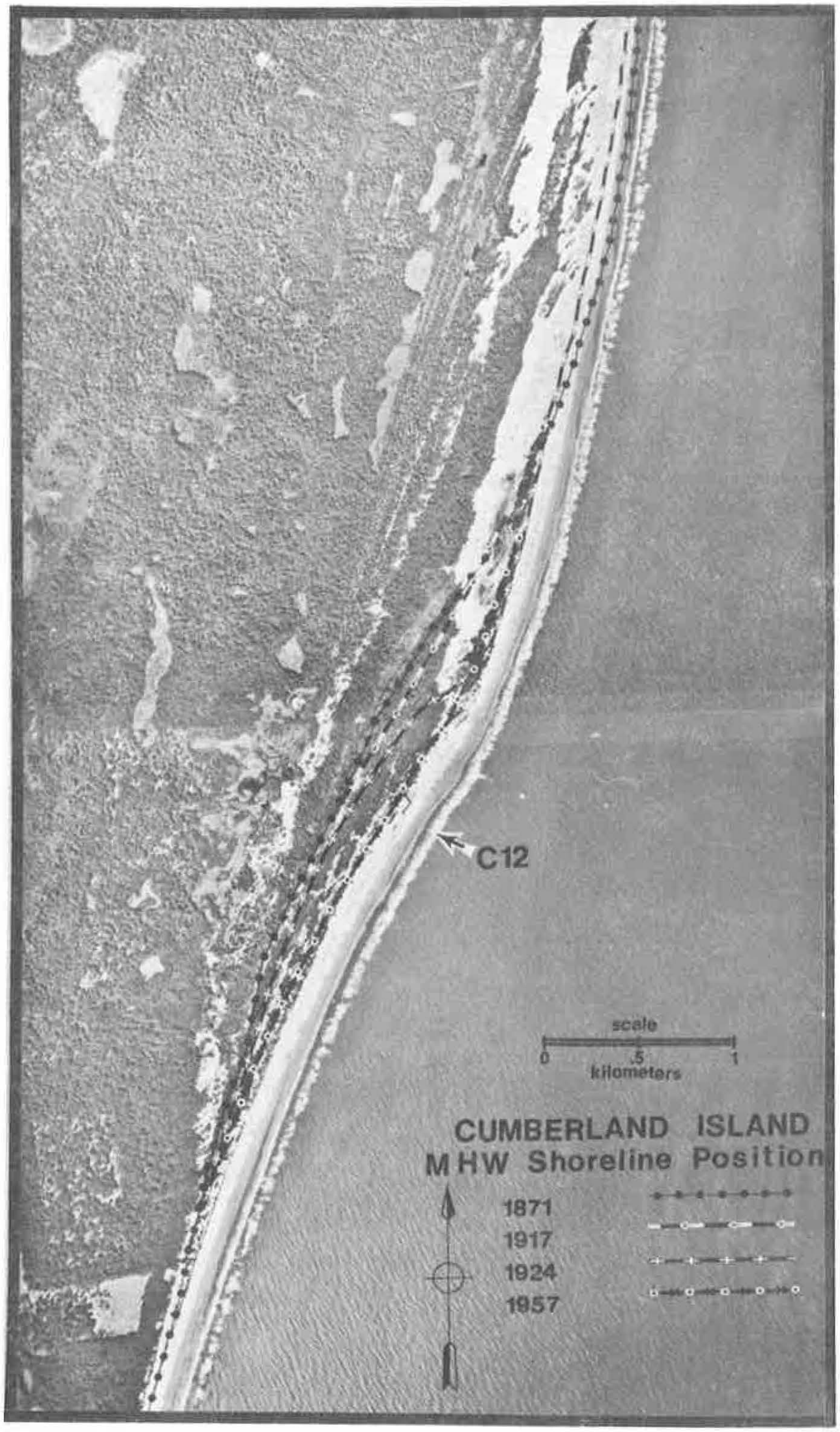

Figure 8—5. M.H.W. shoreline changes in the central part of Cumberland Island, Georgia. C12 refers to a transect location. U.S. C&GS aerial photograph taken in 1962.

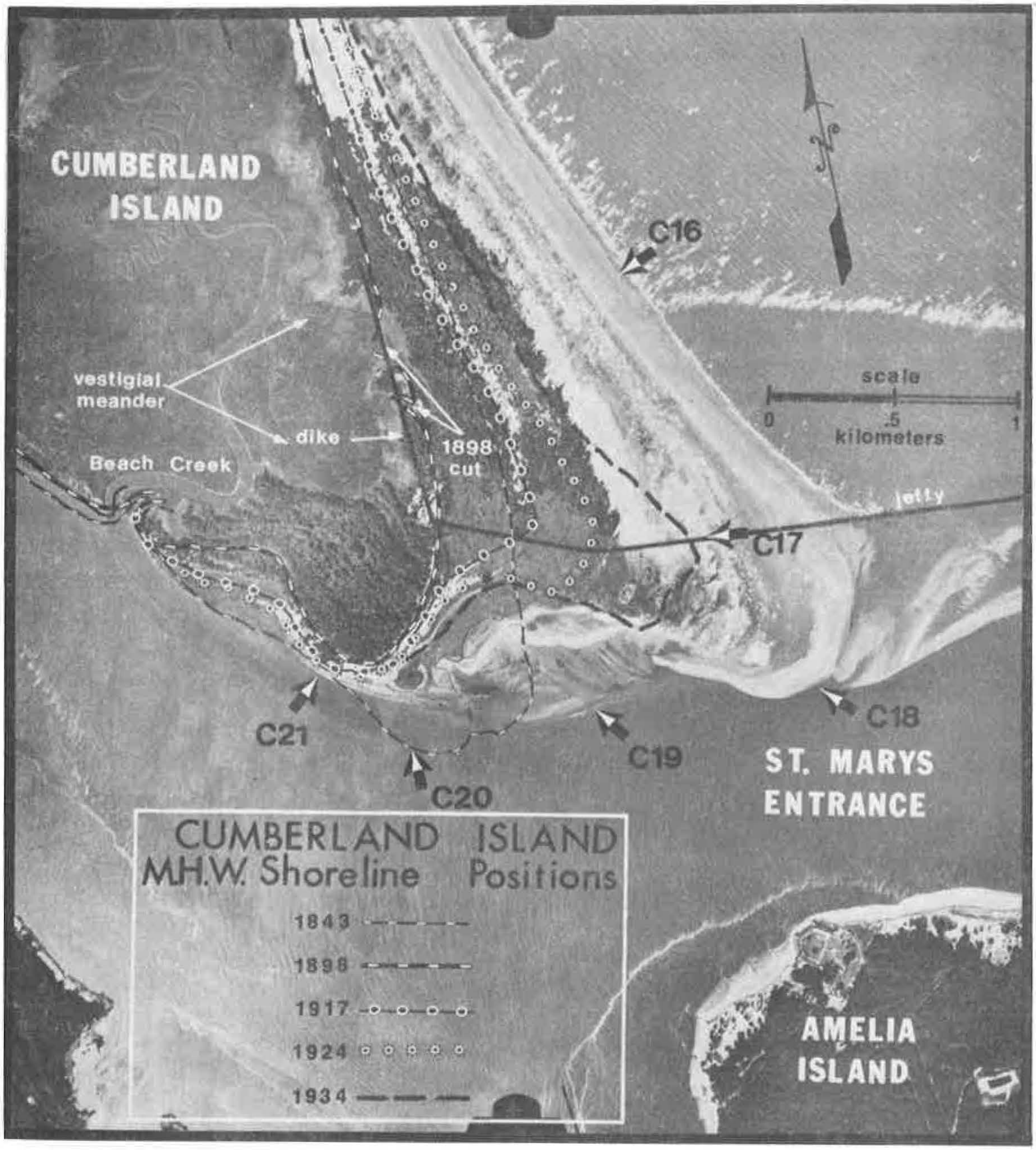

Figure 8-6. M.H.W. shoreline changes on the south end of Cumberland Island, Georgia. C16 through C21 refer to transect locations. U.S. National Ocean Survey aerial photograph taken in 1971.

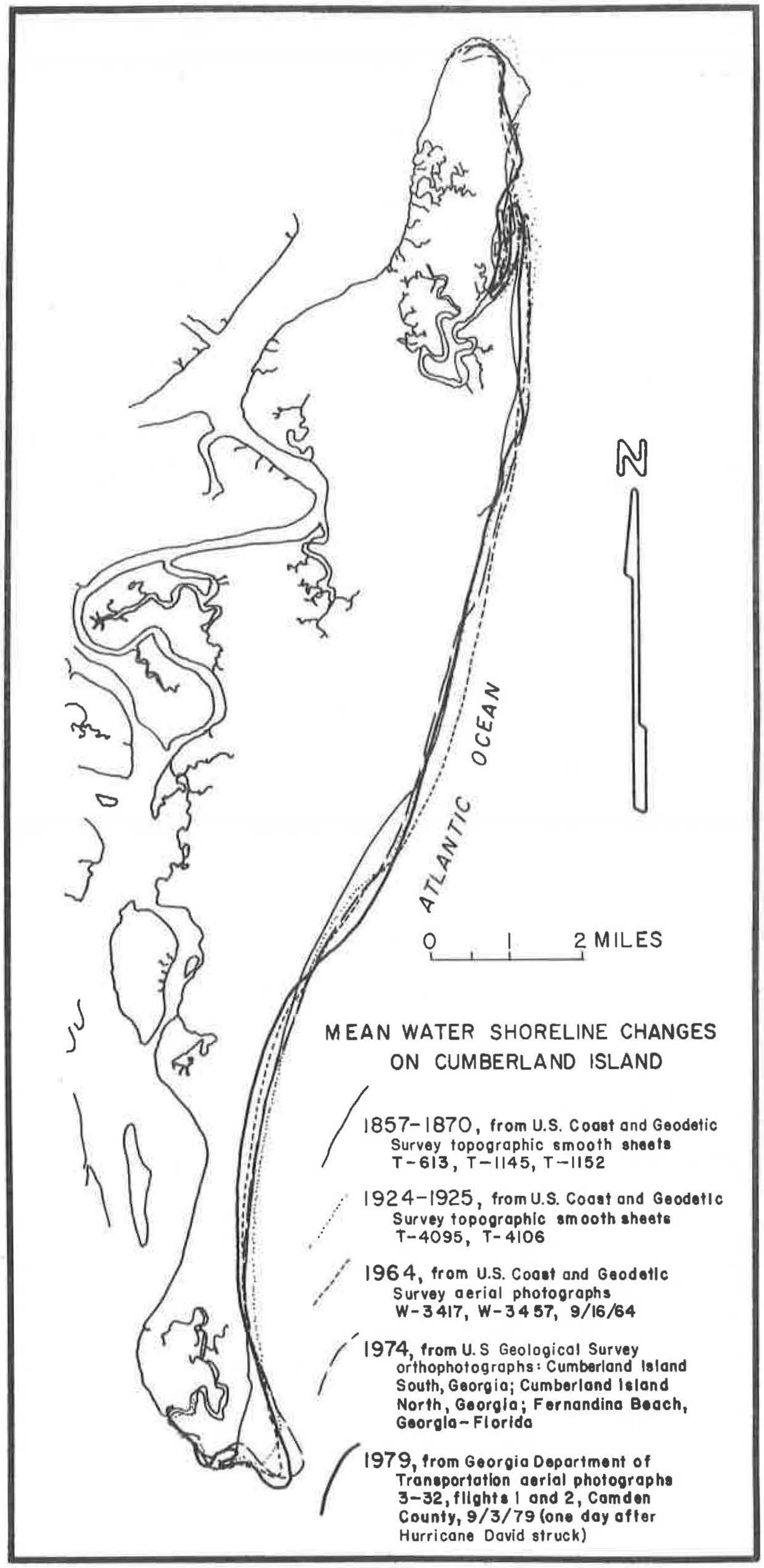

Figure 8–7. Map of shoreline changes on Cumberland Island from 1857-1979.

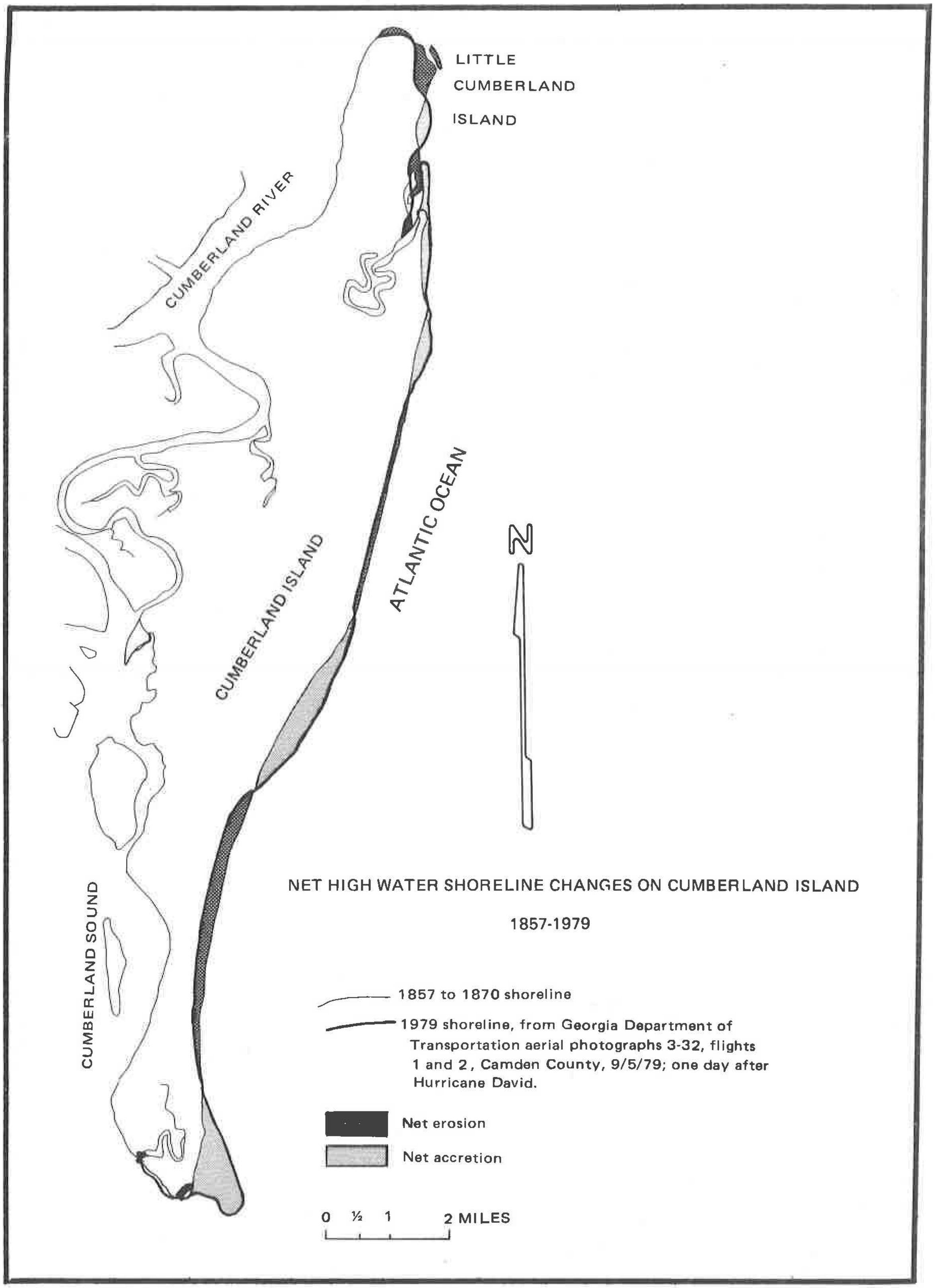

Figure 8—8. Map of net shoreline changes on Cumberland Island from 1857-1979.

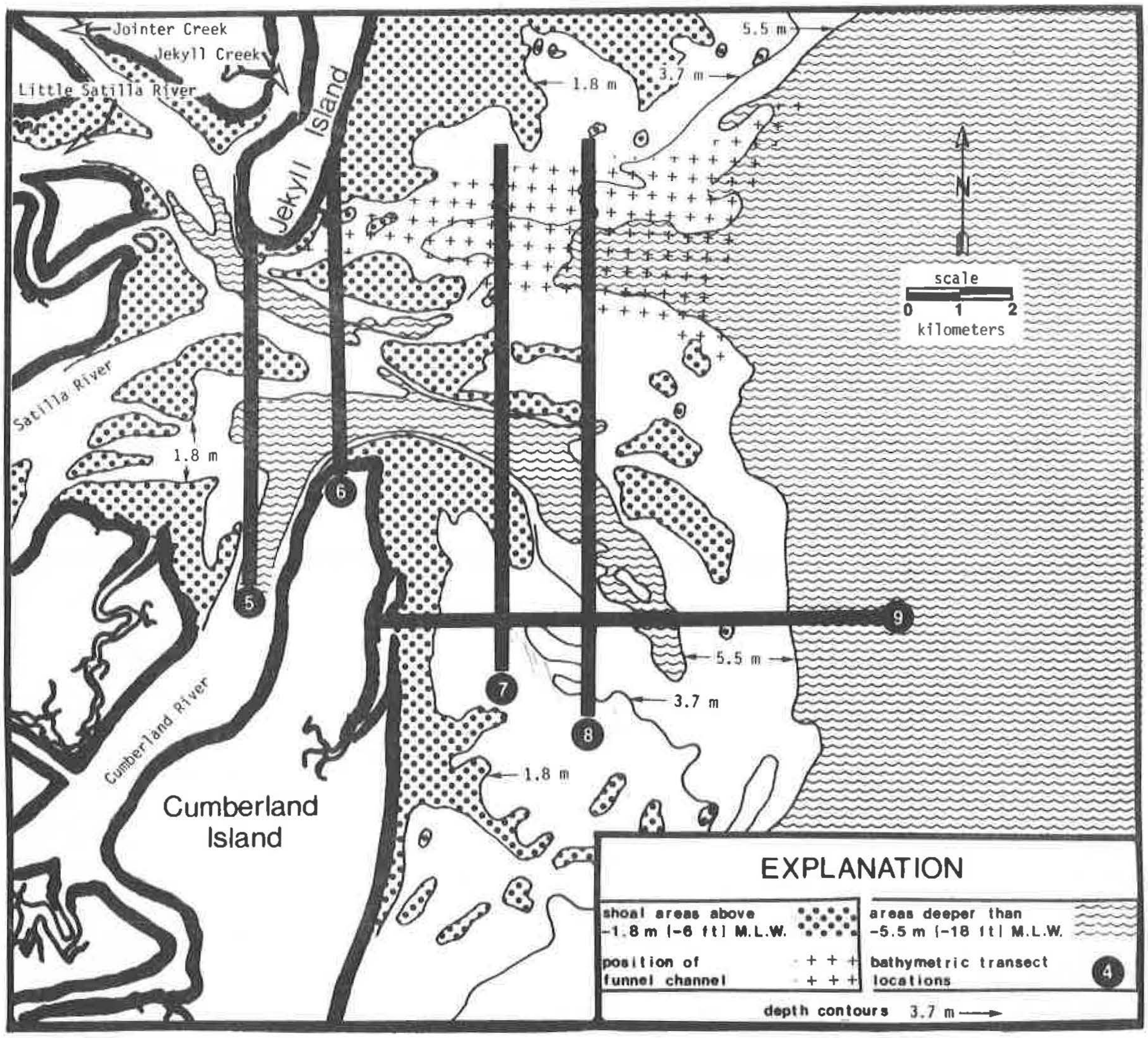

Figure 8–9. Present configuration of St. Andrew Sound and ebb-tidal delta, 1976.

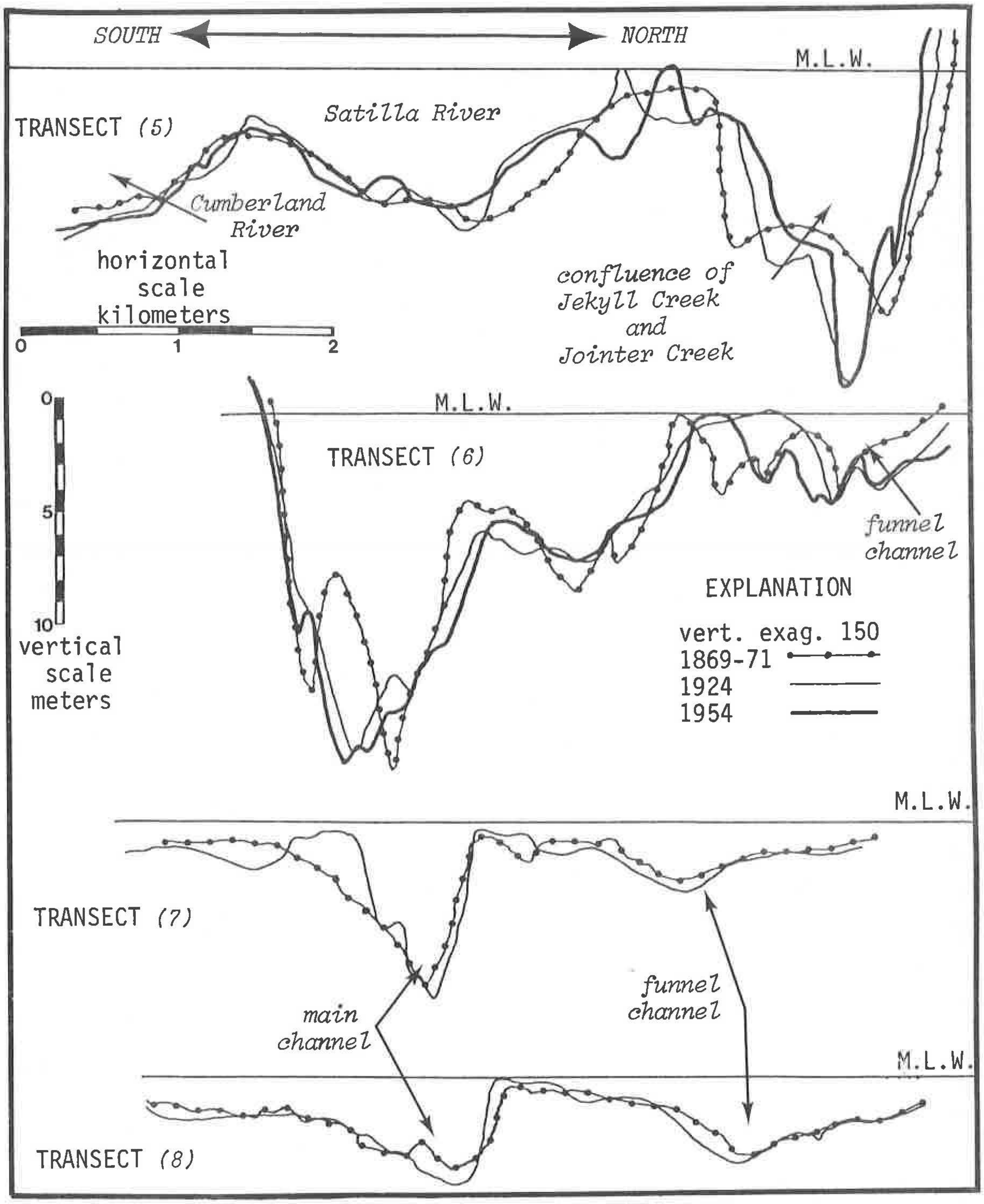

Figure 8–10. Bathymetric profiles taken at transects off St. Andrew Sound, Georgia. Transect locations are shown in figure 8–9.

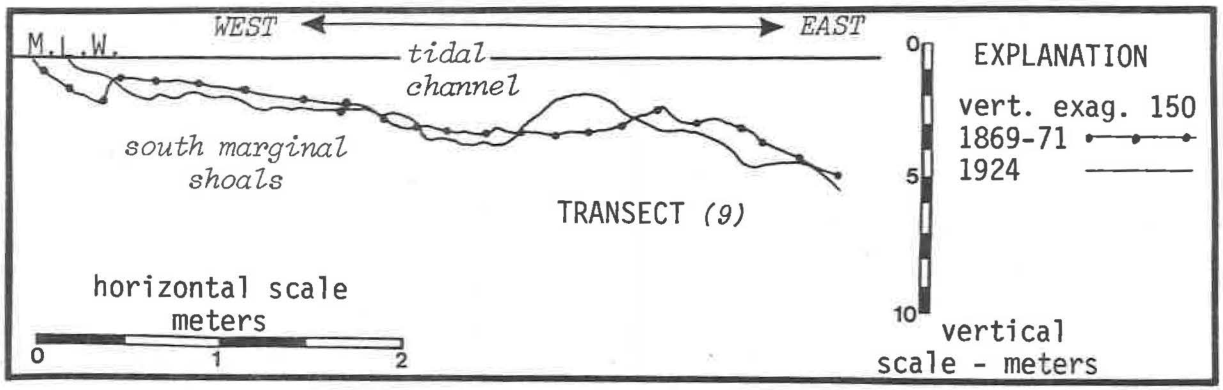

Figure 8–11. Bathymetric profile taken at transect 9 on the north end of Cumberland Island, Georgia. See figure 8–9 for transect location.

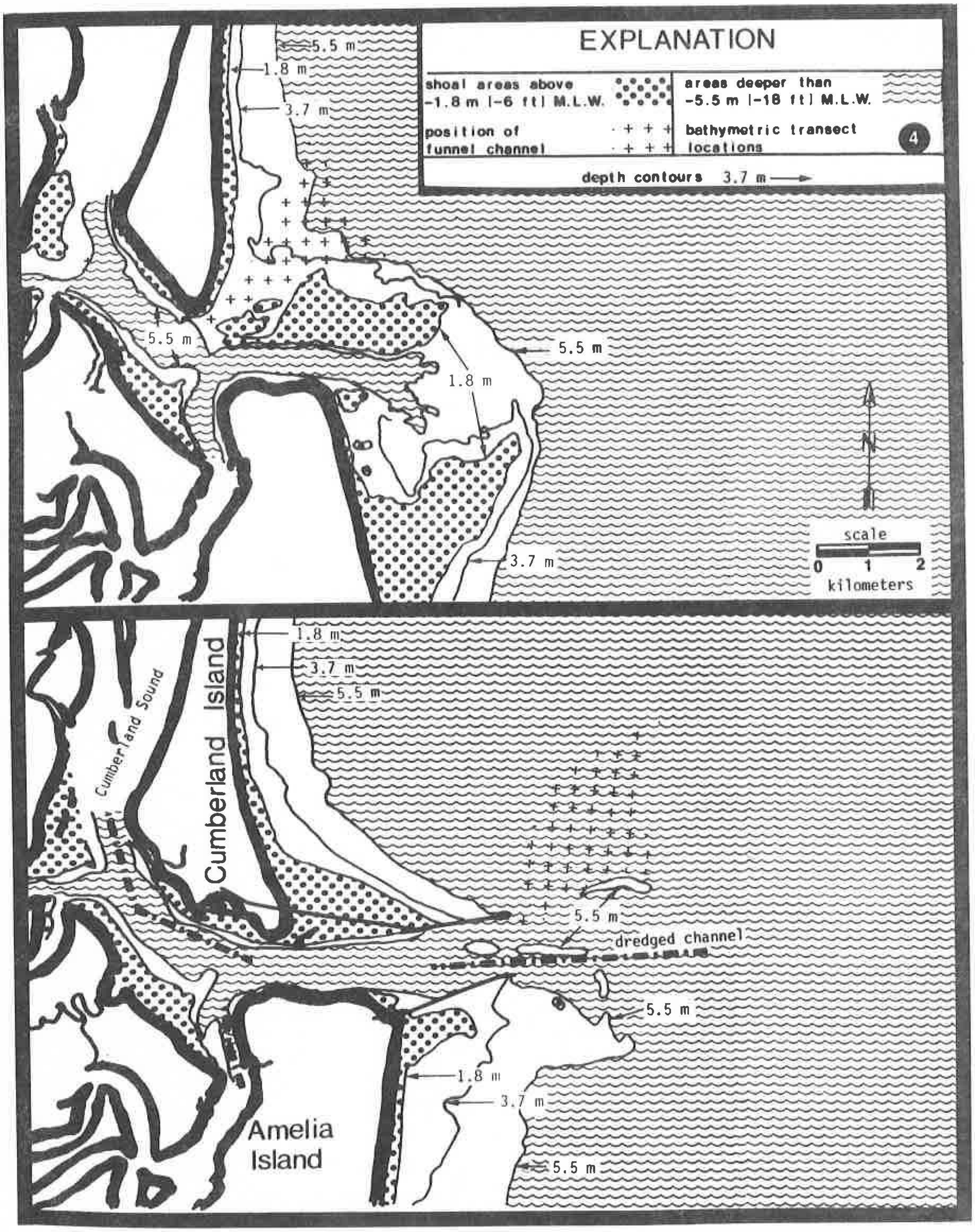

Figure 8–12. Configuration of St. Marys Entrance and Cumberland Sound, Georgia prior to the construction of the jetties, 1876 (upper figure) and present configuration, 1976 (lower figure).

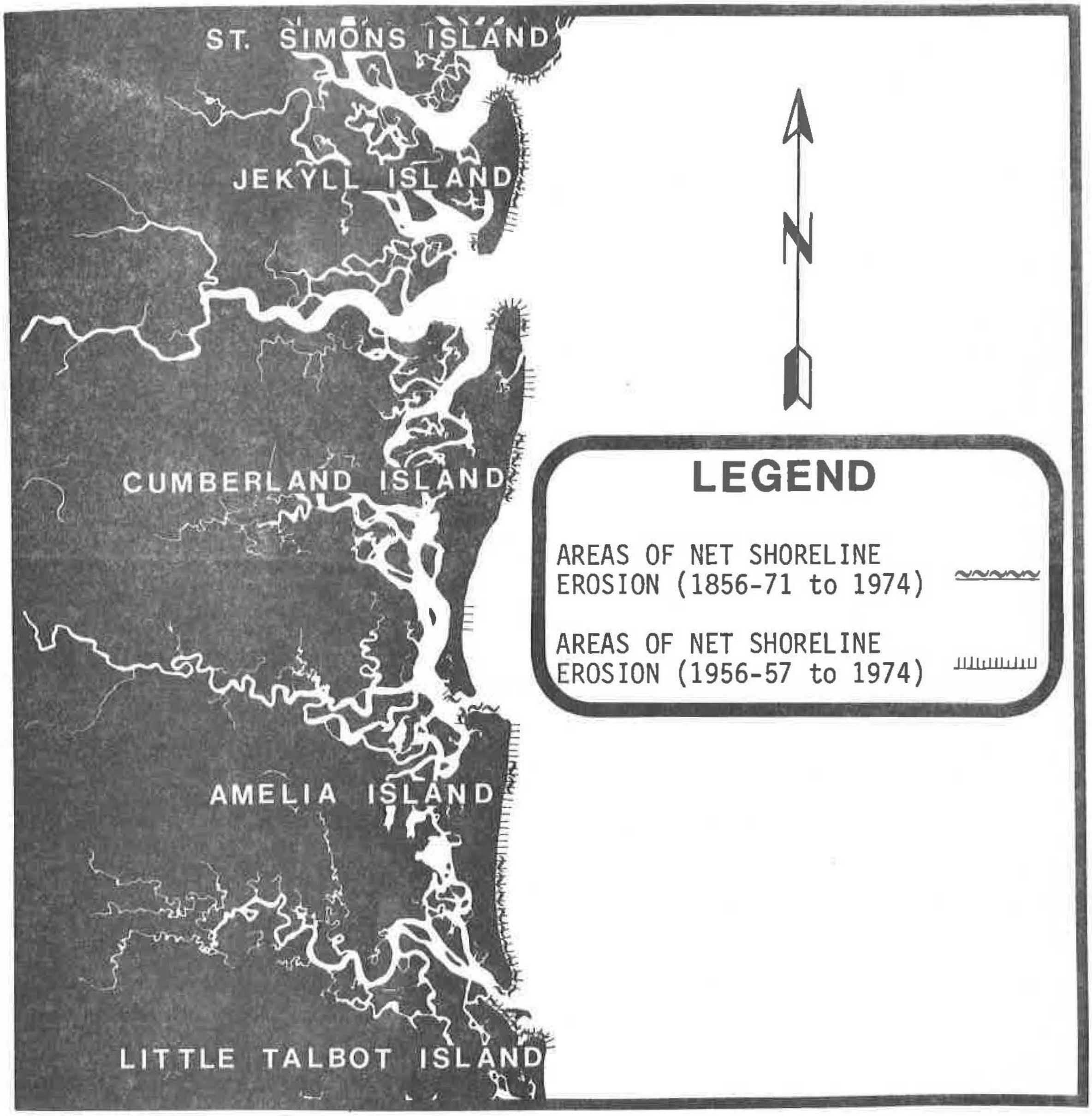

Figure 8—13. Coastal areas of south Georgia and north Florida showing sections of shoreline which have undergone long term and recent net erosion.

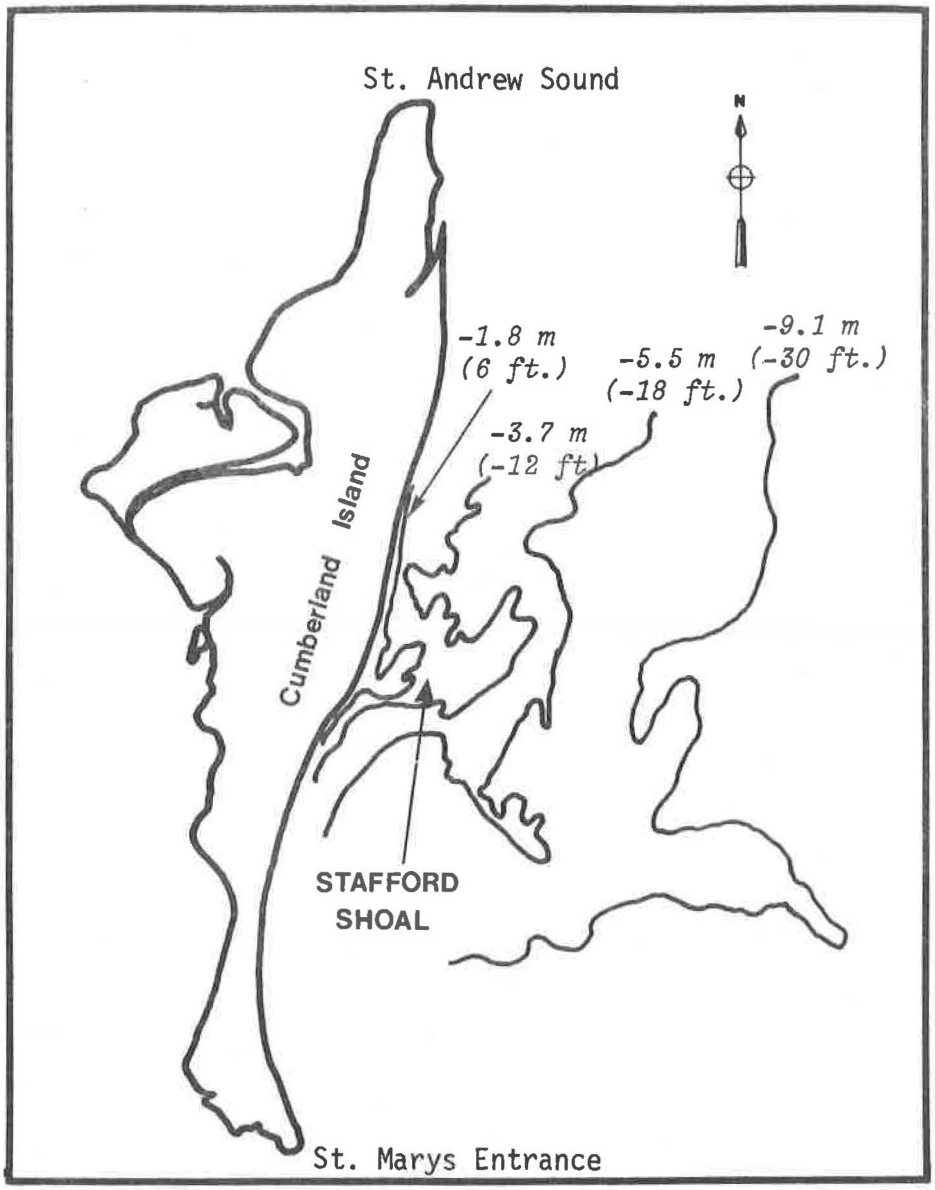

Figure 8–14. Configuration of Stafford Shoal off Cumberland Island, Georgia. Bathymetric data from 1924 hydrographic survey.

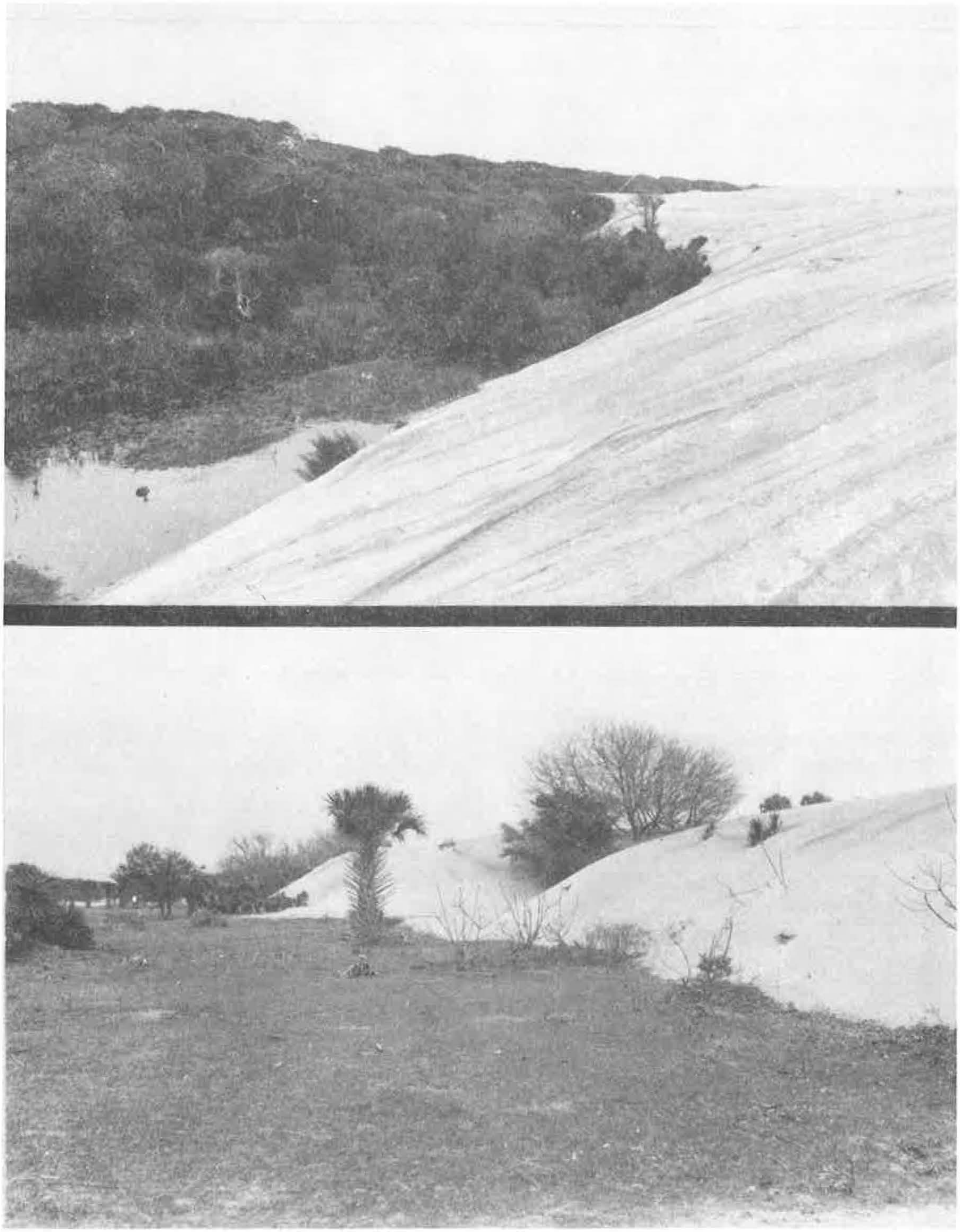

Figure 8–15. Photographs taken near the central (upper photograph) and south-central areas (lower photograph) of Cumberland Island, Georgia approximately 0.5 km inland showing the migration of large unstable dunes over forests, ponds and meadows.

9-0 ENVIRONMENTAL AND GEOLOGICAL HAZARDS ON CUMBERLAND ISLAND

9-1 Introduction

The barrier island complex consists of dynamic and constantly changing environments. Typically, barrier islands undergo the processes of erosion and accretion simultaneously. Many factors influence barrier island environments, and, therefore, play a role in the determination of whether the island grows or is subject to erosion. Some of these factors are rainfall, predominant wind direction, orientation and intensity of oceanic and tidal currents, frequency and strength of hurricanes, wave size and orientation.

The net effect of these factors is important in the proper planning of recreational areas on Cumberland Island. The object of this chapter is to discuss environmental factors which have an effect or potential effect on recreational or cultural features on Cumberland Island. The areas discussed in this chapter are flooding, erosional hazards, accretional hazards, cavity collapse hazard, and pollution hazards associated with septic tank filter fields.

9-2 Flooding

The salt marshes on the western side of Cumberland Island are obvious and predictable areas of flooding. These marshes are flooded to some extent every tidal cycle. The marshes contain extensive growth of *Spartina alterniflora* and are very important areas for the propagation of marine crustaceans which are vital to the local seafood industries. The salt marshes are highly undesirable for any form of development.

The flooding associated with major storms and hurricanes is not easily predictable but can be potentially very destructive. There are a number of factors which determine the amount of flooding in any given storm. The major factors are the amount of rainfall, rate of rainfall, position of tides when the storm hits, surge run-up associated with the storm, wind speed, size of waves and the stage of development of the coastal dune system. Obviously, a detailed examination of all these factors as they relate to Cumberland Island is not possible in this study.

An alternative is the use of flood maps which show areas that can be expected to be flooded in a storm of a given intensity. The intensity is expressed as flooding that can be expected to occur once in a given number of years. For example, the 100-year storm flood is interpreted as being the flooded area associated with a storm of an intensity that is likely to occur once in 100 years. Severity of the storm increases with the given span of years. For example, the 50-year storm is less intense than the 100-year storm.

Plate 4 is a flood hazard map of Cumberland Island. This map represents an integration of flood maps produced by the National Oceanographic and Atmospheric Administration, the United States Geological Survey, the United States Corps of Engineers and the Federal Insurance Administration. Plate 4 has three colors which indicate relative dangers of flooding. The red zone is an area where flooding is common. This area includes the salt marshes and areas that are subject to frequent flooding by storms. The yellow zone represents an area subject to infrequent flooding. This zone approximates the area of maximum flooding associated with the 100-year storm. The white zone area is rarely flooded and then only during the most severe storms. Obviously there should be no habitable buildings placed in the red zone. It also should be noted that many of the inland marsh areas are subject to substantial flooding along their borders and development there should be avoided. The ideal areas for construction are those in the center of the island on topographically high areas; for example, Yankee Paradise and Hickory Hill campsites are well situated away from flood prone areas.

A majority of the structures in the Dungeness area are suitably situated. The Ice House at Dungeness Wharf is located in a marginal area where flooding could be expected infrequently. Areas of 10 feet (3 m) or more elevation are reasonably safe from flooding.

In August, 1979, David, a hurricane of average intensity, moved up the Georgia coast. Although the hurricane did not pass directly over Cumberland Island, it did offer a chance to note the impact on the island. A debris line marked the maximum high water at an elevation of approximately 5 ft (1.5 m) above mean sea level. Flooding was within the red zone of Plate 4. The western side of the island suffered little erosion from the hurricane, but on the eastern side, there appeared to be accelerated erosion of the Pleistocene sands where the waves had access. Although there was no debris line visible in the Old Swamp Field, there was probably minor flooding of areas surrounding it. The eastern edge of Cumberland Island suffered dune erosion as a result of the hurricane, although erosion was restricted to the foredunes. The foredunes south of Sea Camp Beach suffered less erosion than the more northern dunes, such as those in the vicinity of the Willow Pond dune crossing. Differences in dune size and the amount of vegetation played an important role in the amount of erosion sustained. The dunes in the vicinity of the jetty are low and have a sparse population of <u>Uniola panicilata</u> (sea oats), which tends to stabilize the sands. Incoming waves washed over these low dunes and they sustained minor erosion. There was some overwash into the interdune meadow, but waves did not reach the back dunes. The foredunes absorbed all of the wave energy and water that entered the interdune meadow ran in because of overflow between the dunes. The dunes in the vicinity of the Willow Pond dune crossing are large and very sparsely populated by plants. Because the incoming waves could not wash over these large dunes and there was little vegetation to protect them, the effect of incoming waves at this location was more dramatic than on the south end of the island, and erosion was moderate to severe.

On the south end of the island, water entered the interdune meadow, but, apparently as overflow. There appeared to be substantial flooding of the interdune meadow in the vicinity of the Sweetwater outflow. This flooding probably resulted from the combination of heavy runoff from rainfall and water from incoming waves in the interdune meadow. These combined factors caused more extensive flooding at this location than in other places on the island.

9-3 Erosional hazards

There are many factors which influence large scale erosion and erosional rates on Cumberland Island. Some of these factors are the intensity and direction of currents in the surrounding waters, tide range, wave orientation and intensity, the type of sediment being eroded and, in some cases, the abundance of bivalves. All of these factors contribute to the net accretion or erosion of any given portion of Cumberland Island.

The Pleistocene portion of Cumberland Island is composed of fine-grained, unconsolidated sands which are easily eroded. This erodibility is evident from the almost vertical bluffs on the western side of the northern end of Cumberland Island. The erosion results from wave action at high tide when waves undercut the banks and cause sands to slump into the intertidal zone where they are removed by currents and wave action. Buildings such as those at Sea Camp and the Ice House at Dungeness are especially susceptible to damage from erosion, due to their location. The National Park Service has been wise to construct sea walls to slow or stop erosion in these areas. These structures should be periodically monitored to insure there is no undercutting by wave action. Another area of active erosion is at Cumberland Wharf. In this area, wave action is undercutting the Pleistocene sands and causes the sands to slump. There are no structures in the immediate area at present and it is recommended that none be built near the bluff because of this erosion.

Erosion also takes place in the Holocene salt marshes of the island. This erosion is evident on the western edge of Raccoon Keys Salt Marsh where there is a wave-cut bench. Unlike the erosion in the Pleistocene sands, this erosion takes place at low tide. Because the salt marshes are made of clays and have a thick growth of *Spartina alterniflora*, the erosion rates in the marshes are much slower than that in the Pleistocene sands. Because there should be no structures built in the salt marsh, this erosion should not pose any problems.

Another factor which accelerates erosion on the western side of Cumberland Island is the boat traffic. The wakes of boat traffic in the Intracoastal Waterway have the same effect as wind induced waves. The erosion from boat wakes is more active on the Pleistocene sands at high tide. At low tide the erosion from boat wakes is more active in the salt marshes.

Abundant bivalves may also have an effect on erosion rates. Commonly, erosion rates are slowed where the beaches become "armored" by the shells. On Cumberland Island there are isolated beds of *Crassostrea virginica* (common oyster) that produce shells which, where they are abundant enough, protect the beaches from wave erosion. The abundant shells will absorb the energy of the breaking waves and protect the loose sand beneath. Although it is beyond the scope of this report, encouragement of oyster growth on the western side of the island may aid in slowing wave erosion. A detailed study of this factor would be needed to determine the feasibility of such a project.

9-4 Accretional hazards

Just as erosion is an important environmental hazard on Cumberland Island, the opposite process, accretion is also an environmental hazard. Cumberland Island has an extensive dune system. Typically there are two sets of dunes, the foredunes and the back or rear dunes. The back dunes are larger and less susceptible to erosion than the foredunes. On Cumberland Island the back dunes migrate in a westerly direction in response to the prevailing easterly winds. The migration of the back dunes poses an environment hazard to structures built west of them.

The rate of dune migration is not uniform throughout the length of the island; therefore, rates of migration can be discussed only in general terms. The type of vegetation over which the dunes migrate also is a major factor influencing migration rates. On Cumberland Island the dunes migrate slowest through that portion of the island with the climax forests west of the dunes. The rate of dune migration was measured in this type of situation on Nightingale Avenue (Figure 2-1). Within a period of nine months, the back dunes migrated a total of 1.4 ft (0.42 m). This rate is considerably slower than the rate of dune migration measured in Beach Fields where the National Park Service measured three feet (one meter) per year of migration through the fields which are sparsely populated by any vegetation other than grasses. The rate of dune migration should be determined at each proposed structure site located close to the western edge of the back dunes. When a rate of migration is established, the structure should be placed accordingly with relation to the future dune position.

An excellent example of the placement of structures without regard to dune movement is a house located on the eastern end of Nightingale Avenue. This house was built just west of the back dunes. Subsequent dune movement completely buried the house. It is now emerging from the dune on the east side.

A precaution in areas of heavy visitor usage is the establishment of buffer zones between visitor use areas and the dunes. Because vegetation slows dune migration, all vegetation on or near the dunes should be protected from the effects of frequent visitor usage. This buffer zone should be approximately

80 ft (25 m) wide measured from the edge of the dune. Under no circumstances should this zone be shortened to allow the building of any structure or for any other purpose.

9-5 Dune care and protection

The dune environments are delicate and can easily be damaged. Damage to the dunes and the vegetation covering them increases dune migration and lessens the flood protection offered by the dunes during storms. For these reasons the following suggestions are made.

Vehicle and foot path crossing of the dunes should be kept to a minimum. The frequent use of these crossings can cause a local lowering of the dune, resulting in what is often referred to as a "blow out". "Blow outs" occur when a small portion of dune is lowered by vehicle or foot travel and the prevailing easterly winds are funnelled through the lowered area. The erosive action of the winds concentrate in this area and transport the sand from the crest of the dune to the landward site. The result is a marked local lowering of the dune height and a widening of the base. An example of this is at the Dungeness dune crossing where frequent foot travel has resulted in a lowering of dune height and lateral spreading of the sands westward. The result is a small fan of sand spreading beyond the general dune line. The result of numerous "blow outs" is the diminishing of the dune's ability to absorb the energy of storm waves which might otherwise completely cross the island. Boardwalks over the dunes are probably the best solution for foot crossings.

Another suggestion for dune care is the protection of beach and dune grasses. These grasses are important in dune stabilization and migration rates. They are easily affected by foot travel. Goldsmith (1978) reports that a path was formed 16 ft (5 m) long and 2 ft (0.6 m) wide through grass 4 ft (1.2 m) tall by walking over the graases once every two weeks. The importance of these grasses cannot be overly emphasized; therefore, boardwalks should not stop just past the dunes, but continue to the beach.

9-6 Cavity collapse hazards

Calcareous rocks such as limestones and dolostones under certain conditions may form solution cavities or caves. As a cavity enlarges by movement of ground water, the walls become thinner until they are no longer able to sustain the wight of the overlying sediments. The result is a collapse of the roof of the cavity with the overlying material filling the void. If the cavity is large enough, this may appear on the surface as a closed depression termed a lime sink. These lime sinks may appear suddenly without warning or gradually over a long period of time. In areas underlain by thick limestone and/or dolostone beds, the formation of lime sinks is of major concern.

In the course of drilling the shallow stratigraphic water monitor test wells on Cumberland Island, a calcareous unit was encountered at approximately 55 ft (16.7 m) below the surface (CI-01, GGS #3426) and was 20 ft (6 m) in thickness. This unit was encountered in all test wells drilled on Cumberland Island. In boring 12, near Plum Orchard, a cavity was encountered at 77 ft (23.5 m) below the surface. The total depth of the cavity is not known although it is almost 5 ft (1.5 m). Dolostone was encountered in this well at 72 feet (22 m) below the surface; therefore, the roof over the cavity was only 5 feet (1.5 m) thick (see log of boring 12 in Appendix C). Therefore, there exists some possibility, albeit small, of lime sink formation on Cumberland Island. Although there are few of the typical features associated with solution collapse visible on 7.5 minute topographic maps, a few depressions of possible sinkhole origin were noted during other phases of the research. The reason for this may be that the sinkholes are shallow because of the thinness of the calcareous unit, and therefore they are quickly filled by accumulation of sands, clays, and organic debris.

As mentioned earlier, where and when sinkholes will occur cannot be predicted with the information available at present. The occurrence of large, deep sinkholes, however, is not likely because of the thin calcareous unit and thick overlying sediments. Extensive subsurface testing prior to construction of new buildings to determine if cavities exist below the structure is considered unwarranted. Closed depressions commonly indicate active sinkhole formation, and therefore should be avoided as building sites.

9-7 Suitability for septic tank filter fields

The majority of soils on Cumberland Island are unsuited for waste disposal by septic tank systems. Limiting factors of the soils are 1) high permeability, 2) high water table, 3) soils subject to flooding, 4) poor cation exchange capacity and vulnerability to leaching. Lateral percolation presents the hazards of pollution of marshes and nearby surface water from septic tank contaminants. Vertical percolation of septic tank contaminants presents a contamination hazard to the local unconfined water table. Nevertheless, septic tank contamination of the Miocene Sand and Principal Artesian Aquifers is not considered likely because the clays of Pleistocene and Miocene age act as a protective cap above these sand and limestone aquifers.

Water wells drilled into the Miocene and deeper aquifers must penetrate the unconfined water table. Therefore, every effort should be made to see that potential contamination in the unconfined water table is not allowed to move vertically via improperly constructed water wells. To prevent contamination all water wells should be properly cased and grouted. This subject is covered in more detail under the heading of "General Recommendations".

The Lakeland Sand and Chipley Sand are classified as having slight to moderate limitation for septic tank filter fields. These gently sloping soils are excessively to moderately well drained, deep, and highly permeable. These sandy soils are considered to be ineffective in attenuating the contaminants from a filter field. The main limitation on these soils is the potential contamination of nearby surface water due to rapid vertical and lateral percolation rates. Careful engineering can minimize or control these problems.

Sites suitable for septic tank filter fields are widely dispersed on the island (Fig. 9-1) and can probably handle a small number of people without problems. With large numbers of people, the hazards of water table and local well contamination becomes much more of a potential problem. With larger visitor influx, a treatment plant should be considered. All tile filter fields should be a minimum of 100 ft (30 m) away from any water well or surface waters and preferably downslope of the general ground-water flow direction. The bottom of the filter field should be a minimum of 4 ft (1.2 m) above the seasonal high water table (see the Hydrogeology section). All potential sites should be carefully evaluated. Of particular concern would be 1) the site's proximity to nearby surface waters and wells, 2) physical characteristics of the surrounding soils, 3) depth to water table, 4) possibility of flooding, 5) vertical and lateral percolation rates, and 6) density of septic tank filter fields.

Soils with slight to moderate limitation can be used for septic tank filter fields with careful planning and engineering. Information gathered by the shallow drilling program should aid in the determination of water table elevations as well as provide other subsurface information.

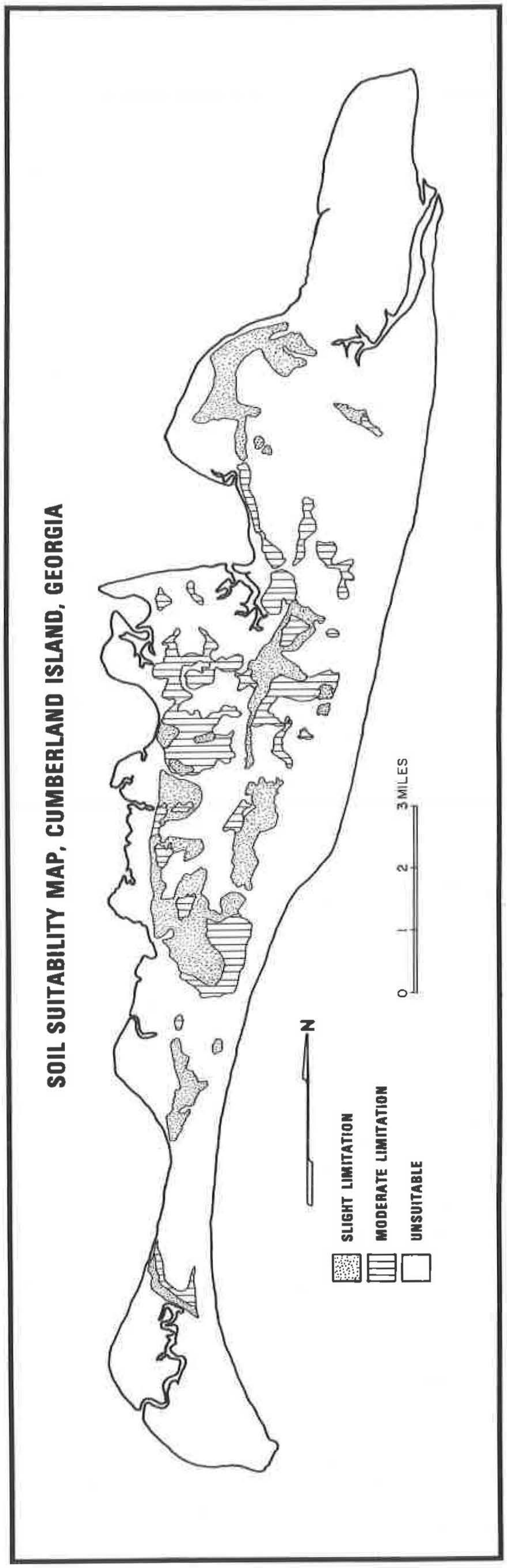

Figure 9–1. Soil suitability map, Cumberland Island, Georgia.

10-0 ECONOMIC MINERALS POTENTIAL

This section will make the National Park Service aware of potential economic minerals on Cumberland Island, but it is not a detailed economic geology study. The economic potential includes heavy mineral deposits, phosphate, as well as oil and gas occurrences. There is some potential for all of the above to occur in commercial quantities in the vicinity of Cumberland Island. Nevertheless, at the present time, none of these are being economically exploited in Camden County.

Dark, heavy minerals have been mined in Charlton County near Folkston, Georgia. In the course of the shallow testing program, dark minerals were noted in the Pleistocene age sediments on Cumberland Island. Portions of Cumberland Island have already been prospected, probably for heavy minerals as well as phosphate (NPS, 1977). Presently, the economic situation makes this type of deposit only marginally profitable; therefore, it is doubtful that any economic deposits of these minerals are on Cumberland Island. However, a regional study by Friddell (1980) suggested that there were some areas along the Georgia coast that did have economic potential for heavy minerals. Phosphate is mined from the Hawthorne Formation in Florida; also, economically viable phosphate deposits are understood to underlie marsh areas in the vicinity of Savannah. Similar deposits may also underlie Cumberland Island.

Oil and gas occurrences are very difficult to determine. There are presently no producing wells in the entire state of Georgia. Several wells have been drilled in Camden and Charlton counties (Fig. 10-1), but none of these have produced oil or gas in economic amounts. Current research has shown a probable basement fault which trends east-west through Cumberland Island (Chowns, personal commun.). This fault could provide a structural trap for oil and gas. This area has yet to be drilled.

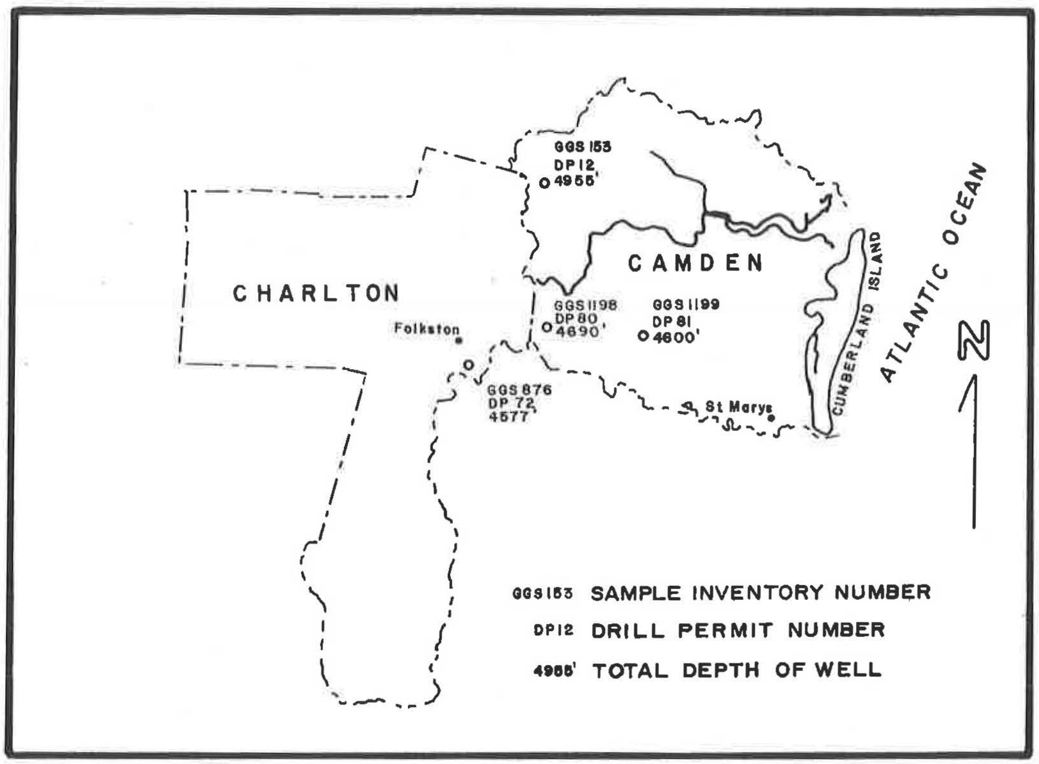

Figure 10—1. Map of oil tests in southeast Georgia.

11-0 VERTEBRATE PALEONTOLOGY OF CUMBERLAND ISLAND

11-1 Introduction

The Pliocene and Miocene age sediments on and around Cumberland Island contain many vertebrate fossils. The sediments in which these fossils are found have a marine origin; therefore, a majority of the fossils are from marine organisms. Shark teeth are the most common vertebrate fossils found in these sediments. Occasionally fossils (such as horse teeth) from land animals are found, but these fossils are believed to have been reworked into the marine environment from older deposits on the mainland.

As a portion of this study, a collection of vertebrate fossils was made from the dredge material in Raccoon Keys Salt Marsh. The fossils were identified and the preferred habitat of each organism was noted. In the following discussion of specimens found in the sampled material, the name, description, and notes on the preferred habitat, if one exists, are presented.

11-2 Sharks

11-2-1 Carcharias or Odontaspis spp. (sand sharks) (Figures 11-1 and 11-2):

The doubt in identification of this group of specimens is based on both the specimens and the taxonomic problems. The problem of classification of these genera has caused much confusion for a century or more. Some authors consider them synonymous, and are divided almost equally on which of the two names is applicable. There is a tendency to utilize the term *Odontaspis* more frequently, despite the deep entrenchment of the term *Carcharias*, especially in the classification of recent sharks.

On the other hand, many authors regard the *Odontaspis* as a distinct genus. These authors regard the primary distinctive feature as the presence of a basal thickening of the enamel of the buccal face of the crowns of the shark teeth.

This feature almost gives the appearance of the enamel having been melted in part and running down to the base, sometimes even as elongate strips partly down the deeply bifurcated root. Species assigned to Carcharias lack this feature. It is definitely beyond the scope of this work to delve into classification problems.

There are well-preserved specimens, mostly of upper teeth, from Cumberland Island, that clearly lack the "Odontaspis bead." These teeth have accessory cusps (one pair in most, though one has the rudiments of a second pair) distinctly separated from the enamel of the main cusp. This feature refers them to Carcharias and not to Lamna. There also are some poorly preserved lower teeth that are more slender than is common in Carcharias and may belong to a species of Odontaspis. With the exception of distinct ridges on the lingual face of the main cusp, these teeth are slender enough to refer to Scapanorhynchus. Modern sand sharks are associated with very shallow water near beaches and in lagoons.

11-2-2 Lamnidae Lamna sp. (near L. nasus--porbeagle shark):

Two specimens of lower teeth definitely can be referred to this genus though they are similar to those referred to above as Carcharias sp. The distinctive character is the presence of accessory cusps whose enamel is clearly joined to the enamel of the main cusp on the buccal face of the tooth. A cosmopolitan form, Lamna prefers shallow waters near shore.

11-2-3 Isurus sp. (near I. oxyrhinchus--mako shark):

Both the upper and lower teeth of this species are common at Cumberland Island. The teeth are stout, erect blades with not a trace of accessory cusps. To each side of the main cusp is a continuation of its cutting edge as a blade across most of the root. Lower teeth of the mako shark are slightly more slender than the upper teeth. The mako is a widespread shark with apparently little regard to depth of water or bottom character. It feeds mainly on fishes somewhat larger than those taken by Odontaspis or Lamna.

11-2-4 Carcharodon megalodon (extinct white shark):

Two partial teeth of this form were recovered among the fossil material from Cumberland Island. Though both are badly battered, they clearly show the large size and coarse serrations of teeth of Carcharodon and the spade-like, as opposed to triangular, outline that sets off the extinct C. megalodon from the living C. carcharias ("Jaws").

Though typically Miocene in age, C. megalodon may range in some areas into the Lower Pliocene. However, the wear and poor preservation of the specimens seems to indicate that this material is reworked from earlier rocks.

11-2-5 Carcharhididae (requiem sharks):

This is the most abundant modern family of common sharks. The teeth are easily distinguished from those of the foregoing families, as the root is very shallow and has a distinct median notch for the nutritive foramen. Teeth of the more primitive sharks have deeper and more massive roots, often deeply forked, and the nutritive foramen does not lie in a notch. Four genera are definitely present at Cumberland Island, and more are likely to be found through further collecting.

11-2-6 Carcharhinus spp.:

The species of Carcharhinus, the most abundant and varied genus of modern sharks, are generally quite difficult to distinguish fully on the basis of teeth. However, some of the extensive numbers of teeth of this genus found at Cumberland Island can be referred, at least tentatively, to teeth of present day sharks or to closely related fossil species.

Three basic types of teeth have been distinguished. These three types can be separated on the basis of comparisons of position of upper teeth in the jaw (teeth from about the 5th to 8th series in each jaw). Type I consists of stout, relatively erect, coarsely serrated teeth. Some of these are almost triangular; others have a slightly convex leading and concave trailing edge. All teeth of Type I can be closely matched with corresponding teeth in the upper jaw of *Carcharhinus leucas* (bull shark), and are provisionally referred to that species. Unfortunately, the bull shark provides us with relatively little information on habitat; it is found in all oceans except the Arctic, and even invades fresh waters in Nicaragua and Guatemala. It is a large, heavy, slow-swimming shark that will eat almost anything, although rays seem to be its preferred prey. It is most common in inshore waters and is found frequently in bays and estuaries. Some of the curved Type I teeth can be confused with those of *Hemipristis serra* (see 11-2-8 below), but posterior serrations on the teeth of *Hemipristis serra* are much larger than the anterior.

Type II seems to be close to, if not conspecific with, *C. milberti*, sometimes called the sandbar shark. Teeth of Type II are lighter in construction than those of *C. leucas* and have finer serrations. The main cusp is triangular, inclined, and not distinctly set off from the tapering posterior blade, which also is serrated. This shark is also a nearshore form, as the name implies, and is found throughout the warmer waters of the Atlantic.

Type III is a form of dubious status. The teeth appear more stoutly constructed than those *C. milberti*, though as finely serrated, and the main cusp is separated by a distinct angle from the less-tapering posterior blade. Despite several attempts to do so, we have found no statistically significant means to quantify these differences to the eye. It is possible that these teeth are simply a variant of Type II, or they may represent a different species, perhaps *C. obscurus* (dusky shark).

The lower teeth of Carcharhinus vary slightly from species to species. They are much more slender than the upper teeth and mostly have nearly upright main cusps. On each side of the main cusp is a tapering blade. While many species shark have serrated lower teeth, quite a number have teeth which lack these serrations. The presence of both types (serrated and nonserrated) in the collections from Cumberland Island strongly suggests that current collections of upper teeth have not yet included all species present. All the species listed above have serrated lower teeth.

11-2-7 Galeocerdo cuvieri (tiger shark):

Several well-preserved teeth, mostly large, represent this species. The uppers and lowers are basically similar, though there are consistent differences. Both have a large, anteriorly placed, triangular main cusp, both edges of which are serrated. The anterior edge of the tooth is strongly convex, and the posterior edge is nearly straight. The trailing end of the tooth is composed of a series of serrated cusps of decreasing size. The whole apparatus forms a jagged saw of considerable slicing power, particularly when driven by the very strong jaw musculature of a tiger shark. These sharks are reported to be able to shear through both shells of large sea turtles with a single bite and are known to make quick work of chopping up even large eagle rays into bite-size pieces.

Tiger sharks will eat almost anything, including such odd items as lumps of coal and tin cans, but they seem to prefer large prey. They are quite unconcerned with water depth and bottom character and may be found almost anywhere in warmer oceanic waters.

Three specimens of Galeocerdo teeth from Cumberland Island show a distinct angulation in the leading edge that is reminiscent of the Miocene G. contortus. However, these teeth are larger and more coarsely serrated than those of the Miocene species and are here regarded as variants of G. curvieri.

11-2-8 Hemipristis serra :

Along with Carcharodon megalodon, this species comprises the only extinct species among the Cumberland Island sharks. The teeth of this species resemble extreme versions of those of Carcharhinus leucas, but are even more strongly curved, and the trailing edge of the main cusp is much more serrated than the leading edge. The pulp cavity of these teeth is unusually large, and a dark area is often visible through the enamel on the lingual face of the tooth. This represents mineral matter filling the pulp cavity.

Though classically "Miocene" in age, H. serra ranges from mid-Oligocene to well into the Pliocene of North America. A single specimen caught in the Red Sea in the late nineteenth century is thought by some students to represent the same genus, if not species. Some of the Hemipristis teeth from Cumberland Island appear to be reworked from earlier deposits, but a few appear to be quite fresh and are most likely contemporaneous with the deposits under consideration.

11-2-9 Physodon sp.:

Only a single small tooth is representative of this shark. Though the genus is still living, it remains poorly known. The tooth is 0.27 in. (8.05 mm) in length and 0.15 in (4.5 mm) in height (both measurements are total, including root). The main cusp of the crown is low and bladelike, with a sharply upturned apex. An accessory blade at the trailing end of the tooth has crude, weak serrations on it and is sharply set off by a notch from the main cusp. Both these latter features serve to distinguish this tooth from those of the even smaller Phizorprionodon (sharp-nosed shark), in which the accessory blade of the tooth is smooth and not set off by a notch.

11-2-10 Family Sphyrnidae (hammerhead sharks):

Sphyrna tiburo (bonnethead sharks)

Teeth of this species are common in the material at Cumberland Island. The teeth are rather small, rarely more than 0.3 in (1 cm) in maximum dimension. The main ridges are short, low, and not obviously serrate, although weak serrations appear under magnification on well-preserved specimens.

Sphyrna zygaena (smooth hammerhead)

This larger species is common in the fauna. The teeth average over 0.3 in (1 cm) across, and the largest approach is 0.7 in (2 cm). The main cusp is stouter than that of *S. tiburo*, and the accessory ridges are higher, clearer and regularly serrated.

Sphyrna ?mokarran (great hammerhead)

A single partial tooth has been provisionally referred to the great hammerhead. It is considerably larger than any referred to *S. zygaena* (0.8 in (2.3 cm) height as preserved, and not complete). As only half the main cusp is present, it is not possible to describe its form, but it seems more strongly inclined than any referred to the species above. The general shape of the accessory ridge (only the anterior is preserved) is similar to that of *S. zygaena*, but the serrations are considerably weaker and more irregular. As the inclination of the main cusp indicates the tooth is quite lateral in placement in the jaw, this would indicate that the specimen represents a shark of considerable size. The specimen is thus tentatively placed in or near *S. mokarran*, which also has teeth that resemble the specimen in form.

11-3 Rays (refer to Figure 11-3)

Among the most abundant fossil material are numerous ray teeth. All seem to belong to the family Myliobatidae (eagle rays), and three genera are represented.

11-3-1 Myliobatis (eagle rays):

The teeth are broad crushing plates with a comblike base. The median teeth are usually less than 5 times as wide as long (lateral diameter vs. midline length). Lateral teeth are small and hexagonal.

11-3-2 Rhinoptera (cownose rays):

The teeth have roots as above, but are much more widened and shortened. Width/length ratios of 8 or more for medium teeth, or lateral teeth with similar proportions, are representative of this genus.

11-3-3 Aetiobatis (spotted eagle rays):

Teeth with the root grooves set at a distinct angle to the margins probably belong to this genus. Typical modern representatives have teeth that are chevron-shaped in occlusal view. At least one fragment from Cumberland Island shows the midline bending of the tooth. Other teeth show the much broader curve of Aetiobatis irregularis, but this species is wide-ranging in time and its name has been used too much as a "catch-all" term.

11-3-4 Other rays:

"Stingers" of either myliobatids or dasyatids are common. Most fossil stingers seem small for myliobatids, and may belong to dasyatids, but rhombic teeth with only a single root groove, distinctive of dasyatids, have not been found. Small stingers may also be from young myliobatids, and small teeth are common in myliobatids.

11-4 Boney fish - Lepisosteus sp. (gar):

Though specifically indeterminate, the material of this fish undoubtedly represents a gar, and is not distinguishable from the living Florida gar (L.

platyrhincus). Although normally considered a fresh-water fish, the genus frequently ranges into bays and lagoons and even into the open ocean.

The fossil material assigned to this species consists of two scales, both with the ganoidine covering unique to the gars among Late Cenozoic North American fishes. One is a lateralline scale from the right side of the body. The scale's pectinated posterior margin is similar to that of L. platyrhincus. A jaw fragment is also tentatively assigned to the gars, but it is worn and lacks preserved teeth.

11-4-1 Sciaenidae; Pogonias sp. (sea drum):

The massive, rounded crushing teeth of sea drums are common and distinctive in the material from Cumberland Island. These are not teeth from the jaws but from the gill arches, located in the pharynx. Their function was to thoroughly crush the shell fish that form much of the diet of these common fishes. Less common but more distinctive are fragments of the pharyngeal bones that bore those teeth.

11-4-2 Didon vetus (extinct porcupine fish)

Jaws of this distinctive fish are common in the Cumberland Island fauna. The paired main crushing teeth are subpentagonal in outline, and wider than long. Successional teeth are visible in most specimens, including some specimens that consist only of stacks of teeth.

While the type from South Carolina is Miocene, as were the specimens described by Casier (1958) and Leriche (1942), the species seems to be wide-ranging in time. Specimens from the middle Eocene of Alabama (Gosport Sand at Little Stave Creek, Clarke Co.) are indistinguishable from others. It also seems possible that the species may range up into the Pliocene, but no direct evidence has been found.

11-5 Mammals

Two mammals are represented in the material from Cumberland Island. These specimens provide little hope for even the flimsiest identification beyond order.

11-5-1 Order Perissodactyla (unidentified horse):

Many splinters of horse teeth were recovered, but none is more than 25% complete. On the basis of the material, it is impossible to determine even the genus. However, the teeth are definitely high-crowned, indicating a post-Oligocene age, and the size of the fragments is more consistent with a Plio-Pleistocene age than with Miocene.

11-5-2 Order ?Cetacea:

A single vertebral epiphysis probably represents a small whale (dolphin or porpoise). It is solidly ossified but not fused with the (missing) centrum of the vertebra. The ossification indicates a mature animal, and the failure to fuse with the centrum is not consistent with land mammals, unless the specimen is abnormal. Thus, the probable assignment of the specimen is to the whales.

11-6 Reptiles

11-6-1 Indeterminate turtle (refer to Figure 11-4):

Various fragments of turtle shell are not uncommon in the material recovered. Intensive work might determine at least the genus, but does not seem justified for the information to be gained. The fragments appear to be ordinary fresh-water turtles of the family Emyidae, perhaps *Pseudemys* (cooters) or *Malaclemys* (terrapins).

11-6-2 ?Alligator sp.:

Two fragments seem to represent crocodilians, but neither identification can be certain as both fragments are badly worn. One specimen is a large rectangular piece of bone about 1 x 1 in (3 x 3 cm) that is most likely a scute (piece of the back armor), and the other is a badly battered large conical tooth. The latter may be from an alligator (as suggested by its stout shape), a Mesozoic reptile (perhaps a mosasaur), or even a whale.

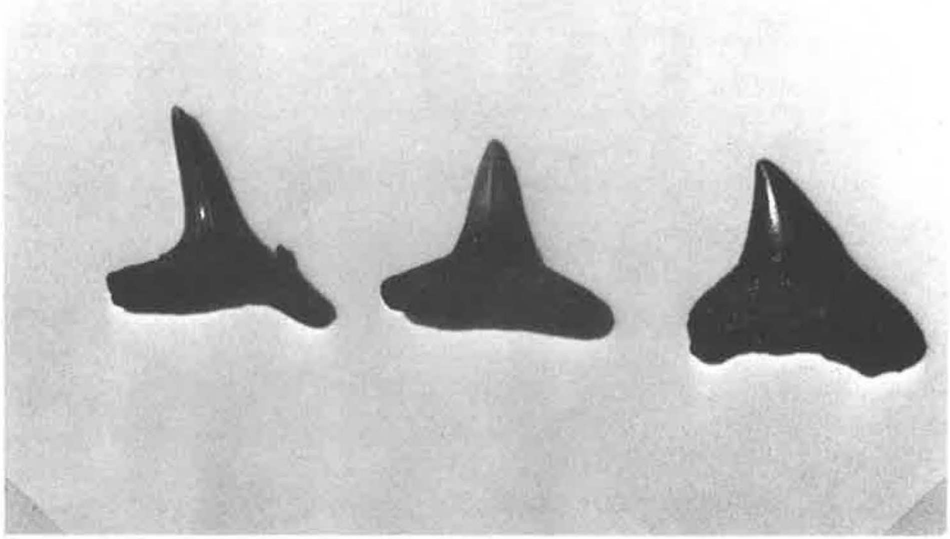

Figure 11-1 Shark teeth from Cumberland Island (L-R) ?Carcharias or Odontaspis sp., Sphyrna zygaena, Neogopria sp.

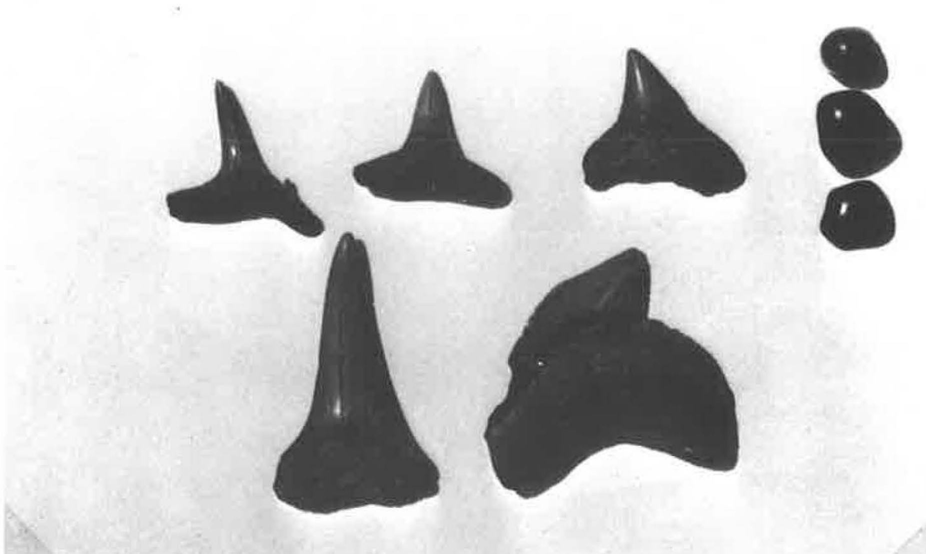

Figure 11-2 Fossil shark and sea drum teeth (L-R) ?Carcharias or ?Odontaspis sp., Sphyrna zygaena, Negopria sp., Pogonias, Isurus, Galeocerdo sp.

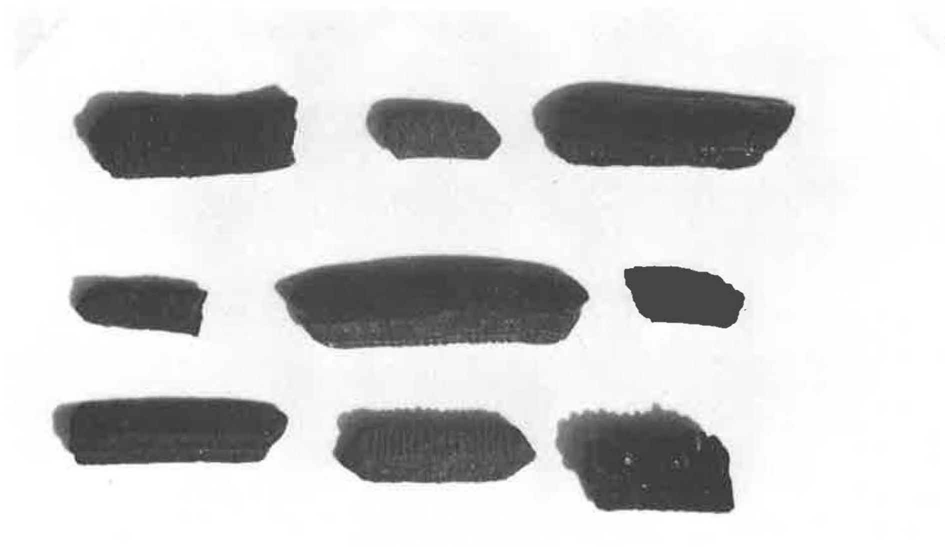

Figure 11-3 Fossil Ray teeth (Rhinopterus spp.)

Figure 11-4 Fossil fragments of turtle plate

12-0 GENERAL RECOMMENDATIONS

12-1 Introduction

The following recommendations have been derived from data gathered as a result of the studies on Cumberland Island. These are recommendations to address existing or potential problems. Some specific aspects need further investigation. In some cases methodology has been furnished, although other methods may be equally applicable. For background data the reader is referred to the related portion of the text and the references cited.

12-2 Recommendations relating to landforms and environments

1. It has been noted that foot travel over the back dunes has resulted in the lowering of the dunes by wind erosion. To avoid this problem it is recommended that boardwalks be constructed over the dunes.

2. Foredune and interdune meadow vegetation are important in the stabilization of the loose sands of the beach-dine complex. Many of these grasses are easily destroyed by foot travel. With this in mind it is recommended that boardwalks be extended to the beach to protect the fragile vegetation.

3. The back dunes are actively migrating from east to west across the island threatening structures located west of the dunes. To avoid this potential problem, it is recommended that the rate of migration of the dunes be determined at each site prior to construction. After the rate of migration is known, the structure can be placed in a less hazardous location. It is assumed that structures not in the vicinity of the back dunes are not covered by this recommendation.

4. The rate of migration of the back dunes is slowed by vegetation; therefore, it is recommended that an area 80 ft (25 m) west of the back dunes be left in a natural state. It would also be advisable to erect a barrier to protect this zone in high visitor-use areas.

5. Erosional areas on the west side of Cumberland Island pose danger to buildings located nearby. It is recommended that no building be constructed within 160 ft (50 m) of these erosional areas. Existing buildings located less than this distance from erosional areas should be appropriately protected.

6. Bivalves such as the common oyster can slow erosion rates by "armoring" the intertidal zone with their valves. All efforts should be made to protect existing bivalve populations and encourage their propagation.

7. Flooding is a major concern with structures on Cumberland Island. Plate 4 is a flood hazard map of Cumberland Island. Areas in red are often flooded, the yellow areas are expected to be flooded once every 100 years, and the white areas are rarely flooded. It is recommended that there be no structures built in the red zone.

8. If long-term erosional patterns continue, there is a possibility the island will be breached at its narrowest portion. This should be kept in mind when permanent structures are built. Past erosional rates in this portion of the island are discussed in the section on coastal changes.

12-3 Recommendations related to ground water

1. The unconfined water table on Cumberland Island is near the ground surface and is easily polluted. It is recommended that the unconfined water table not be used as a source of water for human consumption although it can be used for other purposes.

2. When a structure is removed by the National Park Service, the existing wells are commonly left uncapped or unplugged. This can provide a direct route for contamination of the aquifer. To eliminate this problem all unused wells should be plugged with a cement slurry or bentonite. If further use of the well is intended, then it should be capped. This recommendation does not apply to the flowing artesian wells.

3. The water well inventory of Cumberland Island revealed several artesian wells that flow onto the surface but serve no purpose. Because the Principal Artesian Aquifer is heavily used, such flowing wells should be capped to help reduce aquifer withdrawals. Because of the artesian flow, it would be difficult to plug these wells. A possible use of the artesian wells is a source of fresh water for wildlife. This use is beyond the scope of this investigation.

4. To insure that surface water is excluded from wells, all wells should be properly sealed. This should include a cement pad around the well casing on the surface as well as a grout seal at the base of each string of casing. The grout seal should extend outside the casing from the base of the casing to the land surface. If this is not possible, at least one-half of the casing length should be grouted from the base of the casing. This can be achieved by pumping the grout down into the annular space between the bore hole and the casing.

5. The Principal Artesian Aquifer is a major source of ground water in coastal Georgia. Around areas of heavy use, cones of depression have formed in the potentiometric surface of the aquifer. Increasing pumpage from this aquifer will cause an expansion of the cones and increase the potential of salt water intrusion. Although the Principal Artesian Aquifer is suitable for general use, potential problems on the mainland with this aquifer may be avoided through use of the shallow Pliocene-Miocene or Miocene Sand Aquifers.

6. Data from deep wells on Cumberland Island can provide vital information about the Principal Artesian Aquifer. If salt water intrusion should occur in this aquifer, it might become evident on Cumberland Island prior to the mainland; therefore, it is recommended that chloride content of existing selected wells be determined yearly. In this manner, Cumberland Island possibly could serve the public interest as a first warning of salt water intrusion prior to its reaching the industrial and public supplies on the mainland. Periodic measurements of potentiometric heads on the existing Principal Artesian Aquifer wells would document the extent of the cone of depression centering on St. Marys and Fernandina Beach,

Florida. This periodic measurement is recommended to monitor the condition of the aquifer.

7. The best sources of ground water for park use at the present time are, in order of preferences, the Miocene Sand Aquifer, the Principal Artesian Aquifer, and the Pliocene-Miocene Aquifer. The unconfined water table aquifer should not be used for human consumption.

8. If the Pliocene-Miocene Aquifer is used, the water should be tested yearly for chloride content.

9. The sands of the Satilla Formation are highly permeable and the water is near the surface. For these reasons there are few places suitable for septic tank filter fields. The suitable areas are shown in Figure 9-1. Where filter fields are to be used in unsuitable areas, septic effluent will enter the unconfined water-table aquifer.

10. Because of the nature of the surface sands and the lack of clay beds, there are not suitable areas for significant sanitary landfills.

11. If wells are drilled into the Principal Artesian Aquifer, it is recommended that they not exceed 1000 feet (about 350 meters) in depth to prevent contamination by saline water.

12-4 Recommendations relating to economic minerals and geologic testing

1. Portions of Cumberland Island have been tested for the occurrences of heavy minerals. This investigation has not determined if any leases were signed. The National Park Service should determine if there are valid leases and, if so, where they exist.

2. If subsurface geologic testing is allowed for any reason on Cumberland Island, all test wells should be plugged.

12-5 Miscellaneous recommendations

1. Collection of fossil material from the dredge piles in Raccoon Keys Salt Marsh should be allowed. This would allow the visitor an educational experience in the collection and identification of fossil material (along with identified material provided with this study). The material in the dredge piles has been removed from their original sediments and thoroughly mixed with other material.

2. Livestock such as hogs, cows, and horses can cause extensive damage to the fragile grasses in the beach-dune complex. Therefore it is recommended that grazing and disturbance in this area by livestock should be minimized. This effort was already begun at the onset of this project and should continue.

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APPENDIX A

DETAILED STRATIGRAPHY OF CUMBERLAND ISLAND

Note: This section is quite technical and need not be read for management purposes. Non-geologists should restrict thie reading to Sections A-1, A-6, and A-7.

DETAILED SHALLOW STRATIGRAPHY OF CUMBERLAND ISLAND

A-1 Introduction

The subsurface geology of Cumberland Island has not been previously studied by direct drilling methods. Henry and others (1973a) briefly discussed the surface geology of Cumberland Island in a report to the Science Office of the National Park Service. According to this report, Cumberland Island is a compound barrier that developed during two distinct periods of time. They pointed out that the largest and most landward portion of the present island is a remnant of a barrier island that was formed during the Late Pleistocene Silver Bluff sea level stillstand, approximately 40,000-50,000 years before present (B.P.), at an elevation some seven feet (two meters) above present sea level. Subaerial erosion modified the Silver Bluff Island during the subsequent low stand of the sea. Approximately 20,000 years B.P., the sea began rising, marking the Holocene transgression. Henry and others (1973a) concluded that at about 5,000 years B.P., a marked slowing of sea level rise allowed the formation of a Holocene barrier island system somewhat seaward of its present location. As a result of subsequent island retreat, the new barrier system became welded to the Silver Bluff deposits, and thus the composite Cumberland Island was formed (Plate 2).

Good discussions of the subsurface Pleistocene deposits of coastal Georgia are presented by Herrick (1965), Logan (1968), Henry and others (1973a), Woolsey (1977), and Henry and others (1978) and are based on analysis of borings and seismic profiles. According to these studies, the Pleistocene deposits vary from approximately 30 to 80 ft (10m to 25m) in thickness and consist of alluvial sands and gravels interbedded with thin beds of floodplain silts and clays, fossiliferous marine sands and muds, and estuarine sands and muds. Seismic profiles show that

* All figures referred in this Appendix are provided in Chapter 4.

much of the Pleistocene section is composed of highly cross-bedded, cut-and-fill channel deposits.

Sediments of Pliocene and Miocene age have been described from the subsurface of the mainland and nearshore areas adjacent to Cumberland Island by Herrick (1965), Woolsey (1977), and Henry and others (1978). Henry and others (1973b) pointed out that the Miocene-Pliocene section in Georgia was so poorly understood that future studies would probably result in a significant revision of the regional Neogene stratigraphy. In southeast Georgia, the problem revolves around the Duplin Formation, originally placed in the late Miocene (Herrick, 1965), and the Charlton Formation, originally placed in the Pliocene (Herrick and Vorhis, 1963).

According to Henry and others (1973b), Duplin deposits traditionally have been regarded as late Miocene in age. In Georgia they were described by Veatch and Stephenson (1911) from outcrops along the Savannah, Altamaha, and St. Marys Rivers as being correlative with the Duplin Marl of the Carolinas. Lithologically, the Duplin in the Carolinas consists primarily of olive-green sand, sandy clay, and clayey sand. And, according to Furlow (1969), in the upper Georgia coast it is commonly difficult to distinguish the Duplin from the Miocene Hawthorne Formation except for the latter's higher phosphate content. However, studies of the planktonic foraminifera in the Duplin equivalent strata in west Florida and Virginia by Akers (1972), in Georgia and South Carolina by Herrick (1976), and in Georgia by Huddlestun (oral commun., 1980) indicate a middle Pliocene age for those deposits directly underlying the Pleistocene barrier and back barrier facies.

The Charlton Formation was the name applied to the argillaceous limestone and clay deposits exposed in the banks and bluffs of the St. Marys River. Veatch and Stevenson (1911) described this formation and called it Pliocene in age. Herrick and Vorhis (1963) and Woolsey (1977) noted the lithologic and faunal similarities of the Charlton Formation to the Miocene Hawthorne Formation as well as its stratigraphic position below the Duplin Formation. On this basis, they proposed a middle Miocene age equivalent to the Coosawhatchie Formation of the Hawthorne Group (Huddlestun, oral cummun., 1980). In this study the Duplin Formation is considered to be middle Pliocene in age and the Charlton to be middle Miocene.

Figure 4-1 shows the locations of the deep stratigraphic test well (CI-01), of the shallow borings, and of the seismic profiles. Figures 4-2 thru 4-7 are cross-sections from which the three-dimensional geometry of Cumberland Island can be interpreted.

A-2 Laboratory procedures

The core and cuttings were logged in detail and examined with a binocular microscope to determine textures, lithology, dominant minerals, color, faunal content, and sedimentary structures. Microfaunal studies were limited to the core samples. Depending on continuity of cores and change in lithology, a sampling interval of 3 ft (1 m) or less was used to select material for study. Sieve analyses were carried out using the procedure described by Folk (1974). Samples were split to obtain approximately 25 grams of sediment, weighed on an analytical balance, and seived for 10 minutes through a 1-phi interval set of 3-inch diameter sieves placed on a platform vibrator. For samples containing more than 10% material finer than 4 phi (0.062 mm), the pan fraction was analyzed for total percent silt and clay using an abbreviated pipette method (Folk, 1974).

A computer program based on that described by Slatt and Press (1976) was used to obtain statistical parameters of mean diameter, sorting, skewness and kurtosis (Folk and Ward, 1957) and to determine percentages of gravel, sand, silt, and clay for the 185 core samples.

High resolution seismic profiles from the Cumberland Island area (see Figure 4-1) were provided by V.J. Henry (Henry and others, 1978). These data, obtained with an EG & G UNIBOOM system, were compared with the core information to identify major stratigraphic units and geologic structures. Examples of the profiles are provided in Figures 4-10 thru 4-15.

A-3 Pleistocene stratigraphy

A-3-1 Introduction

Barrier island and back barrier deposits were the two major Pleistocene facies identified in the Cumberland Island cores and cuttings. The barrier island facies consists of a relatively homogeneous, lenticular sand body overlying the back barrier facies and is characterized by clean, fine sand with subordinate amounts of heavy minerals. Sedimentary structures such as horizontal and cross stratification are present and indicate beach and nearshore environments. In contrast, the back barrier facies was recognized in the subsurface by the presence of 1) interbedded silty clay, sandy clay, and clayey sand 2) biogenic reworking indicated by burrows, mottled sand and lack of stratification, and 3) macrofossils and plant remains characteristic of estuarine environments.

The barrier island and back barrier facies grade laterally and vertically into each other as shown in cross section A-A' through F-F' (Figs. 4-2 through 4-7). Their spatial relationship suggests considerable transgression over the back barrier facies by the barrier island facies. The exception was bore hole 7 (Fig. 4-5) where the Pleistocene back barrier facies is in direct contact with the middle Miocene limestone (Charlton Formation). The contact between the Pleistocene and older sediments was defined by microfossils and/or by obvious textural changes. The total thickness of the Pleistocene ranges from 40 to 90 ft (12 to 28 m).

A-3-2 Lithology, texture, and paleontology of the barrier island facies:

The sediments characterizing the Pleistocene barrier island facies on Cumberland Island consist predominantly of fine sand with a mean grain size of 2.84 phi.

However, 35% of the samples from the barrier island facies had a mean grain size value finer than 2.84 phi.

The sand facies varied in color from yellowish-dark brown to white. Dark brown coloration and mottled texture were predominant in the upper portion. More than 90% of the sand that composes the barrier island facies is quartz; the sand contains less than 10% feldspar, heavy minerals, white mica flakes, and phosphate grains. Quartz grains have iron staining which probably reflects reasonably long-term exposure and weathering. Roundness ranged from subangular to rounded with subrounded grains most abundant.

The facies exhibits a wide variation in sorting, with difference of high and low phi sizes ranging from 0.16 phi (very well sorted) to 2.43 phi (very poorly sorted). The majority (93%) of the samples showed positive skewness. Some of these samples coincided with good sorting, suggesting an eolian influence. Contrary to these results, Hails and Hoyt (1969) found positive skewness in only 30% of the samples from an older sequence of Pleistocene barrier island facies within the Georgia Coastal Plain. This difference could be explained by their sampling procedure in that they did not collect samples below the water table, and that no analyses were made of the samples which contained more than 5% silt and clay.

In any case, the large number of Cumberland Island samples exhibiting positive skewness could be due to: 1) concentration of fine material into grain interstices as a result of winnowing of surface materials, 2) alteration (etching) of the sand by circulating groundwater, and 3) eolian influence (addition of finer-grained wind-blown materials). Chappel (1967) mentions that alteration (etching, precipitation, etc.) of the sand by groundwater action and/or offshore paleowinds supplying fine particles commonly obliterated negative skewness. Also, Scott (1976) suggested that chemical weathering of feldspar could account for the high mud content and resultant positive skewness.

In addition to the information provided by the cores, the barrier island facies was examined in outcrops at Cumberland Wharf (see Plate, 1, Figures 4-1, and 4-9). At this locality, the sand body shows characteristics not recognized in the cores: 1) low angle sets of wedge-shaped laminae enhanced by heavy minerals, and 2) horizontal fine lamination interrupted at scour surfaces. Howard and Frey (1980) described similar structures as characteristics of the foreshore environment. With regard to geometry, the sand body defining the barrier island facies is lenticular and has the following dimensions: 12 miles (19 km) in length, 0.6 to 3 miles (1 to 5 km) in width, and up to 60 ft (18 m) in thickness (see Figures 4-2 through 4-7).

Several humate horizons that probably represent perched water tables occur in borings 1, 9, 14, and 16. The humate probably originated by precipitation of organic material derived from overyling deposits. According to Swanson and Palacas (1965), dissolved and colloidal organic material derived by leaching from decaying plant material at the surface may be transported and deposited by percolating groundwaters along impervious layers of clay or tightly packed fine sand.

The upper part of the barrier island facies is characterized by an abundance of plant remains, some still in growth position. The plant remains consist of stems, roots, and leaves with many fragments partially covered with hematitic and limonitic coatings.

Shells and shell fragments occured only rarely in the barrier island facies. Abraded and weathered shell fragments of oysters were found in a few sand beds. The acid waters percolating through the permeable sand probably caused leaching, which left few remains. *Mulinia lateralis* was the only whole shell recovered in the barrier island facies.

The most important trace fossil identified in the barrier island facies was *Ophiomorpha nodosa* (Figure 4-8), the fossil counterpart of the burrow with burrow walls consisting of thin black material, probably fecal pellets. The burrows occurred in boring 3 at 20 ft (6 m) and 33 ft (10 m) below the surface. The presence of this biogenic structure would indicate a nearshore environment (Weimer and Hoyt, 1964). A probable Balanoglossid burrow (Frey, oral commun., 1980) also was present at the 20 ft (6 m) depth. This organism generally produces U-shaped feeding burrows in beaches and tidal flats and conical-shaped mounds on the sediment surface (Mayou and Howard, 1975).

A-3-3 Lithology, texture, and paleontology of the back barrier facies:

Back barrier facies deposits consist primarily of dark green clayey fine sand and clay, commonly separated by beds of sand ranging from virtually nil in thickness up to 10 feet (3.5 m) thick. The latter is yellowish-brown, fine quartz with angular to subangular grains, containing minor amounts of heavy minerals (less than 4%), white mica flakes, (1-3%), and phosphate grains (1%). In borings 5 and 16, the thicknesses of interbedded sands reached 10 ft (3 m) and 3 ft (1 m), respectively. Silt and clay beds grade laterally into silty clay and clayey sand, suggesting variable sedimentation conditions; namely quiet deposition interrupted by periods of high energy.

In terms of average sediment composition, the back barrier facies consists of 44% mud, 29% sand and 27% muddy sand. An important characteristic of the mud in this facies is the relatively high concentration of silt (59%) compared to clay (41%). These data are based on samples from borings 1, 3, 5, 11, 14, and 16, which had a thicker barrier facies than the other borings. In contrast to the barrier island facies, the back barrier facies is a heterogeneous unit composed of a wide variation of sediment textures.

In boring 14 (Figure 4-3), a coarse detritus of coquina limestone, calcareous sandstone and large shell fragments was found at 72 ft (22 m) below the surface (-46 ft (-14 m) MSL). The lithology and texture suggest that the material was reworked from the Miocene by tidal scour and deposited as channel lag. Above that depth, the presence of horizontally bedded muds with thin sand laminae indicates a decrease in energy. The sand laminae are up to 1 in (3 cm) long and 0.3 in (8 mm) thick (boring 6). According to Reineck and Singh (1975) and Howard and Frey (1975b), such lenticular bedding is developed in response to alternate periods of high and low tidal currents with a generally low sand supply. Mayou and Howard (1975) recognized similar lenticular bedding in Doboy Sound, Georgia. Edwards and Frey (1977) indicated that back tidal creeks and estuary margins are the main environments in which lenticular bedding is developed.

In general, the back barrier facies displays an irregular, lenticular shape from east to west but shows a rather uniform thickness in the north-south direction (cross section F-F'). The sequence decreases in thickness seaward (cross sections AA'-DD'), possibly a result of erosion during the Holocene transgression.

Scattered microfossils were found in the back barrier deposits, principally in sandy beds interbedded with mud. Elphidium sp., Elphidium poeyanum, Polymorphina sp., and Ammonia beccarii were the most common species present. These were found only in boring 11. The diatom, Cocconeis superba, was identified in a silt/clay sequence in borings 7 and 11 at 72-75 ft (19-23 m) and 65-72 ft (20-22 m) below surface, respectively. According to W.A. Abbott (oral commun., 1980), Cocconeis superba is present on the west coast, but is extinct on the east coast of the United States and found in middle-late Pleistocene age deposits.

One of the most common bivalves found in the back barrier facies is the oyster, Crassostrea virginica, which appears as fragments in sandy beds interbedded with silty clay beds. The presence of Rangia cuneiata particularly suggests an estuarine back barrier environment for these sediments because this organism is generally restricted to fresh or brackish water (Abbot, 1954). Olivella mutica and Mitrella lunata were found in a sandy facies in boring 14. According to Abbot (1954), the first species is common in warm, shallow water, and the second is mainly found along the low tide line.

Whole shells and fragments of Mulinia lateralis were common. Abra aequalis, reported by Mayou and Howard (1975) to occur along channel margins in Doboy Sound, was found in boring 6. Some of the shells have fresh partings suggestive of fracture by the drill bit rather than by current transport.

Plant fragments were very common in borings 5, 6, 11, and 15. They probably represent fragments of Spartina alterniflora that were incorporated in marsh muds as thin organic laminae. A lignitic plant stem, 3.5 in (9 cm) long and 1.2-1.6 in (3-4 cm) in diameter, was found in boring 16.

A significant characteristic of the back barrier sediments is the intense bioturbation that occurs in both sand and mud. The mud beds commonly lack stratification or have disrupted stratification; also, muds commonly have patches of infilling of "clean" sand. A sand-filled burrow, 0.6 - 0.8 in (1.5 - 2.0 cm) in diameter, was recognized in boring 6 at 56 ft (17 m) depth. This biogenic structure may have been developed by fiddler crabs. Bioturbation of this type has been described by Edwards and Frey (1977) in salt marshes on Sapelo Island, Georgia.

A-3-4 Stratigraphy as indicated by seismic methods:

Seismic data indicate that both barrier island and back barrier facies have been affected by Holocene and Pleistocene tidal creek erosion in the inlet behind Cumberland Island. As a result, cut and fill structures are numerous, and in places the Pleistocene sequence is thin or absent. The upper part of the Pleistocene commonly is truncated by the Holocene erosion (Figure 4-10). Commonly the seismic reflections into the fill channels are quite diffuse and featureless where compared with those from the underlying Pliocene sediments. This may be caused by sand and gravel material filling in the channel. In many instances, it was very difficult to define the upper Pleistocene contact in the seismic records because the lithology of the Pleistocene deposits is similar to that of the Holocene. In this sense, the reflectors for both Pleistocene and Holocene sediments display the same pattern.

Deposits in front of Cumberland Island are observed as a continuous, generally parallel to subparallel sequence overlying the Pliocene sediments. However, the thickness was difficult to estimate because the Holocene-Pleistocene boundary is not clearly defined in the seismic record. Two miles offshore from Cumberland Island, channel cut-and-fill structures are present (Figure 4-11). The channels in front of the island show lack of information in the lower part of the channel fill, similar to the channel cut-and-fill structures behind the barrier island. This would suggest gradation of material into the channel with coarse sand and gravel in the lower part of the channel grading upward to fine and dense sediments. Upward, the reflectors display good resolution with continuous seismic signatures.

A-4 Middle Pliocene stratigraphy

A-4-1 Lithology, texture, and paleontology of the middle Pliocene:

The lithology representative of the upper part of the middle Pliocene is yellowish-brown to greenish-gray, fine-grained sand which has approximately the same composition as the sand in the lower part of the middle Pliocene. Feldspar content is higher in the basal sand than in the upper part. The lower portion of the middle Pliocene is composed of pale green quartz sand that varies from fine to coarse and from subangular to well rounded. The sand contains subordinate amounts of heavy minerals (3-5%), white mica flakes (1-2%), feldspar (less than 10%), and phosphate grains (1-2%). Shell fragments (less than 5%) are present. In general, the composition of the sand that overlies the middle Miocene is relatively constant, but grain size is variable and the sand is poorly sorted. The boundary between the middle Miocene and middle Pliocene generally is characterized by the presence of coarse clastic material and limestone fragments.

In samples from boring 3 at the south end of Cumberland Island, the standard deviation (sorting) varied between 1.18 and 3.48, or poorly to very poorly sorted. In contrast, samples from the north end of Cumberland Island had better sorting and were finer grained. The change in sorting in this unit would suggest a more prolonged and continuous reworking of the sand deposited at the north end of the island. The thickness of this unit is somewhat variable and may not be well represented in most of the cores due to poor recovery.

Muddy sand beds, less than 13 ft (4 m) thick are present in borings 4 and 10. These sediments represent material deposited in tidal creek channels. Sandy and silty clay interbedded with clay and clayey sand with shell fragments were very common. In general, the clay beds are characterized by lignitic plant material appearing as small particles parallel to stratification. The major sedimentary structure in the Pliocene units is horizontal bedding with clay laminae interbedded with thin sand beds. Cross-bedding is present in alternating clay and fine sand beds in boring 3.

These sediments are interpreted to be middle Pliocene in age and correlative with the Duplin Formation. In general, this sequence was identified on the basis of foraminifera and diatoms. The foraminifera were dominated by benthonic species (Appendix F), including abundant Elphidium spp., especially Elphidium gunteri, Elphidium advena and Ammonia beccarii. The large number of Elphidium in these sediments indicates a shallow marine environment. Walton (1964) mentioned Elphidium gunteri and Elphidium advena as being common over a large portion of the northeastern Gulf of Mexico, usually in depths shallower than 5 fathoms. Other important sensitive benthonic forams found in the middle Pliocene on Cumberland Island include Hanzawaia concentrica and Cibicides sapeloensis. Haw and Boersma (1978) identified Hanzawaia and Cibicides as typical shallow marine forams. The different species of Elphidium and Ammonia beccarrii are widely distributed in the basal and upper sand beds. A special characteristic concerning the forams is the mixture of benthonic and planktonic species in the sediment. Probably during the time of deposition of the Duplin Formation, planktonic species were transported inshore by existing currents, suggesting a relatively open circulation.

Several species of planktonic forams were identified. These include *Globigerinoides obliquus*, *Globigerinoides sacculifer*, *Globigerinoides rubra*, *Sphaeroidinellopsis subdehiscens*, and *Globorotalia menardii*. *Globigerinoides obliquus* and *Sphaeroidinellopsis subdehiscens* are also characteristic of the middle Miocene (Woolsey, unpublished Ph.D. thesis, 1977). In addition, Herrick (1976) defined the Doctortown deposits in Georgia as early middle Pliocene based on *Sphaeroidinellopsis subdehiscens* and *Globigerinoides rubra*. According to Bergren (1973), the extinction of *Sphaeroidinellopsis subdehiscens* occurred at 3.1 my B.P. (middle Pliocene?). Berggren also correlates in part the Pliocene-Pleistocene boundary (1.8 my.) with the extinction of *Globigerinoides obliquus*.

Diatoms are present in some sections in silt/clay beds. *Phaphanesis angularis* was found in boring 4 between 60 ft (18 m) and 70 ft (21 m) depth. Abbott (oral commun., 1980) suggested that the Pliocene sediments are near the late Pliocene-early Pleistocene boundary, based on this organism.

The macrofauna of the Pliocene in Cumberland Island includes *Nassarius obsoletus*, found in a sandy facies in boring 3 (Appendix D). Abbott (1954) mentioned this organism as being very common in warm mud flats. Other molluscan fossils recovered in the sediments include *Mercenaria* sp., *Mulinia lateralis*, *Balanus* *Crassatella* sp., *Pecten* sp., *Ostrea* sp., *Anadora ovalis*, *Acteocina canaliculata*, and *Olivella mutica* (Appendix E).

Fragments of *Crassostrea virginica* and of unidentified bivalves were commonly found in thin beds within the silt/clay sequence (boring 15). In the muddy beds, scattered bivalve shell fragments also were found. According to Frey and others (1975), *Crassostrea virginica* is a good indicator of estuarine conditions on the

Georgia coast. In general, the specimens do not reveal signs of prolonged abrasion or weathering. Nevertheless, most of the specimens occur as disarticulated valves. No valves were observed in growth position. On the other hand, small patches of "clean" sand were found in the muddy beds which suggest activity of burrowing organisms, such as fiddler crabs, gastropods, and bivalves, similar to the organisms which burrow in the modern salt marsh.

The sediments described and defined above as middle Pliocene can be correlated lithologically and biostratigraphically with the Duplin Formation (Porter's Landing and Sapelo facies) described by Woolsey (1977) in the northern part of the Georgia coast and on the inner continental shelf. This interpretation is based upon 1) similarity of four planktonic species (Globigerinoides obliquus, Globigerinoides sacculifer, Globorotalia menardii, and Sphaeroidinellopsis subdehiscens) and 2) similar lithologic characteristics of the Cumberland Island facies and the middle Pliocene Porter's Landing and Sapelo facies.

A-4-2 Stratigraphy as indicated by seismic methods:

Correlated with the boring data, the seismic profiles around Cumberland Island show a strong reflector that defines a stratigraphic unconformity between the middle Miocene and the overlying sediments. The seismic profile along the Cumberland River (line 169) shows an incomplete Pliocene sequence, suggesting that the Pliocene has been subjected to varying degrees of erosion during the Quaternary. Some portions of the profile show a thin, diffuse reflector on the top of the Miocene that could be interpreted as a mixing of sediments of different age (west of Stafford Island, Figure 4-13). Five kilometers (3 miles) south of Cumberland Wharf (Figure 4-1), the reflector patterns indicate the Pliocene/Pleistocene contact. The Pliocene shows wavy and interrupted reflectors, probably indicating a heterogenous lithology. In contrast, the Pleistocene shows straight, continuous reflectors that would define the back barrier facies consisting of homogenous, dense clay/silt beds (Figure 4-14).

Southeast of Cumberland Island, the Pliocene sediments, which gently dip seaward, maintain an approximately uniform thickness for almost 3 miles (5 km). These sediments have foreset beds that dip seaward, indicating a deltaic origin (Henry and others, 1978). Northeast of Cumberland Island, the Pliocene deposits tend to thicken rapidly. At the east end of line A-A' (Figure 4-2), the thickness of the Duplin Formation is 70 ft (21 m). This increase in thickness coincides with the erosional scarp developed after deposition of the middle Miocene sediments.

The thickness of the Pliocene varies between 20 and 33 ft (6 and 10 m) 2 miles (3 km) offshore (line 171). At this distance, channels of probable Pleistocene age cut into the Pliocene, with several reaching into the top of the middle Miocene (Figure 4-11).

A-5 Middle Miocene stratigraphy

A-5-1 Lithology, texture, and paleontology of the middle Miocene:

Because of its easily recognized calcareous lithology and induration, drilling operations were stopped upon reaching the Charlton Formation. The top of this unit consists of a yellowish-gray, hard, sandy, phosphatic, locally cherty limestone. One of the most common characteristics of the upper part of this formation is the abundance of detrital quartz in the calcareous mud or calcarenite. However, the texture and composition changes laterally and vertically in the several bore holes. In borings 8, 10, and 12, a coquinoid facies was present, with abundant bivalves occurring in a fine-grained matrix. The rock shows a grain supported framework. Although no samples were chemically analyzed, it is believed that the limestone is partially dolomitized, for the rock effervesced very slowly in cold hydrochloric acid. According to Richards (1955), dolomitic limestone is also present in the Miocene Hawthorne Formation in south Georgia.

The upper contact of the Charlton displays both an erosive and horizontal surface. This contact is seen at the northern end of Cumberland Island (Fig. 4-2, 4-4). Seismic records also show that a rugged morphology is evident on some parts of the Charlton Formation surface (cross section B-B', Figs. 4-3, 4-5, and 4-15). This morphology is interpreted to be the result of paleokarst development (i.e., a characteristic type of topography formed over the limestone by solution, leaving closed depressions or sinkholes).

The main fossils found in the top of the Charlton Formation were *Mulinia* sp. and *Turritella* sp. Some fossils were present as internal molds, which made identification difficult.

A-5-2 Stratigraphy as indicated by seismic methods:

The top of Charlton Formation is represented on seismic records as a prominent reflector that separates the middle Miocene from the overlying sediments. This reflector is well defined around Cumberland Island.

Behind the island, along Cumberland River, seismic data (line 169) indicates the middle Miocene to be near the bottom of the channel, with a depth ranging between 36 and 52 ft (11 and 16 m) below sea level. This change of elevation compared with the data from the cores in the north part of the island suggests a scarp that approximately follows the Cumberland River. However, south of the island, a scarp is not evident. In Kings Bay, west of Cumberland Island, the contact of the limestone is at an average of 25 ft (8 m) below sea level (Corps of Engineers, 1954). According to Henry (oral commun., 1980), the Charlton is exposed in the St. Marys River.

Based upon information from seismic lines 11, 12, 13, and 171, a roughly horizontal surface is consistent for approximately 3 miles (5 km) seaward of Cumberland Island. Beyond this distance, at the northeast of the island, the top of this formation abruptly changes slope due to the presence of an erosional scarp. At the east center of the island, the top of the middle Miocene dips seaward (cross section B-B', C-C', and D-D', Figures 4-3, 4-4, and 4-5). Southeast of Cumberland Island, the top of the limestone is generally horizontal for almost three miles (5 km); however, seaward of this distance, a gentle slope is present (Figure 4-6).

A-6 Stratigraphic framework (middle Miocene to Recent)

The development of the major depositional environments and stratigraphic relationships of Cumberland Island are described in the following discussion from the oldest to the youngest units. The uppermost part of the Miocene Charlton Formation is a shallow marine deposit. The presence of abundant detrital quartz "floating" in the calcareous mud suggests a nearby source of terrigenous clastics which were deposited simultaneously with the mud. The lithologic changes from a calcarenite to a coquina facies in borings 8, 10 and 12 suggest extensive transportation and deposition in the nearshore zone. That is, most of the fossils are fragmented, indicating a history of transportation before deposition.

According to Vail and others (1977), global sea level was high in the middle Miocene and in the late Miocene; if this were the case, these sediments probably were subjected to a later stage of weathering. Karstic conditions then developed an irregular topography on the limestone surface.

The low sea level stand that began in the middle Miocene is interpreted to have continued into the Pliocene, probably interrupted to some degree by short-term oscillations. The sandy Duplin Formation, therefore, represents a regression from the Charlton sediments. Locally, this regression resulted in exposure/weathering/erosion with localized unconformities. Both planktonic and benthonic forams occur in the Pliocene sediments. The planktonic species were probably transported near shore by existing currents. In addition, the abundance of benthonic forams when compared to planktonic and their lack of fragmentation reinforces the concept of a relatively quiet, shallow marine environment. The presence of large and regionally extensive foreset beds in the nearshore area southeast of Cumberland Island indicates that the Pliocene sedimentation was associated with deltaic conditions. The clayey sand and sandy clay interbedded with sand suggest deposition by meandering creeks in a deltaic plain. The presence of plant and wood fragments in the mud also suggests a fresh to brackish water area associated with a delta environment.

During the Pleistocene, the shoreline advanced and retreated across the coastal plain and continental shelf in accordance with fluctuations in the size of the continental ice sheets. Prior to the Silver Bluff high stand of the sea about 35,000-40,000 years ago, the Cumberland Island area was exposed to weathering and erosion by stream action. Near the Pliocene/Pleistocene contact, the presence of clasts of limestone and abraded shell fragments suggests intense reworking by streams. The subsequent high stand of sea level and the formation of the Silver Bluff barrier island chain allowed the development of an estuarine back barrier facies. In the Cumberland Island area, this facies extends some distance off and seaward of the present shoreline, indicating shoreward migration of the barrier island during still-stand or slow rise. Silt and clay beds, which grade laterally into sand and muddy sand, characterize the back barrier facies and reflect intermittent changes in the energy of deposition. Interbedded sands which have poor sorting and random orientation of shell fragments are common and indicate channel deposition. The relative predominance of silt compared to clay in the muddy sediments of the back barrier deposits shows that large amounts of silty material were transported by the rivers and deposited in the estuarine environment during middle-late Pleistocene. On the other hand, some of the clay may have subsequently been removed by ebb tidal currents. Edwards and Frey (1977) studied the salt marsh in Sapelo Island, Georgia, and found proportions of clay and silt more or less constant, but they pointed out that local variations in sand-silt-clay ratios are more pronounced in the subsurface than surface samples.

Barrier island facies are characterized by the presence of Ophiomorpha nodosa burrows and relatively clean sands with parallel to subparallel bedding. The grain-size analysis showed positive skewness, indicating 1) eolian influence and/or 2) alteration of sand by precipitation of fine material into grain interstices subsequent to leaching from the subsurface deposits; or 3) alteration of the sand by circulating groundwater.

During the late Pleistocene, sea level dropped to approximately -330 ft (-100 m) below present sea level. The Cumberland Island area was again exposed to weathering and erosion. Streams modified the topography and developed deep channels as shown by seismic data. Approximately 20,000 years B.P., sea level began to rise, marking the latest glacial retreat, thus allowing a Holocene barrier island to form in front of and weld onto the Pleistocene Silver Bluff shoreline. The present system of estuaries and barrier islands was formed 3,000-5,000 years B.P. as a result of a marked slowing in the rate of transgression.

A-7 Summary and conclusions

Surficially, Cumberland Island is a compound barrier island composed of estuarine and shallow marine sediments of late Pleistocene and Holocene age (Plate 1). The older Pleistocene deposits constitute major portions of the island. The younger Holocene deposits occur mostly as a narrow zone of dune/beach ridges, tidal beaches and shoals along the seaward margin and as an extensive system of tidal marsh and sound sediments behind the barrier (Plate 2).

Core drilling and high resolution seismic profiling were conducted to determine subsurface stratigraphy and sand body geometry. Cores and cuttings were analyzed to determine textural and age relationships. The following conclusions are based on the results of those studies:

1) Pleistocene deposits are principally composed of sandy barrier island facies and clayey back barrier facies with smaller occurences of marginal to transitional facies which were probably deposited in inlets or as shoals.

2) Barrier island facies consist mainly of fine sand. The sand is composed basically of quartz with subordinate amounts of feldspar (less than 10%), heavy minerals (less than 5%), white mica flakes (less than 4%), and phosphatic grains. These sediments exhibit a wide variation in sorting. The barrier island facies comprises a basically lenticular sand body, 12 miles (19 km) long, 0.6-3 miles (1-5 km) wide, and up to 60 ft (18 m) thick. The major sedimentary structures recognized in the same body include fine horizontal laminations, a low angle set of wedge-shaped laminae and *Ophiomorpha nodosa* burrows (Boring 3). This facies also is characterized by scattered shell fragments.

3) Back barrier deposits consist of muddy sand and silty clay beds that change laterally and vertically to silty mud. Horizontal stratification is evident where clay beds are interbedded with thin laminae of sand. The occurrence of thin lenticular bedding indicates estuary, marsh, or creek bank environments. A characteristic of the mud in this facies is the concentration of silt (51%) compared to clay (41%).

Scattered microfossils are present in this sequence, including the foraminifera *Elphidium* sp., *Elphidium poeyanum*, *Polymorphina* sp., and *Ammonia beccarii* and the diatom *Cocconeis superba*. *Crassotrea virginica* was the most common bivalve in this facies. Other bivalves include *Rangia cuneiata*, *Nassarius obsoletus*, *Abra aequlis*, *Olivella mutica*, and *Miteralla lunata*. Mottled texture and patches of clean sand in the clay beds suggest that bioturbation was an important characteristic of the back barrier facies.

4) The middle Pliocene Duplin Formation is characterized by pale coarse sand in the lower part, and is interbedded with sand and mud in the upper part. The thickness of this unit beneath Cumberland Island ranges from zero (in boring 7) to a maximum of 46 ft (14 m) (in boring 17). In general, the Pliocene unit appears as a lenticular body which thins landward and roughly maintains uniform thickness for almost 3 miles (5 km) offshore. However, northeast of Cumberland Island, the Pliocene deposits thicken to 70 ft (21 m).

The Duplin Formation is characterized by the abundance of benthonic foraminifera, including Elphidium gunteri, Elphidium advena, and Ammonia beccarii , as well as the planktonic species, Globigerinoides obliquus, Sphaeroidinellopsis subdehiscens, Globigerinoides sacculifer, Globigerinoides rubra, and Globorotalia menardii. The macrofauna include Nassarius obsoletus, Mercenaria sp., Mulinia lateralis, Crassatella sp., Anadora ovalis, Aceocina canaliculata, and Olivella mutica.

The Duplin Formation, which unconformably underlies the Pleistocene and unconformably overlies the Charlton Formation, was deposited in a nearshore deltaic environment. The interbedded sands and clays that grade into large seaward dipping foresets southeast of Cumberland Island indicate deltaic sedimentation processes.

5) The upper part of the middle Miocene(Charlton Formation) is a sandy limestone, phosphatic and locally cherty. This rock changes facies from calcarenite to a partially dolomitized limestone. The fossils in this formation include Mulinia sp. and Turritella sp. Karst topography is developed on the middle Miocene surface. Beneath Cumberland Island, this surface dips gradually to approximately 3 miles (5 km) offshore. Southeast of Cumberland Island, a well developed erosional scarp is present over which the Pliocene deltaic foresets are draped. The abundance of detrital quartz grains in the calcareous mud suggests a nearby source of terrigeneous clastics which were deposited simultaneously with the calcareous mud.

APPENDIX B

DRILLING PROCEDURES

DRILLING PROCEDURES

One of the major purposes of this investigation was to establish the geological framework for Cumberland Island. To achieve this goal, 19 stratigraphic test/water monitor wells were drilled by the Georgia Geologic Survey. One test well was drilled to monitor the Principal Artesian Aquifer and 18 shallow wells were drilled to monitor the unconfined water table as well as to provide stratigraphic control points for the post Miocene sediments. These wells represent a cumulative total of 2155 ft (657 m) of drilling. A log of each well is provided in Appendix C.

All of the drilling on Cumberland Island was done by standard rotary drilling methods. All wells were cored from the surface to total depth using double tube core barrels and employing conventional as well as wireline coring techniques. All of the drilling mud used in the drilling operation was of bentonite type with no additives being used.

The choice of well locations reflected several considerations including those limitation imposed upon the island because it is a National Seashore. The major considerations listed below are general and may not apply equally to each location. The general consideration for well location was: 1) availability of potential sites; 2) areas where mud pits could be dug without undue visual impact to the island's visitors; 3) areas of heavy visitor use were avoided to prevent possible accidents while the rig was not in use; 4) areas of known archeological resources were avoided; 5) access by roads and trails; 6) areas where destruction of vegetation and the "natural" appearance could be minimized; 7) placement to facilitate the construction of geologic cross-sections; 8) placement to facilitate construction of a potentiometric map of the unconfined water table and its monitoring; 9) location and availability of water source of drilling; and 10) location of existing well logs and their reliability.

Well CI-01 (GGS 3426) is located on the southern end of Cumberland Island just off Nightingale Avenue (Lat. 30°45'22", Long. 81°28'13"). Because of the size of the rig, the use of large amounts of drilling mud and the large casing diameter, the major considerations in locating this well were access to the well, water source and archeological unimportance. This location also provided a natural clearing away from heavy visitor use areas.

CI-01 has a total depth of 645 feet (197 meters) and bottomed in the limestone of the Principal Artesian Aquifer. Because of the large amount of coring needed, this well was drilled with a Failing CF-15 drill rig. Wireline coring techniques were used with a Christensen, double tube and NXWL core barrel.

The first 22.5 feet (7 m) were sampled using dry coring techniques. Below 22.5 feet, standard wet coring techniques were used with a double tube core barrel. The hole from the surface to 90 feet (29 m) was initially cored and then enlarged to 17 inches. This allowed ten inch, thin wall surface casing to be set and cemented into placed in the dolostone encountered at approximately 90 feet. After the cement seal had sufficiently solidified, coring was continued inside the ten inch casing and coring was continued to a depth of 552 feet (168 m) where a limestone suitable for setting casing was encountered. The bore hole was then enlarged to six inches and 552 feet of four-inch casing was set and cemented into the top of the Principal Artesian Aquifer. After sufficient time was allowed for the cement to solidify, coring was continued to a total depth of 645 feet (197 m) where the hole caved-in around the wireline; and the well had to terminated. Figure B-1 illustrates the geology encountered in CI-01 and Figure B-2 is a well construction diagram for CI-01. Appendix C contains the lithologic log for CI-01.

The shallow testing program was carried out on Cumberland Island using a Failing 250 drill rig. This rig was advantageous because its smaller size allowed access to areas with less well maintained roads and with a lower overhead clearance than roads on the south end of Cumberland Island. All the shallow test borings were drilled with a ten foot "R" series, large diameter (2-3/4" x 3-7/8") double tube, Longyear core barrel. Two and three-eights inches "N" drill rods were used throughout this portion of the drilling project. In most cases, the first 12 feet were cored using dry coring techniques. When the dry coring was complete, the bore hole was enlarged and double tube conventional coring techniques were employed to the total depth of the well. All wells were terminated at the top of the calcareous sediments of Miocene age. After coring, the borings were back-filled to a depth of about 20 ft (6 m). The slotted PVC screen was installed and the boring was converted to a well.

There were no wells constructed east of the back dunes because the height of the dune and the looseness of the sand made it impossible to cross the dune with the drill rig and water supply truck.

After the core was retrieved from the core barrel, it was washed, labeled, and placed in standard wax coated storage boxes. The core was logged as it came from the core barrel and a drillers log was also kept. The core was temporarily sorted on the site and later moved to the laboratory where detailed lithologic descriptions were made and samples for microfossils studies were taken. Also, for many shallow wells, core recovery was very poor and cuttings commonly had to be taken.

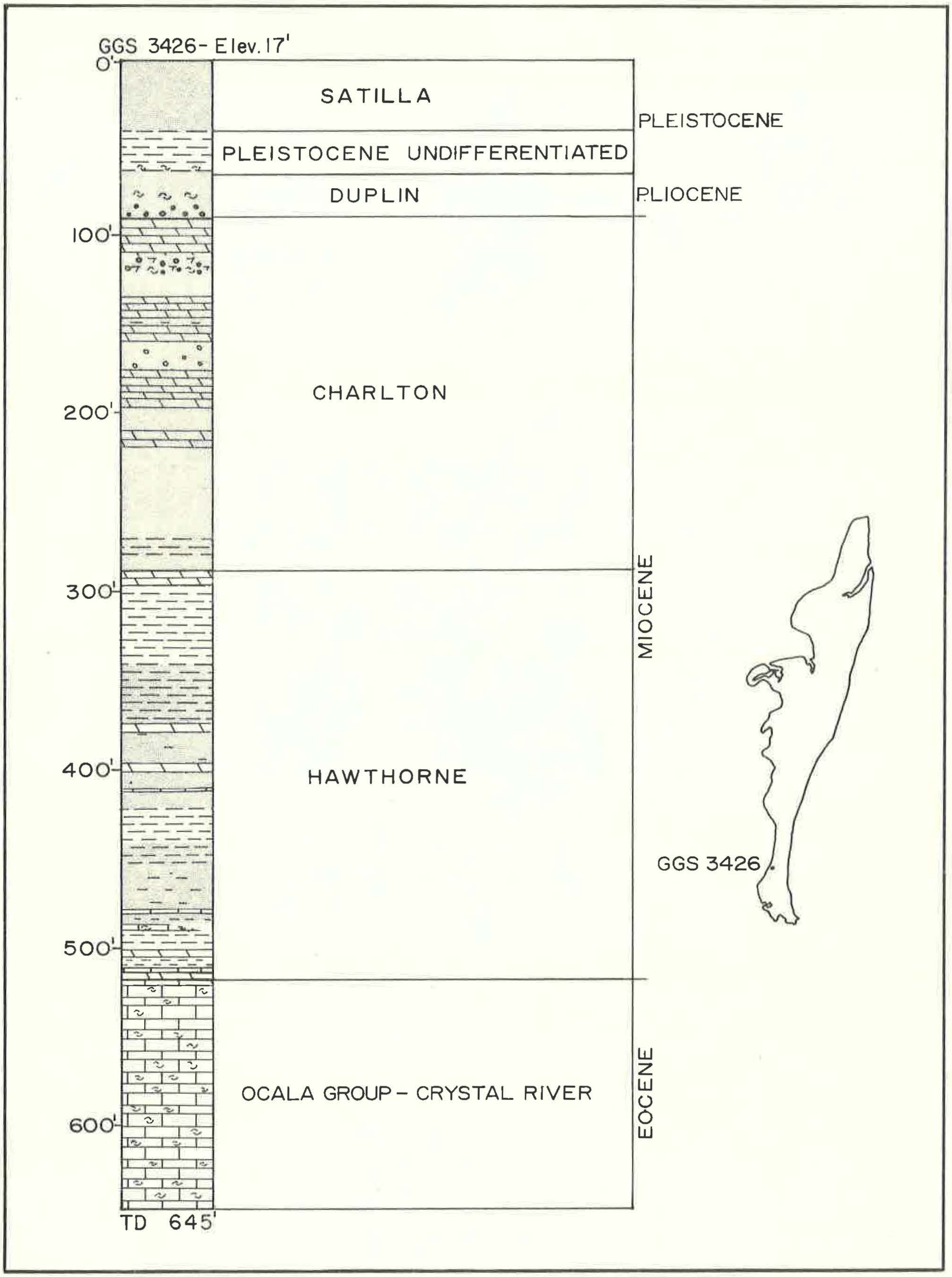

Figure B–1. Geology encountered in well CI-01 (GGS 3426).

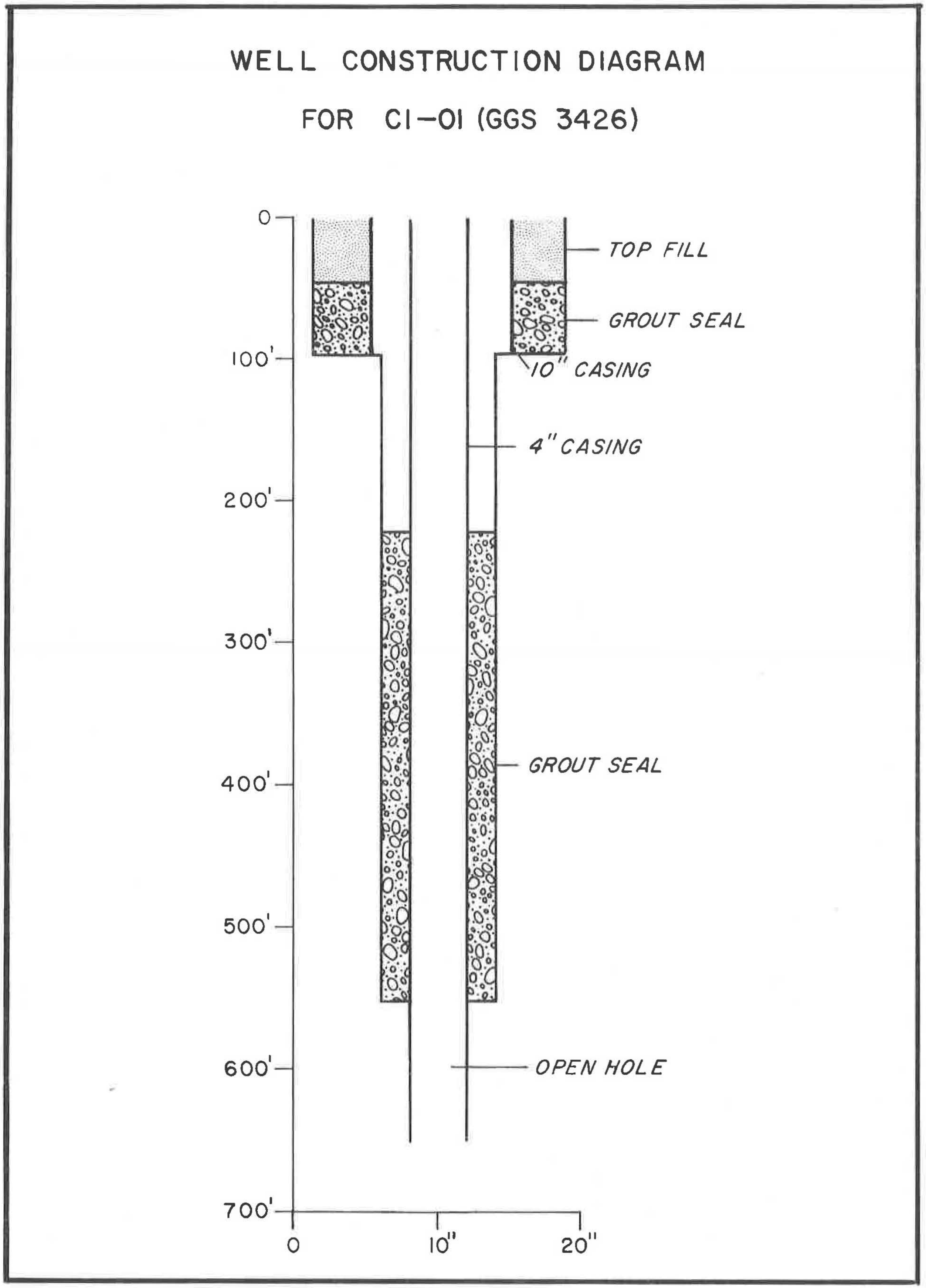

Figure B—2. Diagram of well construction for CI-01 (GGS 3426).

APPENDIX C

LITHOLOGIC LOGS

LITHOLOGIC LOG CI-01

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 4.0	Sand: Medium to fine; subangular to rounded; slightly argillaceous; with dark heavy minerals.
4.0 - 7.25	Sand: Fine; subangular; with dark heavy minerals.
7.25 - 13	Sand: Fine-to medium; subangular; with dark heavy minerals.
13 - 14.2	Sand: Fine; subangular; slightly argillaceous; prominent organic staining at top of bed becoming lighter downward.
14.2 - 16	Sand: Fine to very fine; subangular; argillaceous; with dark heavy minerals; phosphatic.
16 - 22.5	Sand: Fine to medium; subangular to rounded; with dark heavy minerals.
22.5 - 29	Sand: Fine; subangular to rounded; argillaceous; micaceous; with dark heavy minerals.
29 - 67	Clay: Silty; with finely-bedded sand; micaceous; fossiliferous (bivalves, as original shell material).
67 - 73	Sand: Fine; rounded; with dark heavy minerals; fossiliferous (bivalve fragments as original shell material); with clay interbeds.
73 - 85	Sand: Fine to medium; subangular to rounded; with dark, heavy minerals; fossiliferous (bivalves as original shell material).
85 - 90	Sand: Medium to coarse; rounded to subangular; calcareous; phosphatic; becoming indurated at bottom of bed with calcite cement.
90 - 94	Dolostone: Argillaceous; very sandy (fine to very coarse; subangular to well rounded); scattered quartz granules; fossiliferous (bivalves, as molds and casts).
94 - 95.5	Dolostone: Argillaceous; very sandy (fine to coarse; subangular to subrounded); phosphatic; with clasts of clay (silty, micaceous); lighter clay forms rims around a darker core.
95.5 - 100	Dolostone: Argillaceous; very sandy (very fine to coarse; angular to subrounded); sparsley phosphatic; with scattered, rounded quartz granules.

Lithologic Log CI-01 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
100 - 105	Dolostone: Argillaceous; very sandy (very fine to coarse; angular to subrounded), sparsely micaceous; phosphatic; with scattered rounded quartz granules.
105 - 110	Dolostone: Argillaceous; sandy (fine to coarse; subangular to rounded); with clay interbeds (silty, sandy; sparsely micaceous; of maximum thickness of 2.5 cm).
110 - 111	Sand: Fine to very coarse; subangular to rounded; phosphatic; fossiliferous (bivalves as original shell fragments); with rounded quartz granules.
111 - 120	Sandstone: Fine to very coarse; rounded to subangular; rounded quartz to pebble size; phosphatic; fossiliferous (as molds and casts); dolomite cement.
120 - 130	No recovery-lithology appears to be a medium water-saturated sand. (drilling log).
*130 - 130.5	Clay: Silty; fossiliferous (original shell material, molds and casts).
130.5 - 133.5	Sand: Very fine to very coarse; subangular to rounded with rounded quartz granules; silty; micaceous; fossiliferous (original shell material).
133.5 - 144.5	Dolostone: Sandy; argillaceous; phosphatic; fossiliferous (molds and casts); sand fraction is fine to very coarse; rounded to subangular.
144.5 - 152	Sand: Fine to very coarse; subangular to rounded; argillaceous, phosphatic, calcareous.
152 - 156	Dolostone: Sandy; argillaceous; finely phosphatic; sand fraction is very fine to coarse, angular to rounded.
156 - 159	Sand: Very fine to very coarse; subangular to rounded; micaceous; phosphatic; with scattered well-rounded quartz granules.
159 - 160	Dolostone: Sandy; argillaceous; phosphatic; sand fraction fine to very coarse, angular to subrounded.
160 - 172	Sand: Fine to very coarse; subangular to rounded; argillaceous; micaceous; slightly phosphatic; calcareous; with scattered rounded quartz pebbles.
172 - 185	Dolostone: Very argillaceous; coarsely phosphatic; sand fraction fine to coarse, subangular to rounded.

Lithologic Log CI-01 (Cont'd):

DEPTH BELOW SURFACE (ft).	DESCRIPTION
185 - 210.5	Sand: Fine to coarse; subangular to rounded; argillaceous; phosphatic; with scattered rounded quartz granules; becomes fossiliferous at 200-203 ft.; fossils are original shell material.
210.5 - 220	Dolostone: Sandy; argillaceous, phosphatic; sand fraction is fine to very coarse, subangular to rounded.
220 - 240	Sand; Fine to coarse; angular to rounded; argillaceous; phosphatic; with scattered rounded quartz granules.
240 - 243.5	Sand: Fine to medium; angular to subrounded; phosphatic; with scattered rounded quartz granules.
243.5 - 249.5	Sand: Fine to very coarse; angular to rounded, argillaceous; sparsely phosphatic; calcareous; some zones indurated.
249.5 - 252	Limestone: Dolomitic; very sandy, phosphatic; sand fraction is fine to medium, rounded to subangular.
252 - 260	Sand: Coarse to very coarse; subangular to subrounded; coarsely phosphatic; calcareous; locally indurated; fossiliferous (molds and casts in indurated beds).
260 - 269	Sand: Fine to coarse; angular to subrounded; argillaceous; phosphatic.
269 - 275	Clay: Faintly laminated; with fine to medium sand partings; phosphatic.
275 - 282	Sand: Fine to coarse; subangular to rounded; argillaceous; phosphatic.
282 - 288	Sand: Fine to coarse; subangular to rounded; argillaceous; calcareous; micaceous; locally indurated.
288 - 291	Dolostone: Sandy; argillaceous; micaceous; sand fraction is medium to fine, subrounded grains.
291 - 364	Silt: Laminated to thinly bedded; finely carbonaceous; with sand parting (very fine to coarse sand), fossilferous (original shell material, molds and casts).
364 - 374	Sand: Very fine to very coarse; angular to subrounded; argillaceous; very phosphatic; calcareous, glauconitic; sparsely fossiliferous (original shell material).

Lithologic Log CI-01 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
374 - 376	Sandstone; Fine to medium; subangular, argillaceous; micaceous; phosphatic; with scattered rounded quartz granules; calcareous; indurated.
376 - 390	Sand: Fine to medium; subrounded; argillaceous; phosphatic; fossiliferous (original shell material and molds and casts); phosphate at top becoming less concentrated downward.
390 - 400	Dolostone: Very sand; phosphatic; fossiliferous (original shell material and molds and casts); sand fraction is fine to medium, with occasional rounded quartz granules.
400 - 410	Sand: Fine to medium; subangular to subrounded; argillaceous; phosphatic; micaceous.
410 - 410.5	Limestone: Very sandy, finely phosphatic; sand fraction is fine, micaceous.
411 - 413	Clay: Silty; sandy; finely lmainated; finely micaceous; sand fraction is very fine.
413 - 413.5	Limestone: Very sandy; argillaceous; finely phosphatic; sand fraction is fine to medium, angular to subrounded.
413.5 - 419	Sand: Very fine to medium; subrounded; argillaceous; phosphatic, calcareous; micaceous.
419 - 449	Clay: Silty; sandy; very finely carbonaceous; micaceous; sand fraction is very fine, subrounded.
449 - 456	Sand: Fine to coarse; angular to subrounded; argillaceous.
456 - 457	Limestone: Sandy; argillaceous; sand fraction is medium to fine, subangular to rounded.
457 - 482	Clay: Very sandy, calcareous; sparsely phosphatic; sand fraction is very fine to medium, subangular.
482 - 485	Silty: Sandy; calcareous; phosphatic; fossiliferous (molds and casts); sand fraction medium to very coarse; subangular.
483 - 493	Limestone: Dolomitic, sandy; argillaceous; phosphatic; fossiliferous (molds and casts); sand fraction is fine to very coarse, subangular to rounded.

Lithologic Log CI-01 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
493 - 510	No recovery
510 - 531	Clay: Sandy; sparsely phosphatic; fossiliferous (shark teeth); sand fraction is very fine-grained.
531 - 532	Limestone: Sandy; phosphatic; fossiliferous (original shell material, molds and casts); sand fraction is fine - to medium-grained.
532 - 580	Limestone: Sandy at top; fossiliferous (original shell material; bryzoans abundant).
580 - 600	No recovery-very loose calcite sand taken from wash sample.
600 - 645	Limestone: White; abundantly fossiliferous (original shell material, molds and casts).
645	Total Depth
	All sand is quartz unless otherwise specified.

Formational Tops

0 - 29'	Satilla Formation
29'	Pleistocene undifferentiated
67'	Duplin Marl equivalent
90'	Charlton
288'	Hawthorn Formation
537'	Ocala Group-Crystal River Formation
645'	Total Depth

*NOTE: The clay logged in the interval 130' - 130.5' contains Pleistocene bivalves. Those bivalves are considered to be cave material from above.

Latitude: 30o45'22"
Longitude: 81o28'13"

Elevation 17 feet above mean sea level.

BORING 1

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 1.0	Sand: Pale, yellowish-brown; fine-grained; very well sorted; subangular to well rounded; heavy minerals 2-3%; feldspar 3-5%.
1.2 - 3.3	Sand: Light brown; fine-grained; very well sorted; subangular to well rounded; stained quartz grains 90%; heavy minerals 2-3%.
3.3 - 10	Sand: Mottled, very pale-orange and pale yellowish-brown; fine-grained; very well sorted; subrounded grains; heavy minerals 2-3%; feldspar 5-10%.
10 - 13	Sand: Very pale-orange; fine-grained; well sorted; subrounded to well rounded grains; slightly phosphatic; feldspar 5%.
13 - 13.8	Sand: Humitic, moderate brown; fine-grained; well sorted; subrounded grains; feldspar 5%.
14 - 20.5	Sand: Very pale-orange; fine-to very fine-grained; scattered very coarse sand 5%; epidote 2-3%; feldspar 10%; other heavy minerals 3%; opaque minerals 2-3%.
20.5 - 22.5	Sand: Grayish-orange; fine-to medium-grained; scattered very coarse sand 5%; heavy minerals 2-3%; feldspar 5%.
22.5 - 29.0	Sand: Grayish-orange; medium-grained; well sorted; subrounded grains; very coarse sand 5-8%; feldspar 5-7%; heavy minerals 3%.
29.0 - 40	Clayey sand: Greenish-gray; white mica flakes 2%; large shell fragments (Crassostrea virginica). Recovery 3 ft.
40 - 67	Clayey sand: Greenish-gray; abundant oyster shell fragments; scattered quartz pebbles in sand. Recovery 1.4 ft.
67 - 73	Sand: Light greenish-gray; coarse-grained; very coarse sand 2%; heavy minerals 3%; oriented shell fragments; bored oyster fragments; subangular to rounded quartz grains. Recovery 0.9 ft.
73 - 75	Sand: Very light-gray; coarse-grained; well sorted; subangular to well rounded; very coarse sand 2-3%; heavy minerals 2-3%; shell fragments 10%. Recovery 0.8 f
75 - 80	Sand: Very light-gray; coarse-grained; oyster shell fragments; scattered pebbles. Recovery 2.4 ft.

Boring 1 (Cont'd)

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
80 - 90	Sand: Conglomeratic; quartz pebbles 75%; limestone pebbles 25%. The quartz grains size increases to the bottom. Recovery 2.4 ft.
90 - 96	Limestone: Yellowish-gray; very coarse quartz grains in fine calcareous mud; phosphate grains 3-5%; chert 1%. Recovery 3.6 ft.

INTERPRETATION

0 - 67	Pleistocene
67 - 90	Middle Pliocene
Below 90	Middle Miocene

BORING 2

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 0.9	Sand: Dark yellow-brown; medium to fine-grained; subrounded grains; quartz as aggregates; fine, long roots.
0.9 - 3.0	Sand: Moderate yellowish-brown; fine-grained; well sorted; heavy minerals 2%; white mica flakes 2%; small roots; subrounded grains.
3.0 - 8.0	Sand: Grayish-orange; fine-grained; well sorted; subangular to subrounded grains; oxidized stems; epidote 5%; hornblende 3%; pink grains (feldspar?).
8.0 - 10	Sand: Pale yellowish-brown; fine to medium-grained; well sorted; subrounded grains; quartz grains as aggregates.
10 - 12	Sand: Grayish-orange; fine-grained; well sorted; subangular to subrounded grains; epidote 2-3%; oxidized plant stems; quartz grains as aggregates; stained quartz grains (less than 5%).
12 - 15	Sand: Pale greenish-yellow; very fine-grained; subangular to subrounded grains; fine sand mixed with silty material and very coarse sand; sample partially "washed" during sampling; oxidized stem fragments. Recovery 2.2 ft.
15 - 18	Sand: Yellowish-gray; very fine-grained; very well sorted; opaque minerals 2%; sample "washed" during sampling. Recovery 1.9 ft.
18 - 20	No recovery.
20 - 21.5	Sand: Yellowish-gray; very fine-grained; well sorted; 5 mm white sand layers forming cross bedding.
21.5 - 27	No recovery.
27 - 30	Clayey sand: Yellowish-gray; white mica flakes 1-2%; lignitic stem fragments; stained quartz grains 5-10%; 2-3 mm clay layers; limonitic patches in sand.
30 - 50	No recovery.
50 - 51	Sand: Dusky-yellow; with clay patches (bioturbation?); abundant oxidized stem fragments.
51 - 52	No recovery.

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
52 - 53	Sand: Light olive; fine-to medium-grained; heavy minerals 3%; white mica flakes 2%; Mulinia lateralis, Venericardia sp. (Sample 1).
53 - 60	Sand: Greenish-gray; medium-grained; very coarse sand 10%, quartz pebbles 5%; dark gray limestone fragments, 1-2 cm diameter; abundant shell fragments.
60 - 72	Sand: Greenish-gray; medium to coarse-grained; subangular to subrounded grains; scattered limestone fragments 2-5%; Mulinia lateralis (Sample 2). Recovery 0.9 ft.
72 -	Limestone (no recovery).

INTERPRETATION

0 - 50	Pleistocene
50 - 72	Middle Pliocene
Below 72	Middle Miocene

BORING 3

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 2.7	Sand: Pale red; fine- to medium-grained; subangular to subrounded quartz grains; thin stems of *Spartina alterniflora*; stained quartz grains.
2.7 - 3.4	Sand: Dark yellowish-brown; medium-grained; subrounded grains; quartz grains as aggregates.
3.4 - 7	Sand: Moderate yellowish-brown; medium-grained; subangular grains; stem fragments; stained quartz grains 10-20%.
7 - 10	Sand: Dark yellowish-brown; fine-to medium-grained; subrounded to rounded quartz grains; coarse grains 2-3%; stem fragments. The quartz grain size increases to the bottom of this interval.
10 - 13	No recovery.
13 - 17	Sand: Moderate yellowish-brown; fine-grained; moderately sorted; subrounded quartz grains; coarse sand 2-3%.
17 - 24	Sand: Grayish-orange; very fine-grained; thin brown layers forming cross-bedding; *Ophiomorpha nodosa* at 21 ft (Sample 20); stained quartz grains.
24 - 27	Sand: Yellowish-gray; very fine-grained; subangular to rounded quartz grains; quartz grains partially covered with limonite; thin clay layers forming cross bedding; plant remains.
27 - 28	No recovery.
28 - 30	Sand: Yellowish-gray; fine-grained; subrounded quartz grains; lignitic plant remains; interbedded thin sand-clay layers.
30 - 31	No recovery.
31 - 35	Clayey sand: Gray; white mica flakes; oyster fragments; lignitic stem fragments; *Ophiomorpha nodosa* burrow at 32 ft.
35 - 46	Silty clay: Dark greenish-gray; small patches of fine white sand; bioturbation; *Rangia cunneiata*; *Nassarius obsoletus* (Sample 4). Recovery 2.8 ft.
46 - 47.5	Silty clay: Dark greenish-gray; patches of fine sand; *Mercenaria* sp., *Mulinia lateralis*.

Boring 3 (Cont'd)

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
47.5 - 53	Sand: Olive gray; fine-grained; subangular to subrounded quartz grains; coquina limestone fragments; slightly mottled, with minor amounts of clay (probably due to contamination); carbonaceous wood remains. Recovery 1.2 ft.
53 - 57	Sand: Yellowish-gray; fine-grained; 0.5 ft clay layers; epidote 1-2%; opaque minerals 2-3%; abundant foraminifera; Elphidium gunteri, Ammonia beccarii, Polymorphina guttulina Nonionella sp., Hanzawaia concentrica, Elphidium advena Globigerinoides rubra, Elphidium sp. Recovery 0.7 ft.
57 - 61	Sand: Mottled, light gray and pale green; medium-grained mixture of clay and sand at the top of this interval, probably due to contamination; Elphidium gunteri, Ammonia beccarii, Elphidium sp., Globorotalia menardii. Recovery 1.0 ft.
63 - 73	Sand: Mottled, medium gray and dusky yellow; medium-grained; subrounded quartz grains; very coarse sand 2-3%; white mica flakes 3%; Mulinia lateralis Acteocina canaliculata (Sample 6). Recovery 1.3 ft.
73 - 80	Sand: Olive gray; medium to coarse-grained; shell fragments 5-10%; limestone fragments 5%; Elphidium sp., Hanzawaia concentrica, Quinqueloculina sp., Elphidium gunteri, Ammonia beccarii. Recovery 2.5 ft.
80 - 81	Sand: Olive gray; very coarse-grained; poorly sorted; limestone fragments 30%; shell fragments 15%; wood remains; Nassarius obsoletus (Sample 7). Recovery 0.7 ft.
81 - 91	Sand: Light olive gray; coarse to very coarse-grained limestone fragments 5-10%; shell fragments 10%; Mulina lateralis, Acteocina canaliculata (Sample 8). Recovery 1.3 ft.
91 - 92	Limestone: Light olive gray; clay-supported framework; fine quartz grains in fine matrix.

INTERPRETATION

0 - 51	Pleistocene
51 - 91	Middle Pliocene
Below 91	Middle Miocene

BORING 4

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 0.56	Sand: Medium light gray; fine-grained; well sorted; subangular to rounded grains; large roots.
0.66 - 2.2	Sand: Very light gray; fine-grained; well sorted.
2.2 - 2.7	Sand: Brownish-gray; very fine-grained; subrounded to subangular grains; abundant roots and stems.
2.7 - 5.5	Sand: Yellowish-gray; fine-grained; subangular to rounded grains; oxidized stems; quartz grains as aggregates.
5.5 - 10	Sand: Brownish-gray; fine-grained; stained quartz grains 90%; silty quartz grains 10%; large stems of *Spartina alterniflora*; phosphate grains 2-3%.
10 - 32	No core sample.
10 - 17	* (Cut) Sand: Very pale orange; fine-grained; subangular quartz grains; very coarse sand 1-3%; opaque minerals 1-2%; feldspar 2%; epidote less than 1%.
17 - 22	*(Cut) Sand: Yellowish-gray; fine to very fine-grained subrouned quartz grains; epidote 1-2%; white mica flakes 2%; prismatic grains (sillimanite?) 1%; feldspar 3-5%; shell fragments.
22 - 32	*(Cut) Sand: Yellowish-gray; fine to very fine-grained; subrounded to rounded quartz grains; white mica flakes 2%; feldspar 3-4%; prismatic grains 2%.
32 - 41	Sand: Dusky yellow; fine-grained; heavy minerals 2-3%. The heavy minerals increase to the bottom; thin clay layers forming cross-bedding. Recovery 1.8 ft.
41 - 42	Clay: Greenish-gray; shell fragments; *Mercenaria* sp., *Crassostrea* sp. (Sample 10). Recovery 0.2 ft.
42 - 50	Clay: Medium bluish-gray; thin sand layers interbedded the clay (1-2 mm thick); small shell fragments. Recovery 3.0 ft.
50 - 62	Clayey sand: Mottled olive gray and dark greenish-gray; fine-grained; sand 75%; mud 25%; oriented shell fragments; *Elphidium gunteri*, *Globigerinoides sacculifer*, *Elphidium* sp., *Globigerinoides obliquus*, *Cibicides sapeloensis*; *Elphidium poeyanum*, *Polymorphina* sp., *Globigerinoides* rubra, *Hanzawaia* concentrica. Recovery 0.5 ft.

* (Cut) - Cuttings sample.

Boring 4 (Cont'd)

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
62 - 72	Clay: Bluish-gray; high content of Rhaphaneis angularis (diatom). Some diatoms are replaced by pyrite; thin sand layers in the clay (2-3 mm thick); thin sand layers forming cross-bedding. Recovery 2 ft.
72 - 92	No core sample.
72 - 77	* (Cut) Sand: Yellowish-gray; fine-grained; subrounded quartz grains; heavy minerals 2-4%; feldspar 8%; scattered shell fragment 2%.
77 - 82	* (Cut) Sand: Yellowish gray; fine-to medium-grained; subrounded quartz grains; epidote 2-3%; white mica flakes 1-2%; feldspar 8%; other heavy minerals 3%; shell fragments 10%.
82 - 87	* (Cut) Sand: Yellowish gray; fine- to very coarse-grained; subrounded to rounded quartz grains; feldspar 5%; hornblende 1%; white mica flakes 1%; opaque grains 2%; epidote 1%; shell fragments 25%.
87 - 76	* (Cut) Sand: White; fine- to very coarse-grained; subrounded to well rounded quartz grains; fine sand 70%; granules 20%; pebbles 5%; opaque minerals 2-3%; feldspar 5-10%; limestone fragments, 5mm diameter; shell fragments and whole shells of Mulinia lateralis.
92 - 93	Sand: Light olive gray; fine grained; very coarse sand 2-3%; limestone fragments, 3-4 cm diameter; shell fragments.
93 - 95	Limestone: Fragments, 7-9 mm diameter; fine quartz grains in fine calcareous mud.

INTERPRETATION

0 - 50	Pleistocene
50 - 93	Middle Pliocene
Below 93	Middle Miocene

* (Cut) - Cutting Samples

BORING 5

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 0.9	Sand: Dark yellowish-brown; fine-grained; subrounded quartz grains; epidote 1-2%; heavy minerals 2-3%; oxidized roots and stems.
0.9 - 2.0	Sand: Light brownish-gray; fine-grained; well sorted; sillimanite (?) 1-2%; opaque minerals 3%; stem fragments 2%.
2.0 - 3.3	Sand: Pale yellowish-brown; fine-to very fine-grained; sdubangular quartz grains; stained quartz grains 80%. The stained quartz grains decrease to the bottom.
3.3 - 7.0	Sand: Brown; fine-grained; well sorted; subangular to rounded quartz grains; slightly phosphatic; oxidized roots and stems.
7.0 - 10.0	Sand: Moderate yellowish-brown; fine-grained; subrounded quartz grains; white mica flakes 1%; stained quartz grains 90%; epidote less than 1%; other heavy minerals 2-3%.
10.0 - 11.5	Sand: Grayish-orange; fine-grained; subrounded to rounded quartz grains; phosphate grains 5%; epidote 1-2%.
11.5 - 12.0	Sand: Moderate yellowish-brown; fine-grained; rounded grains; stained quartz grains 15%.
12 - 16	No core sample.
12 - 16	* (Cut) Sand: Grayish-orange; very fine-grained; subangular to subrounded quartz grains; phosphate grains 2%; feldspar 5-10%; epidote 1-2%; other heavy minerals 3%.
16 - 20	No recovery.
20 - 35	No core sample.
20 - 22	* (Cut) Sand: Grayish-orange; fine-grained; subangular to subrounded quartz grains; feldspar 5-10%; epidote 1-2%; opaque minerals 2%; *Mulinia lateralis* (Sample 11).
22 - 27	* (Cut) Sand: Grayish-orange; fine-grained; subangular to subrounded quartz grains; feldspar 5%; opaque minerals 3%.
27 - 32	* (Cut) Sand: Very pale orange; fine-grained; very well sorted; subangular to rounded quartz grains; epidote 2%; heavy minerals 2%; white mica flakes 1%.

Boring 5 (Cont'd)

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
32 - 35	* (Cut) Sand: Yellowish-gray; fine-grained; subangular to subrounded quartz grains; very coarse sand 3%; phosphate grains 1%; feldspar 5-10%; heavy minerals 2%.
35 - 42	Silty clay: Pale green; heavy minerals 2%; white mica flakes 2%; shell fragments forming layers. The shell fragments increase to the bottom; Oliva sayana (Sample 16), Elphidium sp. Recovery 0.7 ft.
42 - 52	No core sample.
42 - 52	* (Cut) Sand: Yellowish-gray; fine-grained; subangular quartz grains; heavy minerals 3%; white mica flakes 2%; feldspar 3-5%; shell fragments 10%.
52 - 55	Silty clay: Olive gray; 2 in sand layer interbedded the clay; sand- filled burrows.
55 - 57.5	Sand: Light olive gray; fine-grained; subangular to rounded quartz grains.
57.5 - 62	Silty clay: Olive gray; shell fragments, 1-2 cm diameter; oxidized stem debris. The plant remains lie parallel to the stratification; pieces of indurated clay with scattered quartz grains.
62 - 72	Sand: Pale greenish-yellow; fine-grained; subangular to rounded quartz grains; epidote 2%; white mica flakes 1%; feldspar 5-8%; shell fragments 1%. The coarse sand increases to the bottom. Recovery 0.9 ft.
72 - 82	Limestone: Yellowish gray; clastic quartz grains in fine matrix, 0.5 to 3mm diamter; scattered chert grains.

INTERPRETATION

0 - 62	Pleistocene
62 - 72	Middle Pliocene
Below 72	Middle Miocene

* (Cut) - Cutting Sample

BORING 6

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 1.3	Sand: Light brownish-gray; fine-grained; well sorted; heavy minerals 3-4%; *Spartina alterniflora* stems.
1.3 - 2.8	Sand: Moderate yellowish-brown; fine-grained; subrounded to rounded quartz grains; stained quartz grains 90%.
2.9 - 6.7	Sand: Very pale orange to grayish-orange; fine-grained; well sorted; subrounded quartz grains; stained quartz grains; epidote 2%; other heavy minerals 2-3%.
6.7 - 8.3	Sand: Moderate brown; fine-grained; rounded quartz grains; hyaline grains 5%; stained quartz grains 95%.
8.3 - 8.6	Sand: Moderate yellowish-brown; subrounded quartz grains; heavy minerals 3%.
8.6 - 9.8	Sand: Dark grayish-orange; fine-grained; well sorted; subrounded to rounded quartz grains; heavy minerals 3%.
9.8 - 12.8	Sand: Dark grayish-orange; fine-grained; subrounded to rounded quartz grains; epidote 2%; other heavy minerals 3%.
12.8 - 42	No core sample.
12.8 - 17	* (Cut) Sand: Grayish-orange; fine-grained; subangular quartz grains; heavy minerals 5%.
17 - 18.7	* (Cut) Sand: Grayish-orange; fine-grained; subrounded to well rounded quartz grains; coarse sand 3%; stained quartz grains 5%; feldspar 5-10%; heavy minerals 2%.
18.7 - 42	* (Cut) Sand: Yellowish-gray; fine-grained; subangular to subrounded quartz grains; feldspar 5%; heavy minerals 1-3%; white mica flakes 3%.
42 - 44.5	Clay: Dark greenish-gray; plant remains lain parallel to the stratification; 8 mm thick sand lenses.
44.5 - 46	Clayey sand: Dusky yellow green; shell fragment layers; whole shells of *Mulinia lateralis*, *Abra aequalis* (Sample 12), *Elphidium* sp.
46 - 52	Silty clay: Olive gray; thin sand layers, 1-2 mm thick; mixture of clay and sand, probably due to bioturbation. Recovery 3 ft. for 42-52 ft. interval.

Boring 6 (Cont'd)

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
52 - 62	Silty clay: Olive gray; thin sand layers, 1-2 mm thick; fine dissemination of pyrite in the clay; small plant remains parallel to the stratification; sand-filled burrows, 1.5-2.0 cm wide; 5 in sand layers interbedded the mud in the lower part of this interval; Elphidium sp.
62 - 79	No core sample.
62 - 76	* (Cut) Sand: Yellowish-gray; fine-grained; subangular to rounded quartz grains; very coarse sand 2-3%; epidote 2%; opaque minerals 2-3%; sillimanite (?) 1-2%; white mica flakes 2%; feldspar 5%.
76 - 82	Limestone: Yellowish-gray; quartz granules; 5-6 cm thick sand layer interbedded in calcareous clay; very coarse grained; finely disseminated pyrite.

	INTERPRETATION
0 - 61.5	Pleistocene
61.5 - 79	Middle Pliocene
Below 79	Middle Miocene

* (Cut) - Cutting sample.

BORING 7

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 10	Sand: Grayish-yellow; fine-grained; very well sorted; subrounded quartz grains; stained quartz grains 70%; heavy minerals 3-4%. Recovery 2 ft.
10 - 12	Sand: Grayish-orange; fine-grained; well sorted; subrounded to rounded quartz grains; heavy minerals 5%.
12 - 52	No core sample.
12 - 22	* (Cut) Sand: pale grayish-yellow; fine-grained; subrounded to subangular quartz grains; heavy minerals 4-5%.
22 - 32	* (Cut) Sand: Very pale orange; fine-grained; subangular to subrounded quartz grains; very coarse sand 10%; heavy minerals 3-5%; white mica flakes 2%; feldspar 6%.
32 - 52	* (Cut) Sand: Yellowish-gray; fine-grained; subangular to rounded quartz grains; feldspar 3-6%; sillimanite 2%; white mica flakes 2%; other heavy minerals 3%.
52 - 53	Sand: Light olive gray; medium- to coarse-grained; shell fragments 5-10%; rounded limestone fragments; *Elphidium* sp.
53 - 62	Clay: Olive gray; 1-2 mm sand layers interbedded the clay; sand-filled burrows, 2 cm wide, 3-4 cm long; carbonaceous plant remains; *Elphidium* sp., *Cocconeis superba* (diatom). Recovery 3 ft.
62 - 73.3	Silty clay: Olive gray; thin sand layers interbedded the clay; scattered wood remains; finely disseminated pyrite in the sand beds. *Cocconeis superba* (diatom). Recovery 3 ft.
73.3 - 75.5	Sand: Yellowish-gray; fine-grained; well sorted; subrounded quartz grains; opaque minerals 2-3%; epidote less than 1%; *Ammonia beccarii*; quartz pebbles.
75.5 - 79	Limestone: Light olive gray; fine quartz grains 5%; chert 3%.

Boring 7 (Cont'd)

	INTERPRETATION
0 - 75.5	Pleistocene
0	Middle Pliocene
Below 75.5	Middle Miocene

BORING 8

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 3.3	Sand: Yellowish-brown; fine-grained; well sorted; subrounded quartz grains; plant remains; stained quartz grains.
3.3 - 5.4	Sand: Grayish-orange; fine-grained; subrounded quartz grains; heavy minerals 5%.
5.4 - 8.2	Sand: White; fine-grained; well sorted; subrounded to rounded quartz grains; heavy minerals 3-5%.
8.2 - 8.6	Sand: Pale yellowish-brown; fine-grained; very well sorted; subrounded to rounded quartz grains; heavy minerals 2-3%.
8.6 - 9.8	Sand: Moderate brown to dark greenish-orange; fine-grained; well sorted; subrounded grains; slightly phosphatic.
9.8 - 12	No recovery.
12 - 47	No core sample.
12 - 32	* (Cut) Sand: Yellowish-gray; fine-grained; subangular to subrounded quartz grains; feldspar 5-8%; epidote 2-3%; white mica flakes 3%.
32 - 37	* (Cut) Sand: Yellowish-gray; fine to very fine-grained; very well sorted; subrounded grains.
37 - 42	* (Cut) Sand: Yellowish-gray; fine to very fine-grained; subangular grains; epidote 1-2%; other heavy minerals 3-5%; mud 5-10%; shell fragments 5%.
42 - 47	* (Cut) Sand: Yellowish-gray; fine to very fine-grained; very well sorted; subangular grains; heavy minerals 5%.
47 - 52	Clay: Medium bluish-gray; horizontal thin sand layers interbedded the mud. Recovery 0.4 ft.
52 - 54.3	Sand: Light olive gray; very fine-grained; well sorted; subangular quartz grains; <u>Cibicides</u> sp., <u>Ammonia beccarii</u>, <u>Elphidium</u> sp.
54.3 - 60	Clay: Medium bluish-gray; oyster shell fragments. Recovery 0.2 ft.

Boring 8 (Cont'd)

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
60 - 62	Clayey sand: Light olive green, abundant shell fragments; white mica flakes 3-4%; plant remains.
62 - 72	Sand: Light gray; very fine-grained; well sorted; sand and clay mixed; sand 85%, mud 15%; epidote 2%; phosphate grains 1%.
72	Limestone: Gray dark; fine quartz grains; white mica flakes; coquina facies in the lower part of this interval; mollusk molds.

	INTERPRETATION
0 - 52	Pleistocene
52 - 72	Middle Pliocene
Below 72	Middle Miocene

BORING 9

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 3.0	Sand: Dark yellowish-brown; fine-grained; very well sorted; subrounded quartz grains; heavy minerals 3-5%; stained grains 85%.
3.0 - 6.4	Sand: Pale yellowish-orange; fine-grained; well sorted; subrounded quartz grains; heavy minerals 3-5%.
6.4 - 10	Sand: White; fine-to medium-grained; well sorted; subrounded quartz grains; epidote 1-2%; opaque minerals 3-5%.
10 - 11	Sand: Brownish-gray; fine-grained; well sorted; subrounded to rounded grains.
11 - 12	Sand: Grayish-orange; fine-grained; well sorted; subrounded grains. Recovery 0.5 ft.
12 - 22	No core sample.
12 - 17	* (Cut) Sand: Moderate yellowish-brown; fine-grained; subangular to rounded quartz grains; heavy minerals 3-5%; plant remains 2%; feldspar 5-7%.
17 - 22	* (Cut) Sand: Grayish-yellow; fine-grained; subangular to rounded grains; heavy minerals 4%; plant remains 3%.
22 - 32	Humitic sand: Dark brown; very fine-grained lignitic plant debris; heavy minerals 2%; white sand lenses. Recovery 0.3
32 - 62	No core sample.
32 - 37	* (Cut) Sand: Very pale orange; fine-grained; subrounded grains; feldspar 5%; epidote 1-2%; plant remains 2%.
37 - 42	No recovery.
42 - 52	* (Cut) Sand: Yellowish-gray; fine-grained; coarse sand 5-10%; heavy minerals 3-5%; white mica flakes 2-3%; shell fragments 5%; clay 20%.
52 - 62	* (Cut) Sand: Yellowish-gray; fine-grained; subangular to well rounded quartz grains; heavy minerals 3-5%; feldspar 5-10%; shell fragments 33-40%; clay 10%; clay interbedded with sand (%?).

Boring 9 (Cont'd)

DEPTH BELOW SURFACE (ft)	DESCRIPTION
62 - 71	Shelly sand: Yellowish-gray; fine-grained; very well sorted; heavy minerals 4%; shell fragments 50-60%. Recovery 5.3 ft.
71	Limestone: Dark gray; fine and rounded quartz grains in calcareous clay; partially dolomitized.

	INTERPRETATION
0 - 52	Pleistocene
52 - 71	Middle Pliocene
Below 71	Middle Miocene

* (Cut) - Cuttings sample.

BORING 10

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 3.5	Sand: Light gray; fine-grained; well sorted; subrounded to rounded grains; stained grains 15%.
3.5 - 4.8	Sand: Pale yellowish-orange; fine-grained; well sorted; subrounded quartz grains; stained grains 95%; oxidized plant remains; heavy minerals 3-4%.
4.8 - 7.5	Sand: Pale grayish-orange; fine-grained; very coarse sand 5%; heavy minerals 2-3%.
7.5 - 8.0	Sand: Brownish-black; fine-grained; subrounded quartz grains; stained quartz grains.
8.0 - 10.0	Sand: Light brown; fine-grained; subrounded grains; heavy minerals 2-3%; sand partially "washed" during sampling.
10.0 - 11.8	No recovery.
11.8 - 22	Sand: Brownish-black; medium grained; well sorted; subrounded grains; hematitic stains on quartz grains; Recovery 1.3 ft.
22 - 32	No core sample.
22 - 32	* (Cut) Sand: Very pale orange; fine-grained; subrounded to well rounded quartz grains; rounded phosphatic grains 3%; epidote 2%; feldspar 5-8%; white mica flakes 3%.
32 - 33.3	Sand: Greenish-gray; fine-grained; subrounded to rounded grains; phosphate grains 2-3%; white mica flakes 3%; epidote 1-2%.
33.3 - 42	Silty clay: Dark greenish-gray; sand-filled burrows, 0.3 in. wide; horizontal, thin sand layers interbedded the clay. Recovery 2.5 ft.
42 - 46	Clayey sand: Greenish-gray; subrounded quartz grains; heavy minerals 3%; epidote 1%; white mica flakes 2-3%; plant remains 2%; _Elphidium_ sp., _Nonionella_ sp., _Hanzawaia concentrica_, _Ammonia beccarii_, _Globigerinoides rubra_, _Nonionella_ sp. Recovery 2.0 ft.
46 - 52	Clayey sand: Light olive gray; well-sorted; subrounded to rounded grains; white mica flakes 3%; heavy minerals 2%; shell fragments 5%; _Ammonia beccarii_, _Elphidium_ sp.

Boring 10 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
52 - 62	Sand: Very pale orange; fine-grained; subangular to well rounded; stained grains 15%; heavy minerals 3%; shell fragments 5%.
62	Coquina limestone: Pale gray; whole shells of *Mulinia* sp.; fragments of *Turritella* sp.

	INTERPRETATION
0 - 40.7	Pleistocene
40.7 - 62	Middle Pliocene
Below 62	Middle Miocene

* (Cut) - Cutting sample.

BORING 11

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 3	Sand: Moderate yellowish-brown; fine-grained; well sorted; subrounded quartz grains; heavy minerals 4%; stems of *Spartina alterniflora*.
3 - 6	Sand: Pale yellowish-orange; fine-grained; well sorted; subrounded grains; heavy minerals 3-4%;
12 - 32	No core sample.
12 - 17	* (Cut) Sand: Grayish-yellow; fine-grained; subangular to well rounded quartz grains; heavy minerals 1-2%.
17 - 32	* (Cut) Sand: Very pale orange; fine-grained; subangular quartz grains; heavy minerals 4%.
32 - 42	Clayey sand: Mottled, olive gray; heavy minerals 3%; stained quartz grains 5%. Recovery 0.2 ft.
42 - 62	No core sample.
42 - 47	* (Cut) Sand: Very pale orange; fine-grained; subangular grains; heavy minerals 3-5%; wood fragments.
47 - 62	* (Cut) Sand: Pale yellowish-gray; fine-grained; subangular to well rounded grains; white mica flakes 3%; feldspar 10%; epidote 2%.
62 - 66	Mixture of sand and clay: Sand 75%; clay 25%; abundant shell fragments and whole shells of *Mulinia lateralis* (Samples 9-13). *Elphidium* sp.
66 - 72	Clay: Greenish-gray; sand layers 1-2 mm thick; plant debris parallel to the stratification; *Cocconeis superba*, *Ammonia beccarii*, *Elphidium* sp., *Elphidium poeyanum*. Recovery 3.8 ft.
72 - 83	Clayey sand: Dark greenish-gray; fine-grained; subrounded quartz grains; epidote 2%; phosphate grains 2-3%; white mica flakes 3%; shell fragments 5%; *Elphidium* sp. Recovery 1.8 ft.
83 - 92	Clay: Greenish-gray; lignitic plant remains; diatoms; sand patches. Recovery 1.8 ft.
92 -100	Sand: Olive gray; fine-grained; well sorted; heavy minerals 3%; feldspar 5%; limestone fragments, 5 cm diameter. Recovery 0.7 ft.

Boring 11 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
100	Limestone: Fragments; very coarse quartz grains in calcareous clay; phosphatic bone fragment, 5 cm diameter.

	INTERPRETATION
0 - 92	Pleistocene
92 -100	Middle Pliocene
Below 100	Middle Miocene

* (Cut) - Cutting sample.

BORING 12

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 2.0	Sand: Dark yellowish-brown; fine-grained; well sorted; rounded grains; epidote 2-3%; sillimanite (?) 1-2%; quartz as aggregates.
2.0 - 6.4	Sand: Grayish-orange; fine-grained; very well sorted; subrounded quartz grains; feldspar 5%; heavy minerals 3-5%.
6.4 - 10	Sand: Very pale orange; fine-grained; subrounded quartz grains; very coarse sand 5%; heavy minerals 3%; oxidized stem fragments.
10 - 12	Sand: Very pale orange; fine-grained; well sorted; subrounded quartz grains; heavy minerals 2%; phosphate grains 1-2%.
12 - 32	No core sample.
12 - 27	* (Cut) Sand: White; fine-grained; subangular to rounded grains; stained quartz grains 2-3%; heavy minerals 5%.
27 - 32	* (Cut) Sand: Yellowish-gray; fine-grained; subangular to subrounded grains; very coarse grained 3%; plant remains 1%; heavy minerals 2%; white mica flakes 2-4%; feldspar 5%.
32 - 35	Sand: Mottled pale olive and greenish-gray; well sorted; subangular grains; heavy minerals 3%.
35 - 42	Clay: Dark greenish-gray; 5 mm sand layers.
42 - 52	No core sample.
42 - 52	* (Cut) Sand: Yellowish-gray; fine-grained; heavy minerals 4-5%; white mica flakes 2%; feldspar 5-10%; clay 15-20%. This interval is interpreted as silt/clay sequence.
52 - 62	Sand: Light olive gray; coarse-grained; heavy minerals 3%; Globigerinoides sacculifer, Hanzawaia concentrica, Globorotalia sp., Cibicides duplinensis (?). Recovery 1.0 ft.
62 - 72	Sand: Light-olive gray; calcareous; medium-to coarse-grained; heavy minerals 2-3%; quartz pebbles 3%; Cancris sp., Cibicides sapeloensis, Globorotalia menardii, Globigerinoides sacculifer, Shaeroidinellopsis subdehiscens, Globigerinoides obliquus, Pseudo polymorfina rutila, Elphidium sp., Globigerinoides rubra, Nonionella sp.

Boring 12 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
72 - 77	Coquina limestone: Light olive gray; mollusk external molds; grain supported framework; shell skeletal 90%; clay 10%.

	INTERPRETATION
0 - 52	Pleistocene
52 - 72	Middle Pliocene
Below 72	Middle Miocene

* (Cut) - Cutting Sample.

BORING 13

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 4.4	Sand: Mottled brown and dark gray; fine-grained; subangular to rounded quartz grains; heavy minerals 2%; large roots and stems of *Spartina alterniflora*.
4.4 - 5.0	Sand: Grayish-yellow; fine-grained; subrounded grains; heavy minerals 3%.
5.0 - 9.4	Sand: Yellowish-gray; fine-grained; well sorted; subrounded to rounded grains; heavy minerals 2-3%.
9.4 - 32	No core sample.
9.4 - 22	* (Cut) Sand: White; fine-grained; subangular grains; epidote 3%; feldspar 5-10%.
22 - 27	No recovery.
27 - 32	* (Cut) Sand: White; fine-grained; subangular to rounded grains; feldspar 5%; slightly phosphatic; epidote 1-2%; plant remains 2%.
32 - 42	Sand: Yellowish-gray; fine-grained; very well sorted; subrounded grains. Recovery 1.0 ft.
42 - 52	Clay: Dark greenish-gray; oyster fragments; white mica flakes 2%; the clay is partially mixed with the sand, clay 85%, sand 15%; *Elphidium* sp. Recovery 0.2 ft.
52 - 68	Sand: Medium-dark gray; calcareous; moderately sorted; very coarse-grained; shell fragments 15%.
68	Limestone: Fragments; scattered quartz granules.

INTERPRETATION

0 - 52	Pleistocene
52 - 68	Middle Pliocene
Below 68	Middle Miocene

* (Cut) - Cutting sample.

BORING 14

DEPTH BELOW SURFACE (ft)	DESCRIPTION
0 - .66	Sand: Medium light gray; fine-to medium-grained; very well sorted; subrounded to rounded grains; heavy minerals 3%; small pieces of roots and stems.
.66 - 7.0	Sand: Brownish-gray; fine-grained; very well sorted; subrounded quartz grains; stained quartz grains; heavy minerals 2-3%.
7.0 - 17.0	Humus: Brownish-black; fine-grained; clayey organic matter.
17.0 - 23.4	Sand: Yellowish-brown; fine-grained; very well sorted; subrounded to rounded grains; phosphatic grains 2%; epidote less than 1%.
23.4 - 28	Sandy Humus; Brownish-black; fine-grained; abundant organic matter.
28 - 32	Sand: Yellowish-brown; fine-grained; well sorted; subrounded quartz grains; slightly phosphatic epidote 1%.
32 - 42	No core sample.
32 - 42	* (Cut) Sand: Yellowish-brown; subangular grains; white mica flakes 2%; feldspar 5-8%; heavy minerals 3%.
42 - 46.4	Sand: Light olive gray; fine-grained; very well sorted; angular to subangular grains; white mica flakes 3%.
46.4 - 49	Clay: Greenish-gray; small pieces of plant remains; shell fragments 10%; patches of sand.
49 - 52	Shelly clayey sand: Dark greenish-gray; fine-grained; abundant shell fragments; whole shells of _Mulinia laterlais_, _Elphidium_ sp., _Elphidium poeyanum_ _Polymorphina_ sp.
52 - 62	No core sample.
52 - 62	* (Cut) Sand: Pale yellowish-brown; fine-grained; subangular to rounded grains; heavy minerals 2-3%; white mica flakes 2%; shell fragments 10%; clay 10-20%.
62 - 65	Sand: Yellowish-brown; fine-grained; well sorted; subrounded to well rounded grains; heavy minerals 2%; shell fragments 5-10%.

Boring 14 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
65 - 72	Sand: Yellowish-brown; fine-grained; moderately sorted; oyster fragments; calcareous sandstone fragments; subordinate amounts of clay; Mitrella lunata, Olivella mutica, Mulinia lateralis, Anadora ovalis (Sample 14).
72 - 77	No core sample.
72 - 77	* (Cut) Sand: Pale yellowish-brown; coarse-grained; subrounded grains; white mica flakes 2%; feldspar 1-2%; heavy minerals 2%.
77 - 92	Sand: Light olive gray; fine-grained; well sorted; subrounded to rounded grains; quartz granules 15-20%; shell fragments. Recovery 1.3 ft.
92 - 96	Limestone: Pale olive green, sandy; internal gastropod molds; clay supported grains. Recovery 2.0 ft.

	INTERPRETATION
0 - 77	Pleistocene
77 - 92	Middle Pliocene
Below 92	Middle Miocene

* (Cut) - Cutting sample.

BORING 15

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - .56	Sand: Yellowish-gray; fine-grained; subangular to well rounded grains; epidote 2-3%; other heavy minerals 3%; oxidized quartz grains.
.56 - 4.4	Sand: Yellowish-orange; fine-grained; very well sorted; subrounded quartz grains; epidote 1-2%; stained quartz grains.
4.4 - 9.0	Sand: very light gray; fine-grained; very well sorted; subrounded quartz grains; phosphate grains 2%; heavy minerals 3%.
9.0 - 10.0	Sand: Yellowish-brown; fine-grained; well sorted; subrounded quartz grains; slightly phosphatic; heavy minerals 3%.
10.0 - 12	No recovery.
12 - 42	No core sample.
12 - 22	* (Cut) Sand: Grayish-orange; fine-grained; subangular to rounded grains; heavy minerals 3%; feldspar 5%; white mica flakes 2%.
22 - 27	* (Cut) Sand: Pale yellowish-brown; medium-to coarse-grained; subangular to well rounded grains; heavy minerals 2%; white mica flakes 2-3%; plant remains 1-2%.
27 - 32	* (Cut) Sand: Pale yellowish-brown; fine-grained; subangular grains; heavy minerals 1-3%; white mica flakes 2%.
32 - 42	* (Cut) Sand: Pale yellowish-brown; coarse-grained; subangular grains; epidote 2%; other heavy minerals 3%; shell fragments 4%.
42 - 52	Sandy clay: Light olive gray; very well sorted; subrounded grains; 0.4 in thick sand layers interbedded with clay in the lower part of this interval; plant remains parallel to the stratification. <u>Ammonia beccarii</u>, <u>Elphidium</u> sp., <u>Discorbis</u> sp., <u>Hanzawaia concentrica</u>.
52 - 62	No core sample.

Boring 15 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
52 - 62	* (Cut) Sand: Pale yellowish-brown; fine-grained; heavy minerals 3%; white mica flakes 2%; shell fragments 10%; clay 25%. This interval is interpreted as silt/clay sequence.
62 - 71	Clay: Dark greenish-gray; small pieces of plant remains parallel to the stratification; large shell fragments of *Crassostrea virginica*; scattered quartz pebbles. Recovery 0.9 ft.
71 - 92	Sand: Light olive gray; coarse-grained; subrounded to rounded quartz grains; quartz pebbles 15%; phosphatic grains 3%; epidote 1-2%; shell fragments 5%. Recovery 1.2 ft.
92	Bed rock (no recovery).

	INTERPRETATION
0 - 42	Pleistocene
42 - 92	Middle Pliocene
Below 92	Middle Miocene

* (Cut) - Cutting sample

BORING 16

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 2.0	Sand: Brownish-gray; fine-grained; subrounded to rounded quartz grains; heavy minerals 2%; thin roots; shell fragments 2%; stained quartz grains.
2.0 - 7.4	Sand: Light olive gray; fine-grained; very well sorted; subrounded quartz grains; phosphatic grains 3%; epidote 1-2%; hornblende (?) 2%.
7.4 - 9.0	Humus: Brownish-black; fine quartz grains in organic material.
9.0 - 12.4	Mixture of brownish-gray sand and black clay, small shell fragments.
12.4 - 17	Clay: Brownish-black; abundant plant debris; patches of sand; high content of organic matter; large lignitic stem debris, 9 cm long, 3-4 cm diameter. Recovery 3.9 in.
17 - 22	Clayey sand: Dark greenish-gray; subrounded quartz grains; heavy minerals 3%.
22 - 32	Clay: Dark greenish-gray; thin sand layers interbedded the clay.
32 - 62	No core sample.
32 - 52	* (Cut) Sand: Very pale orange; fine-to medium-grained; subangular grains; white mica flakes 2%; heavy minerals 4%; feldspar 5-10%; wood fragments; clay 15-30%. This interval is interpreted as clay/sand sequence.
52 - 62	* (Cut) Sand: Pale yellowish-brown; fine-grained; subangular quartz grains; shell fragments 40%; heavy minerals 4%.
62 - 64	Clay: Dark greenish-gray; 3-4 mm sand layers; shell fragments 3%; scattered quartz grains. Recovery 2 in.
64 - 72	Sand: Dusky yellow; medium-grained; very well sorted; rounded quartz grains; calcareous sandstone fragments; large shell fragments. Recovery 0.7 ft.
72 - 82	Sand: Light olive gray; fine-grained; very well sorted; subrounded to well-rounded quartz grains; shell fragments 5%; the sand in the lower part changes gradually to clayey sand. Recovery 1.0 ft.

Boring 16 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
82 - 94	Sand: Light olive gray; fine-grained in the upper part and coarse in the bottom; subrounded quartz grains; heavy minerals 3%; white mica flakes 2%; *Pecten* sp., *Balanus* (barnacle) (Sample 17); *Cibicides sapeloensis*, *Ammonia beccarii*. Recovery 1.0 ft.
94	Bed rock (no recovery).

	INTERPRETATION
0 - 52	Pleistocene
52 - 94	Middle Pliocene
Below 94	Middle Miocene

* (Cut) - Cutting sample.

BORING 17

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 1.5	Sand: Very light gray; fine-grained; abundant roots and stems; heavy minerals 3-5%.
1.5 - 2.4	Sand: Yellowish-brown; fine-grained; subangular to well-rounded quartz grains; phosphatic grains 2%; feldspar 10%.
2.4 - 6.0	Sand: Grayish-orange; fine-grained; subrounded grains; epidote 1-2%; prismatic grains (sillimanite (?)) 1-2 %.
6.0 - 10	No recovery.
10 - 12	Sand: Moderate brown; fine-grained; very well sorted; subrounded to rounded quartz grains; heavy minerals 4%; shell fragment 5%.
12 - 32	No core sample.
12 - 32	* (Cut) Sand: Moderate yellowish-brown; fine-grained; subangular to rounded quartz grains; feldspar 5-10%; white mica flakes 3%.
32 - 42	Sand: Mottled yellow and greenish-yellow; fine grained; subrounded quartz grains; heavy minerals 3%; wood fragments 2%. Recovery 0.5 ft.
42 - 52	No core sample.
42 - 52	* (Cut) Sand: Pale orange; fine-grained; subrounded quartz grains; dark minerals 1%; white mica flakes 2%; clay 5-10%. This interval is interpreted as silt/clay sequence based on clay content.
52 - 56	Sand: Light olive gray; very-fine grained; well sorted; subrounded quartz grains; white mica flakes 5-10%; epidote 2%; shell fragments 3%; Elphidium sp., Globigerinoides obliquus, Cibicides sapeloensis.
56 - 62	Sandy clay: Dusky yellow green; scattered shell fragments; Ammonia beccarii, Elphidium sp., Hanzawaia concentrica, Globigerinoides sacculifer.
62 - 72	No core sample.
62 - 72	* (Cut) Sand: Light olive gray; fine-grained; white mica flakes 2-3%; heavy minerals 2%; shell fragments 15%.

Boring 17 (Cont'd):

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
72 - 82	Mixture of sand and clay: clay 75%; sand 25%; the sand is fine-grained; limestone fragments 5 cm diameter; Pecten sp., Anadora ovalis, Mulinia lateralis (Sample 19). Recovery 0.8 ft.
82 - 92	Sand: Brownish-yellow; coarse-to very coarse-grained; shell fragments; mixture of sand and clay; Ostrea sp., Crassatella sp.
92 - 98	Sand: Greenish-gray; fine-to medium-grained; subangular to rounded grains; white mica flakes 3%; epidote 2%. Recovery 1.0 ft.
98	Bed rock (no recovery).

	INTERPRETATION
0 - 52	Pleistocene
52 - 98	Middle Pliocene
Below 98	Middle Miocene

* (Cut) - Cutting sample.

BORING 18

DEPTH BELOW SURFACE (ft.)	DESCRIPTION
0 - 2.0	Sand: Grayish-orange; fine-grained; subrounded to well-rounded quartz grains; feldspar 5%; heavy minerals 2%; root fragments.
2.0 - 7.5	Sand: Grayish-orange; fine-grained; subrounded quartz grains; prismatic grains (sillimanite (?)) 2%.
7.5 - 10	Sand: Mottled dakr brown and pale brown; fine-grained; well-sorted; rounded to well-rounded quartz grains; phosphatic grains 1-2%.
10 - 12	No recovery.
12 - 32	No core sample.
12 - 32	* (Cut) Sand: Very pale orange; subangular to rounded quartz grains; white mica flakes 3%; epidote 1-2%.
32 - 42	Silty clay: Dark greenish-gray; sand layers interbedded the clay, 0.5-1.0 cm thick. Recovery 1.2 ft.
42 - 52	No core sample.
42 - 52	* (Cut) Sand: Yellowish-gray; fine-grained; subangular to rounded quartz grains; white mica 2-3%; heavy minerals 4%.
52 - 62	Silty clay: Dark greenish-gray; shell fragments 5%; sand patches; lignitic plant remains; Mercenaria sp. (Sample 15). Recovery 0.4 ft.
62 - 72	Sandy clay: Shell fragments (interpretation based on field log).
72 - 79	Sand: Light olive gray; fine-to coarse-grained; rounded to well-rounded grains; epidote 3%; other heavy minerals 2%; Pecten sp. fragment.
79 - 82	Limestone: Light olive gray; medium to very coarse quartz grains in calcareous clay. Recovery 2.1 ft.

INTERPRETATION

0 - 42	Pleistocene
42 - 79	Middle Pliocene
Below 79	Middle Miocene

* (Cut) - Cutting sample.

APPENDIX D

GRAIN SIZE DATA

GRAIN SIZE DATA

DEPTH BELOW SURFACE (m)	MEAN (Mz)	SKEWNESS (Sk)	STANDARD DEVIATION (SD)	KURTOSIS (K_G)	GRAVEL %	SAND %	SILT %	CLAY %	SILT & CLAY %
<u>Boring 1</u>									
0.60	2.73	-0.03	0.40	2.59	0.0	99.20			0.80
1.52	2.53	-0.20	0.56	2.48	0.0	99.33			0.67
2.74	2.79	0.29	0.31	1.78	0.0	99.72			0.28
3.65	2.75	0.0	0.41	2.64	0.0	99.43			0.57
3.96 - 4.26	2.77	0.29	0.27	1.73		99.31			0.69
5.48	2.53	-0.31	0.57	2.57	0.0	99.73			0.27
6.82	2.75	0.01	0.44	2.65	0.0	98.29			1.71
8.83	3.04	0.31	0.59	0.90	0.0	99.29			0.71
9.75 Approx.	3.08	0.56	1.31	2.34	0.0	89.52	5.36	5.02	
12.19	5.58	0.30	0.59	1.82	0.0	0.0	85.07	14.92	
21.33	2.10	0.19	0.65	0.87	0.04	99.71			0.25
25.90	1.03	0.03	1.38	0.90	13.53	86.27			0.10
<u>Boring 2</u>									
0.20	2.75	-0.27	0.48	3.35	0.06	97.73			2.21
0.67	2.77	0.06	0.39	2.54	0.0	98.83			1.17
1.31	2.77	0.07	0.38	2.49	0.0	99.14			0.86
2.13	2.77	0.29	0.30	1.79	0.0	99.55			0.45
2.74	2.77	0.06	0.39	2.54	0.0	98.98			1.02
3.35	2.79	0.30	0.31	1.84	0.0	98.10			1.90
3.65	5.04	0.58	2.43	0.47	0.0	53.41	9.18	37.42	
4.57	4.08	0.53	1.52	1.58	0.0	83.01	13.14	3.84	
5.18	4.26	0.61	1.50	2.18	0.0	81.37	4.69	14.06	
15.84	2.73	-0.13	1.16	4.25	2.44	88.43			9.12
16.76	2.61	0.35	3.04	1.78	9.77	73.57	6.87	9.78	
18.59	2.51	-0.37	0.73	3.08	0.04	97.68			2.28
18.89 - 21.94	2.63	0.12	3.41	0.91	23.58	51.57	16.58	88.26	

GRAIN SIZE DATA
(Continued)

DEPTH BELOW SURFACE (m)	MEAN (Mz)	SKEWNESS (Sk)	STANDARD DEVIATION (SD)	KURTOSIS (K_G)	GRAVEL %	SAND %	SILT %	CLAY %	SILT & CLAY %
<u>Boring 3</u>									
0.02	2.99	0.32	0.57	2.49	0.13	98.02			1.85
0.30	2.99	0.31	0.58	2.54	0.33	97.20			2.47
0.60	3.00	0.36	0.56	2.39	0.01	97.50			2.48
0.72	2.77	0.06	0.41	2.64	0.0	97.34			2.66
1.01	2.96	0.31	0.56	2.59	0.14	97.43			2.43
1.21	2.78	0.06	0.41	2.53	0.0	98.47			1.53
1.62	2.95	0.32	0.54	2.56	0.06	97.92			2.01
2.13	2.78	0.07	0.40	2.48	0.0	99.80			1.20
3.04	4.36	0.55	1.88	0.78	0.0	69.08	22.27	8.65	
3.96	3.11	0.46	0.52	0.59	0.0	98.94			1.06
4.87	2.94	0.26	0.50	2.60	0.0	98.10			1.90
5.18	3.14	0.44	0.51	0.58	0.0	99.71			0.29
6.09	3.11	0.50	0.50	0.59	0.0	99.61			0.39
6.70	3.07	0.55	0.50	0.63	0.0	98.16			1.84
7.31	3.05	0.55	0.50	0.65	0.0	98.55			1.45
8.22	3.05	0.56	0.50	0.67	0.0	98.01			1.99
8.83	3.16	0.71	0.98	1.57	0.0	84.70	15.15	0.14	
9.75	5.62	-0.22	2.26	0.65	0.0	45.81	37.71	16.49	
10.78	6.32	-0.28	2.21	0.57	1.60	29.12	26.44	42.84	
11.58	7.64	-0.63	1.47	1.01	0.29	13.51	28.53	57.68	
12.49	5.32	-0.50	3.45	0.75	8.87	28.12	25.78	37.23	
13.41	7.91	-0.56	1.35	1.00	0.00	5.58	25.95	68.47	
14.02	2.96	0.28	0.59	2.66	0.0	97.15			2.85
16.15	2.07	-0.58	1.18	1.31	4.23	95.18			0.59
17.06	2.05	-0.62	1.32	0.59	7.46	91.75			0.79
17.67	4.95	0.58	2.58	0.51	0.0	53.92	3.24	42.84	
18.28	0.02	0.51	1.46	1.44	48.37	50.94			0.68

GRAIN SIZE DATA
(Continued)

DEPTH BELOW SURFACE (m)	MEAN (Mz)	SKEWNESS (Sk)	STANDARD DEVIATION (SD)	KURTOSIS (K_G)	GRAVEL %	SAND %	SILT %	CLAY %	SILT & CLAY %
Boring 3 (Cont'd)									
18.89	1.78	-0.69	1.49	0.98	8.16	90.54			1.30
19.20	5.58	-0.37	3.10	0.64	2.77	46.12	3.90	47.21	
20.11	0.70	0.07	1.59	0.79	21.62	77.89			0.49
22.25	3.27	0.26	2.71	1.56	0.98	79.65	11.47	7.99	
22.86	2.84	0.43	3.09	1.24	2.88	78.58	3.59	14.95	
23.77	3.65	0.31	3.48	0.65	2.26	68.00	8.19	21.56	
24.38 - 24.68	0.50	0.56	1.25	1.31	10.61	87.73			1.66
24.68 - 27.73	0.51	0.43	1.59	0.79	18.45	81.42			0.13
Boring 4									
0.30	2.76	0.02	0.42	2.68	0.0	98.73			1.27
1.21	2.77	0.04	0.40	2.58	0.0	99.39			0.61
2.20	2.78	0.29	0.31	1.79	0.0	99.25			0.75
2.99	2.74	-0.02	0.39	2.62	0.0	99.23			0.77
9.75 - 11.27 App.	3.03	0.31	0.59	0.94	0.0	99.54			0.46
11.27 - 12.80 App.	6.25	-0.25	2.14	1.20	0.0	21.13	47.98	30.89	
14.02	6.32	-0.25	2.11	1.19	0.0	18.67	48.20	33.13	
14.93	5.01	0.57	2.35	0.50	0.0	52.91	21.92	25.17	
15.84 - 18.89	4.51	0.50	1.98	0.65	0.0	53.51	32.55	13.94	
19.81	7.22	0.48	1.02	0.59	0.0	2.05	58.58	39.37	
20.87	7.09	0.55	0.98	0.65	0.0	2.54	70.37	27.09	
28.04 - 28.34	3.00	0.17	0.75	3.13	0.0	95.48			4.52
Boring 5									
0.12	2.55	-0.30	0.54	2.51	0.0	99.33			0.67
0.45	2.75	0.01	0.39	2.63	0.0	99.11			0.99

GRAIN SIZE DATA
(Continued)

DEPTH BELOW SURFACE (m)	MEAN (Mz)	SKEWNESS (Sk)	STANDARD DEVIATION (SD)	KURTOSIS (K_G)	GRAVEL %	SAND %	SILT %	CLAY %	SILT & CLAY %
Boring 5 (Cont'd)									
1.06	2.76	0.04	0.39	2.63	0.0	98.42			1.58
1.52	2.78	0.30	0.31	1.81	0.0	98.97			1.03
1.94	2.55	-0.30	0.54	2.51	0.0	99.37			0.63
2.20	2.78	0.29	0.30	1.80	0.0	99.49			0.51
2.43	2.78	0.30	0.29	1.86	0.0	98.74			1.26
2.89	2.79	0.30	0.30	1.85	0.0	99.11			0.89
3.47 - 3.65	2.79	0.30	0.30	1.83	0.0	99.54			0.46
3.65 - 12.80	4.53	0.49	1.96	0.67	0.0	53.49	33.60	12.91	
16.47 Approx.	7.17	0.10	1.50	1.19	0.0	7.95	54.24	37.82	
17.47 Approx.	4.39	0.57	1.94	0.68	0.0	64.99	23.89	11.12	
18.89 - 21.94	2.98	0.57	0.46	1.77	0.0	98.76			1.24
Boring 6									
0.25	2.72	-0.02	0.42	2.55	0.0	99.31			0.69
1.38	2.78	0.30	0.30	1.80	0.0	99.42			0.58
2.74	2.77	0.30	0.30	1.80	0.0	98.80			1.20
3.80	2.77	0.30	0.29	1.81	0.0	98.93			1.17
13.53 Approx.	3.40	0.01	1.26	2.32	0.0	88.03	6.22	5.74	
15.64 Approx.	7.72	-0.62	1.39	1.03	0.0	6.94	33.05	60.01	
18.28	7.69	-0.59	1.36	0.99	0.0	5.45	39.05	55.49	
18.71	2.79	0.30	0.31	1.87	0.0	97.63			2.37
Boring 7									
0 - 3.0	2.77	0.07	0.38	2.47	0.0	99.25			0.75
3.35 - 3.65	2.74	-0.01	0.41	2.54	0.0	99.45			0.55
15.84 - 18.89	7.20	0.51	1.0	0.59	0.0	0.0	63.19	36.81	
18.89 - 21.94	7.69	-0.41	1.01	0.57	0.0	0.0	47.91	52.09	
22.09 Approx.	2.73	-0.11	0.87	2.97	0.51	97.22			2.28

GRAIN SIZE DATA
(Continued)

DEPTH BELOW SURFACE (m)	MEAN (Mz)	SKEWNESS (Sk)	STANDARD DEVIATION (SD)	KURTOSIS (K_G)	GRAVEL %	SAND %	SILT %	CLAY %	SILT & CLAY %
Boring 8									
0.60	2.74	0.0	0.42	2.67	0.0	98.69			1.31
1.67	2.76	0.03	0.40	2.52	0.0	99.12			0.86
2.43	2.78	0.30	0.31	1.80	0.0	99.21			0.79
2.89	2.75	0.0	0.42	2.66	0.0	99.14			0.86
14.32 - 15.84	7.57	-0.50	1.57	1.09	0.0	15.69	33.43	50.88	
16.45 Approx.	3.07	0.54	0.52	0.53	0.0	96.67			3.33
17.82 Approx.	4.77	0.31	2.86	1.02	6.56	52.28	24.15	17.02	
18.99 Approx.	2.69	-0.01	0.79	0.99	0.0	98.70			1.30
19.91 Approx.	2.77	0.30	0.31	1.84	0.0	98.11			1.89
Boring 9									
0.60	2.73	-0.02	0.41	2.63	0.0	98.88			1.12
1.52	2.76	0.29	0.28	1.72	0.03	99.87			0.09
2.92	2.75	0.0	0.41	2.64	0.0	99.57			0.43
3.50	2.78	0.29	0.30	1.77	0.0	99.63			0.37
6.70 - 9.75	2.75	0.01	0.46	2.53	0.0	98.41			1.59
Boring 10									
0.17	2.73	-0.05	0.40	2.53	0.10	99.08			0.81
1.57	2.75	-0.02	0.36	2.44	0.04	99.74			0.22
2.28 - 2.43	2.78	0.30	0.30	1.83	0.0	98.84			1.16
2.43 - 3.0	2.78	0.07	0.42	2.61	0.0	96.28			3.72
3.65 - 6.70	2.50	-0.57	0.46	1.73	0.0	99.86			0.14
10.05 Approx.	3.03	0.30	0.60	0.96	0.0	98.91			1.09
12.49 Approx.	6.02	-0.16	2.10	0.78	0.0	40.56	37.66	21.78	
12.80 - 14.02	4.62	0.54	1.93	0.80	0.0	55.63	28.59	15.78	
14.02 - 15.87	6.12	-0.10	1.97	0.68	0.0	37.68	37.74	24.58	

GRAIN SIZE DATA
(Continued)

DEPTH BELOW SURFACE (m)	MEAN (Mz)	SKEWNESS (Sk)	STANDARD DEVIATION (SD)	KURTOSIS (K_G)	GRAVEL %	SAND %	SILT %	CLAY %	SILT & CLAY %
<u>Boring 11</u>									
0 - 0.60	2.78	0.07	0.39	2.48	0.0	99.12			0.88
1.52	2.78	0.29	0.31	1.75	0.0	99.70			0.30
2.74	2.99	0.57	0.46	1.74	0.0	99.23			0.77
2.65	3.06	0.56	0.49	0.65	0.0	98.78			1.22
9.75 - 12.80	4.19	0.85	2.02	0.65	0.0	60.27	24.36	15.37	
19.37 Approx.	4.54	0.48	2.00	0.66	0.0	52.46	32.11	15.43	
20.94 Approx.	7.12	0.12	1.49	1.21	0.0	9.45	56.89	33.66	
21.94 - 25.29	6.11	-0.23	2.04	0.84	0.0	26.65	53.28	20.09	
25.29 - 28.04	7.18	0.53	0.99	0.60	0.0	0.0	65.55	34.45	
29.04 - 30.0	2.74	-0.01	0.74	2.49	0.0	98.72			1.28
<u>Boring 12</u>									
2.74	2.73	-0.04	0.40	2.57	0.08	99.18			0.74
1.82	2.77	0.29	0.30	1.77	0.0	99.52			0.48
1.99	2.76	0.03	0.37	2.52	0.0	99.39			0.61
3.65	2.76	0.07	0.37	2.51	0.0	98.60			1.40
10.86 Approx.	2.78	0.30	0.29	1.82	0.0	99.77			0.23
12.19 Approx.	6.30	-0.17	1.97	1.03	0.0	22.09	47.23	30.67	
18.89	2.02	0.32	0.61	2.45	0.37	98.82			0.81
<u>Boring 13</u>									
0.35	2.74	-0.04	0.38	2.53	0.0	99.43			0.57
1.52	2.77	0.29	0.30	1.78	0.0	99.44			0.56
1.82 - 2.43	2.78	0.29	0.30	1.79	0.0	99.40			0.60
9.75 - 12.80	2.79	0.30	0.30	1.82	0.0	99.58			0.32
12.80 - 15.84	7.25	0.48	1.01	0.58	0.0	0.0	58.74	41.26	

GRAIN SIZE DATA
(Continued)

DEPTH BELOW SURFACE (m)	MEAN (Mz)	SKEWNESS (Sk)	STANDARD DEVIATION (SD)	KURTOSIS (K_G)	GRAVEL %	SAND %	SILT %	CLAY %	SILT & CLAY %
Boring 14									
0 - 0.60	2.43	-0.53	0.50	0.62	0.10	99.45			0.44
1.52	2.45	-0.53	0.50	0.63	0.0	99.39			0.61
1.82 - 2.13	2.75	-0.01	0.40	2.64	0.0	99.18			0.82
2.13 - 4.26	4.07	0.86	1.89	0.65	0.0	66.71	26.05	7.24	
4.26 - 6.70	2.76	0.05	0.37	2.49	0.0	99.86			0.14
8.27 Approx.	5.21	-0.37	1.97	0.64	0.0	48.33	39.11	12.56	
13.90 Approx.	3.06	0.32	0.59	0.96	0.0	99.27			0.73
14.98 Approx.	5.92	-0.20	2.37	0.54	0.0	43.80	18.94	37.25	
19.77 Approx.	2.73	-0.07	0.42	2.69	0.0	99.66			0.34
20.42 Approx.	1.05	-0.36	1.65	0.50	23.57	75.83			0.61
21.03 - 21.94	0.74	0.03	1.69	0.48	37.16	52.23			0.60
24.99 - 28.04	2.56	-0.28	0.57	2.61	0.09	99.27	0.63		
Boring 15									
0.30	2.75	0.0	0.38	2.50	0.0	99.35			0.65
1.33 - 2.74	2.54	-0.29	0.56	2.54	0.0	99.34			0.66
2.74 - 3.0	2.74	-0.03	0.36	2.45	0.0	99.57			0.43
12.80 - 15.84	5.53	-0.32	1.71	0.81	0.0	46.74	41.50		11.75
18.89 - 21.94	7.09	0.22	1.30	1.10	0.0	5.19	66.57	28.24	
21.94 - 28.04	2.15	0.32	0.83	1.19	0.0	95.38			4.62
Boring 16									
0.60	2.47	-0.56	0.49	0.57	0.11	99.57			0.32
1.52	2.75	0.01	0.39	2.61	0.12	99.24			0.64
2.25 - 2.74	2.76	0.28	0.27	1.67	0.0	98.54			1.46
3.12 - 3.77	2.76	0.0	0.16	0.74	0.0	99.70			0.30
3.77 - 5.18	5.32	-0.45	1.98	0.64	0.0	36.33	49.99	13.68	
6.1 Approx.	4.18	0.86	2.00	0.65	0.0	58.56	27.23	14.21	
19.50 - 21.94	2.57	-0.03	1.08	1.32	1.24	89.62			9.14
21.94 - 24.99	2.75	0.01	0.82	2.17	0.0	96.33			3.67
24.99 - 28.65	2.37	-0.45	0.79	1.14	0.30	98.56			1.13

GRAIN SIZE DATA
(Continued)

DEPTH BELOW SURFACE (m)	MEAN (Mz)	SKEWNESS (Sk)	STANDARD DEVIATION (SD)	KURTOSIS (K_G)	GRAVEL %	SAND %	SILT %	CLAY %	SILT & CLAY %
Boring 17									
0.91	2.75	-0.02	0.36	2.48	0.0	99.42			0.58
1.82	2.75	0.03	0.37	2.54	0.0	99.34			0.66
3.0 - 3.65	2.75	-0.03	0.36	2.45	0.02	98.90			1.08
9.75 - 12.80	2.77	0.29	0.30	1.78	0.0	99.37			0.63
15.84 - 17.06	3.75	0.25	0.70	5.19	0.0	89.86	7.45	2.69	
17.06 - 18.89	4.22	0.13	2.49	0.96	2.62	53.77	34.98	8.63	
21.94 - 24.99	5.78	-0.34	3.00	0.73	5.59	40.94	16.89	36.58	
29.87	3.11	0.15	0.70	0.92	0.09	95.37			4.54
Boring 18									
0 - 0.03	2.73	-0.07	0.38	2.40	0.05	99.28			0.57
1.21	2.76	0.28	0.27	1.66	0.0	99.37			0.63
2.13	2.75	0.01	0.41	2.67	0.0	99.0			1.0
3.00	2.56	-0.28	0.56	2.50	0.0	99.13			0.87
9.75 - 12.80	6.28	-0.25	2.17	0.58	0.0	25.41	37.80	36.79	
15.84 - 18.89	4.50	0.35	2.14	0.73	0.0	50.61	36.11	13.28	
20.23	2.76	0.01	0.42	2.69	0.05	98.98			0.97

APPENDIX E

LIST OF MACROFOSSILS

MACROFOSSILS	BORING NUMBER(S)
Abra aequalis (Say)	6
Acteocina canaliculata (Say)	3
Anadora ovalis (Bruguiere)	14, 17
Balanus sp.	16
Chione latirilata (Conrad)	3
Crassatella sp.	17
Crassostrea virginica (Gmelin)	3, 15
Mercenaria sp.	3, 4, 18
Mitrella lunata (Say)	14
Mulinia lateralis (Say)	2, 3, 5, 6, 11, 14, 17
Nassarius obsoletus (Say)	3
Oliva sayana (Ravenel)	5
Olivella mutica (Say)	3, 14,
Ophiomorpha nodosa	3
Ostrea sp.	17
Pecten sp.	16, 17, 18
Rangia cuneiata (Gray)	3
Turritella sp.	10
Venericardia sp.	2

Figure G-11. Inland salt marshes located on South Cut road, Cumberland Island. Grass in the foreground is Spartina alterniflora.

Figure G-12. Raccoon Keys salt marsh with active back dunes in background.

APPENDIX F

LIST OF MICROFOSSILS

MICROFOSSILS	BORING NUMBER(S)
Ammonia beccarii (Linne)	3, 7, 8, 10, 11, 15, 16, 17
Cancris sp.	12
Cibicides sapeloensis (Darby and Hoyt)	4, 12, 16, 17
Cocconeis superba	7, 11
Discorbis sp.	15
Elphidium advena (Cushman)	3
Elphidium gunteri (Cole)	3, 4
Elphidium poeyanum (d'Orbigny)	4, 11, 13, 14
Globigerinoides obliquus (Bolli)	4, 12, 17
Globigerinoides rubra (d'Orbigny)	3, 4, 10, 12
Globigerinoides sacculifer (Brady)	4, 12, 17
Globorotalia menardii (d'Orbigny)	3, 12
Hanzawaia concentrica (Cushman)	3, 4, 10, 12, 15, 17
Nonionella sp.	3, 8, 10, 12
Polymorphina guttulina (d'Orbigny)	3
Polymorphina sp.	4, 14
Pseudo polymorphina rutila (Cushman)	12
Quinqueloculina sp.	3
Rhaphaneis angularis	3
Sphaeroidinellopsis subdehiscens (Blow)	12

APPENDIX G

MISCELLANEOUS PHOTOGRAPHS

Note: The photographs provided in this Appendix are not referenced in the text. Rather the photographs are provided so that the reader can obtain a visual image of several concepts discussed in the narrative.

Figure G–1. Exposure of the Satilla Formation at Terrapin Point, Cumberland Island.

Figure G–2. Holocene Dunes advancing over the Pleistocene age Satilla Formation in the Beach Fields, Cumberland Island.

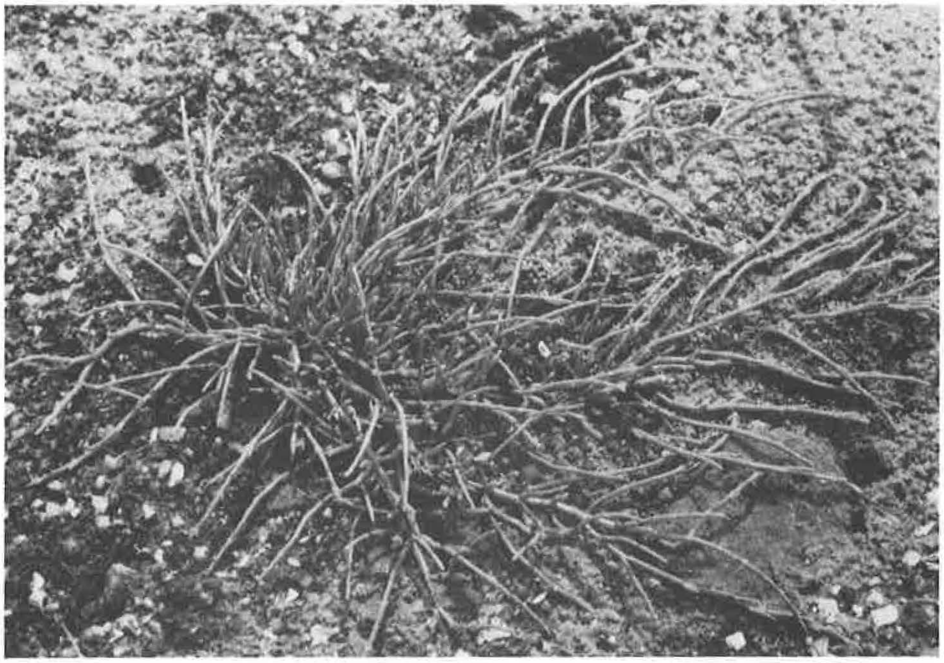

Figure G–3. Salicornia sp. (glasswort) located on the high marsh in the Raccoon Keys salt marsh.

Figure G–4. Uniola paniculata (see oats) growth on foredunes tends to stabilize the sands and retard erosion.

Figure G-5. Stabilizing vegetation on the back dunes near the Little Greyfield dune crossing, Cumberland Island.

Figure G-6. Typical vegetation of the interdune meadow near the Little Greyfield dune crossing.

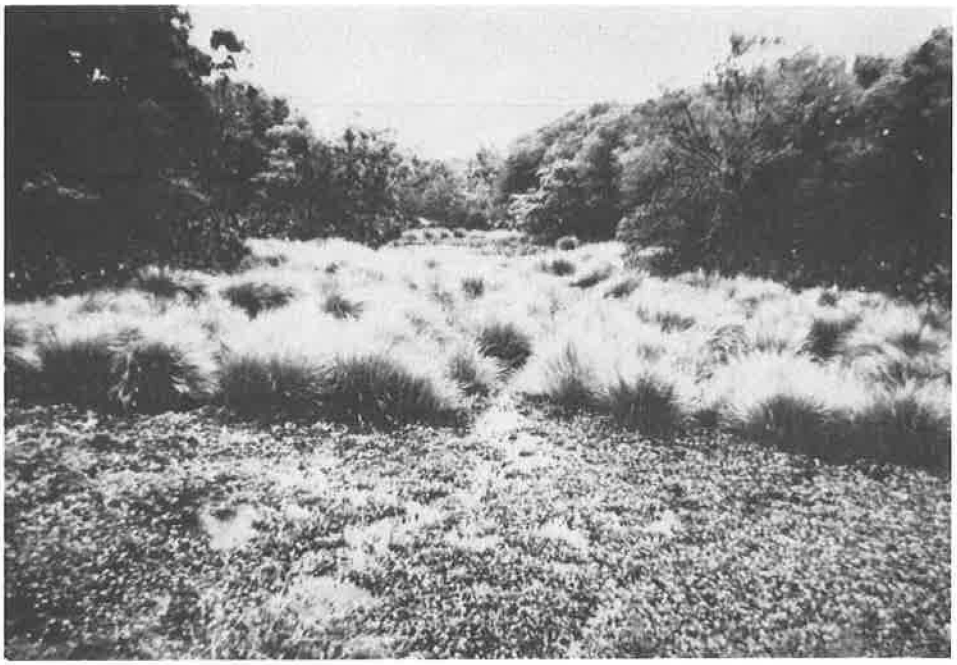

Figure G-7. Freshwater marsh on Cumberland Island, notice the vegetation changes from foreground to background.

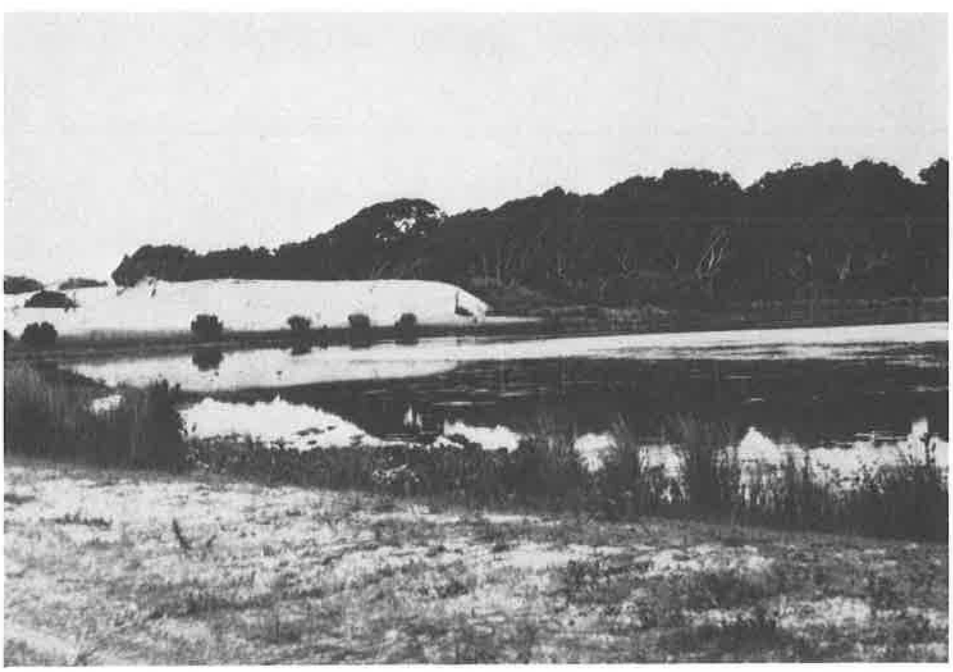

Figure G-8. Lake Whitney, a fresh water pond near the north end of Cumberland Island.

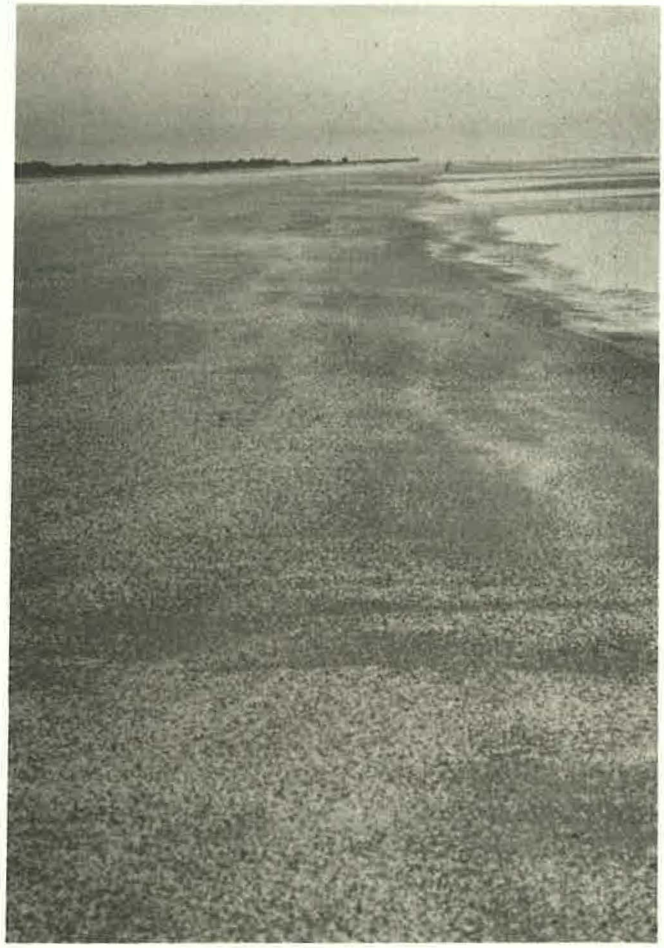

Figure G-9. Beach on the south end of Cumberland Island at low tide.

Figure G-10. The jetty located on the south end of Cumberland Island is acting as a sediment trap causing growth of the island.

Figure G-13. Dune erosion as a result of Hurricane David, near Willow Pond crossing.

Figure G-14. Close up of dune erosion resulting from Hurricane David.

Figure G-15. Erosion of the Pleistocene sands on Terrapin Point, Cumberland Island.

Figure G-16. Marsh erosion in the Raccoon Keys salt marsh, Cumberland Island.

Figure G-17. Back dune encroachment over live oaks at the edge of the Raccoon Keys salt marsh.

Figure G-18. This house was built west of the back dunes. Subsequent dune migration covered the house and it is now emerging on the east side of the dunes. Nightingale Avenue, Cumberland Island.

Figure G-19. Uncontrolled flow of artesian well at Carriage House, Cumberland Island

Figure G-20. Hydraulic ram used to pump water without electricity, Dungeness, Cumberland Island.


GEOLOGIC MAP OF CUMBERLAND ISLAND, GEORGIA
CUMBERLAND SOUND
DUNGENESS WHARF
SEA CAMP WHARF
DUNGENESS
GREYFIELD
STAFFORD
BRICKHILL RIVER
PLUM ORCHARD
TABLE POINT
TERRAPIN POINT
BURBANK POINT
HALFMOON BLUFF
STOCKWELL BLUFF
HIGH POINT
WHITNEY LAKE
LITTLE CUMBERLAND ISLAND
CHRISTMAS CREEK
ST. ANDREW SOUND
ATLANTIC OCEAN
EXPLANATION
QUATERNARY
HOLOCENE UNDIFFERENTIATED
PLEISTOCENE – SATILLA FORMATION
(REFER TO TEXT FOR EXPLANATION)
N
0 1/2 1 2 MILES
0 1 2 3 4 5 6 7 8 9 10 FEET, IN THOUSANDS
Mapping by CHARLES T. SWANN
Cartography by JEANE S. BARRETT
BASE FROM U.S. GEOLOGICAL SURVEY 1:24,000 QUADRANGLES

PLATE I

CLASSES OF LAND-SURFACE FORMS AND NATURAL VEGETATION, CUMBERLAND ISLAND, GEORGIA

PLATE 2

BASE FROM U.S. GEOLOGICAL SURVEY 1:24,000 QUADRANGLES


LAND USE MAP OF CUMBERLAND ISLAND, GEORGIA
CUMBERLAND SOUND
DUNGENESS WHARF
SEA CAMP WHARF
GREYFIELD
STAFFORD
DUNGENESS
PLUM ORCHARD
TABLE POINT
BRICKHILL RIVER
TERRAPIN POINT
BURBANK POINT
HALFMOON BLUFF
STOCKWELL BLUFF
WHITNEY LAKE
HIGH POINT
LITTLE CUMBERLAND ISLAND
CHRISTMAS CREEK
ST. ANDREW SOUND
ATLANTIC
OCEAN
EXPLANATION
MARGINAL MARINE LANDS
BEACH
SALT MARSHES
AGRICULTURAL LANDS
PINE PLANTATIONS
PASTURE
ABANDONED AGRICULTURAL LANDS
RESIDENTIAL LANDS
RESIDENTIAL AREAS
UNUSED RESIDENTIAL AREAS
PROPERTY OF NATIONAL PARK SERVICE — PUBLIC USE
RECREATIONAL LANDS
NATURAL AREAS
DEVELOPED CAMPING AREAS
DUNE COMPLEX
FOREST AND MARSH COMPLEX
MISCELLANEOUS
AIRSTRIP
ABANDONED AIRSTRIPS
N
0 1/2 1 2 MILES
0 1 2 3 4 5 6 7 8 9 10 FEET, IN THOUSANDS
Mapping by CHARLES T. SWANN
Cartography by JEANE S. BARRETT
PLATE 3
BASE FROM U.S. GEOLOGICAL SURVEY 1:24,000 QUADRANGLES

FLOOD HAZARD AREAS, CUMBERLAND ISLAND, GEORGIA
CUMBERLAND SOUND
DUNGENESS WHARF
SEA CAMP WHARF
DUNGENESS
GREYFIELD
STAFFORD
PLUM ORCHARD
TABLE POINT
BRICKHILL RIVER
TERRAPIN POINT
BURBANK POINT
HALFMOON BLUFF
STOCKWELL BLUFF
HIGH POINT
WHITNEY LAKE
LITTLE CUMBERLAND ISLAND
CHRISTMAS CREEK
ST. ANDREW SOUND
ATLANTIC OCEAN
EXPLANATION
DANGER ZONE – FREQUENT FLOODING
CAUTION ZONE – 1/100 CHANCE OF FLOODING ANY ONE YEAR
SAFE ZONE – RARELY FLOODED
(REFER TO TEXT FOR EXPLANATION)
N
0 1/2 1 2 MILES
0 1 2 3 4 5 6 7 8 9 10 FEET, IN THOUSANDS
Mapping by CHARLES T. SWANN
Cartography by JEANE S. BARRETT
BASE FROM U.S. GEOLOGICAL SURVEY 1:24,000 QUADRANGLES

PLATE 4