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Geomorphology, Shallow Structure, and Sediments of the Florida Inner Continental Shelf, Cape Canaveral to Georgia

by

Edward P. Meisburger and Michael E. Field

TECHNICAL MEMORANDUM NO. 54

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The following changes should be made:

Figure 10, page 27 - The lower photograph has been turned upside down in printing.

Section IV, para 1, pages 67, 71, and 72 - reflection unit designations should be changed as follows:

blue unit should be - unit A
red unit should be - unit B
white unit should be - unit C
purple unit should be - unit D
green unit should be - unit E

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The inner Continental Shelf off eastern Florida between Cape Canaveral and Georgia was surveyed to obtain information on bottom morphology and sediments, subbottom structure, and sand deposits (borrow sites) suitable for restoration and nourishment of nearby beaches. Primary survey data consist of 1,153 statute miles of high-resolution seismic reflection surveys and 197 sediment cores.

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The major structural trend in the study area shallow subbottom is a broad coastal plain high consisting of truncated strata judged to be of Eocene and Miocene ages. Overlying strata not affected by the high are late Miocene to Holocene in age and are characterized by a predominant eastward dip, common occurrence of internal bedding features, and filled erosional channels. The Pleistocene and Holocene sediments disconformably overlie late Tertiary sediments which crop out in many places north of St. Augustine, Florida. The dominant lithology of both surficial and shallow subsurface strata is quartz sand. Detrital accessory silicate minerals, carbonates, and phosphorite comprise the remaining 5 to 10 percent of the sediments. Surface exposures and near-surface occurrences of Tertiary unconsolidated quartzose sands are recognized by diagnostic microfauna or dolomite silt matrix.

Quaternary sediments are unusually thin and discontinuous. The paucity of recognizable Pleistocene fluvial deposits in this region and the thin nature of the Holocene sand blanket suggests that shelf sands were derived in part from transgressive erosion and that Georgia streams supplied little material to the inner shelf.

Sand suitable for beach restoration and maintenance on the adjacent north Florida coast occurs abundantly in places on the inner shelf. Ten potential borrow sites and an additional 21 possible sites have been delineated, each comprising a sand reserve ranging in volume from 5 to 178 million cubic yards, all within 13 nautical miles of the coast. Underlying quartzose Tertiary deposits contain an estimated 100 billion cubic yards of sand.

Filled erosional channels in shallow subbottom strata, especially north of Jacksonville, and the occasional occurrence of sinkholes, complicate generalization of foundation conditions. Clays and cohesive sandy silts occur throughout the area in various stratigraphic associations. The character and strength properties of these fine-grained deposits are variable; however, soft watery clays, usually interbedded with fine sand, are most common in the area from Jacksonville to Georgia.

PREFACE

This report is one of a continuing series which describes results of the Inner Continental Shelf Sediment and Structure (ICONS) study. One aspect of the ICONS study is locating and delineating offshore sand and gravel deposits suitable for beach nourishment and restoration. The work was carried out under the coastal processes program of the U.S. Army Coastal Engineering Research Center (CERC).

Edward P. Meisburger and Michael E. Field, CERC geologists, prepared the report with the assistance of Dr. David B. Duane, former Chief, Geological Engineering Branch, and his successor Dr. William R. James. As part of the research program of the Engineering Development Division, the ICONS study is under the general supervision of Mr. George M. Watts, Chief of the Division. The field work involving coring and continuous seismic profiling was accomplished under contract with Alpine Geophysical Associates, Inc.

Discussions with S. Jeffress Williams of the CERC staff were helpful in preparation of the study. Miss Ruth Todd and Mr. J. E. Hazel of the U.S. Geological Survey, provided important data on the fauna and geological age of sediments in several core samples.

Microfilm copy of all seismic data are stored at the National Solar and Terrestrial Geophysical Data Center (NSTGDC), Rockville, Maryland 20852. Cores collected during the field survey program are in custody of the University of Texas at Arlington, Arlington, Texas 76010, under agreement with CERC. Requests for information relative to these items should be directed to NSTGDC or the University of Texas.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

James L Trayers

JAMES L. TRAYERS
Colonel, Corps of Engineers
Commander and Director

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GEOMORPHOLOGY, SHALLOW STRUCTURE, AND SEDIMENTS OF THE FLORIDA INNER CONTINENTAL SHELF, CAPE CANAVERAL TO GEORGIA

by

Edward P. Meisburger and Michael E. Field

I. INTRODUCTION

1. Background.

Ocean beaches and dunes constitute a vital buffer zone between the sea and populated coastal areas, and also provide much needed recreation areas for the public. The construction, improvement, and maintenance of beaches through the artificial placement (nourishment) of sand on the shore is one of several protection methods. This technique has gained prominence in coastal engineering largely as a result of the successful program initiated at Santa Barbara, California, in 1938 (Hall, 1952).

Where a specified plan of improvement involves shore restoration and periodic nourishment, large volumes of sandfill may be needed. In recent years it has become increasingly difficult to obtain suitable sand from lagoonal or inland sources in sufficient quantities and at an economical cost for beach fill purposes. This difficulty is due in part to increased land value, diminution and depletion of previously used nearby sources, and added cost of transporting sand from areas increasingly remote. Material composing the bottom and subbottom of estuaries, lagoons, and bays, is often too fine-grained and unsuitable for long-term protection. Regardless of the source of replacement material, the loss of some fines is inevitable as replacement beach sediment seeks equilibrium with its environment. However, it is possible to estimate amount of material that will be lost through sorting in the surf zone by quantitative comparison with the native material and therefore minimize losses through selection of the most suitable fill material (Krumbein and James, 1965; James, 1974).

The problem of locating suitable sand supplies led the Corps of Engineers to a search for new unexploited deposits of sand. The search focused offshore with the intent to explore and inventory deposits suitable for future beach-fill requirements. This exploration program is conducted through the U.S. Army, Coastal Engineering Research Center (CERC).

In 1964, a program was initiated to survey offshore regions of the Atlantic, Pacific, gulf, and Great Lakes coastal areas to delineate the character of sand deposits. Formerly called the Sand Inventory Program, it was begun with a survey off the New Jersey coast. Subsequent surveys have included the inner Continental Shelf off Florida, New England, New York, Maryland, and parts of North Carolina, Delaware, Virginia, and California. Recognizing a broader application to the CERC mission of information collected in conduct of the research, the program is now referred to as the Inner Continental Shelf Sediment and Structure Program (ICONS). The ICONS program is directed not only towards mapping of sand deposits suitable for beach restoration but also delineation of shelf structural characteristics (Meisburger and Duane, 1969), analysis of shelf history and sediment sources (Duane, et al., 1972; Pilkey and Field, 1972; Field, 1974) and determination of regional engineering properties of shelf sediments (Williams and Duane, 1972; Field and Duane, 1972; Williams, 1973).

An early study by the Corps of Engineers in evaluating techniques for transferring offshore sand to the beach is described by Mauriello (1967). This experiment at Sea Girt, New Jersey, involved dredging of 250,000 cubic yards of sand by use of the hopper dredge *Geothals* at a location 2 miles offshore from the beach segment to be restored. The loaded dredge, which had a pumpout capability, docked alongside an anchored barge and the sand was pumped ashore through a submerged pipeline.

At Redondo Beach, California, in 1967-68, the U.S. Army Engineer District, Los Angeles, contracted dredging of over 1.4 million cubic yards of sand from offshore in 40 feet of water and transfer to the beach. The dredging contractor used a 16-inch hydraulic dredge with powerful water jets for agitation in lieu of a normal cutterhead on the ladder. These operations as well as others conducted in open-ocean inlet mouths and in Long Island Sound and along the gulf coast have demonstrated the feasibility of using offshore marine and lake deposits for beach restoration and periodic nourishment operations.

2. Field and Laboratory Procedures.

The exploration phase of the ICONS program uses seismic reflection profiling supplemented by cores of the marine bottom. Additional supporting data for the studies are obtained from National Ocean Survey (NOS) hydrographic smooth sheets and pertinent published literature. Planning, seismic reflection profiling, coring, positioning, and analysis of sediment obtained in the cores are detailed in *Geomorphology and Sediment Characteristics of the Nearshore Continental Shelf, Miami to Palm Beach, Florida* (Duane and Meisburger, 1969). However, a brief description of techniques follows:

a. Planning. Survey tracklines were laid out initially in grid or reconnaissance lines. A grid pattern (line spacing of about 1 or 2 statute miles) was used to cover areas where a more detailed development of bottom and subbottom conditions was desired.

Selection of core sites was based on a continuing review of the seismic profiles as they became available during the survey. This procedure allowed core-site selection based on the best information available; it also permitted the contractor to complete coring in one area before moving his base to the next area.

b. Seismic Reflection Profiling. Continuous seismic reflection profiling is a technique for delineating subbottom structures and bedding planes in sediments and rocks underlying water-covered areas. Continuous reflections are obtained by generating repetitive high-energy, sound pulses underwater near the water surface and recording "echoes" reflected from the bottom-water interface, and subbottom interfaces between acoustically dissimilar materials. In general, compositional and physical properties which commonly differentiate sediments and rocks also produce acoustic contrasts. Thus, an acoustic profile is roughly comparable to a geologic cross section.

Seismic reflection surveys of marine areas are made by towing sound-generating sources and receiving instruments behind a survey vessel which follow predetermined survey tracklines. For continuous profiling, the sound source is fired at a rapid rate, and returning signals from bottom and subbottom interfaces are received by one or more hydrophones. Returning signals are amplified and fed to a recorder which graphically plots the two-way signal travel time. Assuming a constant speed for sound in water and shelf sediments, a vertical depth scale can be constructed to the chart paper. Horizontal location is obtained by frequent (2-minute intervals) navigational fixes keyed to the chart record by an event marker.

A more detailed discussion of general seismic profiling techniques can be found in several technical publications (Ewing 1963; Hersey, 1963; Miller, Tirey, and Mecarini, 1967; Moore and Palmer, 1968).

Seismic reflection profiles for this study were made with an Alpine Engineering Sparker. Two sound sources, one operated at 50 to 100 joules and the other operated at 100 to 200 joules, were fired alternately during the survey. Returns from the sound sources were recorded by a dual channel recorder which displayed the results on a single strip chart.

c. Coring Techniques. An Alpine Geophysical Associates, Inc. pneumatic vibrating hammer-driven coring assembly was used for obtaining cores from the survey area. The apparatus consists of a standard 20-foot core-barrel (nominal 3-inch diameter) liner, shoe and core catcher with the driver element fastened to the upper end of the barrel. These are enclosed in a self-supporting frame which allows the assembly to rest on the bottom during coring, thus not influenced by limited motion of the support vessel in response to waves. Power is supplied to the vibrator from a deck-mounted air compressor by means of a flexible hoseline. After the core is driven and returned, the liner containing the cored material is removed and capped. Denser materials (compact sands, partially lithified rocks) are more difficult to penetrate than loose materials. Cohesive materials cause drag on the liner walls and give some distortion.

d. Navigation. Position location was determined during the survey by use of the Alpine Precision Radar System which accurately locates the vessel with respect to two onshore reference points. Navigation fixes were made at 2-minute intervals during all seismic reflection survey work and at each core position. Final plots of trackline and core location compiled from survey data were prepared at scales of 1:24,000 and 1:80,000.

e. Processing. Seismic records are analyzed to establish the principal bedding, erosional, constructional, and structural features in upper subbottom strata. After preliminary analysis, typical records are reduced to detailed cross-sectional profiles showing all reflective interfaces within several hundred feet of the bottom. Selected reflectors, considered significant because of their extent and relationship to the general structure and geology of the study area are mapped. If possible, the uppermost mapped reflector is correlated with core data to provide a measure of continuity between cores.

Cores are visually inspected and logged aboard ship. After delivery to CERC, these cores are sampled every foot by drilling through the liners and removing samples of representative material. After preliminary analysis, a number of representative cores are split to determine details of the bedding.

Cores are set up for splitting on a wooden trough. A circular powersaw mounted on a base which is designed to ride along the top of the trough is set so as to cut just through the liner. By making a cut in one direction and then reversing the saw base and making a second cut in the opposite direction, a 120° segment of the liner is cut. The sediment above the cut line is then removed with a spatula, and the core is logged, sampled, and photographed.

Samples from cores are examined under a binocular microscope, and described in terms of gross lithology, mineralogy, and the type and abundance of skeletal fragments of organisms. Petrographic analysis through transmitted-light microscopy was performed on certain core samples that coincided with prominent acoustic reflectors to further delineate their nature and origin of associated sediments.

Foraminifera in 200 representative samples were concentrated by panning and the more common types were identified; primary references were Cushman (1930, 1947), Cushman and Ponton (1932), Parker (1948), Phleger and Parker (1951), Puri (1953b), Bandy (1956), Loeblich and Tappan (1964), Wilcoxon (1964), Buzas (1966), Schnitiker (1971), and Akers (1972). Mollusks contained in the sediments were identified primarily with reference to Mansfield (1930, 1932), Gardner (1943, 1948), and Abbot (1954, 1968). A representative sample of Type L sediment was also submitted to the Paleontology and Stratigraphy Branch, U.S. Geological Survey, for detailed analysis and age determination.

3. Scope.

The area covered in this report comprises the east Florida coast and adjacent Continental Shelf from the Florida-Georgia boundary (30°42'N.) to False Cape (28°40'N.) on Canaveral Peninsula. A map of the study area (Fig. 1) shows the major geographic features of the region; Figures 2 through 5 show the ICONS survey coverage. ICONS studies of the Florida Atlantic coast south of this study area are contained in three CERC Technical Memorandums: No. 29, Miami to Palm Beach (Duane and Meisburger, 1969); No. 34, Palm Beach to Cape Canaveral (Meisburger and Duane, 1971); and No. 42, Cape Canaveral (Field and Duane, 1974).

Field survey and data collection for this study were accomplished by contract between August 1966 and February 1967. This work produced 1,153 statute miles of continuous seismic reflection profiles and 197 vibratory cores (3-inch diameter) of sea floor and subfloor sediments ranging from 1 to 15.5 feet long.

Data processing included analysis of all seismic reflection records and reduction to line profile drawings. Cores were logged and sampled to provide sediment representative of each sediment or rock facies penetrated. The samples were visually described and size analysis was made by means of a fall velocity-type rapid sediment analyzer. The positions of cores and seismic reflection profile lines were plotted at 1:80,000 and 1:24,000 scale (Fig. 2).

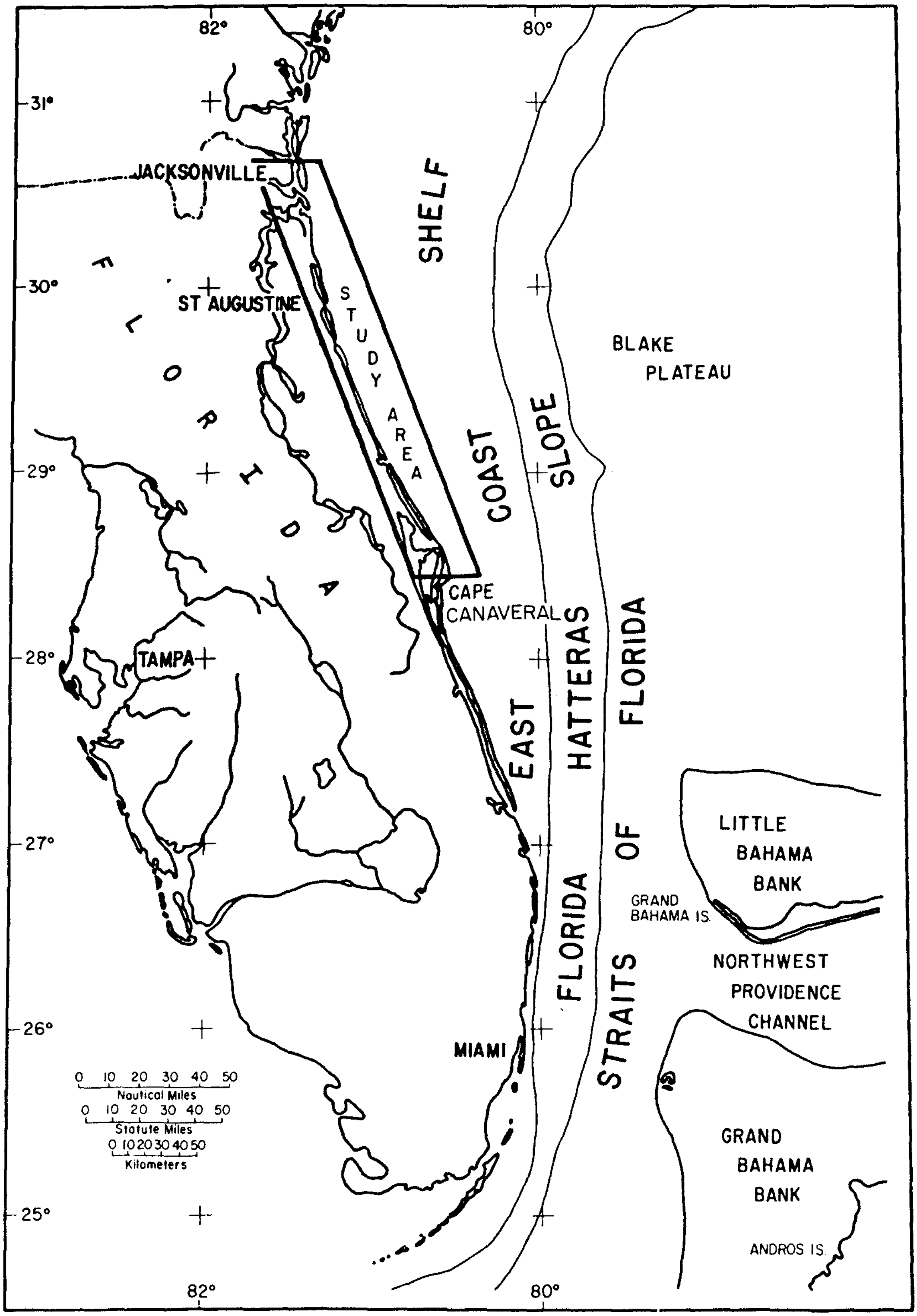


Figure 1. General map of the Florida peninsula showing location of the study area.

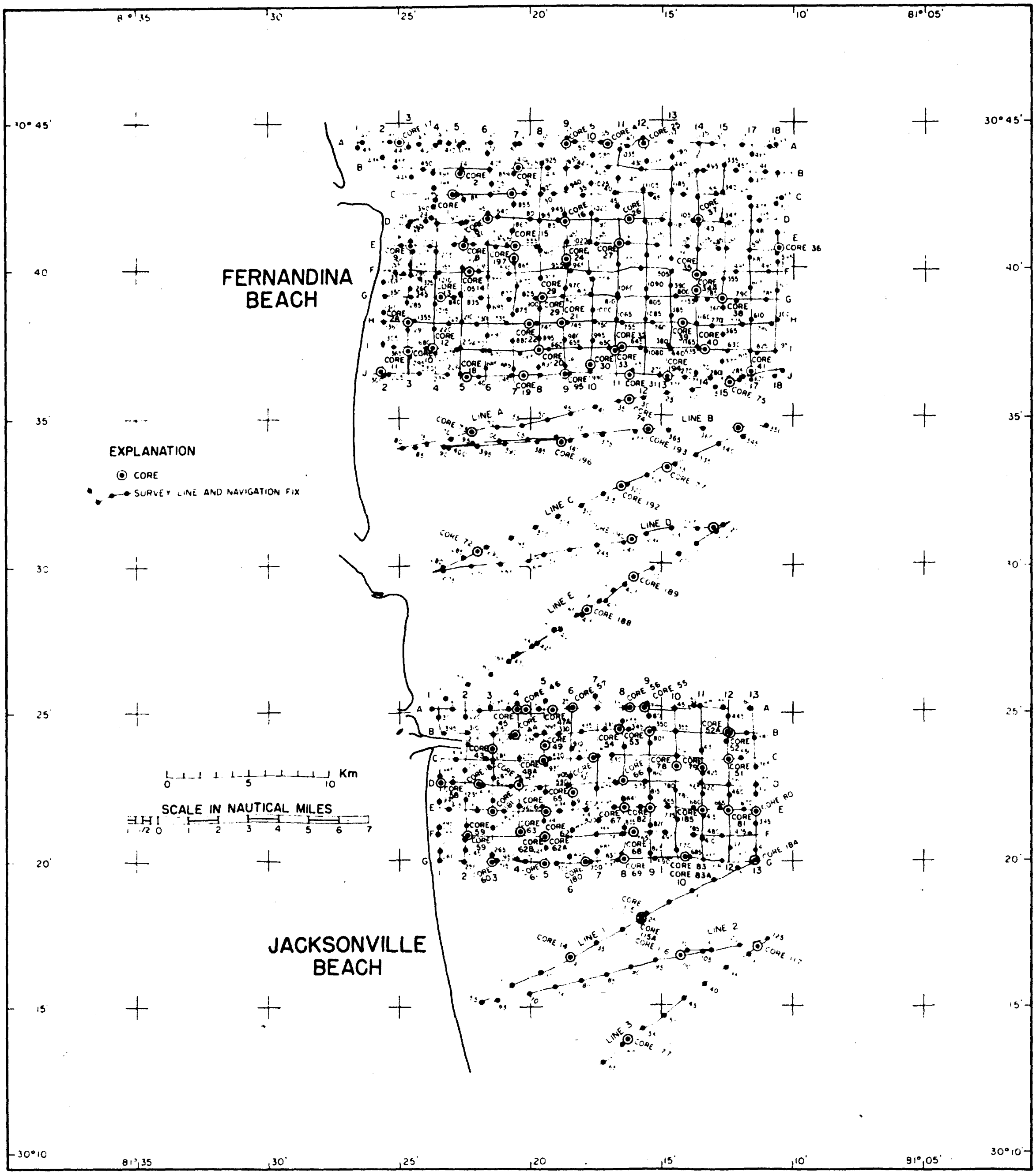


Figure 2. Survey tracklines and core locations, Fernandina to Jacksonville.

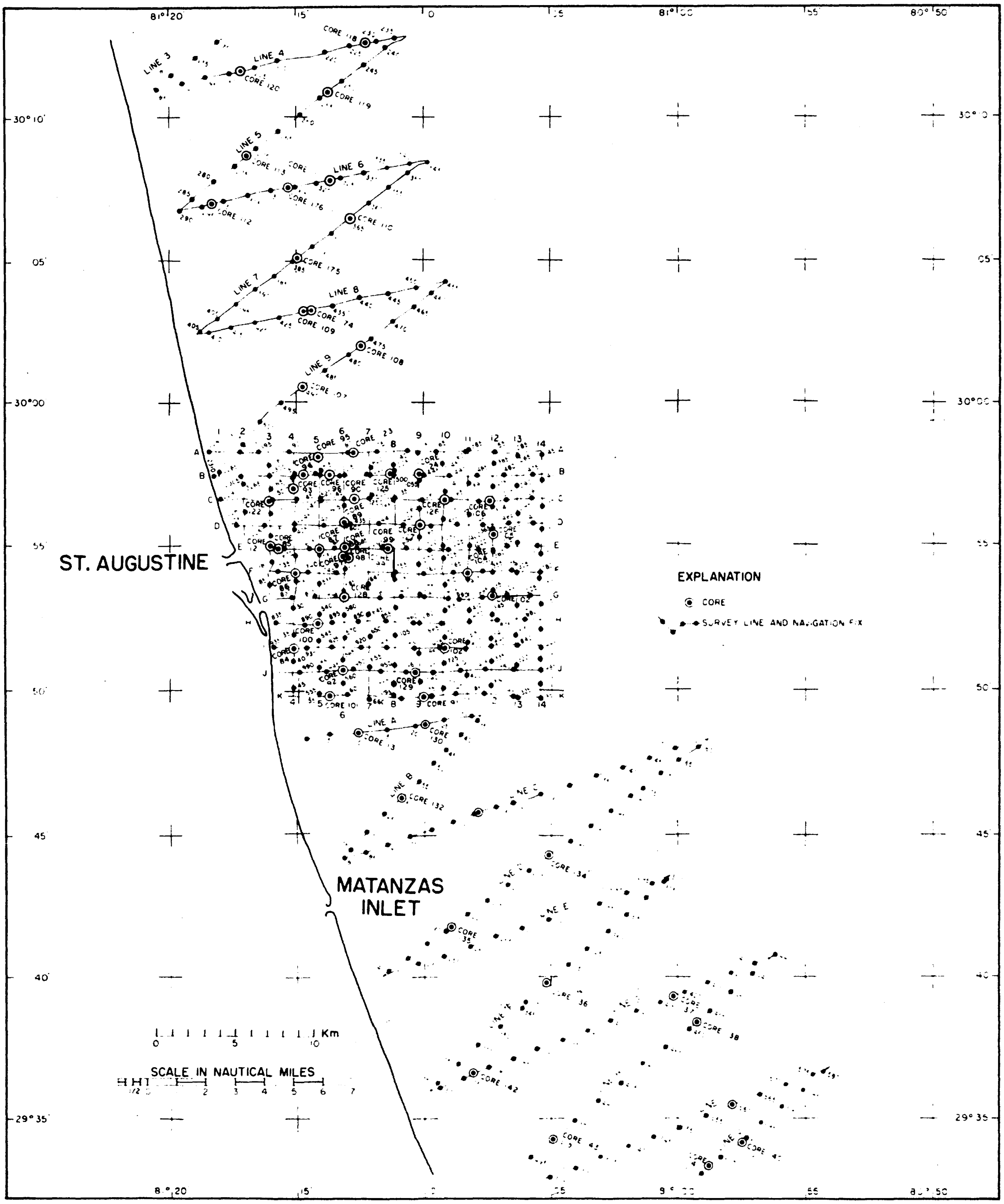


Figure 3. Survey tracklines and core locations, St. Augustine area.

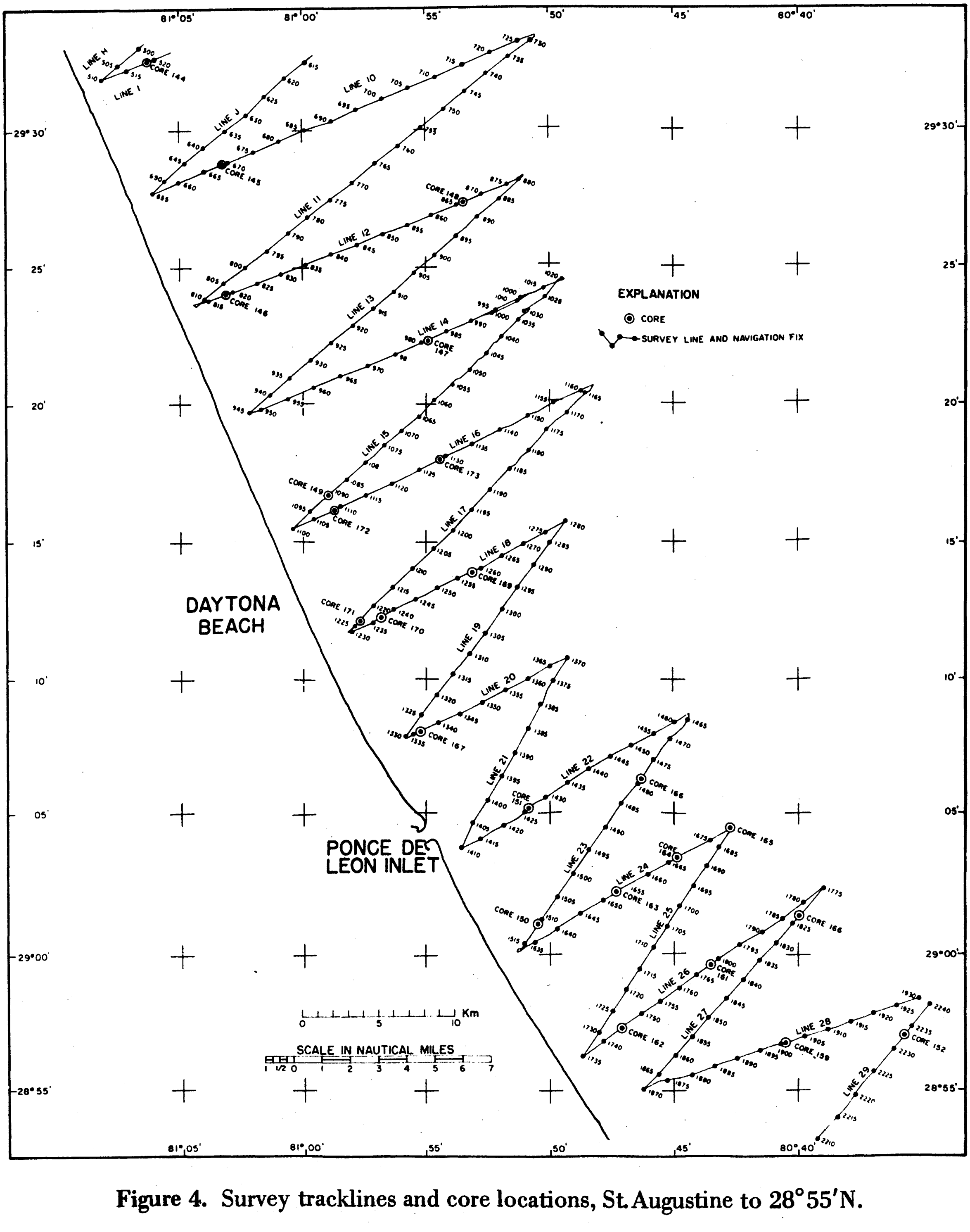


Figure 4. Survey tracklines and core locations, St. Augustine to 28°55'N.

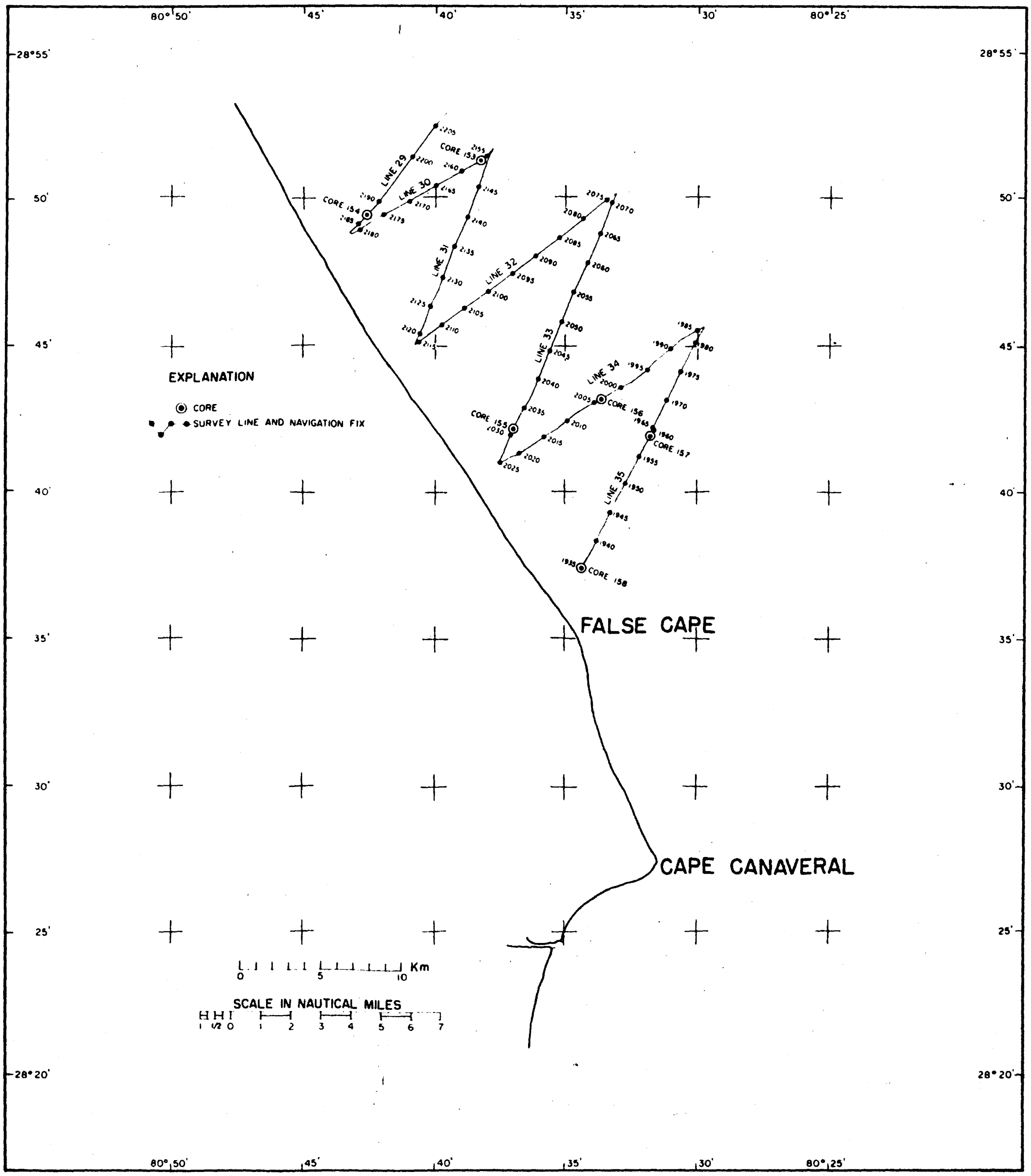


Figure 5. Survey tracklines and core locations, 28°55'S. to Cape Canaveral.

Basic field data were supplemented for this study by pertinent scientific and technical literature dealing with the region and by the National Ocean Survey hydrographic smooth sheets.

4. Hydrography.

Tides in the study area vary from 3.5 to 5.8 feet, mean range, and from 4.1 to 6.8 feet, spring range. Tidal ranges decrease progressively from north to south (National Oceanic and Atmospheric Administration, 1973a). Tidal currents have not been reported for shelf waters in this region (National Oceanic and Atmospheric Administration, 1973b). Drift bottle studies of circulation over the shelf are sketchy but indicate that over the inner shelf off the northern and central parts of the study area a northward drift predominates in spring and autumn and a southward drift predominates in winter and summer. Off the southern part, the inshore drift is toward the north in summer and south in autumn and spring; winter drift is unknown. The speed of the surface drift is generally under 4 miles per day but a high speed of 10 to 15 miles per day was reported for January off the northern part of the study area (Bumpas and Lauzier, 1965).

Salinity of the inner shelf waters in the northern and central part of the study area tends to be lower than in deeper waters to seaward. They range from about 33.5 to 36 parts per thousand over the inner shelf while salinities farther seaward are generally 36 parts per thousand or higher. Off the southern part where the narrow shelf facilitates mixing of oceanic and coastal waters, inshore salinites are generally higher than in the north (Anderson, Moore, and Gordy, 1961).

The wave climate of the study region is relatively mild. Wave gages at Daytona Beach and off Savannah, Georgia, show that waves more than 5 feet high occur less than 10 percent of the time. About 75 percent of the waves recorded off Savannah had a 4- to 9-second period and about 75 percent of the waves at Daytona Beach had periods between 6 and 11 seconds (from CERC wave data).

5. Stratigraphy and Geologic History.

a. General. Knowledge of the geology of the Florida Atlantic coastal region is scant. Most available data concerning the coastal zone are derived from drilled wells, few of which have been subject to detailed stratigraphic study. Cooke (1945) and, more recently, Puri and Vernon (1964) have summarized the known geology of Florida. Coastal Plain geology of the adjacent Georgia region is summarized in Herrick and Vorhis (1963). Specific regional studies of Florida east coast geology are available in several Florida Geological Survey Bulletins describing geology and water resources of individual counties. Those pertinent to this study are: Tarver (1958), Bermes (1958), Wyrick (1960), Leve (1961a, b), and Brown, et al., (1962).

There are two prominent subsurface structural features in the region covered by this study. One is the Southeast Georgia Embayment (also called "Atlantic Embayment of Georgia") which is centered just north of the Florida border and probably influences structure underlying northeastern Florida. Under the Georgia Atlantic Coastal Plain the axis of the embayment trends southeastward. It has been traced offshore under the Atlantic shelf by Antoine and Henry (1965).

The second significant structural feature is the Sanford High (Vernon, 1951). Vernon described this feature as a half dome truncated by a fault bounding the eastern border of the Kissimmee faulted flexure.

Because of their proximity to the surface, only rocks of late Eocene age and younger are pertinent to this study; these rocks include limestone of Eocene and Miocene age and clastic sediments of Miocene through Holocene age (Table 1). An important nonstratigraphic unit within these strata is the Floridan aquifer (Parker, 1951) which locally cuts across stratigraphic boundaries. In the main the aquifer is associated with limestones of Eocene and Oligocene age but includes permeable units in the lower Miocene section as well. The aquiclude consists of impermeable strata in the Miocene section; consequently in most places the Miocene and pre-Miocene contact is the upper boundary of the aquifer.

b. Eocene Strata. All upper Eocene strata underlying Florida have been designated the Ocala Group by Puri (1953a). The group includes three lithologically similar limestone formations. In ascending order these formations are the Ingles, Williston, and Crystal River. In coastal areas where data on these formations must be based on well samples the three are often undifferentiated in well logs. The Ocala Group overlies the eroded surface of the middle Eocene Avon Park limestone. The lowermost formation, the Ingles, consists of cream-colored to white fossiliferous marine limestone. The overlying Williston Formation is similar to the Ingles. Puri and Vernon (1964) describe the uppermost Crystal River Formation as a microcoquina made up almost entirely of foraminifera tests; however, the basal section may contain beds of secondary dolomite. The surface of the Crystal River Formation has been subject to post-Eocene erosion, and in Volusia County and northern Brevard County it is reported that the formation has probably been removed (Wyrick, 1960; Brown, et al., 1962).

c. Post-Eocene Strata. Miocene stratigraphy of Florida is best known in the panhandle region and in the central and western parts of the Florida peninsula where outcrops and shallow subcrops are accessible for study. Within study limits only reports from Brevard, Duval, and Nassau Counties provide a breakdown of sediments of Miocene and Pliocene age. In these three counties, which underlie the north and south ends of the study area, the basal Miocene unit is identified as the Hawthorn Formation of Miocene age (Leve, 1961a, b; Brown, et al., 1962). This formation is found lying directly on the eroded surface of Eocene rocks and is in turn overlain by undifferentiated beds of upper Miocene and Pliocene age.

In Volusia and St. Johns Counties—and presumably Flagler County in between—the Hawthorn Formation is apparently absent and sediments of upper Miocene and Pliocene age directly overlie the Eocene surface (Tarver, 1958; Bermes, 1958; Wyrick, 1960).

Table 1. Generalized upper Eocene to Holocene stratigraphy of northern Florida.

Geologic age		Formation	Approximate depth below MSL (feet)			Predominant lithology
			Jacksonville	Daytona Beach	False Cape	
Holocene		Undifferentiated	10	10	10	Sand, silt, clay, shell gravel
Pleistocene		Anastasia	40	60	70	Coquina
Upper Miocene and Pliocene		Undifferentiated	90		80	Sand, silt, clay, shell gravel, limestone
Miocene	Middle Early	Hawthorn	550	Not present	180	Sand, silt, clay, limestone
Eocene	Upper (Ocala group)	Crystal River		80		Limestone
		Williston				Limestone
		Ingles	900	160	250	Limestone
	Middle	Avon Park				Limestone

In Brevard County the Hawthorn beds are described as light green to greenish gray sandy marl with streaks of green clay, phosphatic radiolarian clay, black and brown phosphorite, and thin beds of phosphatic sandy limestone (Brown, et al., 1962). Under the northern half of Brevard County, Hawthorn beds are 10 to 25 feet thick in the area west of Banana River, and possibly thicker under the coast and inner Continental Shelf. In Duval and Nassau Counties, Hawthorn beds are reported to be 450 feet thick in wells near Jacksonville and Fernandina. The beds consist of greenish calcareous phosphatic sandy clay and clayey sand with lenses of limestone and dolomite (Leve, 1961a, b).

Late Miocene and Pliocene deposits of the study area are heterogeneous and consist of beds and lenses of shells, sand, calcareous clay, clay, phosphatic pebbles and limestone. Most of these units have not been sufficiently studied in the Atlantic coastal area to be correlated or to determine age relationships and they are generally undifferentiated in coastal well logs. Presumably Miocene sections of these deposits are referable to Choctawhatchee Stage sedimentation.

Various marine formations in the Florida peninsula have at one time or another been assigned to the Pliocene but most have subsequently been ascribed to late Miocene or Pleistocene deposition. Akers (1972) has recently assigned a Pliocene age to late Choctawhatchee Stage sediments. The existence of a marine sedimentary unit of Pliocene age under the Florida Atlantic inner Continental Shelf based on data obtained for this study is discussed later in this report.

The most important Pleistocene deposit of the Florida Atlantic coast is the Anastasia Formation. Locally the Anastasia Formation outcrops along the shore and nearshore and forms the core of the Atlantic ridge north of Boca Raton where it grades southward into the Miami Formation. Tentative correlation of the Anastasia with one or more Pleistocene interglacial stages has been made by various workers but no definitive assignment is now possible. Lithologically, the Anastasia Formation is composed of a loosely cemented sandy coquina consisting primarily of mollusk shells.

6. Coastal Morphology and Development.

The Atlantic coast of north Florida is a low relief, low elevation, coastal plain surface overlain by relict Pleistocene terraces and beach ridges. Geomorphology of the area has been recently interpreted by White (1970), who states that surface morphology is shaped primarily by the preservation of relict Pleistocene strand lines and offshore profiles and secondarily by modification of these features through differential surface erosion and solution collapse.

The term *Atlantic Coastal Ridge* is applied to the series of relict beach ridges and bars that extend from Georgia on the north to south of Miami. In the study area, the Atlantic Coastal Ridge is nearly parallel to the modern coastline and displays an overall decrease in lagoon and beach ridge width from north of Daytona to Canaveral Peninsula. Indian River, an open water lagoon at Cape Canaveral, ends and becomes an elevated valley just north of the Volusia-Brevard County line and merges with the modern analog, Mosquito Lagoon. Crest elevations along the Atlantic Coastal Ridge are about 30 feet, which is interpreted by White (1970) as evidence that the entire ridge system represents deposition during Pamlico time (probably the Sangamon Interglacial).

White (1970) has noted that the eastern slope of the Atlantic Coastal Ridge is similar to the modern offshore slope discussed later in this report. The relict offshore slope reaches a nearly horizontal attitude at about 30 feet below the Pleistocene sea level and approximately 1 mile offshore of the Pleistocene beach. The relict Atlantic Coastal Ridge is wider and higher than older progradational beach ridges, a fact that White attributes to an abundant terrigenous source of material and diminished shell contribution, hence little or no loss of elevation through solution collapse. White's observation that prograding beaches, which he states may develop under stable or regressing sea level, receive little nourishing sand from sources to landward seems to be applicable only to this region and is not in accord with studies by investigators from other areas. Curray (1965) has pointed out that shoreline deposition and beach ridge construction are more common to regressions, whereas erosion and only discontinuous deposition occur during transgressions. This is due in part to lowering of stream base level and increased sediment discharge to the coast as sea level recedes. During a rise in sea level, stream channels are flooded and sediments become impounded in their lower reaches.

In the study area no important sources of fluvial sediments exist south of the St. Johns River. Therefore, prograding and regressing shorelines can be constructed only from preexisting shelf sediments or organic production of materials. As evidence of this assumption, relict strand deposits lying at shallow depths and occasionally exposed along the coast are more highly enriched in shell material than are modern beaches. These shelly deposits (coquinas) are believed to be the result of regressional deposition (Osmond, May, and Tanner, 1970; Field, 1974) and are formed through diminished supply of terrigenous quartz material and consequent relative increase in concentration of calcareous material.

At least four, and in some locations as many as seven, terraces lie along the Atlantic coast of north Florida. They range in elevation from 10 to over 150 feet and are particularly well developed in Volusia County. Morphology, age, and stratigraphy of the terrace surfaces have been reviewed by Field and Duane (1974). In general, they are surfaces planed by higher (than present) transgressing seas during Pleistocene and Pliocene eustatic events. The terraces have been described by Flint (1940), Cooke (1945), Doering (1958), Altschulter and Young (1960), and Alt and Brooks (1965), and found to correlate on a regional basis with terraces in Georgia (Hoyt, Henry, and Weimer, 1968) and on the west coast of Florida (Schnable and Goodell, 1968).

The same eustatic events which have shaped the terrain of eastern Florida were influential in modifying the submerged shelf area. Receding seas leave behind a veneer of beach ridges and lagoons; advancing seas inundate those same areas and cut new terraces, level off topographic features, and redistribute the sea floor materials.

7. Regional Marine Geology.

The name East Coast Shelf was proposed by Uchupi (1968) for the gently seaward-sloping submarine plain bordering the Altantic coast from near Cape Cod to the Florida Keys. The north Florida Atlantic shelf area is part of the southeastern shelf. This shelf has been widely studied and therefore the geology is well known relative to other shelves of the world (Emery, 1969). Age and lithology of the sediment cover, as well as physiography and subsurface structure have been reported by numerous investigators. Discussions of regional aspects of the Atlantic shelf marine geology have been presented by Tyler (1934), Stetson (1938), Gorsline (1963), Curray (1965), Emery (1965), Pilkey (1968), Uchupi (1968, 1970), Pilkey, et al. (1969), MacIntyre and Milliman (1970), Duane, et al. (1972), Milliman, Pilkey, and Ross (1972), Pilkey and Field (1972), and Swift, et al. (1972). While such studies provide useful background material, their direct application to the objectives of this report are limited because of sampling methods (surface grab), sample low density, and area of study, which usually include deeper parts of the central and outer shelf.

These studies have shown that the shelf is comprised of gently dipping Tertiary strata with a thin overlying layer of Quaternary deposits that has been deposited in response to Pleistocene sea level fluctuations. Terraces and ledges mark the site of former sea level positions, and topographic highs or shoals are common features which some believe originally formed along the shoreface and are now in a quasi-equilibrium stage. Surface sediments likewise are in a quasi-equilibrium stage, in that their textural character indicates equilibrium with the wave conditions but their composition suggests in place reworking of older relict deposits. A vast majority of shelf surface sediments has been derived from the complex metamorphic Piedmont Province; streams draining the Piedmont are far more significant than streams draining Coastal Plain regions in terms of sediment quantities to the shelf. Locally on the shelf, biogenic (shell material) and residual (Tertiary surface exposures) sediments are abundant.

II. GEOMORPHOLOGY AND SHALLOW SUBBOTTOM STRUCTURE OF THE CONTINENTAL SHELF

1. Continental Shelf Geomorphology.

a. General. The East Coast Shelf in the study area (Fig. 6) is transitional between the narrow, topographically irregular shelf characterizing the region at, and south of Canaveral Peninsula and the broad, topographically subdued shelf typical off most of the southeastern United States.

For descriptive purposes the Atlantic shelf off northern Florida can be divided into three major geomorphic units: shoreface, shelf floor, and shelf edge (Fig. 7). These units, based on the primary subdivisions of Price's (1954) idealized shelf equilibrium profile, are used here in a strictly geomorphic sense without implication as to genesis or equilibrium state of the units.

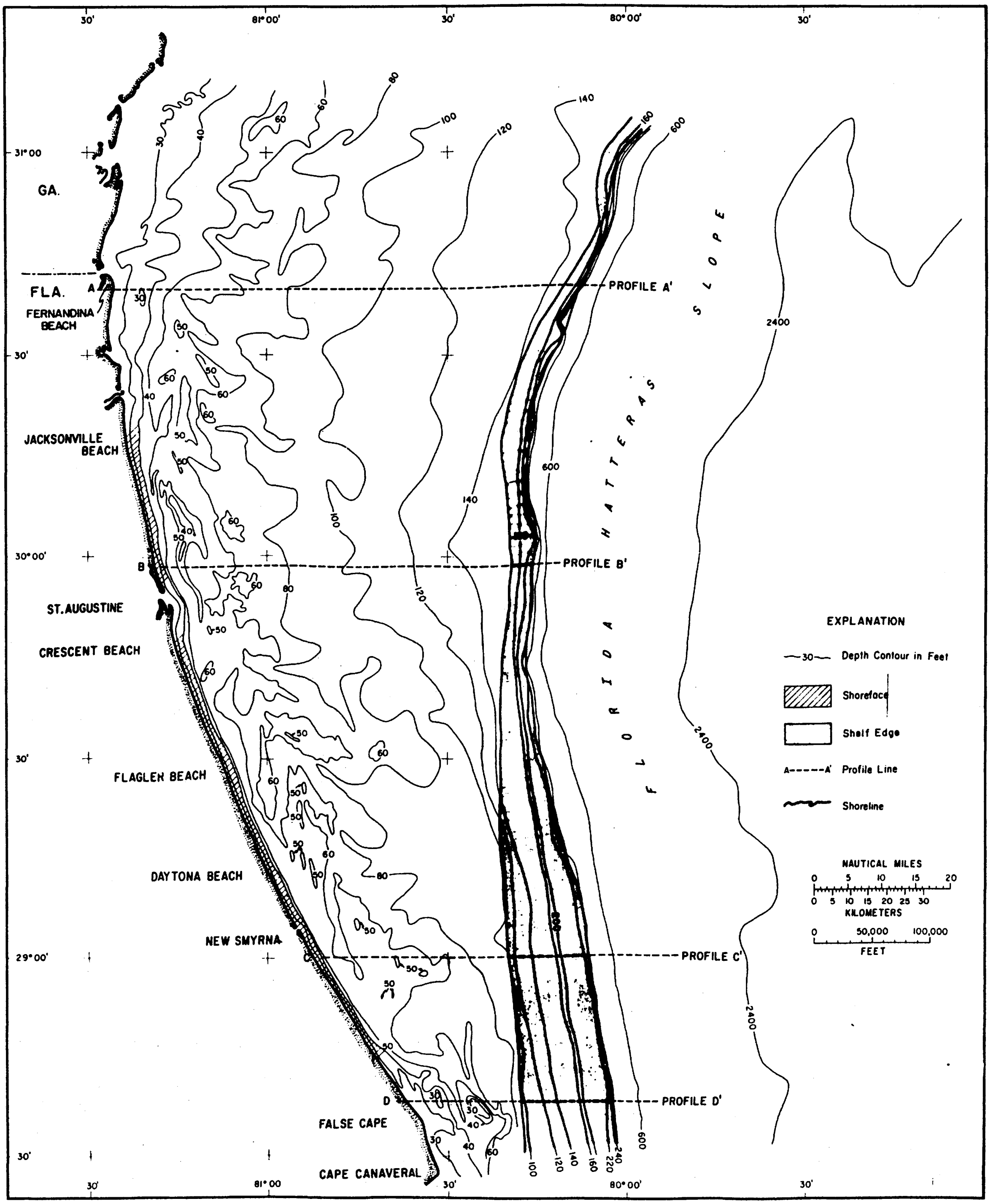


Figure 6. Generalized bathymetry of the East Coast Shelf off north Florida. Profiles are presented in Figure 8.

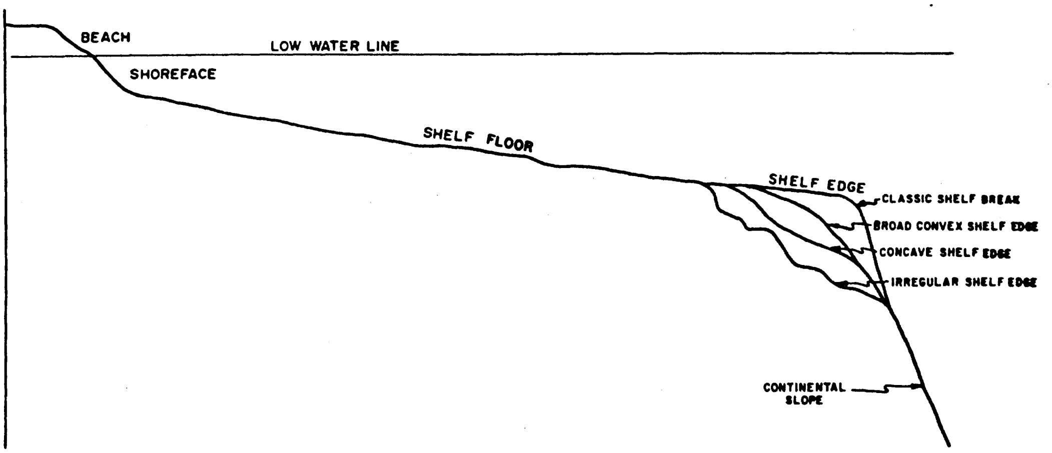
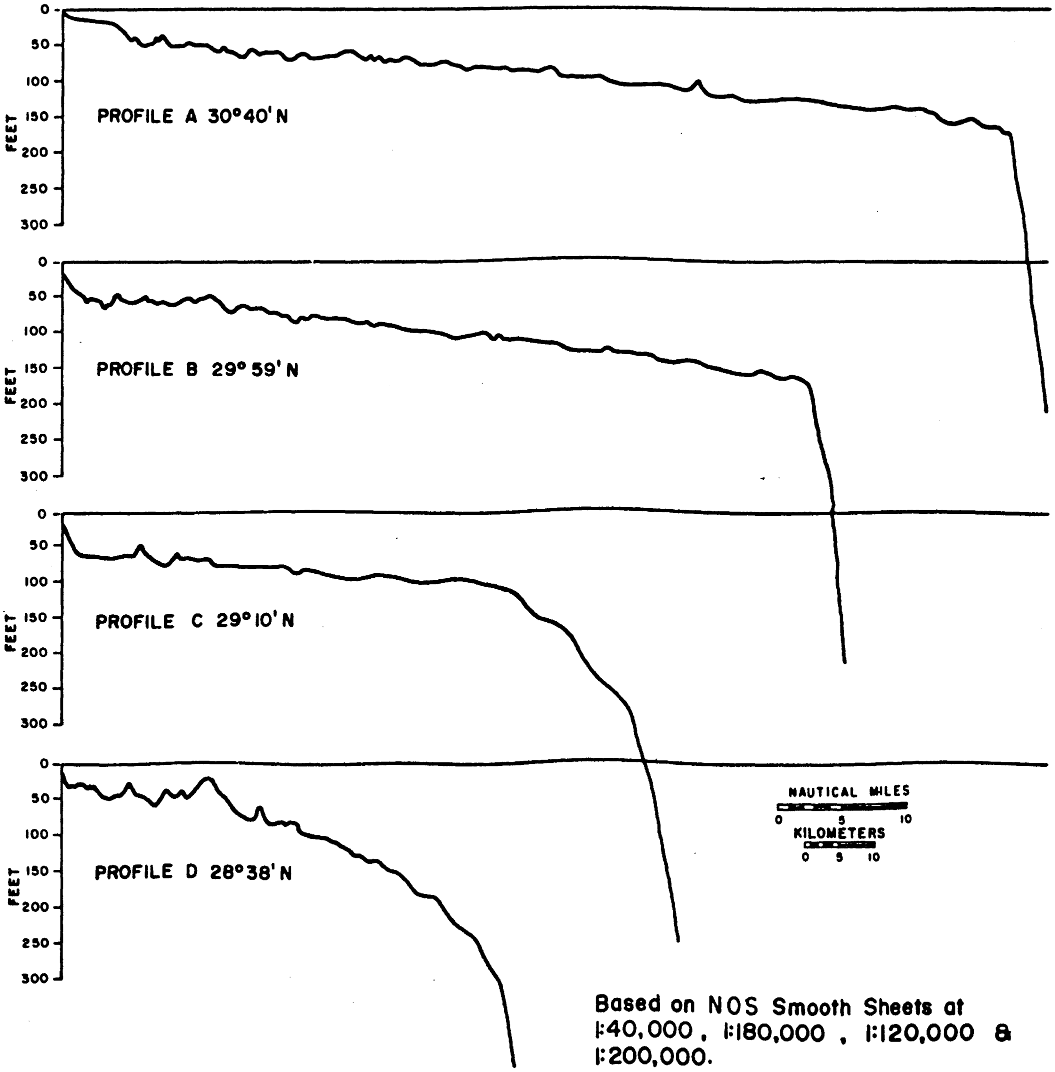


Figure 7. Idealized profile of the Continental Shelf showing major geomorphic elements.

As used in this study, shoreface refers to a relatively steep slope descending from the low water line or an inshore terrace to a break in slope at the level of the shelf floor. The shelf floor ("ramp" of Price, 1954) is typically a broad, gently seaward sloping submerged plain generally comprising the bulk of the shelf surface. The shelf edge ("camber" of Price, 1954) lying at the outer margin of the shelf, is a transitional zone between the gently sloping shelf floor and the relatively steep upper continental slope. It lies between the first significant inflection of the outer shelf floor downward toward the continental slope and the first significant inflection of the upper slope toward the shelf floor. This transitional zone may consist of a convex, sharply rounded shoulder as in the classic shelf profile or be either concave, irregular, steplike or broadly rounded.

b. Description. North of Cape Canaveral the shelf has an atypical configuration (Fig. 8, profile D) with a 13.5-nautical mile wide broadly rounded shelf edge and a shelf floor of about the same width. The floor is highly irregular because of overlying sediment accretions in the form of linear and arcuate cape-associated shoals. The seaward edge of the shelf floor is obscured in places by these shoals but lies near –80 feet mean low water (MLW). The break between the shelf edge and the Florida-Hatteras slope in this area lies at about –250 feet MLW. The inshore sediments north of Cape Canaveral are not disposed in a shoreface slope, forming rather, several north-trending shore-connected linear shoals.

A more typical shelf profile develops to the north of profile D as the shelf takes on the aspect typified by profile C (Fig. 8). Inshore there is a prominent shoreface with the toe lying at about 45 to 50 feet deep and within 1.2 nautical miles of shore. The shelf floor widens to about 27 nautical miles while the edge narrows and become distinctly steeper than the ramp. Except for groups of prominent linear shoals off Turtle Mound (28°56′N.) and Daytona Beach (29°12′N.) irregularities of shelf floor topography north of the cape area are subdued. They are mostly broad, flat-topped topographic highs of irregular outline and broad linear topographic depressions; typically these features have less than a 20-foot



Based on NOS Smooth Sheets at 1:40,000, 1:180,000, 1:120,000 & 1:200,000.

Figure 8. Representative shelf profiles from the north Florida East Coast Shelf. See Figure 6 for location of profiles. Note progressive increase in shelf floor width and decrease in shelf edge width northward.

local relief. In addition, minor irregularities of a few feet relief are common. While these small irregularities are clearly visible on the seismic reflection profiles, they are too small and discontinuous to be delineated with existing bathymetric data.

From profile C northward to the Georgia border the shelf floor continually widens and reaches about 59 nautical miles off Fernandina. The surface topography remains similar to that at profile C but, in addition, several broad shallow southeast-trending depressions appear crossing the mid and outer shelf floor (60-, 80-, and 100-foot-depth contours in Fig. 6). The alinement and configuration of these lows suggest a stream drainage pattern while many of the flat-topped highs are so situated as to suggest they are relict interfluves.

Near St. Augustine (Fig. 6, profile B) the edge is narrow and convex, taking on the sharply rounded profile of the classic shelf "break" which it maintains to the Georgia border. The shelf floor-edge junction remains between –140 and –160 feet MLW throughout the segment north of profile C; this characteristic depth range persists as far north as Cape Hatteras. The break between the camber and Florida-Hatteras Slope seems to be at about –180 feet but available bathymetric data for this zone are poor.

The steep narrow shoreface is very consistent from profile C north to near St. Augustine where it is interrupted by a broad shoal area (ebb tidal delta) around St. Augustine Inlet. From St. Augustine to Jacksonville Beach there is again a well developed shoreface slope with the toe at about –45 feet MLW. North of Jacksonville a distinct shoreface does not exist and the broad inshore part of the ramp is comparatively shallow with locally complex topography.

2. Shallow Subbottom Structure and Bedding.

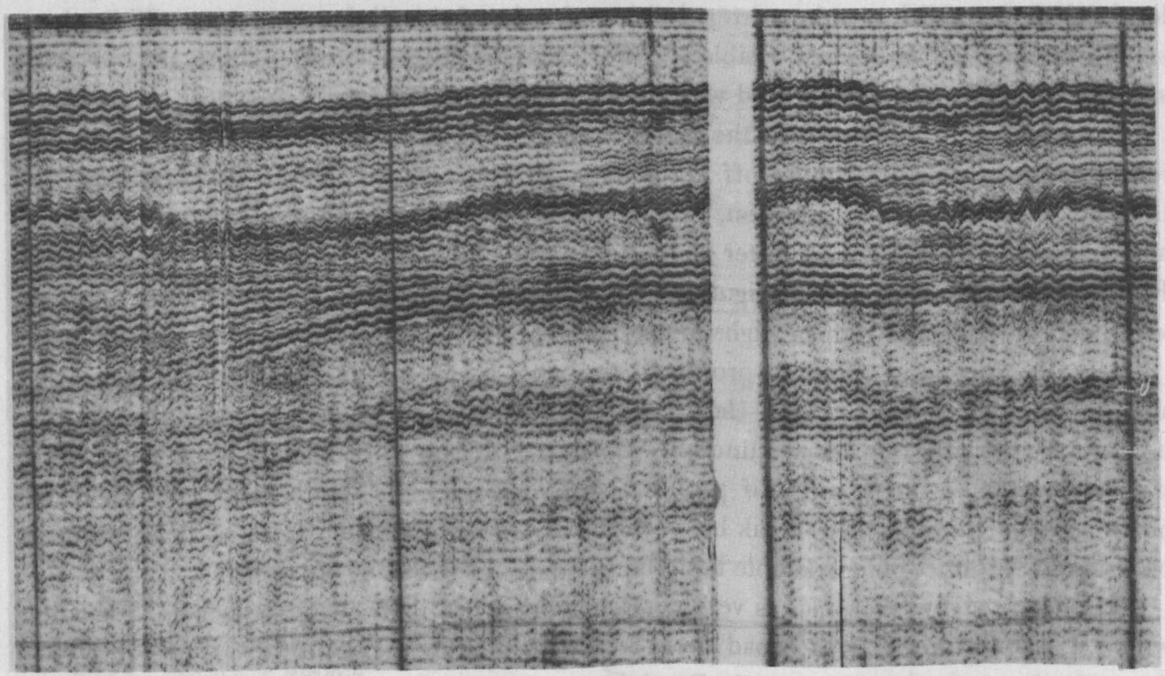
a. Background. Seismic reflection records from this ICONS study show reflectors to depths of 500 feet below MLW. As a working assumption, reflections are considered representative of some geologically significant interface.

Reflectors which persist over a large area are called *primary reflectors*, and presumably delineate extensive stratigraphic breaks (Figs. 9 and 10). Between primary reflectors there are usually numerous localized reflectors, called *secondary reflectors*. Most secondary reflectors appear to be associated with internal bedding surfaces, local erosional discontinuities such as stream channels, or relatively small sediment bodies (Figs. 9 and 10).

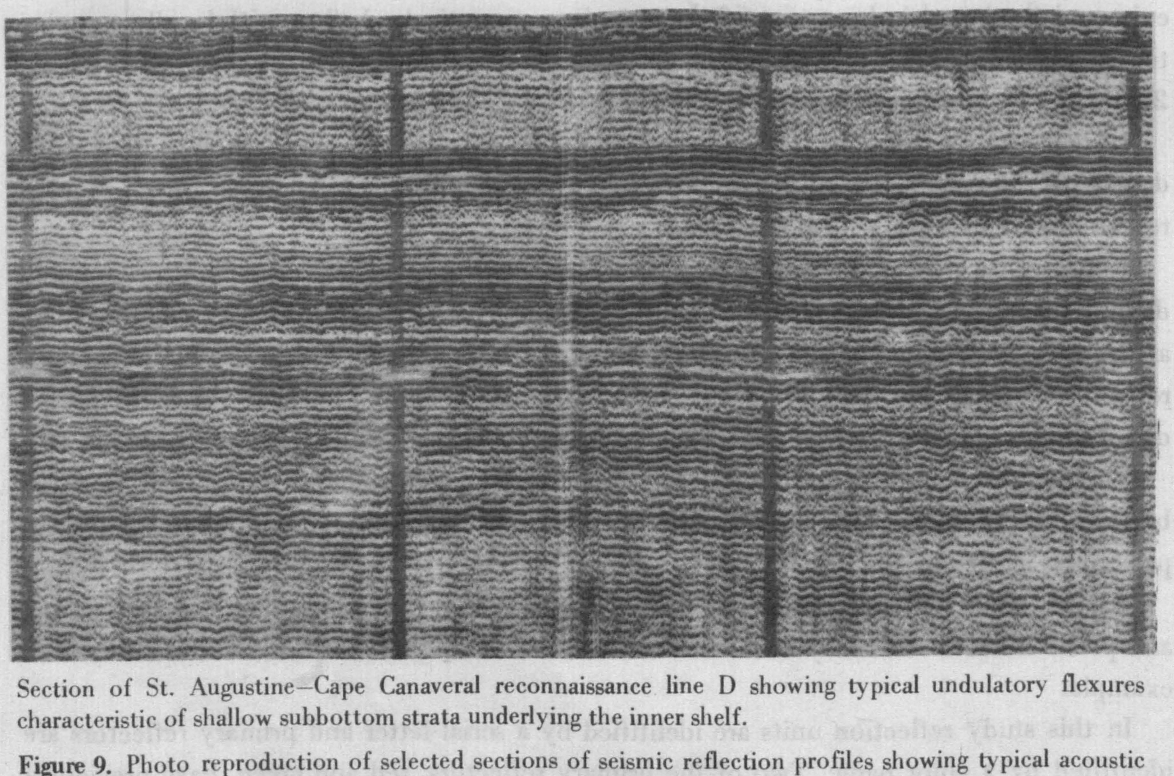
The term *reflection unit* is used to designate layers distinguished by their position between two specific primary reflectors or by persistent internal reflector characteristics and patterns (Figs. 9 and 10).

Primary reflectors are most often located between two reflection units; however, strong and persistent reflectors may occur internal to a unit. The blue reflector of this study is an example.

In this study reflection units are identified by a serial letter and primary reflectors are identified by a color name. Two of the primary reflectors, red and green, have previously been identified and discussed (Meisburger and Duane, 1969, 1971; Meisburger and Field, 1972; Field and Duane, 1974).

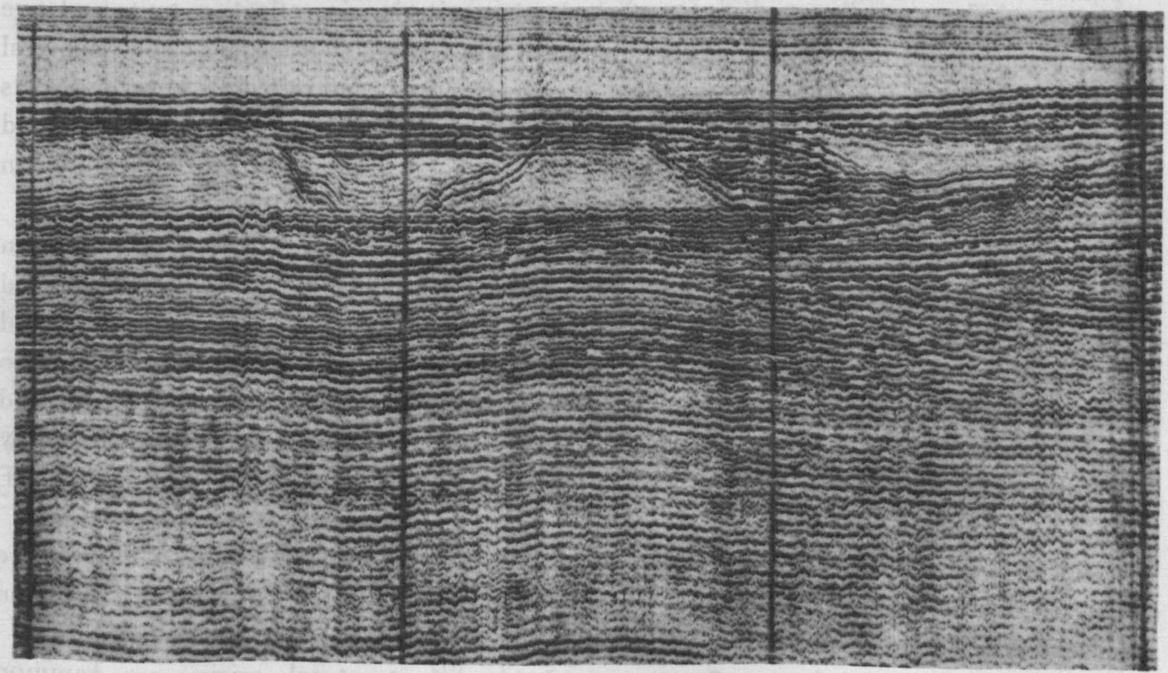


Section of line E, Fernandina grid, showing seaward-inclined beds in the red and white reflection units truncated by erosion.

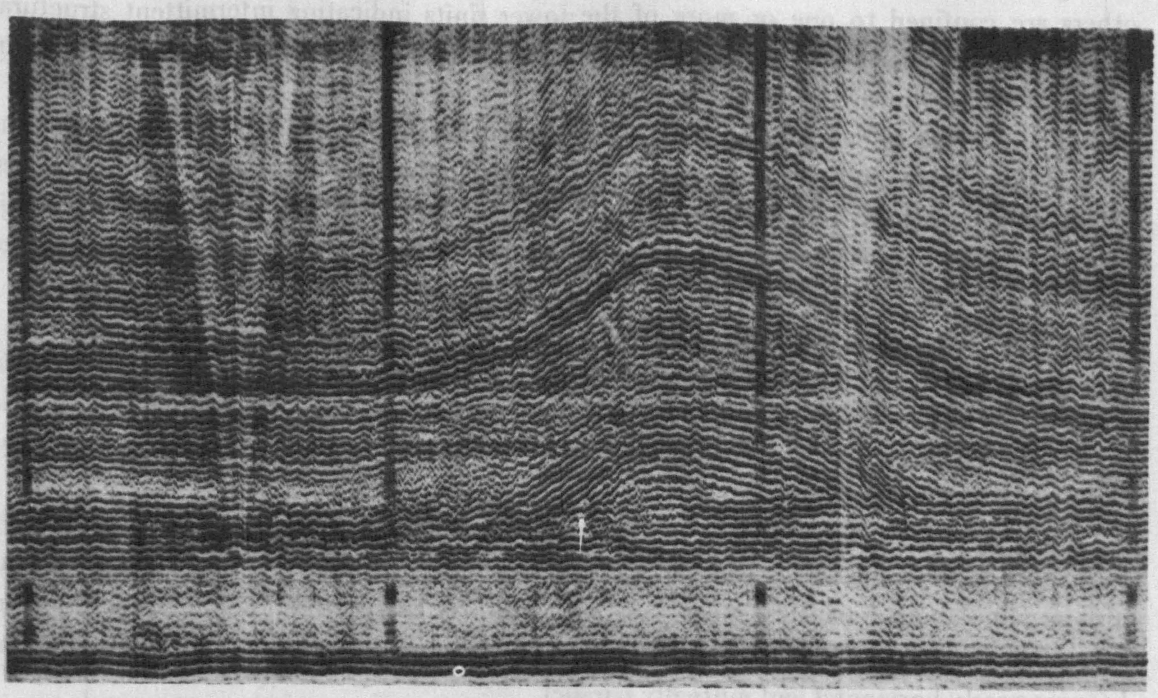


Section of St. Augustine–Cape Canaveral reconnaissance line D showing typical undulatory flexures characteristic of shallow subbottom strata underlying the inner shelf.

Figure 9. Photo reproduction of selected sections of seismic reflection profiles showing typical acoustic reflections under the north Florida East Coast Shelf.



Section of line H, Fernandina grid, showing filled channels incised into the blue and red reflection units. These channels are common off Jacksonville and northward.



Section of St. Augustine–Cape Canaveral reconnaissance line B showing truncated syncline. Such pronounced structural features are rare in shallow subbottom strata under the inner shelf.

Figure 10. Photo reproduction of selected sections of seismic reflection profiles showing typical acoustic reflections under the north Florida East Coast Shelf.

b. General. Based on partly subjective selection criteria, six reflection units and five primary reflectors under the inner shelf between the Georgia border and Cape Canaveral have been defined. The typical disposition of reflection units and reflectors in various parts of the study area is shown by a series of schematic shore-normal profiles (Figs. 11, 12, and 13) and by a schematic shore-parallel profile (Fig. 14). Location of the profiles is shown in Figure 11; selected reduced seismic reflection profiles are shown in Appendix A.

All but one of the identified reflection units and all five primary reflectors are present in the Jacksonville-Fernandina area as depicted on profiles A and B, Figure 12. Shore-normal profiles to the south and the shore-parallel profile (Fig. 14) show progressive southward changes in the section. These changes are primarily the result of a southward rise of the two lower units, D and E, to a truncated crest near Daytona Beach. Between Jacksonville and Flagler Beach, units B and C pinch out against the flank of this high and are supplanted by underlying units. Unit D is truncated over the crest of the high and only units A and E appear to be present in that area.

Dip in primary and secondary reflectors within study limits is almost everywhere eastward. In the two lowermost units, D and E, predominant north or south dip occurs in places. Westward dip is very rare and occurs only locally in secondary reflector patterns.

Broad shallow undulatory flexures, probably of structural origin, are common throughout the area (Fig. 9). Many of the flexures affect the entire vertical section while others are confined to one or more of the lower units indicating intermittent structural deformation may have occurred over a long period of time. Pronounced folding is evident in a few places by truncated synclinal features (Fig. 10).

No convincing evidence of faulting was observed on the records but there are numerous small displacements in reflectors which could be attributed to faulting among other causes.

Reflection patterns indicate the common presence of filled channels or inlets (Fig. 10) incised into the upper two units, A and B. Neither the filled channels or the structural features appear to have topographic expression on the shelf floor.

c. Reflection Units.

(1) Unit A. Unit A includes all sediments lying above the red reflector (Figs. 15, 16, and 17). The unit, usually less than 20 feet thick, is missing in places. Internal reflectors in unit A generally dip gently eastward and are often discontinuous and variable in intensity. Locally there are complex bedding patterns reflected from channel or inlet fill.

(2) Unit B. Unit B is 70 feet thick near the Georgia border and thins progressively southward to near Flagler Beach where it pinches out. A distinctive feature of unit B is an inshore zone about 5 nautical miles wide with uniform eastward-dipping internal reflectors suggesting a progradational bedding sequence. Seaward of this zone the internal reflectors become nearly horizontal and mutually parallel.

The upper part of unit B is incised by many channel-like features which generally originate in the overlying unit A. The largest of these channels trends southeast from the present St. Johns River Entrance and is presumed to be a relict Pleistocene channel of the St. Johns River.

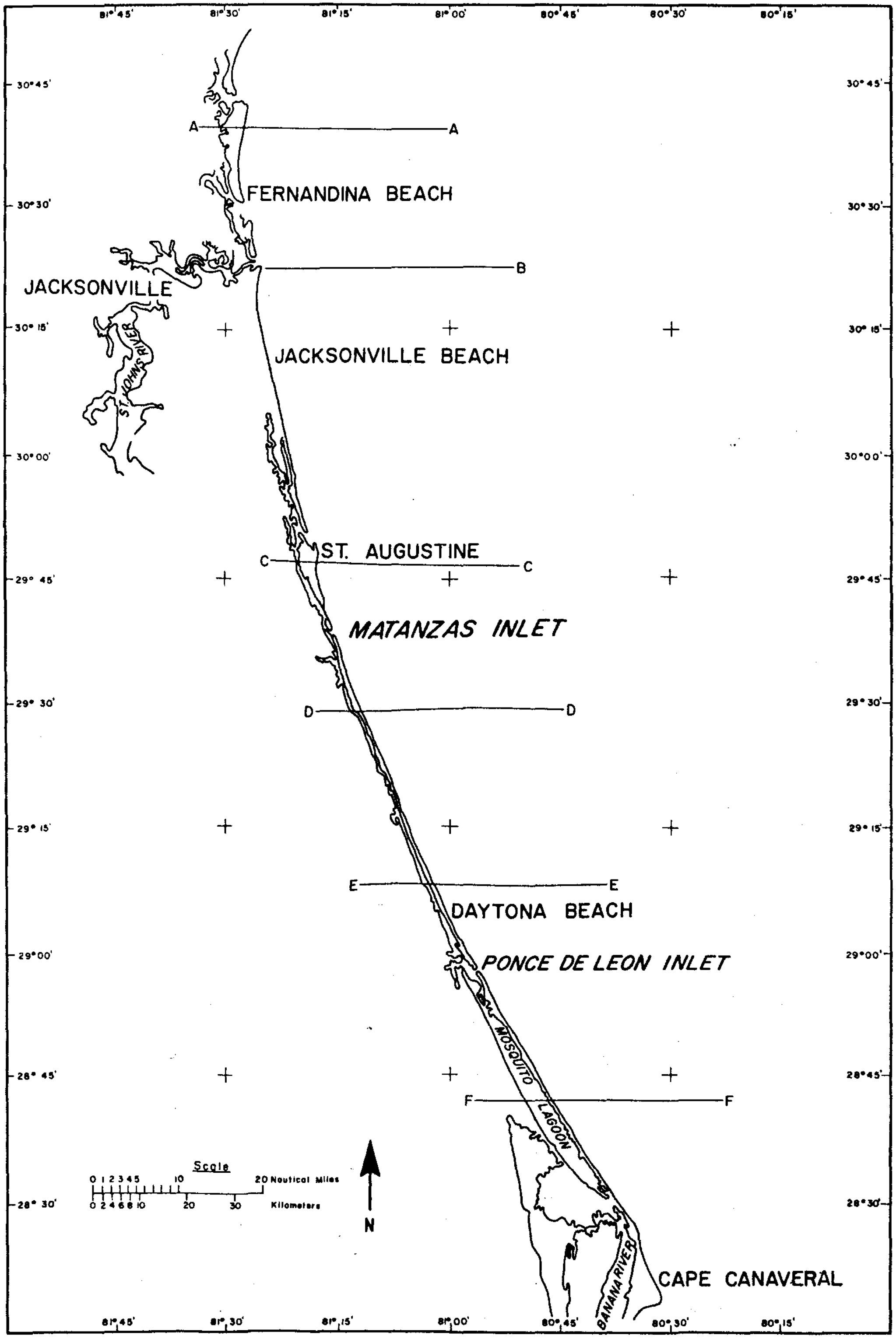


Figure 11. Location of schematic profiles presented in Figures 12 and 13.

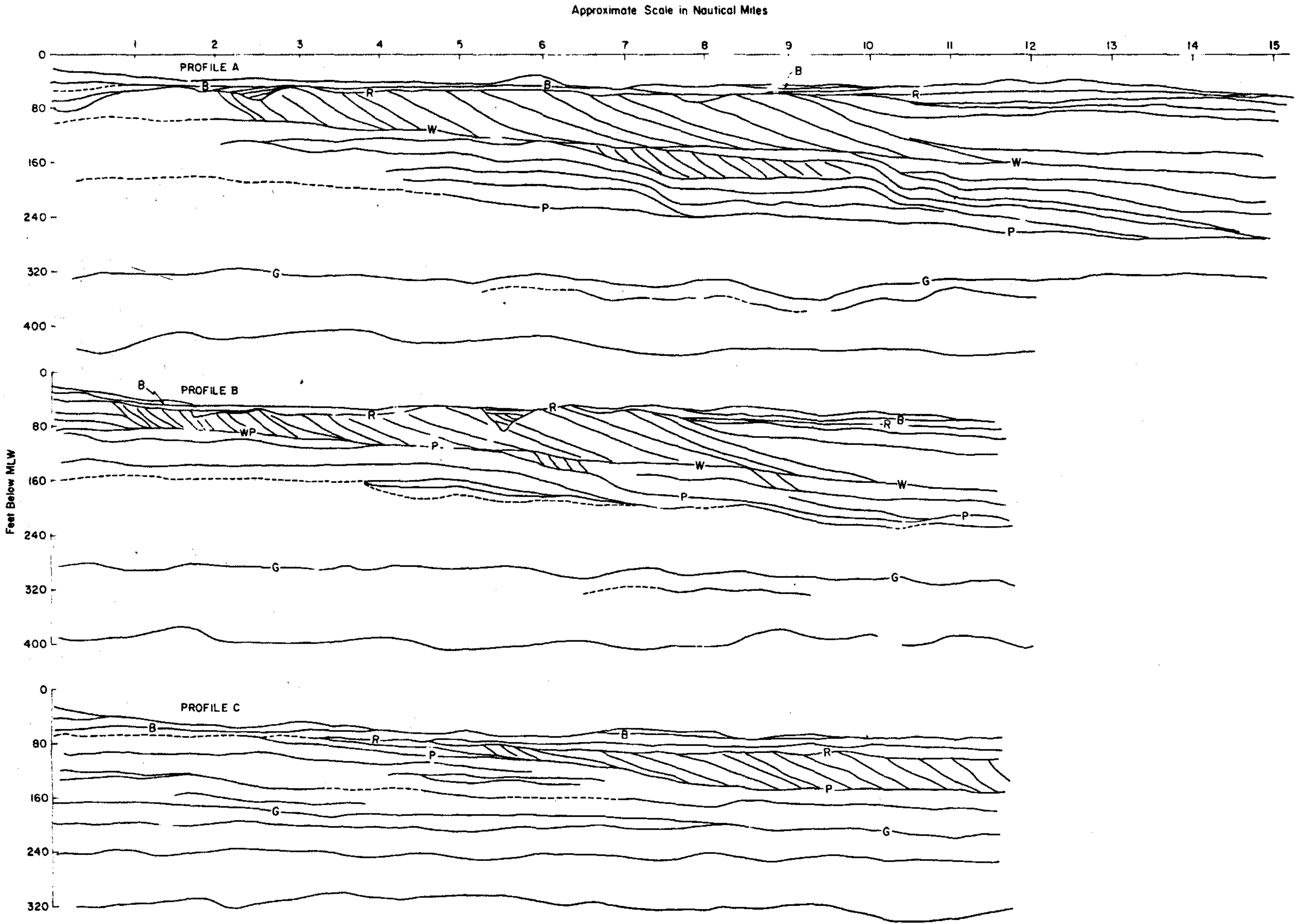


Figure 12. Schematic shore-normal profiles showing typical subbottom reflection patterns in the shallow strata underlying the East Coast Shelf off north Florida.

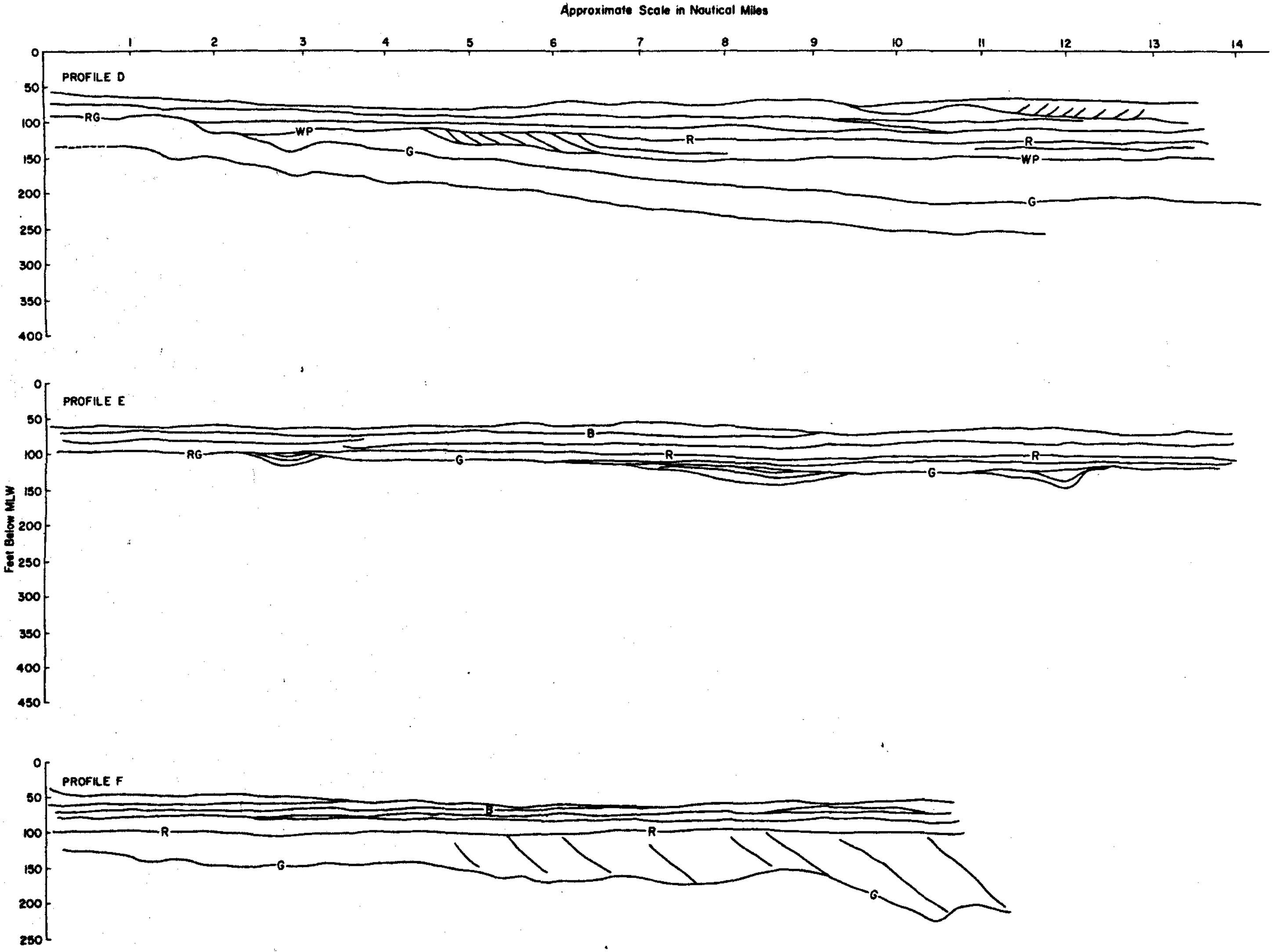


Figure 13. Schematic shore-normal profiles showing typical shallow subbottom bedding and structure in the southern half of study area.

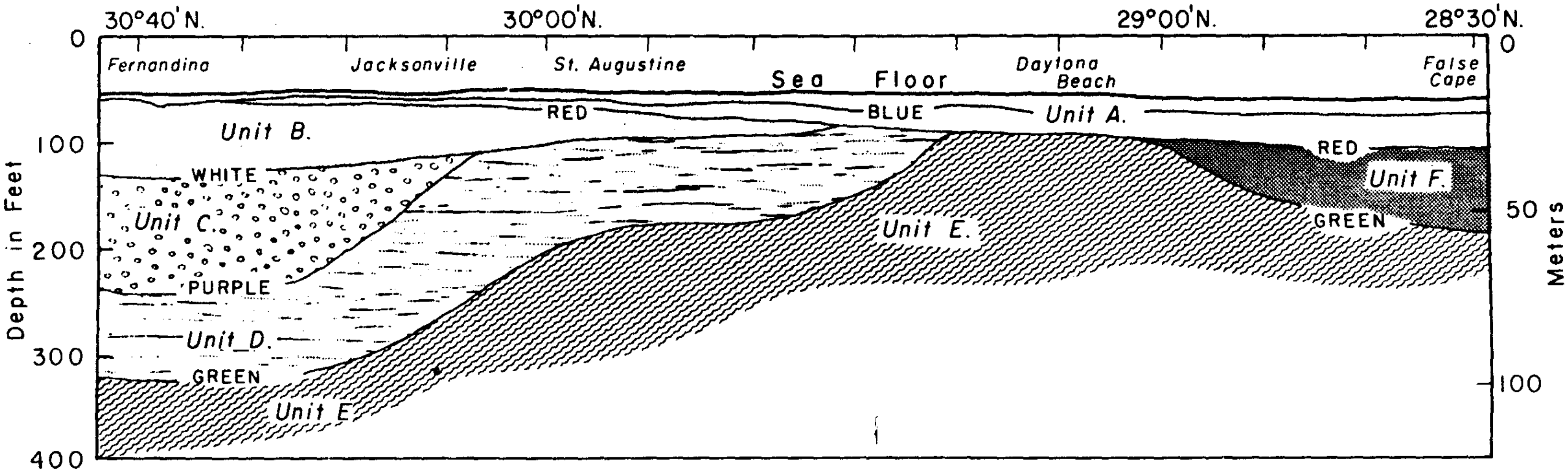


Figure 14. Schematic shore-parallel profile showing configurations of primary reflectors and reflection units under the East Coast Shelf off north Florida. Note terminology of designated reflection units and primary reflection horizons.

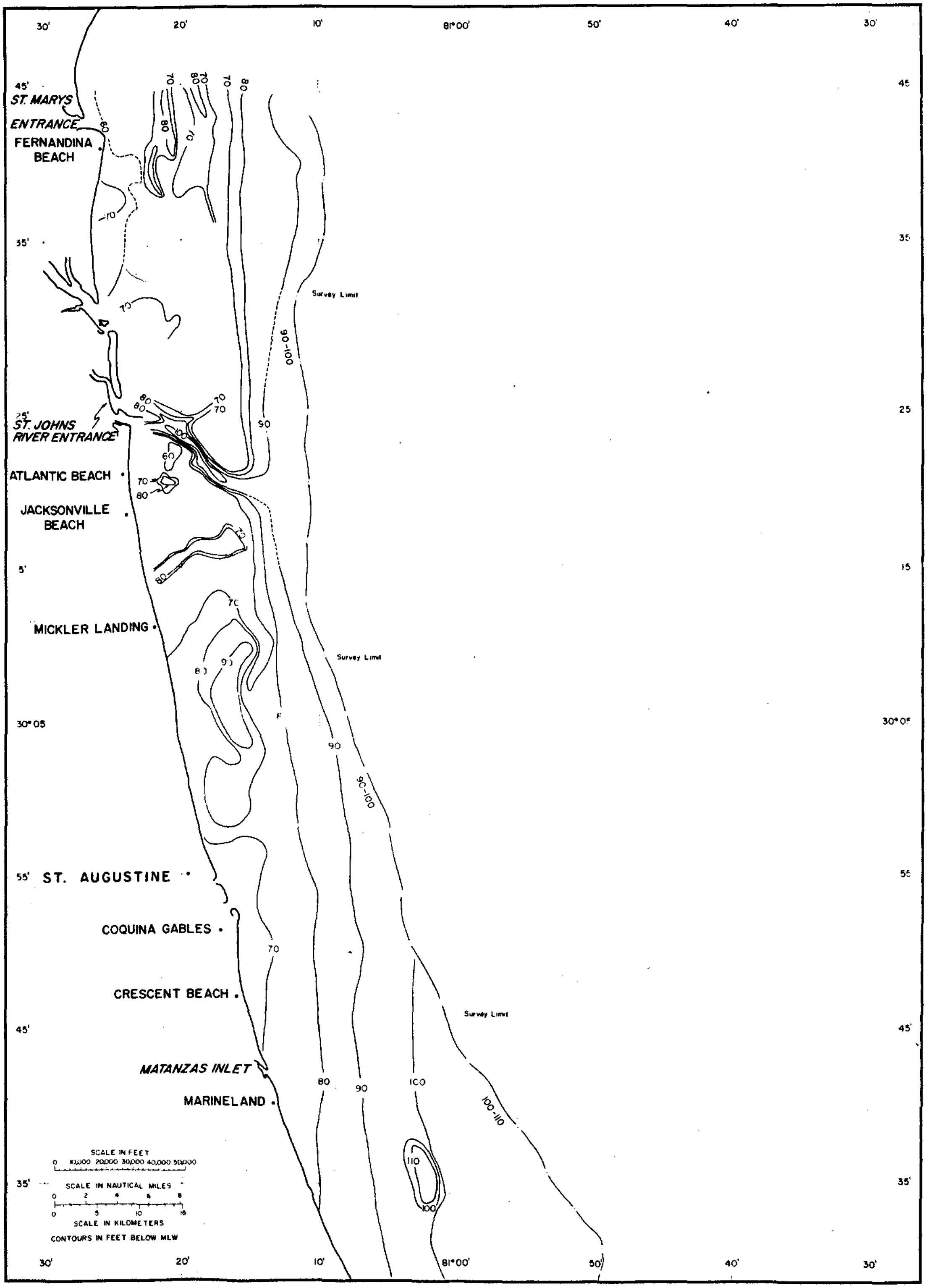


Figure 15. Contour map of red reflector (north part) which transgresses the surfaces of reflection units B, D, E, and F. Note erosional irregularities in the north and the large stream valley off St. Johns River Entrance.

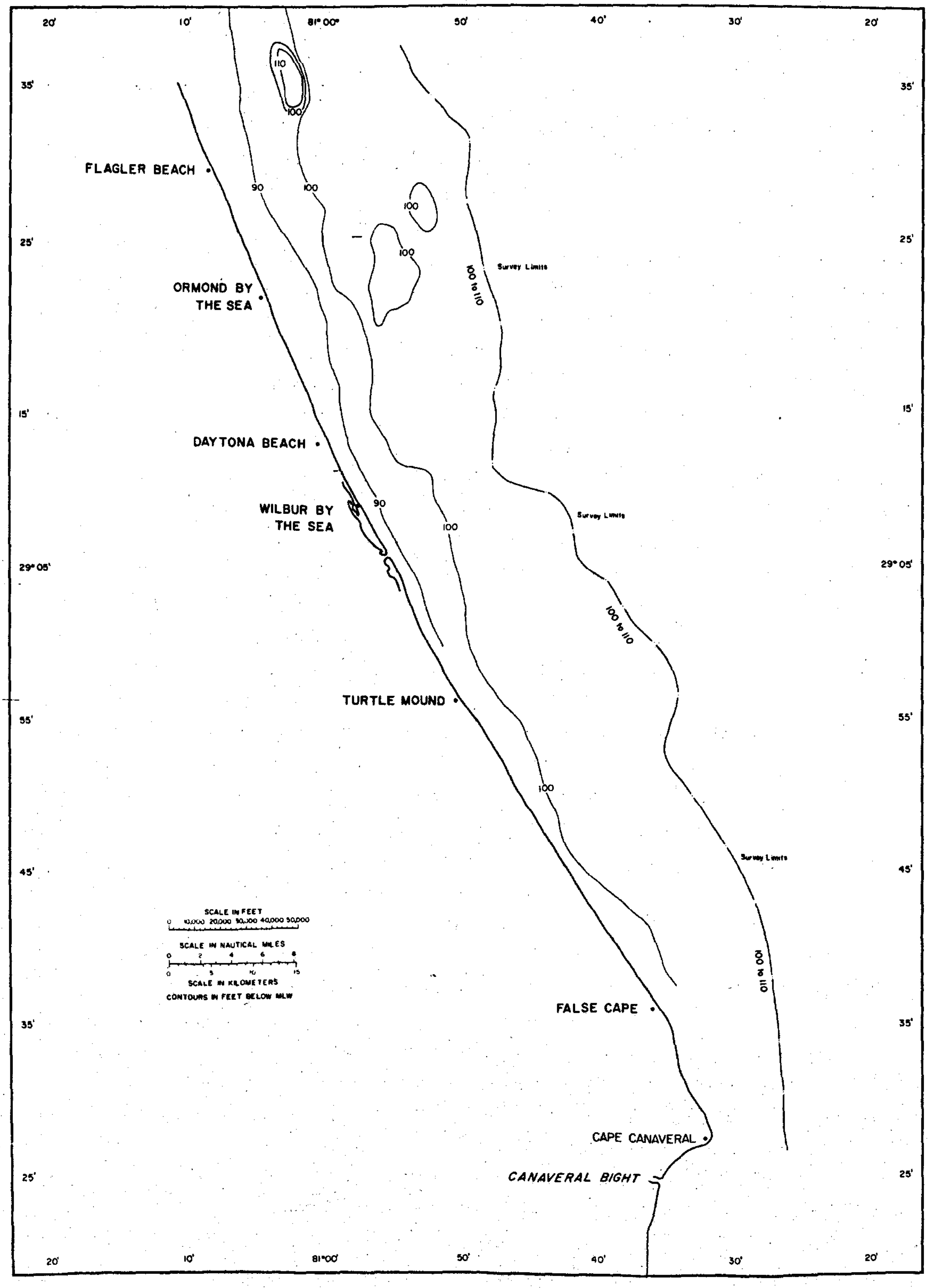


Figure 16. Contour map of the red reflector (south part).

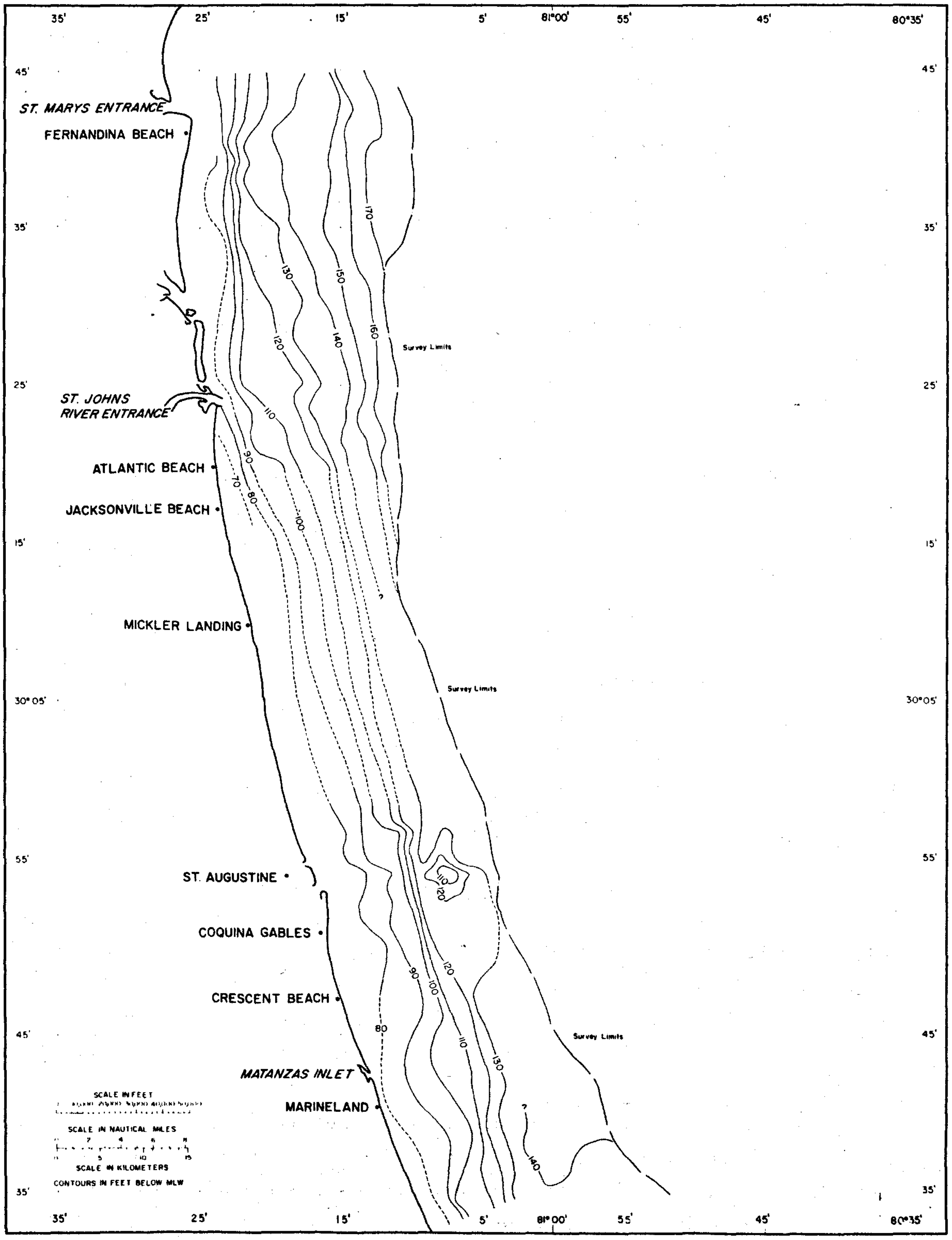


Figure 17. Contour map of the white primary reflector which transgresses the surfaces of reflection units C and D. Note the uniform and consistent slope of the surface.

(3) Unit C. Unit C is 90 feet thick near the Georgia border but thins rapidly toward the south and pinches out between Jacksonville and St. Augustine. This unit is characterized by internal reflectors suggesting a series of foreset-type beds followed by stretches of bottomset-type beds overlain by gently dipping subparallel beds. In contrast to the overlying unit B where internal reflectors dip almost due east, internal reflectors in unit C tend to tip in a southeasterly direction.

(4) Unit D. Unit D is not well defined in the northern part of the study area because it generally lies in a zone of strong multiples. As the unit rises southward its boundaries and internal reflector pattern become clearer. The internal reflectors, where clearly visible near St. Augustine, are weak but definite, closely spaced and mutually parallel. The internal reflectors dip generally in the same direction as the unit as a whole which ranges from north to southeast. Over the high at Daytona Beach the unit appears to have been entirely removed by erosion.

(5) Unit E. Unit E includes all strata below the green reflector and within penetration range of the records. Internal reflectors within unit E are scarce and discontinuous; there is very little information available concerning its possible structural and bedding characteristics.

(6) Unit F. Unit F includes all strata between the green and red reflectors south of the Daytona Beach high (Fig. 14). This unit is characterized by regular seaward-dipping internal reflectors. Offshore the unit thickens rapidly eastward and reaches a thickness of over 300 feet within 5 nautical miles of Cape Canaveral. No direct connection of this unit with any of the intermediate units (B, C, or D) north of the Daytona High has been established; however, unit F is most likely a time equivalent of one or more of these units, and its internal reflectors suggest a progradational bedding and stratigraphic position similar to unit B.

d. Primary Reflectors. The uppermost reflector in the blue unit which is traceable over a large part of the grid areas was selected to serve as a basis for sediment thickness maps of the three gridded areas. By convention the isopach surface in ICONS studies is called the *blue* reflector. This does not imply that the blue reflector of this study is necessarily continuous with blue reflectors described in other ICONS studies. It is not known if continuity exists between grid areas, although core data and similarities in elevation indicate a probability.

The blue reflector probably represents an eroded surface. In the inner parts of the Jacksonville and Fernandina grids where the red unit is high, the blue reflector is coincident with the top of the unit and truncates internal reflectors within the unit. Elsewhere up to 20 feet of sediment separate the blue reflector and the top of the red unit.

The blue reflector dips eastward at a very gentle gradient nearly parallel to the shelf floor; it often intersects offshore and becomes continuous with the shelf floor.

The *red* reflector was previously reported by Meisburger and Duane (1969) as an extensive acoustic horizon of regional significance underlying the Atlantic inner shelf off Florida. This reflector is easily recognized inshore between the Georgia border and Flagler Beach because it overlies distinctive seaward-dipping internal reflectors in unit B and also truncates unit D and parts of unit E over the Daytona Beach high (Figs. 13, 14 and 15). From near False Cape southward, a reflector judged to be continuous with the red reflector is directly underlain by unit F having seaward-dipping internal reflectors. Meisburger and Duane (1971) and Field and Duane (1974) have discussed the red reflector in the Cape Canaveral area and southward.

A contour map on the surface of the red reflector is shown in Figures 14 and 15. The overall slope of the red surface is generally eastward about 3 feet per nautical mile. The red reflector is judged to be an erosional unconformity because it truncates internal reflectors of underlying units and progressively overlies older units to the south.

The *white* reflector like the overlying primary reflectors slopes consistently eastward (Fig. 17). Within study limits the slope of the white surface averages about 8 feet per nautical mile. In the north it overlies unit C and southward of the pinchout of that unit it overlies unit D. Throughout its extent the white reflector is overlain by unit B and can readily be located inshore by its position at the base of the distinctive seaward-dipping internal reflectors of unit B. The white reflector is judged to be an erosional unconformity because it transgresses two distinct units and truncates internal reflectors in these units.

The *purple* reflector in the northern part of the study area is rarely visible because of multiples and perhaps insufficient acoustic contrast between bounding units. Therefore, it is primarily an inferred surface between the white and purple units and its position can only be approximated in most places. Southward of the pinchout of unit C the purple reflector is supplanted by the presumably younger white reflector (Fig. 14).

The deepest reflection surface which can be continuously followed throughout the study area is the *green* reflector. Like the red reflector it is of regional significance and has been identified in seismic reflection profiles as far south as Fort Pierce (Meisburger and Duane, 1969, 1971; Field and Duane, 1974).

In the northern part the green reflector dips northeastward. South of St. Augustine the dip is predominantly eastward (Figs. 18 and 19). Slopes vary from near horizontal to 40 feet per statute mile with an average in most places of 6 feet per nautical mile. The green reflector surface map in Figures 18 and 19 depicts the broad structural trends related to the high off Daytona Beach and many of the larger fluxures which affect units D and E in particular and in places the overlying units. The marked increase in the slope of the green surface evident from about 28°45'N. to south of Cape Canaveral may also be structural in origin. The projected alinement of this slope north of 28°45'N. places it eastward of the survey area and how far the slope extends to the north is unknown.

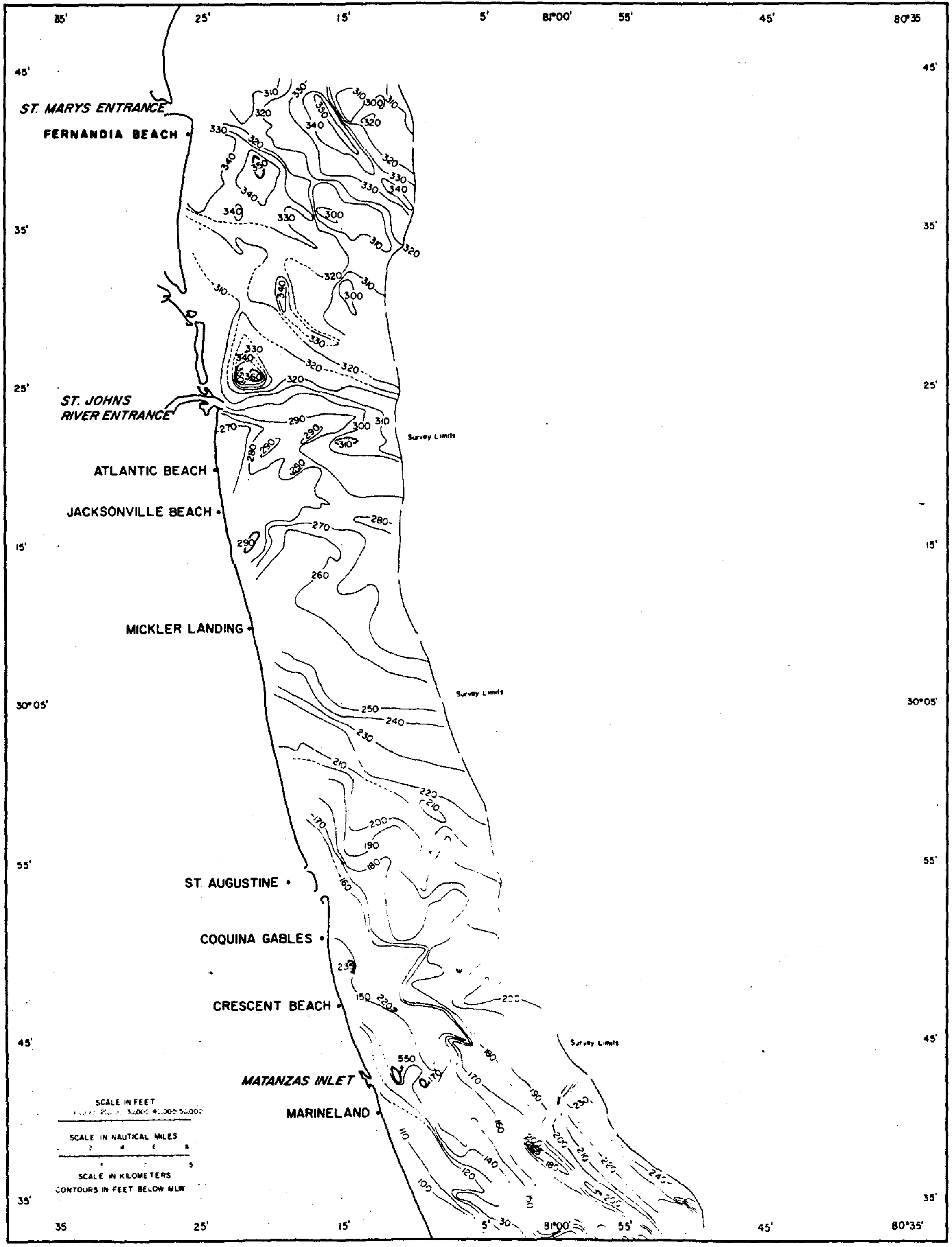


Figure 18. Contour map of the green primary reflector (north part). Note the development of a broad structural high centered off Daytona Beach.

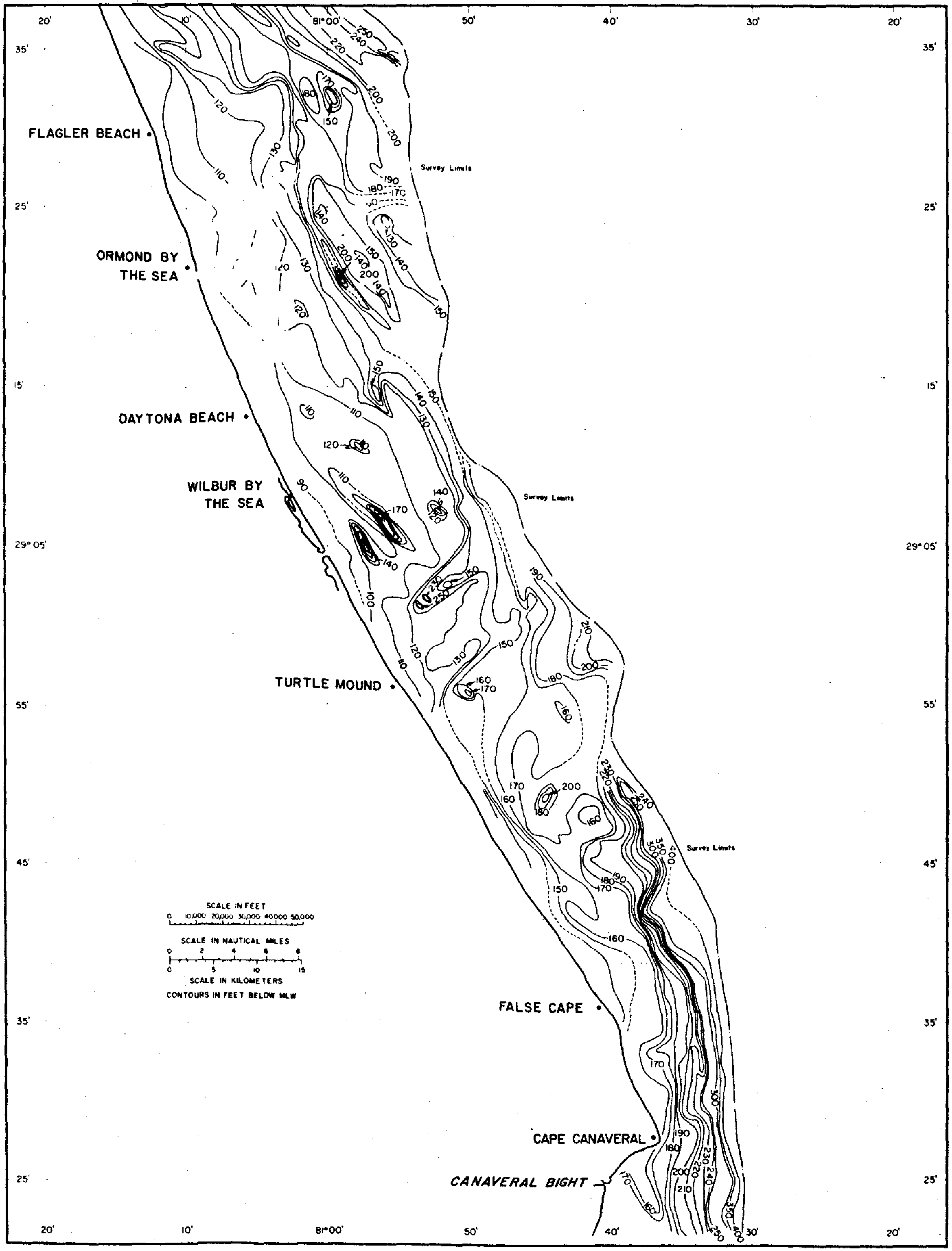


Figure 19. Contour map on the surface at the green reflector (south part).

g. Seismic Refraction Data. Seismic refraction studies on the East Coast Shelf off Georgia and north Florida (Wollard, Bonini, and Meyer, 1957; Hersey, et al., 1959; Antoine and Henry, 1965; Sheridan, et al., 1966) reveal three velocity layers within the 0- to 500-foot maximum depth range of CERC reflection records. Only a few shelf data points are available from these studies but they are in fair agreement on velocity-depth relationships (Table 2).

Table 2. Tentative correlation of seismic refraction layers and reflection units.

Reflection unit	**Refraction layers**		
	Hersey, et al. (1959)	**Antoine and Henry (1965)**	**Sheridan, et al. (1966)**
Recent A	Layer with characteristic velocity near that of seawater		
Miocene B, C, and D	A	1	V2
Eocene E	C	2	V3

The uppermost layer in these refraction studies is thin and discontinuous 0- to 90-feet thick, and has a characteristic velocity near that of seawater. Below this layer is a second layer characterized by variable thickness and sound velocities ranging from 5,169 to 6,300 feet per second. This second layer is called Layer A by Hersey, et al. (1959), Layer 1 by Antoine and Henry (1965), and V2 by Sheridan, et al. (1966). The base of the second layer and top of the third layer range from about –200 to –900 feet MSL; the few data points indicate that the base is shallowest inshore and dips generally eastward. Antoine and Henry (1965) believe that the contact between the second and third layer is the top of the Oligocene or Eocene section.

The third layer within range of the CERC subbottom records is characterized by a velocity range of 7,218 to 9,514 feet per second. This is Layer C of Hersey, et al. (1959); Layer 2 of Antoine and Henry (1965); and V3 of Sheridan, et al. (1966), (Table 2). The top of the third layer is probably within range of CERC reflection records only under the innermost part of the shelf.

From the sparse data available it seems probable that the uppermost velocity layer determined from these refraction studies corresponds to reflection unit A of this study. The second velocity layer may correspond to the reflection units B, C, and D. The contact between velocity layers two and three would thus correspond to the green reflector of this study.

h. JOIDES-1 Reconnaissance Lines. Two seismic reflection lines were run from the Fernandina and Jacksonville grids across the shelf to the site on the central shelf where boring J-1 (Fig. 2) of the Joint Oceanographic Institutes Deep Earth Sampling Program (JOIDES) was collected. This boring is described in Schlee and Gerard (1965), Charm, Nesteroff, and Valdes (1969), and Hathaway, McFarlin, and Ross (1970). Line profiles based on the two seismic records are presented in Figures 20 and 21.

Few primary reflectors identified in the main study area can be traced with confidence along these two profiles as far as the site of J-1 because there are extensive discontinuities in most reflectors. Projections along the general trend of the reflector surface suggest probable connections in most cases. The reflector patterns show that the gentle seaward dip of strata in the Neogene section underlying the study area persists as far as J-1 with occasional sections where they are flat-lying or the dip is reversed.

In terms of gross lithology, the Neogene section at J-1 does not show close similarities to the succession constructed from cores and borings in the study area. In particular, the pronounced lithologic division between quartz sand which appears to be characteristic of units A, B, and C, and the silt-clay of underlying unit D, are not apparent in the Neogene section of J-1 which is logged as predominantly silt with some sandy intervals.

The purple reflector, which in this part of the study area separates unit C and D, was tentatively traced to a position about 171 feet below the sea floor at J-1; there are some lithologic changes at this depth but not as marked as the changes observed inshore. According to Charm, Nesteroff, and Valdez (1969), at about 167 to 151 feet downhole in J-1, there is a sharp decrease in phosphate content where quartz increases substantially in particle size and abundance. The white reflector at the base of unit B is also traceable with fair assurance on the Jacksonville J-1 line but cannot be traced back to Fernandina. At J-1, this reflector lies about 98 feet beneath the sea floor near a horizon in J-1 above which there is a marked increase in planktonic foraminifera and a decrease in quartz. The increase in planktonic fauna may be roughly correlative with unit B which contains abundant planktonics; however, the low quartz content is lithologically dissimilar to unit B as closer inshore.

III. SURFACE AND SUBBOTTOM SEDIMENT CHARACTERISTICS AND DISTRIBUTION

1. Inner Shelf Sediment Characteristics.

a. General. Sediment data are based on macroscopic and microscopic examination of about 1,200 samples from 197 vibratory cores of 3-inch diameter and averaging 10 feet in length. Numbered core locations are plotted in Figures 2 through 4. Sediment samples were collected at 1-foot intervals from each core; selected cores were split and samples collected at closer intervals for examination. Textural parameters of sands visually ascertained to be suitable for beach nourishment were determined by sieving and fall velocity; results are given in Appendix B.

Sediments of the north Florida inner Continental Shelf are highly variable in both size characteristics and in particle shape and mineralogy. These variations are mappable over

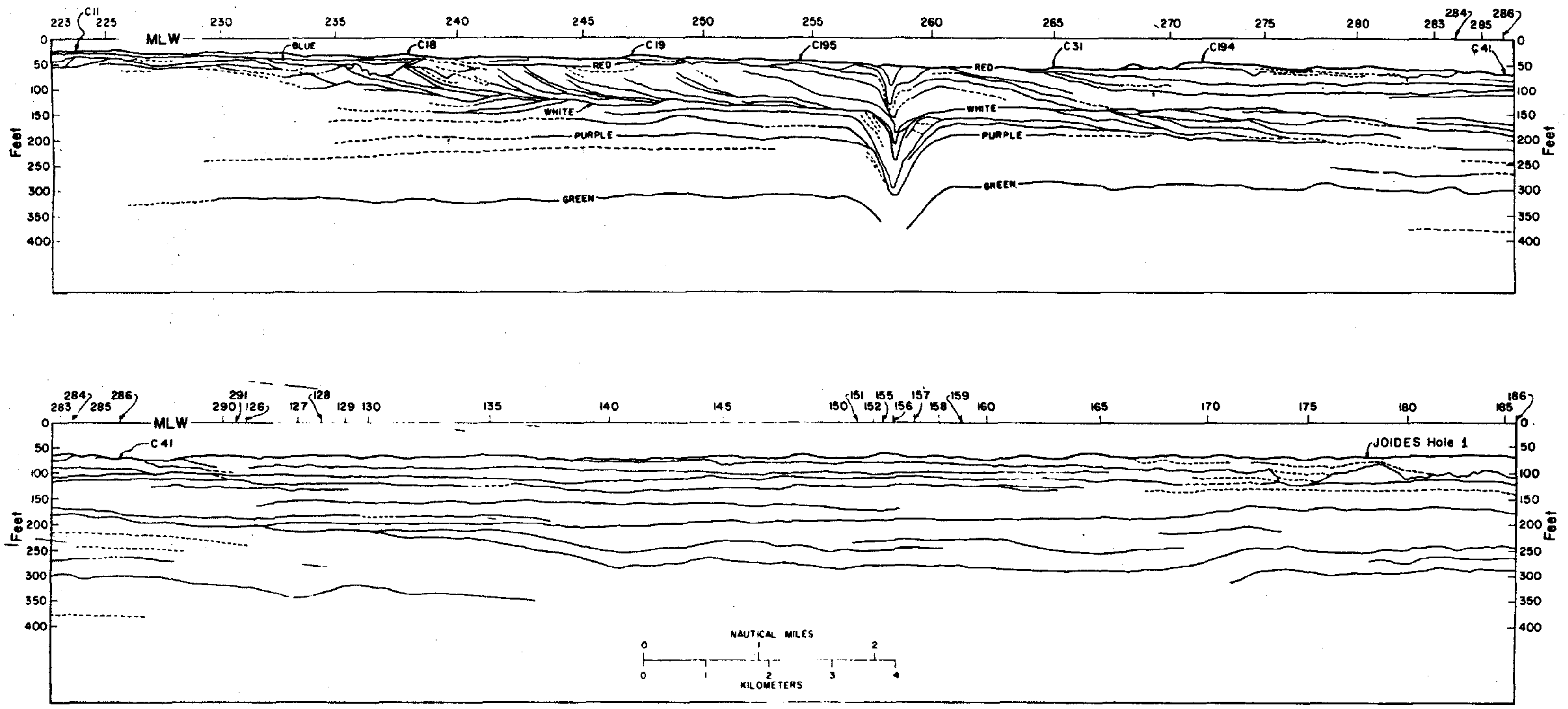


Figure 20. Line profile reduction of seismic reflection profile line J; Fernandina grid area extended seaward to JOIDES Hole No. 1 at approximately 30°33′N., 81°00′W. Note flattening of reflectors offshore.

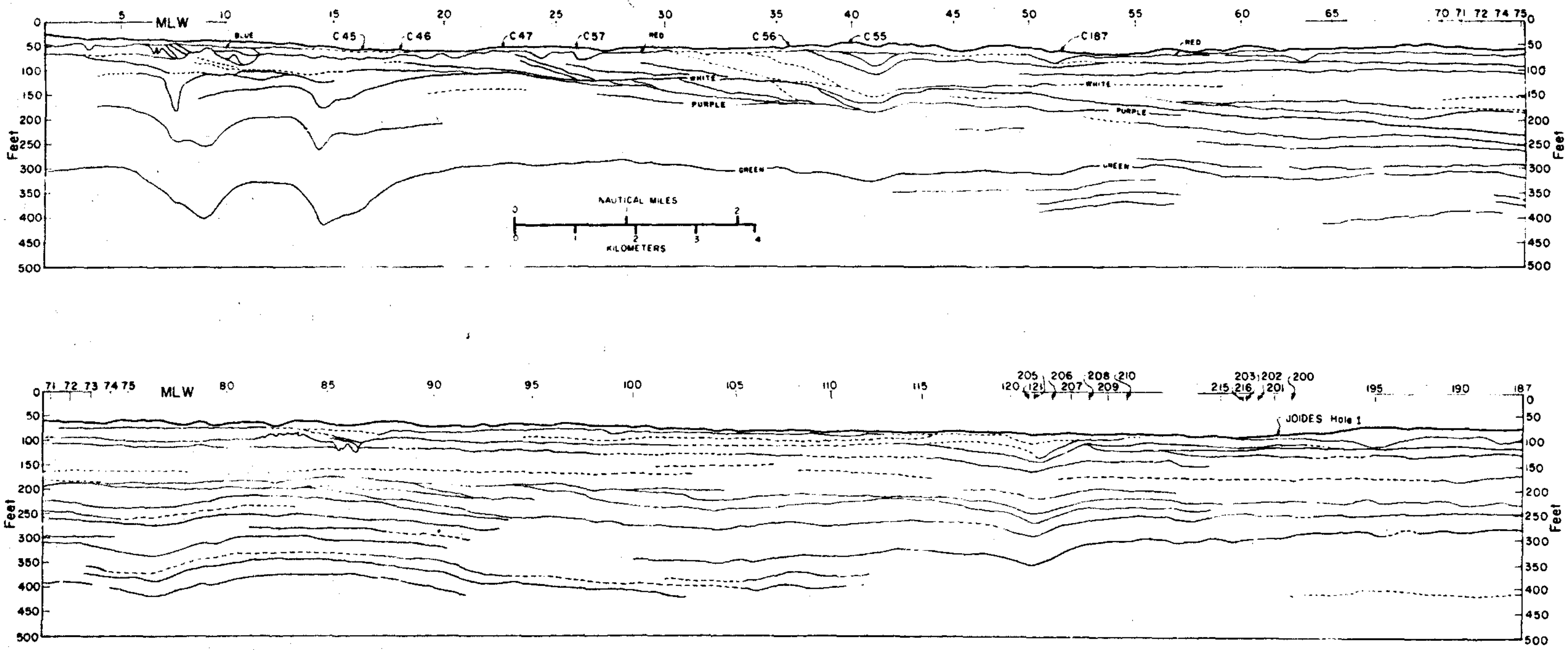


Figure 21. Line profile reduction of seismic reflection profile line A; Jacksonville grid area extended seaward to JOIDES Hole No. 1 at approximately 30°33′N., 81°00′W.

broad areas and can be correlated between individual cores and with distinct acoustic horizons in some cases. Trends in sediment distribution appear to be related to both shelf surface morphology and subbottom structure; e.g., shoreface sediments retain certain similar characteristics throughout the survey area, as do shallow water sands mantling flanks and crests of shoals and banks. Similarly, anomalous surface sediment samples or patterns are related to surface exposure of older underlying strata.

Major sediment types appear in stratigraphic configurations which relate to their origin and age. These broad trends and transitions in sediment character are evident between the survey limits of Cape Canaveral to the south and Georgia to the north and provide a basis for regional interpretation of shelf sediment history. Recent studies of the inner shelf off Cape Canaveral to the south (Field and Duane, 1974) and off Georgia to the north (Henry and Hoyt, 1968; Howard, 1972) provide contiguous data for extrapolation of results and comparative interpretation of evolution of the shallow shelf surface.

General lithologic characteristics and shallow stratigraphic relationships of major sediment types on the north Florida inner shelf are summarized in Table 3. Surficial sediments are generally detrital quartz sands. These overlie older carbonate-rich quartz sand deposits. Major sediment categories are:

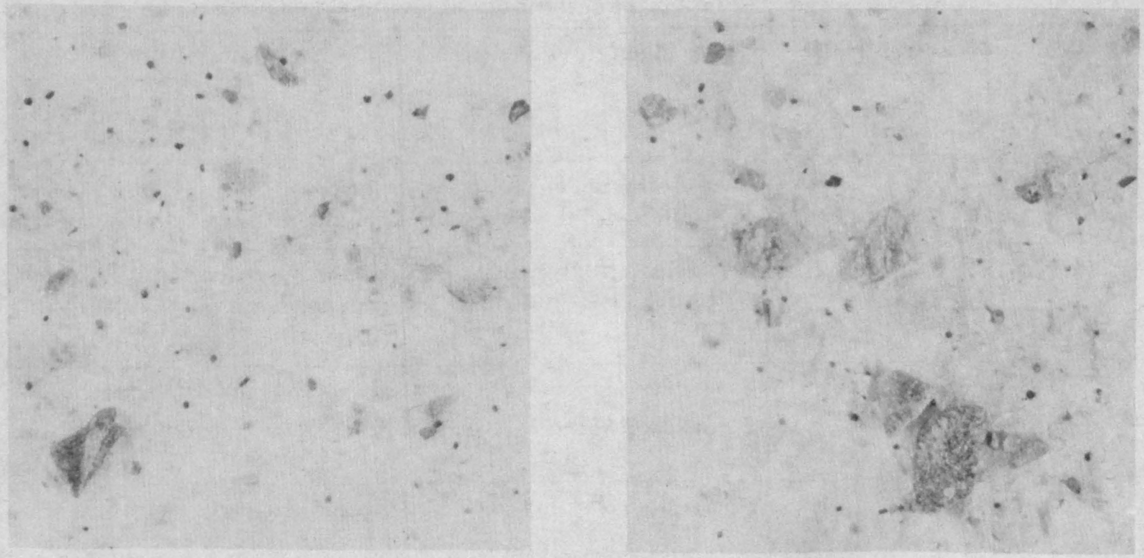
(a) Type A. Well sorted, fine to coarse quartz sands.
(b) Type F. Very fine silty quartz sands.
(c) Type G. Gray, occasionally slightly indurated, shelly quartz sand to shell hash.
(d) Type L. White, medium-grained foraminiferal sands.
(e) Type M. Sand and dolomite silt.

Letters assigned to lithologies are arbitrary and established for this program (Meisburger and Duane, 1971) to simplify correlation and associations of sediment from one area to another. Therefore, type A sand is similar in character to sediments designated by that letter in the Fort Pierce-Cape Canaveral areas. Sediment types L and M are not present in the Fort Pierce or Cape Canaveral areas. These deposits are strictly defined lithologies, based on particular constituents such as foraminifera or dolomite silt.

Fine shoreface sands similar to type F sediment are generally common to the south, but have not been given a letter designation in two ICONS studies of this region (Duane and Meisburger, 1969; Field and Duane, 1974). In the Fort Pierce area Meisburger and Duane (1971) identified the shoreface sands as type U sediment. In some respects type G sediments are similar to the semilithified calcarenite (designated Type E) mapped from Cape Canaveral south to Fort Pierce (Meisburger and Duane, 1971; Field and Duane, 1974). However, no direct relationship has yet been established.

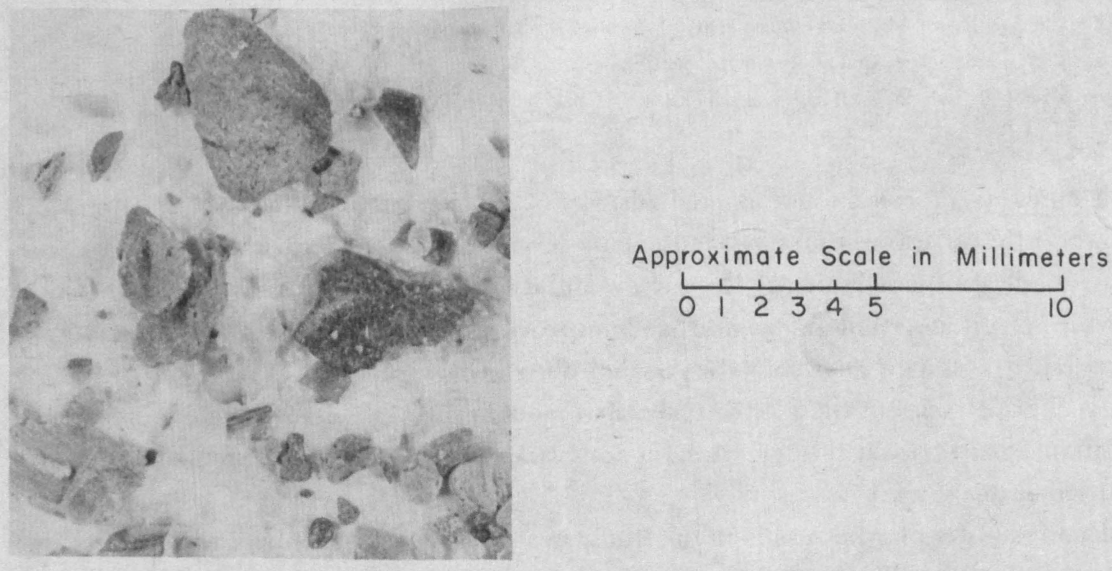
b. Lithology.

(1) Type A Sediments. One of the most common lithologies of the north Florida inner Continental Shelf is a fine to medium, moderately well to well-sorted, quartz sand called type A sediment. Examples are shown in Figure 22. Type A sediment contains only



Sand

Sand



Sand

Figure 22. Photos of typical type A sediment samples.

Table 3. Lithologic classification of major sediment categories in north Florida.

Classification	Recognized at:		Major lithologic characteristics	Remarks
Type	Cape Canaveral	Fort Pierce		
A	yes	yes	Sand, quartzose; fine to coarse, moderately well to well sorted.	Carbonate content 15 percent; phosphorite grains locally abundant.
F	yes[1]	yes[2]	Sand, quartzose; very fine to fine, silty, poorly sorted.	Benthic forams; ostracods common; mica and heavy minerals locally abundant.
G	no[3]	no	Sand, quartzose; shelly, and sandy shell hash.	*Mulinia lateralis* abundant; uniform white to ivory or light brown in color.
L	no	no	Sand, calcareous; silty fine.	Silt and clay particles are both degraded biogenic carbonates and terrigenous material.
M	no	no	Silt, dolomitic; and Sand, quartzose-phosphatic	Shell fragments absent; dolomite grains show various stages of disintegration.
U[4]	no	no	Clay, green; (desiccated).	Carbonate molds common.
			Clay, brown and black; fissile.	
			Sand, fine; poorly sorted.	Similar to Type F; occurs in patches on the shelf.

[1] Fine, silty, poorly sorted sands at Cape Canaveral classified as Type H and includes clayey silts.

[2] Fine, silty, poorly sorted sand at Fort Pierce identified as Type U.

[3] Quartzose shell sands and shell hashes at Cape Canaveral included with Type A sediments.

[4] Unclassified.

small amounts of calcareous material (usually < 15 percent of total sand fraction) and displays little variation in textural and compositional characteristics within the survey area. Towards the southern limits of the survey area type A becomes increasingly enriched in biogenic constituents and grades into medium to coarse, quartzose-calcareous sand at Cape Canaveral. The Cape Canaveral type A sand, described by Field and Duane (1974), is the central Florida facies of the Florida inner shelf modern surficial sand sheet, and represents a transition zone between the type A calcareous sands of the south and the quartzose sands discussed in this study.

Mean grain size of type A sand in the study area ranges from the upper limits of very fine sand class (0.125 millimeters; 3.0 phi), to the upper limits of medium sand class (0.500 millimeters; 1.0 phi). Most samples have a mean size between 0.5 millimeters (0.1 phi) and 0.177 millimeters (2.5 phi); a few samples have a coarse mean grain size. Sorting of these sands is good relative to other lithologies within the survey area and to type A deposits at

Cape Canaveral. Standard deviations range from about 0.5 phi to over 1.5 phi, which is moderately well-sorted to poorly sorted in terms defined by Friedman (1962). In particular, the good sorting distinguishes fine-grained type A sands from type F shoreface sands.

Increases in standard deviations of some samples are due principally to anomalously high shell content, which adds a coarse mode to the sand; also, some silt content derived from subjacent deposits adds a fine mode to the sand.

Most type A deposits are light gray (10 yr. 7/1 by Munsell Color Code). Color variations adjacent to and south of Cape Canaveral as noted by Field and Duane (1974) and Meisburger and Duane (1971) are generally absent because of the lack of variegated carbonate grains, and the general overall fine grain size of quartz in which iron staining may be more rare than in medium and coarse sands. Color of quartz sands in this region has been examined by Judd, Smith, and Pilkey (1969) who found that less than 40 percent of medium and coarse quartz grains are iron stained. Surface and subsurface samples identified as type A sediment show little or no iron staining, in contrast to anomalous high staining values for the coarser sands at Cape Canaveral (Field and Duane, 1974). Previous shelf workers have identified iron staining as an indication of a relict history. However, recent studies by Swift and Boehmer (1972) suggest staining may occur in the active submarine environment and is dependent on mean grain size, with medium and coarser sands becoming stained and fine sands remaining free of iron stain.

Detrital quartz is the chief constituent of type A sands, normally accounting for 80 to 90 percent of the total grains. Other constituents include accessory detrital light and heavy minerals and biogenic carbonate grains. The fine and medium quartz grains are clear and subangular to subrounded; internal discoloration and inclusions are rare. Surface textures of coarse and very coarse sand grains are occasionally well rounded, probably as a result of solution. Electron micrographs of grains from both the inner and outer shelf show solution features to be more common in the Florida shelf sands than elsewhere on the Atlantic shelf (Blackwelder and Pilkey, 1972). This may indicate a secondary or residual origin of the grains from local quartzose sources. Other detrital minerals in type A sands are feldspar, mica, phosphorite, and accessory heavy minerals. Field and Pilkey (1969) and Milliman (1972) have reported the feldspar content of north Florida surficial deposits to average about 1.5 percent and range from 0.5 to 4 percent with values increasing gradually from Jacksonville towards Georgia. Mica flakes occur sporadically in trace quantities in north Florida type A sands, whereas in central Florida they are absent (Field and Duane, 1974). Phosphorite is a common constituent of sands in the survey area and has previously been reported by Gorsline (1963) and Milliman (1972), and on the Georgia shelf by Pevear and Pilkey (1966). In type A sands phosphorite grains are black, brown and amber, and range from silt to gravel size; their high luster and high degree of rounding indicate softness and transport history. Individual samples having a high phosphorite content occasionally contain fish and shark teeth.

Heavy minerals are present in trace quantities in type A sands. No studies of the heavy mineral fraction were conducted as part of this investigation. Previous analyses of the Florida shelf in heavy mineral assemblage are contained in Tyler (1934), Pilkey (1963), Gorsline (1963), Pilkey and Field (1972), and Milliman, Pilkey, and Ross (1972).

The calcareous fraction of type A sand comprises less than 15 percent of the sand and is composed principally of mollusk fragments, with lesser amounts of echinoid fragments, barnacles, bryozoa, worm tubes and benthic foraminifera. Calcareous ooids, characteristic grain-types off Cape Canaveral, are absent from cores collected in this study, although they have been reported in deeper deposits seaward of the survey area by Terlecky (1967). Other calcareous grains reported farther to the south by Meisburger and Duane (1971) and Field and Duane (1974), which are absent or occur only in small quantities in the survey area, are barnacles, calcarenite lithoclasts and algal clasts.

It is principally the difference in total carbonate content and in composition of the carbonate fraction that distinguishes type A surficial shelf sands of the north Florida region from those adjacent and south of Cape Canaveral.

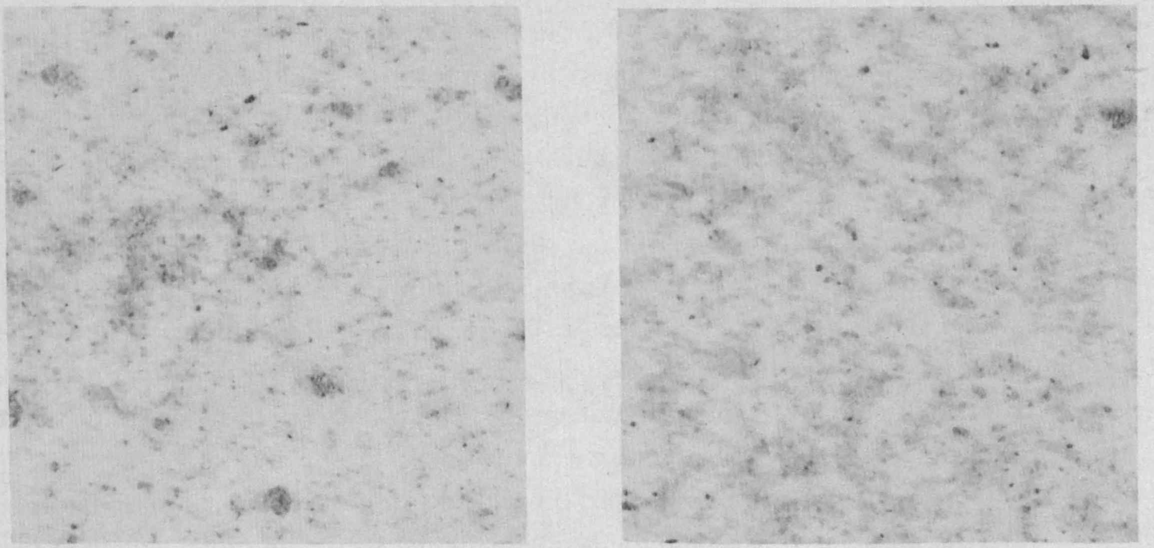
The mollusk assemblage in type A sands is quite diverse and includes forms judged to have been reworked from the substrata or introduced as a detrital element as well as forms presently inhabiting the area.

The most important mollusks in type A sediment are species of *Aequipecten, Anadara, Anomia, Lucina, Mulinia,* and *Ostrea,* all pelecypods. Gastropods are scarce in this sediment type as they are in general throughout the study area.

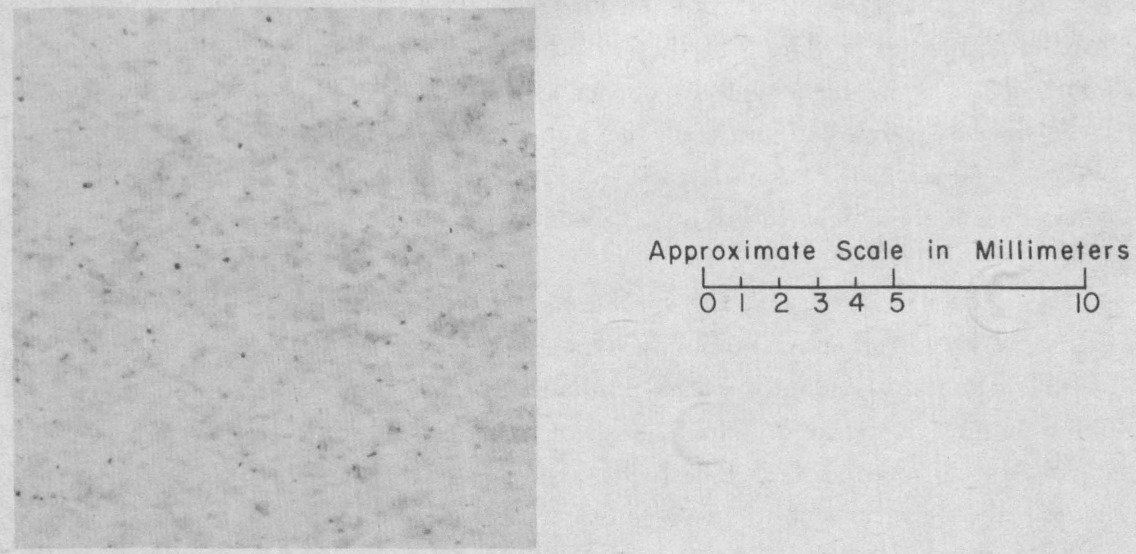
Foraminiferal fauna in type A sediment ranges from sparse to abundant. The assemblage is dominated by species of *Quinqueloculina* and *Elphidium* with *Hanzawaia* spp. of equal importance south of Marineland (20°40′N.). The assemblage is diverse in some places with 30 or more species represented in a count of 300 specimens, and comparatively restricted in other places.

(2) Type F Sediments. Type F sediment is a very fine to fine, poorly sorted silty quartz sand (Fig. 23) characterized in particular by its distinctive faunal assemblage and close relationship to shelf morphology. This sand is the characteristic sediment of the shoreface and contiguous innermost ramp along the length of the survey area from Cape Canaveral to Georgia. About 70 percent of cores containing type F sediment are within 4 nautical miles of shore; only 10 percent of cores within 4 nautical miles does not contain this sediment.

Accessory detrital minerals comprise several percent of the sediment, and biogenic carbonates account for about 20 percent of the sediment. Quartz grains are polished, clear and subrounded to angular. Accessory minerals include phosphorite, feldspar, mica, and heavy minerals. Mineralogic properties of type F sand are similar to those of type A with the exception of high mica content in some samples. Phosphorite grains are also locally abundant.



Sand Sand



Forams

Figure 23. Photos of typical type F sediment samples.

Type F sediment is distinguished from type A sediment on textural and compositional bases. Type F is finer, often contains a significant quantity of silt, and is less well sorted than type A sand. In addition it contains a distinctively different carbonate composition. Carbonate content generally is less than 20 percent of total sample weight. Calcareous grains are biogenic in origin; ooids and lithoclasts are absent. The carbonate assemblage is largely derived from mollusks, echinoids, and microfauna. None of the macrofaunal fragments display significant black or brown coloration, a feature of coarser deposits in adjacent areas (Pilkey, et al., 1969) and attributed to deposition in a former coastal area. Dominant mollusks in type F sediment are *Mulinia lateralis* (Say), *Abra aequilis* (Say), and *Corbula* spp. The assemblage is generally uniform but abundance of each species is variable. In comparison to type A sand the fauna are not diverse.

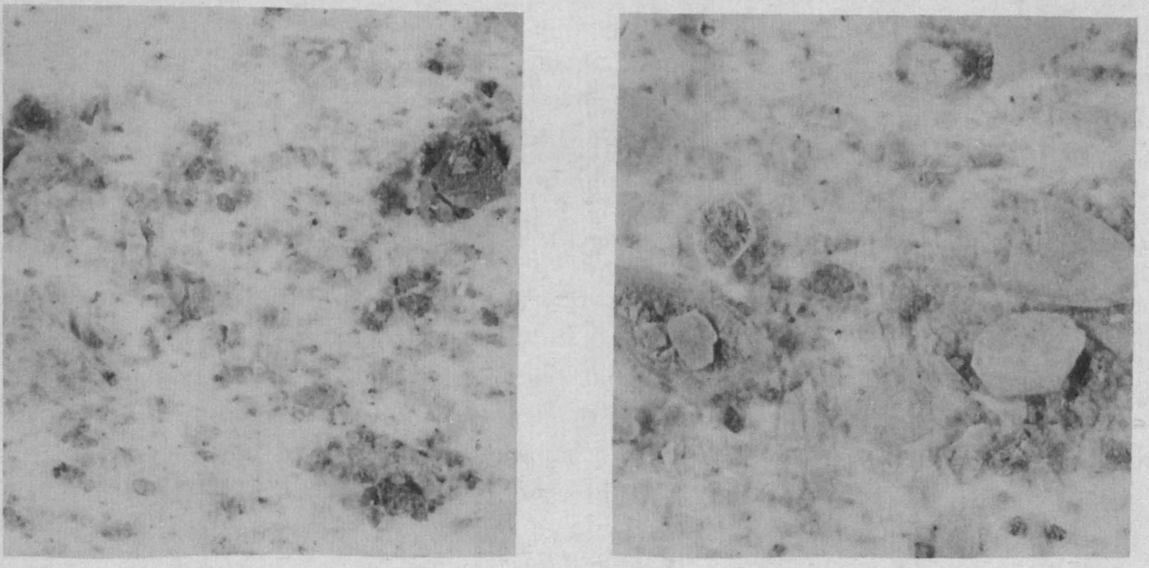
The foraminifera of type F sediment are generally uniform and not diverse in comparison to the type A fauna. The assemblage is dominated by species of *Elphidium* and varieties of *Ammonia beccarii* (Linné) which together generally comprise more than 75 percent of the population. Other than the dominant species the only types occurring with any regularity in this sediment are *Buccella hannai* (Cushman), *Florilus atlanticus* (Cushman), and *Quinqueloculina* spp., all in small quantities.

(3) Type G Sediments. White, ivory, and light tan (10 yr. 7/2) shelly sand and *Mulinia* shell hash, locally interbedded with fine sand, commonly occur in cores between St. Augustine and Cape Canaveral (Fig. 24). There are also isolated occurrences of these sediments to the north, possibly representing small erosional remnants of the same deposit. A few surface outcrops occur, but this material is largely buried by overlying types A or F sediment and thus is older than these deposits. In cores where type G occurs with type L sediment it is always higher and of younger age.

Distinctive features of the shelly deposit are the uniform coloration of included shells and predominance of *Mulinia lateralis* (Say) shell hashes. The general lack of contrasting colors indicates postdepositional loss of distinctive coloration as many of the species present are strongly colored in life.

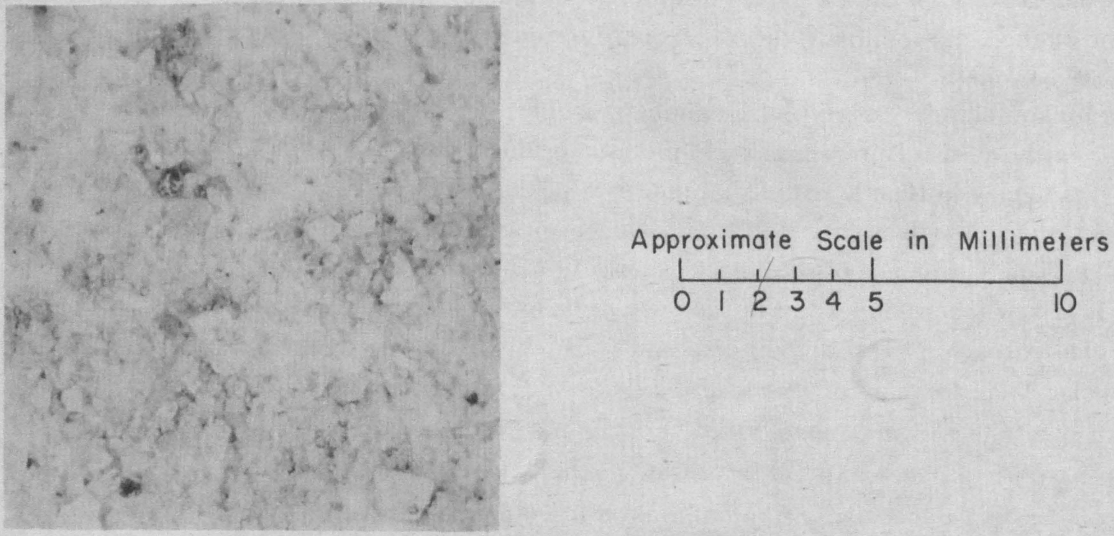
Most species of mollusks in the shelly sand and shell-hash deposits are common to type A sediment; however, several common type A forms are either missing or appear to be considerably less abundant. *Ilynassa obsoleta* (Say), an intertidal gastropod is commonly found in shell sand and shell hash, but not in other sediments of the study area and is apparently distinctive of shell-hash deposits. Along with the predominance of *Mulinia lateralis* the occurrence of *Ilynassa obsoleta* indicates initial deposition in shallow (and probably brackish) water. Another distinctive mollusk present in some samples are thick-bodied shells and fragments of *Mercenaria* sp. which have been highly bored by sponges and algae.

In many respects, the uniform light color, presence of abundant *Mulinia* and occasional semilithification of the shelly sand and shell-hash deposits resemble characteristics of the



Sand

Mud



Sand

Figure 24. Photos of type G sediment samples.

widespread deposit on the inner shelf between Cape Canaveral and Palm Beach described by Meisburger and Duane (1971) and Field and Duane (1974). There are essential differences, especially the rarity of lithification and the absence of oolites and pelletoid calcareous particles which are common features of most type E sediment. Further study may show that these two units are time equivalents as they seem to occupy a similar stratigraphic niche.

Foraminiferal assemblages in the *Mulinia* shell hash and associated shelly sand and fine quartz sand are variable. *Elphidium* and *Quinqueloculina* are generally important genera, whereas *Hanzawaia* is rarely so; in several places a distinctive suite containing abundant *Elphidium gunteri* (Cole) occurs. Most mollusks and foraminifera in type G deposits indicate deposition in a shallow nearshore or marginal marine environment. The variability in the assemblage plus lithologic differences suggest that the deposit as a whole probably contains several facies.

A more detailed study of the mollusks and foraminifera may produce a clearer definition of these facies and indicate distinct time breaks between some of the units. However, in terms of the scope of this study and wide core spacing in the area of occurrence it seems more practical to treat the interbedded shell hash, shell sand, and sand as a single unit.

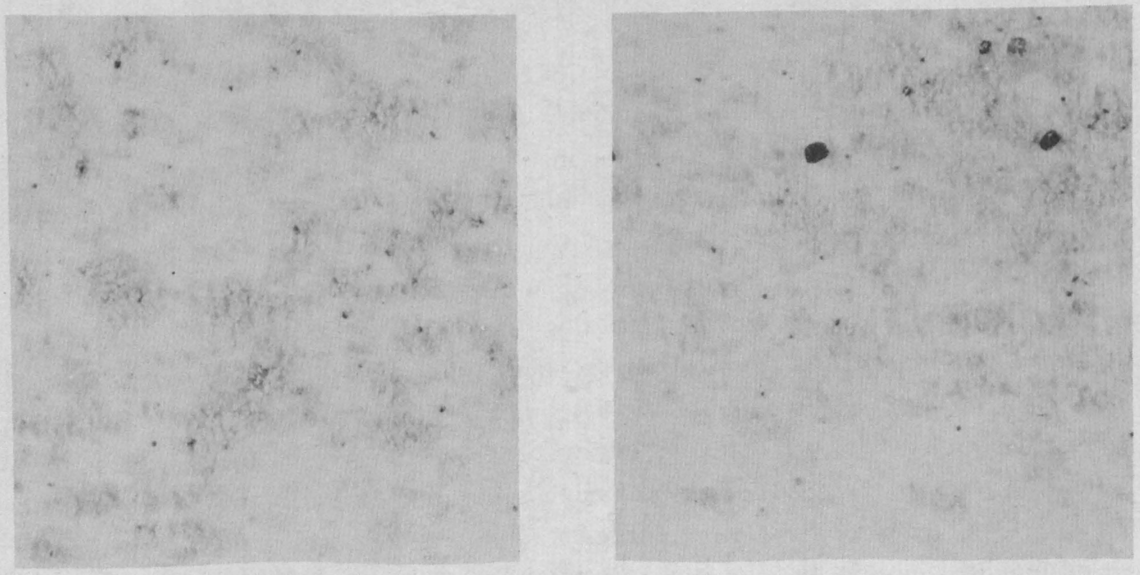
(4) Type L Sediment. Type L sediment is a white to light gray (2.5 yr. N8 to N7), fine to medium foraminifera-rich quartz sand and is restricted in areal distribution and stratigraphic position. It is locally exposed at the surface and commonly overlies type M sediments. Faunal analysis of this sediment indicates it is a late Tertiary deposit (App. C).

Detrital fraction of type L sediment is composed principally of quartz and phosphorite (Fig. 25). Quartz grains are generally fine to medium in size but very coarse-size grains occur frequently. The grains are well rounded and polished. With the exception of phosphorite grains, accessory minerals are rare. Phosphorite abundance varies but is always less than 10 percent of the total sediment; most grains are rounded and highly polished although platy grains are common.

Carbonate content of type L sediments is between 25 and 75 percent by weight. Constituents are mainly foraminifera; most other contributors are echinoids and ostracods. Fine silt and clay in type L sediments appear to be degraded biogenic carbonate, in contrast to the terrigenous fines in types F and G deposits. Individual biogenic grains in type L sediment display evidence of secondary calcification and recrystallization.

Only a few macrofaunal specimens have been found in type L sediment. These include occasional barnacle plates, sharks teeth and fragments of the pelecypod *Amusium mortoni* (Ravenel). A single valve of *Placunanomia plicata* (Tuomey and Holmes) and a few valves and fragments of *Chlamys comparilis* (Toumey and Holmes) complete the list. All of these species have been reported in Tertiary strata of the Atlantic Coastal Plain.

In contrast to the sparse macrofauna, type L sediment contains an abundant and diverse microfauna dominated by *Cibicides* spp. with either planktonic species or species of *Textularia* of secondary importance. Occasional layers in the type L sediment, sampled by only one or two cores, contain an anomalous microfauna indicating that there may be several biofacies associated with this deposit; however, none seem to be widespread.



Sand

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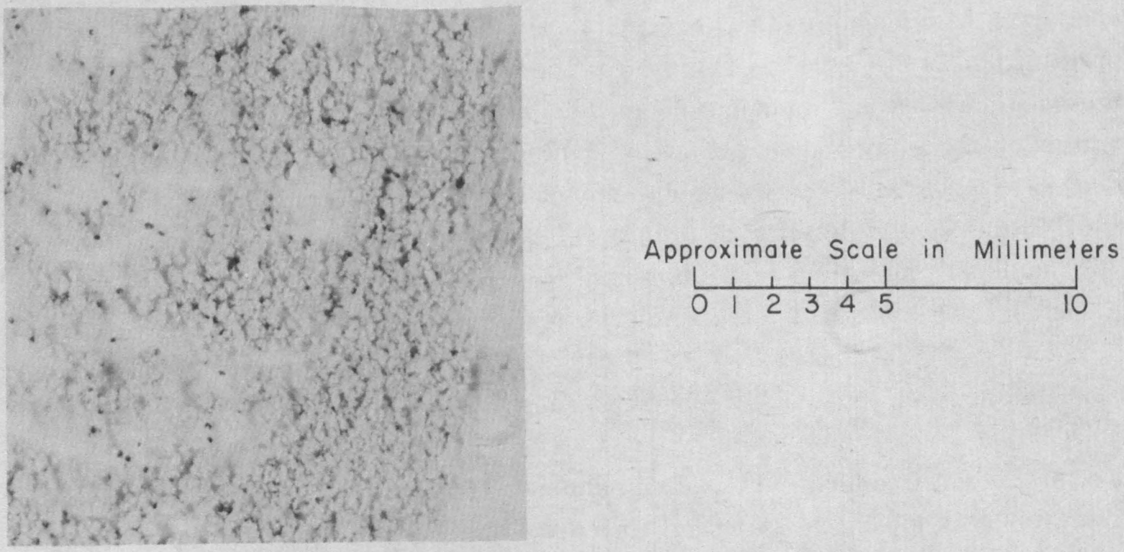


Forams

Figure 25. Photos of type L sediment samples.

(5) Type M Sediment. The stratigraphically lowest lithologic unit sampled in the survey area is a brown and silty sand deposit identified as type M sediment. Views of the sediment in reflected light and in polarized light are shown in Figure 26. The sand grains are chiefly quartz and phosphorite. Silt component in most cores is composed of quartz, dolomite, and amorphous aggregates of an unidentified mineral. About one-fourth of the cores recovering type M sediment contained a matrix of finely particulated organic matter and little or no dolomite silt. In cores 181 and 196 both facies occurred and in both instances the organic facies was stratigraphically lower than the dolomite silt facies.

Silt-sized dolomite grains occur in a rhombohedral shape; most have sharp edges and lack the abrasional features that would indicate a significant transport history. In the shelf survey area off Jacksonville several cores contain evidence of upward chemical degradation of dolomite grains (Sec. IV). The grains gradually disappear upward along with a noted change in grain shape from rhombic to semiangular and a decrease in grain transparency in transmitted light, the latter indicating degradation in crystal structure through chemical weathering.

In type M sediment the only macrofossils recovered were a few small fragments of a thin-shelled pelecypod, probably *Amusium mortoni* (Ravenel). Most type M samples contained no microfossils; however, a few contained abundant tests of a varied assemblage.

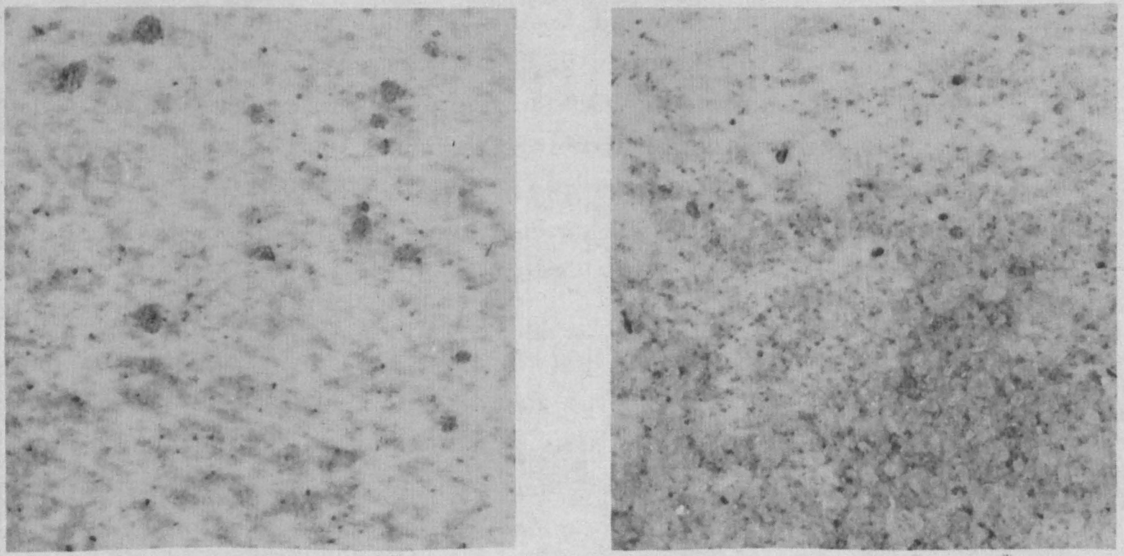
The assemblage in most samples is dominated by *Cibicides* spp. and usually contains sparse to abundant tests of planktonic types. *Cassidulina laevigata* (d'Orbigny), *Bulimina gracilis* (Cushman), and *Buccella* spp. are generally abundant and appear to be characteristic of this sediment; in places, species of *Guttulina* are also important. The assemblage resembles type L sediment in its dominant constituents, but there appears to be some significant differences of type and abundance. The foraminifera in type M sediment suggest that it is of Tertiary age and was deposited in water depths greater than 150 feet.

Because of the stratigraphic import of types L and M sediments, faunal lists of foraminifera in these two Tertiary sediments are included in Appendix C.

(6) Unclassified Sediments. A number of sediments with characteristics different from the commonly occurring types discussed was encountered in cores from the study area. Generally, these sediments occur in only a few cores and have not been categorized as types but are grouped as unclassified (U). Because cores are widely separated, especially in the reconnaissance area south of St. Augustine, some of these sediments may occur over a large area.

Clays are the most common unclassified sediments. These include gray to nearly black, sandy clay which is apparently associated with the silty fine sand (Type F) of the shoreface zone since the strata in which it is found are nearly always directly beneath a deposit of type F material. This appears to be an extensive deposit but probably discontinuous.

Olive to light grayish-green clay, in some places massive, and in others fissile, and containing varying amounts of included sand, occurs mostly south of St. Augustine.



Sand

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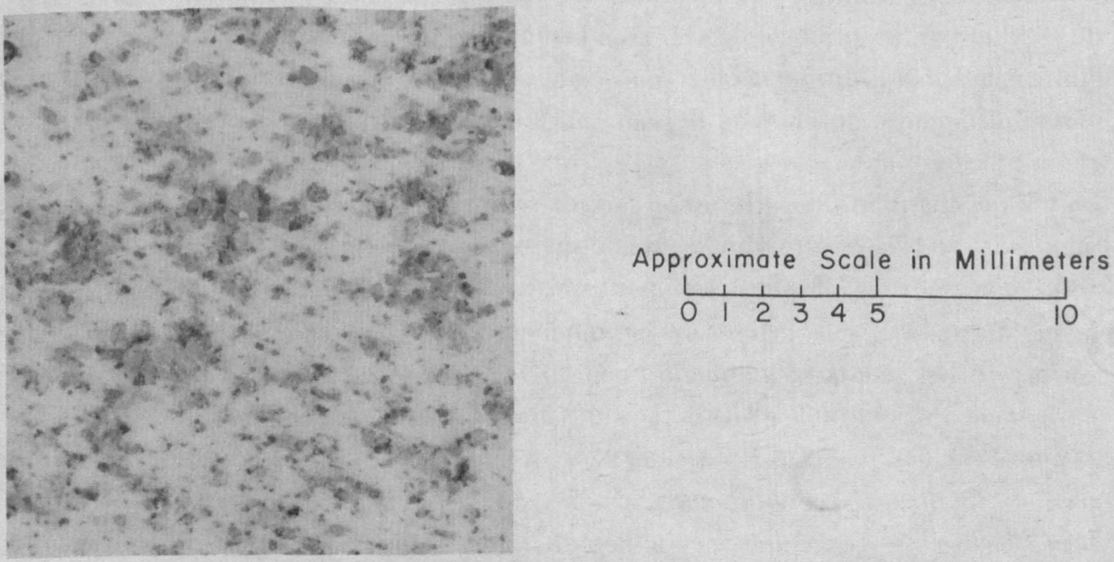

Thin Section

Figure 26. Photos of type M sediment samples.

Amorphous carbonate modules and weathered molds are often included in these clays. Whether a correlation exists between all greenish-colored clays has not been determined. If so, these deposits may underlie extensive areas of the inner shelf south of St. Augustine.

A few samples of gray, black, and brown fissle clay have been obtained from scattered locales within the study area and appear to be unrelated localized deposits.

Brown silty fine sand similar in character in type F sediment occurs in isolated patches seaward of the type F deposit on the shoreface and continuous innermost ramp. There is no evidence that these isolated deposits are continuous with the type F deposit but they probably formed under similar conditions.

Very coarse shelly quartz sand and granules with pebbles and granules of phosphorite occur in a few cores from various parts of the study area. This material has been found directly overlying type L calcarenite and probably contains a residual lag formed by weathering of the underlying type L material. Since it occurs in only a few widely scattered cores this material is probably present only as an erosional remnant of a previously more extensive deposit.

Other unclassified sediments occurring in only one or two cores include lime mud, brown and green friable sandstone, peat, chalky calcareous pebbles, chalky friable limestone with casts and molds of pelecypods, and reddish brown sand with carbonized wood fragments.

2. Sediment Distribution on the Inner Shelf.

a. Surface Distribution Patterns. The dominant characteristic of surface sediments on the north Florida inner shelf is the abundance of fine quartz sand. Over 90 percent of the sediments lying landward of the 70-foot contour are very fine to medium sand size (0.088 to 0.35 millimeters; 3.5 to 1.5 phi); and composed principally of quartz. Surface sediments not included in this generalization comprise a very fine silty quartz-sand facies, an occasional coarse, quartz-sand deposit, and some surface exposures of carbonate-rich quartz sands.

Overall distribution patterns of surface sediment on the inner shelf floor of the study area are largely a result of the thin and discontinuous nature of Pleistocene and Holocene sediments. Patches of older sediment are exposed where the overlying younger layer or layers are missing due to erosion or nondeposition. Thus, adjoining patches of the shelf surface often contain sediments deposited at different times and under different environmental conditions. Within the study limits, sediments as old as probable late Miocene (Type M) and as young as Holocene (Types A and F) are locally exposed in adjacent surface patches. Boundaries between these patches are sharp and not gradational as with lateral facies changes in contemporaneous deposits, and both the lithologic character and faunal assemblages of the separate patches may be strikingly dissimilar. In addition to the exposure of sediments of different age at the surface, there are lateral gradations within contemporaneous deposits and the disposition of surface sediments in detail is locally complex and irregular. However, there is a relatively uncomplicated dominant sediment distribution pattern. Poorly sorted fine quartz sands (Type F) mantle the entire shoreface from Georgia to Cape Canaveral. The shoreface extends out to depths of 45 to 55 feet, usually within 1 to 2 nautical miles of the shoreline. Seaward of this zone type A moderately well-sorted fine to coarse quartz sands are dominant (shown as inner shelf facies in Figure 27). This relatively uncomplicated distribution pattern is typical of the inner shelf, but along the reconnaissance line between Cape Canaveral and St. Augustine, surface sediments generally display more variation than to the north.

Surface occurrence of sediments between the Georgia border and Flagler Beach is shown in Figure 26. The shoreface facies type F (fine poorly sorted quartz sand) is common only within the generally narrow shoreface zone and the adjacent innermost shelf floor; farther seaward type A sands are dominant. This is particularly well illustrated by cores collected along the reconnaissance line between Fernandina and Jacksonville. The anomalous appearances of medium sand on the shoreface are adjacent to St. Marys River Entrance and St. Johns River Entrance and are probably related to inlet influence. Areas of outcropping Tertiary sediments are indicated by the residual facies. These locations are restricted to the southeast corner of the Fernandina grid and two locations in the Jacksonville grid. Seismic reflection profiles indicate that there are probably more exposures in this area that were not sampled.

Few cores were collected from the shoreface along the reconnaissance line between Jacksonville and St. Augustine; hence, there are little data to provide accurate documentation of the distribution of a shoreface facies in this region. Most cores from the region contain thick sequences of inner shelf type A sand, and surface outcrops of underlying strata do not occur. The surface distribution and thickness of type A sand can be directly related to the complex bottom morphology and probably represent a large potential sand reserve. Adjacent to St. Augustine Inlet, type A sediments are distributed over a large region, probably as a result of tidal transport near the inlet. Type F deposits are generally limited to within 2 nautical miles of the shoreline, which may in part be related, since the shoreface is steeper and more narrow in this area than it is farther north. South of St. Augustine the shoreface narrows to about 1 nautical mile in width and the seaward toe lies at −50 feet MLW.

Because of the lower density of data coverage relative to the gridded survey areas to the north, sediment patterns between St. Augustine and Cape Canaveral are interpreted with less reliability. Most landward cores contain fine poorly sorted sands at the top (Type F), and seaward cores contain medium sands (Fig. 28). Several subsurface units lie near the surface and exhibit some influence on sediment character and although most sediments are identified as types A or F, there are variations. In addition, the spatial distribution of sediments (Sec. IV) indicate that the simple distribution pattern of type F deposits on the shoreface, and of type A seaward of the shoreface, is the result of a complex succession of strata.

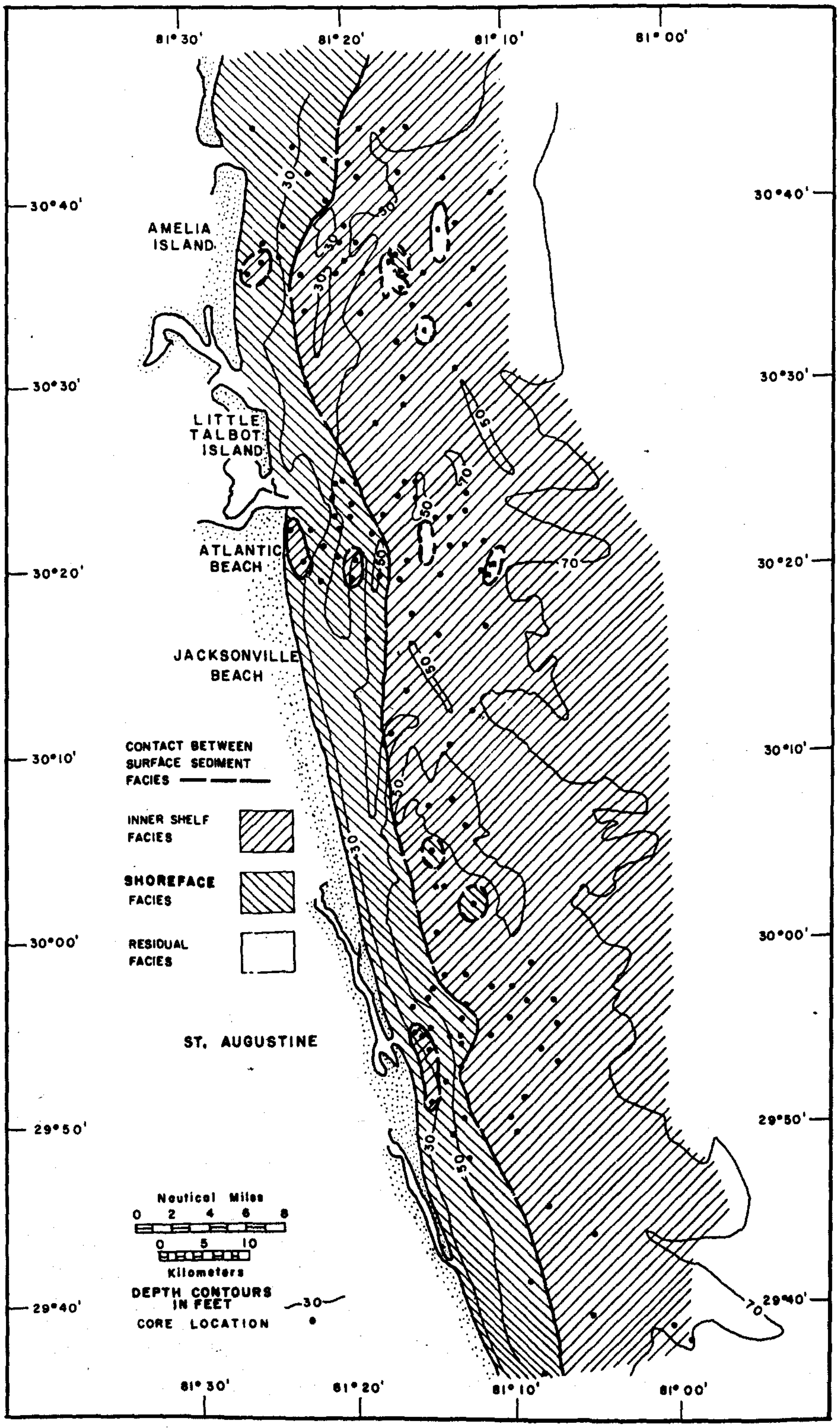

Figure 27. Surface distribution of sediments on the north Florida shelf. Sediments are grouped in facies according to dominant occurrence. Inner shelf facies is composed of type A sands; shoreface facies is predominantly type F sand. Type L (quartz-foraminiferal sands) and type M sediments (quartz sand-dolomite silt) occurrences are designated residual facies and delimit the approximate area of outcrops of underlying Tertiary strata.

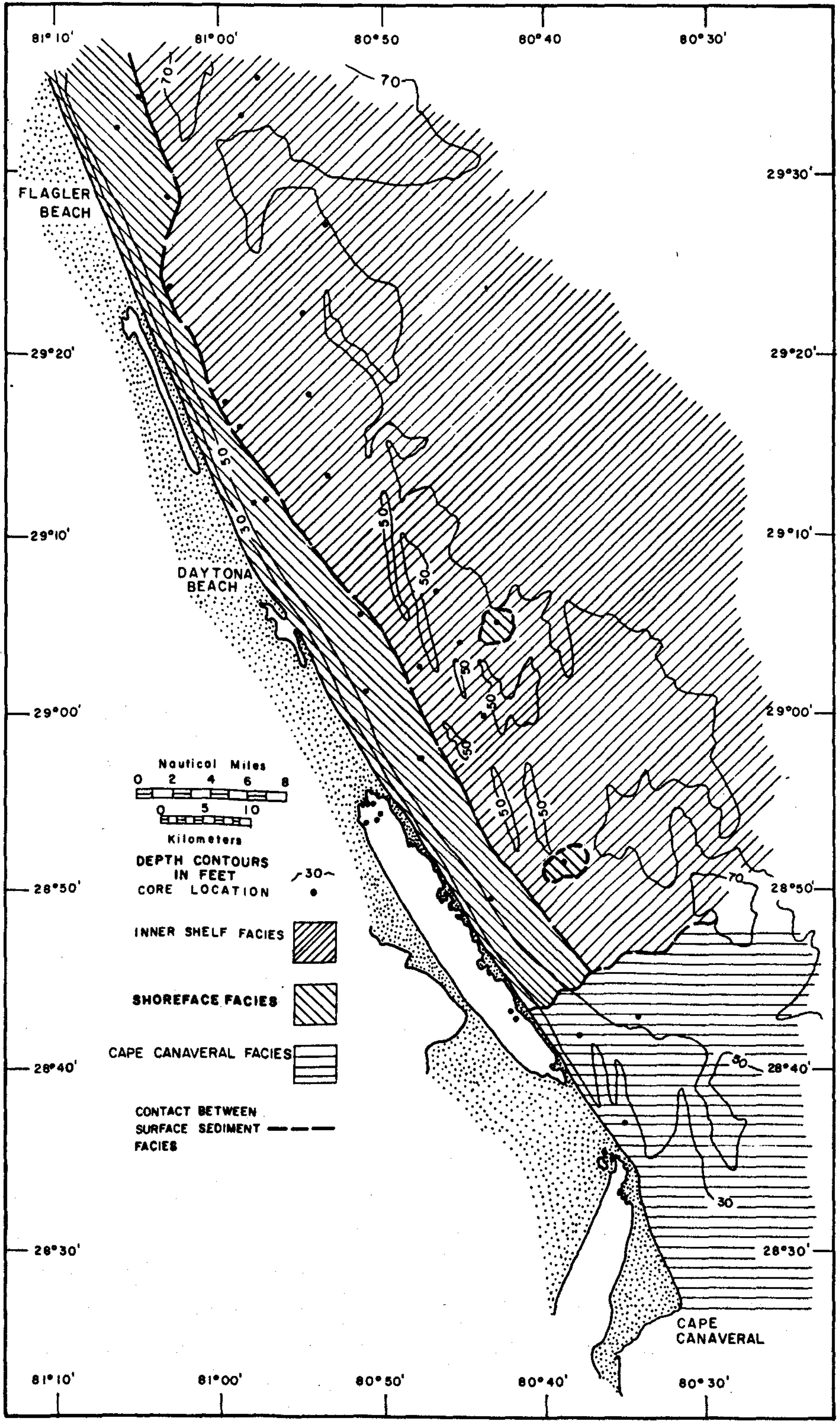

Figure 28. Surface distribution of sediments on the north Florida shelf. Sediments are grouped in facies according to dominant occurrence. Inner shelf and shoreface facies are as in Figure 27. Cape Canaveral facies refers to the dominant medium quartz-calcareous sand associated with Canaveral shoals.

Type A deposits adjacent to Mosquito Lagoon and south are more calcareous than those to the north and represent a transition to the medium to coarse, quartzose-calcareous deposits of Cape Canaveral. These deposits are designated the Cape Canaveral facies in Figure 28 and described by Field and Duane (1974) as a modern sand sheet derived from reworking of Pleistocene substrata.

b. Thickness and Spatial Distribution of Lithologic Units.

(1) Georgia Border to Jacksonville Beach. South from the Georgia border to Jacksonville the shallow shelf is characterized by three distinct litholigies: (a) fine to medium quartz sand (Type A); (b) poorly sorted very fine to fine quartz sand (Type F); and (c) an assemblage of dolomite silt and quartz sand (Type M) overlain in places by quartzose foraminiferal sands (Type L).

As discussed previously, type F sands characteristically mantle the shoreface and innermost ramp areas along the entire survey area and are mostly restricted to that zone. The shoreface is topographically indistinct in the Jacksonville to Georgia area but roughly extends 4 to 5 nautical miles offshore. Most cores from this region are relatively short (6 feet) but provide evidence that these deposits extend in most places to sediment depths of 4 feet and are not simply a thin veneer overlying the outcropping shoreface deposits. Some of the seismic reflection and core data suggests that in some locales there may be an older sedimentary framework underlying the shoreline. Similar fine-grained silty sands occur seaward of the shoreface in a few isolated locations on the shelf surface or at shallow sediment depths but are not continuous with or genetically related to the modern shoreface deposits.

Most of the shelf region between Georgia and Jacksonville is covered by type A fine to coarse quartz sand. Deposits are normally 1- to 3-feet thick but in a few places are thicker than 6 feet. Off Fernandina and Jacksonville type A quartz sand is thicker and more uniform in lateral extent. This pattern appears to be related to the presence of St. Johns and St. Marys Rivers, although it may be only an apparent pattern due to the lack of detailed surveying between the two areas. However, near St. Johns River the surface sand sheet is less than 8 feet thick.

A marked characteristic of sediment distribution in the region is the widespread occurrence at or near the surface of late Tertiary dolomite silts (Type M) and foraminiferal sands (Type L). These sediments are usually present several feet below the sea floor in cores from the Fernandina and Jacksonville grids and the reconnaissance line connecting the two grid areas. Joint occurrence of these two Tertiary-age deposits is fairly common. Cores containing only the white planktonic foraminiferal sand (Type L) appear not to have penetrated deep enough to reach the underlying dolomite silt (Type M). In the Jacksonville grid several cores containing only type M, the stratigraphically lower unit, appear to have an erosional surface separating them from the higher type A sands, indicating that the associated type L may have been removed through erosion.

Distribution of cores containing late Tertiary sediments (Types L and M) and their relation to the depth of penetration to the first mappable sonic reflector is shown in Figure 29. There is a subtle suggestion of parallel alinement of the coast and shape of the shelf sediment lying over the mapped horizon. Cores from the gridded areas correlate well with the structure; cores from areas showing an overburden of 10 feet or less on top of the uppermost acoustic reflector often contain Pliocene-age foraminiferal sands or dolomite silts. Cores collected from areas having greater than 10 feet of sediment consistently contain only fine to medium quartzose sands.

The influence of the shallow structure on sediment distribution is further demonstrated in the cross-sectional profiles shown in Figures 30 and 31. These profiles document the relatively close association between acoustic and lithologic data and demonstrate that post-Tertiary sediments are often quite thin on the north Florida shelf, and are even absent in some places.

Within the Jacksonville grid at shallow subsurface depths and atop the surface of an older (Type M) underlying unit, are found what is interpreted to be the remnants of a weathered surface (soil or ground water profile). This interpretation is based on the presence of iron-stained and organic-coated quartzose sands several feet down in eight cores, all within a well defined area. The lithologic boundaries correlate with the red (R) acoustic reflector. Core location, depth of discolored sands and extent of the soil horizon are shown in Figure 32. Outside the soil horizon area (Fig. 22) but at the same subsea depths, dolomite silts (Type M) are encountered in cores 59, 61, 63, and 184. Individual dolomite grains show a progressive upward degradation towards the soil horizon in both grain shape and crystal structure, suggesting effects of chemical deterioration through exposure to subaerial processes. Overlying the soil horizon in cores 46 and 47, are organic-rich muds and peat. The peat sample in core 46 at –60 feet MLW has a radiocarbon age of 9,625 years (B.P.) and represents initial accumulation upon the exposed surface as the Holocene sea transgressed to that elevation. No other distinct, laterally continuous, soil horizons are apparent within the survey region. However, isolated cores offshore from Fernandina and St. Augustine contain similar lithologic transitions which probably record a partially obliterated erosional surface. The same criteria of upward degradation and depletion of carbonate grains towards a stained, quartzose sand deposit is present. Furthermore, the depths of these transitions correlate with depths of strong acoustic reflectors which lie near the surface and correlate with marked lithologic transitions to Tertiary sediments.

(2) Jacksonville Beach to St. Augustine. South of the Jacksonville survey area overall sediment character is similar to that from Jacksonville north (Fig. 33). However, the relative distribution of the different sediment types changes significantly both laterally and vertically. Fine to medium quartz sands (Type A) are thicker and more laterally extensive; pre-Pleistocene dolomite silts and foraminiferal sands are less abundant and more restricted in lateral extent. Fine, poorly sorted quartz sands (Type F) characterize the shoreface region, as they do in the northern sector.

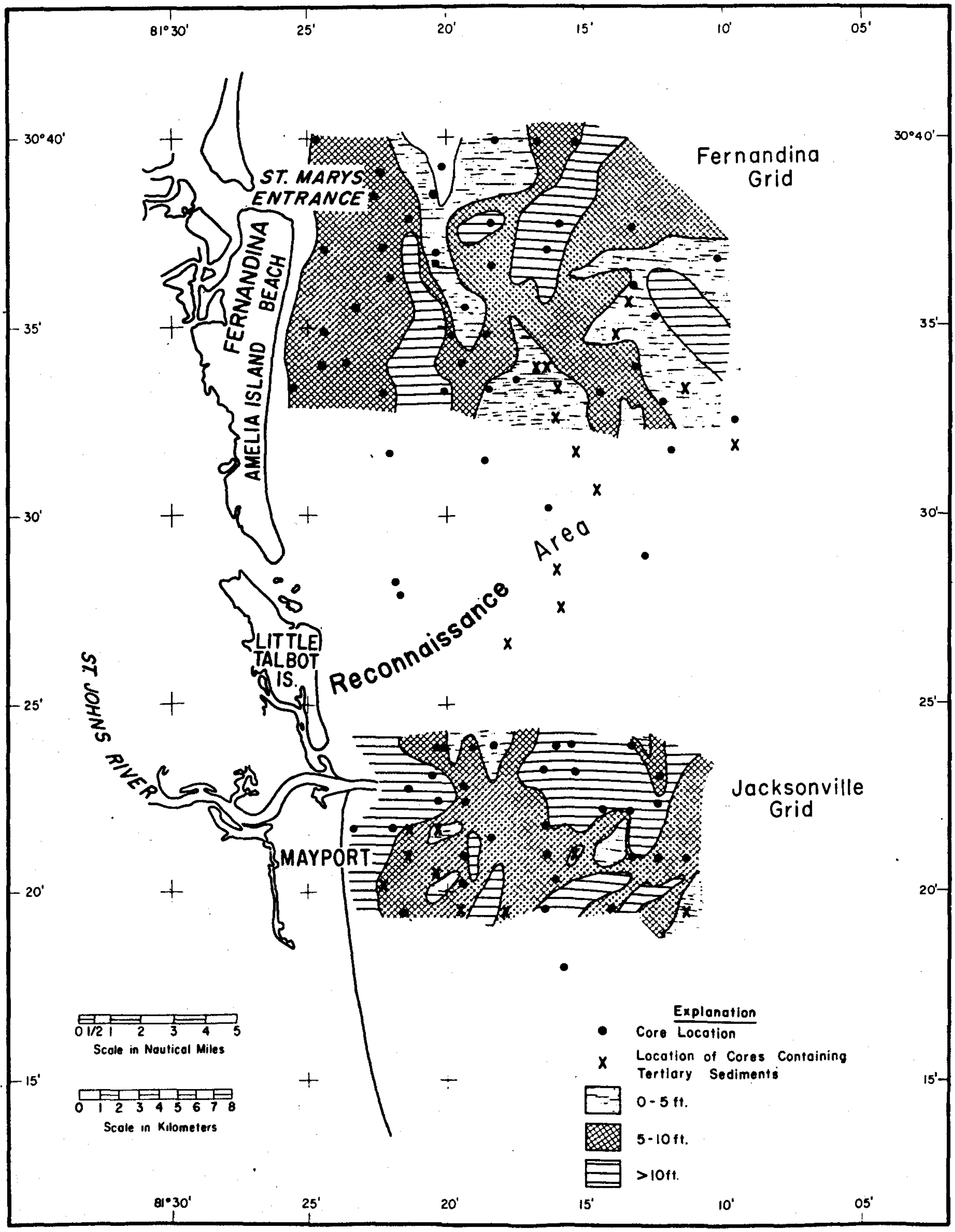

Figure 29. Map of the Georgia border to Jacksonville area showing relationship between depth to first sonic reflector and locations of cores bearing Tertiary sediments. Depths to first reflector, or overburden thickness, is indicated by Zip-a-tone patterns. Note close association of cores containing Tertiary-age material (X's) with seismic data showing areas of thin (< 10 feet) overburden. Shore-normal profile lines in each grid give locations of lines shown in subsequent figures.

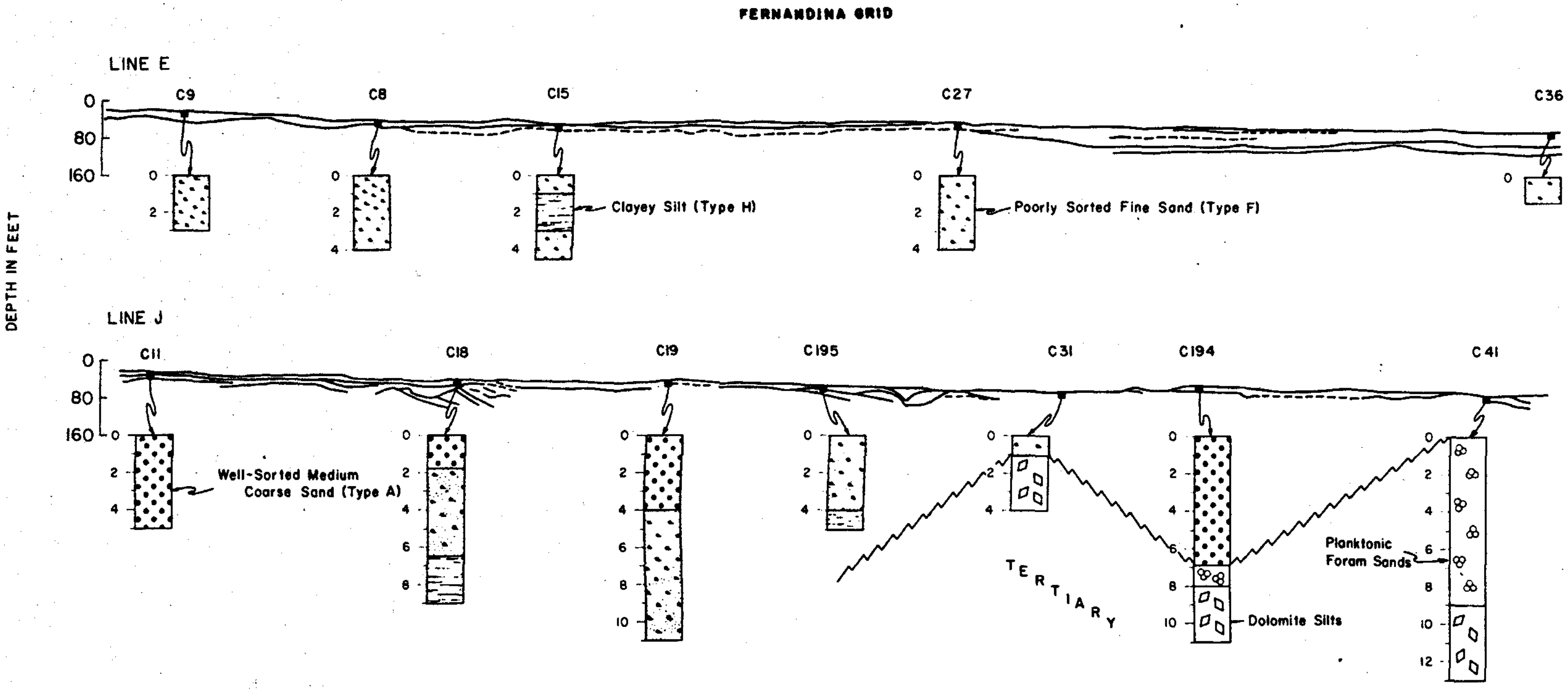

Figure 30. Shallow shelf stratigraphy along lines E and J in the Fernandina grid. Cores are plotted to scale on the reduced seismic profile and expanded below the line to show lithology. Tertiary sediments are correlated on basis of fauna and mineralogy.

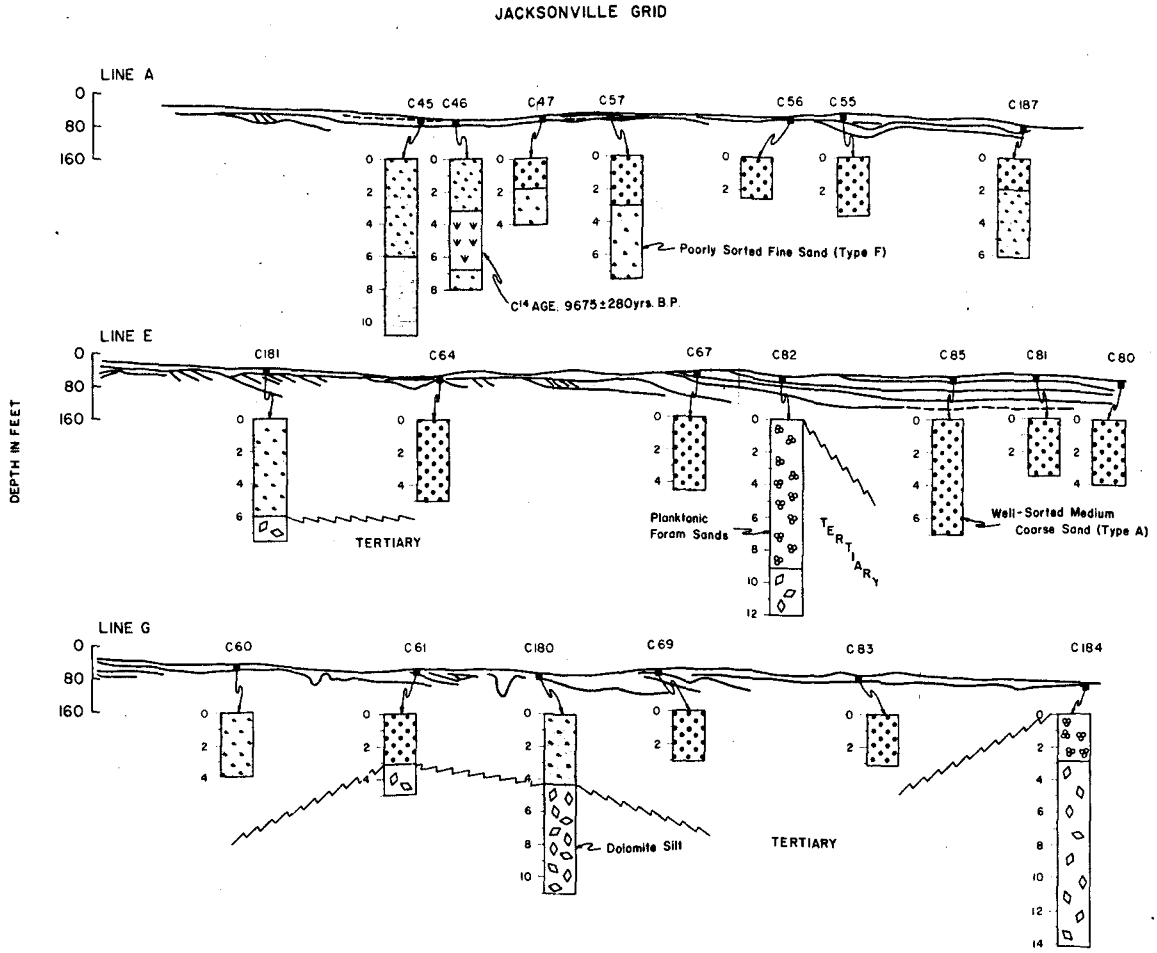

Figure 31. Shallow shelf stratigraphy along lines A, E, and G in the Jacksonville grid. Cores are plotted to scale on the reduced seismic profile and expanded below the line to show lithology. Tertiary sediments are correlated on basis of fauna and mineralogy.

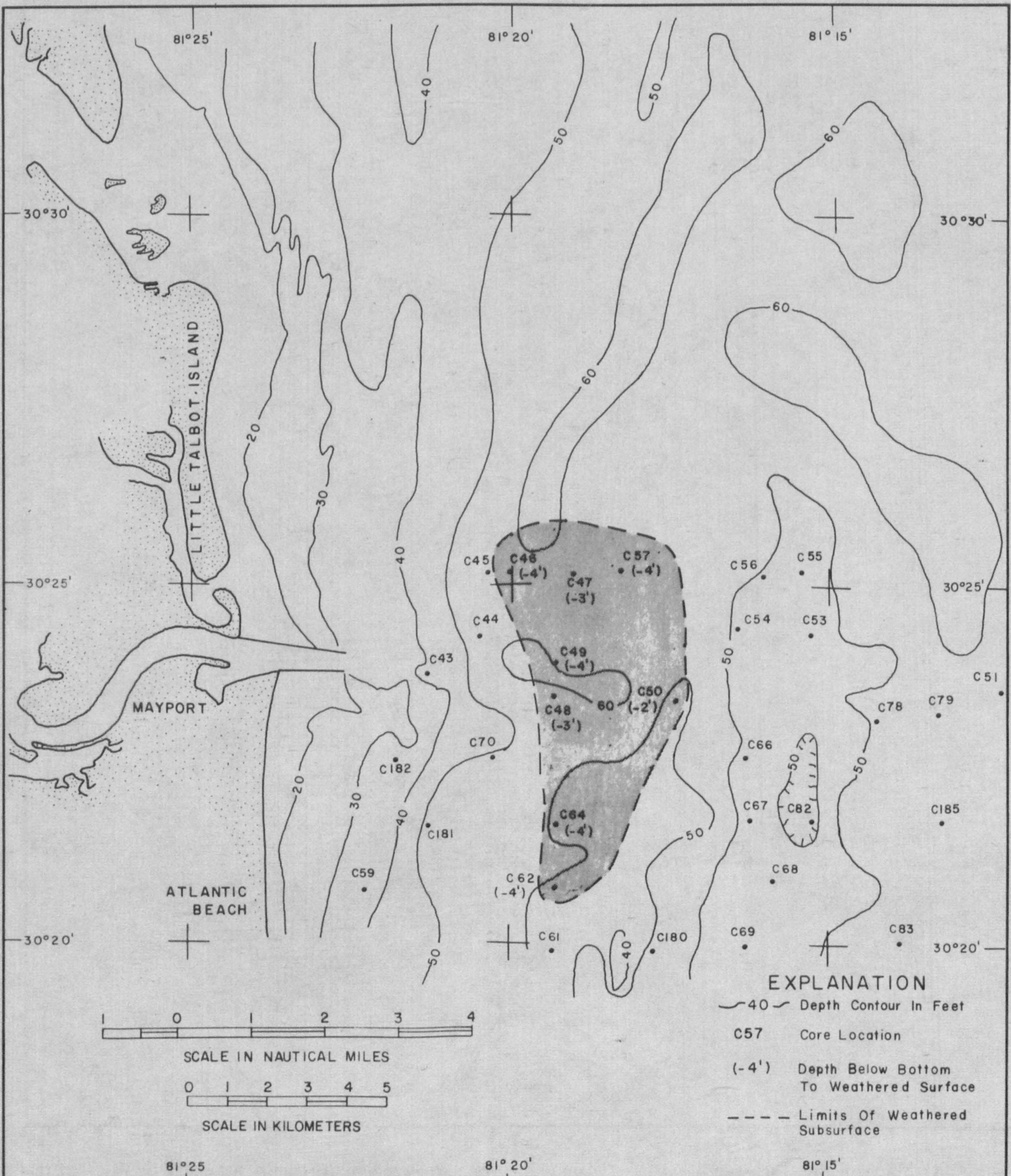

Figure 32. Bathymetric map of the inner shelf near St. Johns Inlet showing location of a subsurface soil horizon. Subsurface depth of weathered sediments is given for each core. The weathered zone unconformably overlies Tertiary deposits.

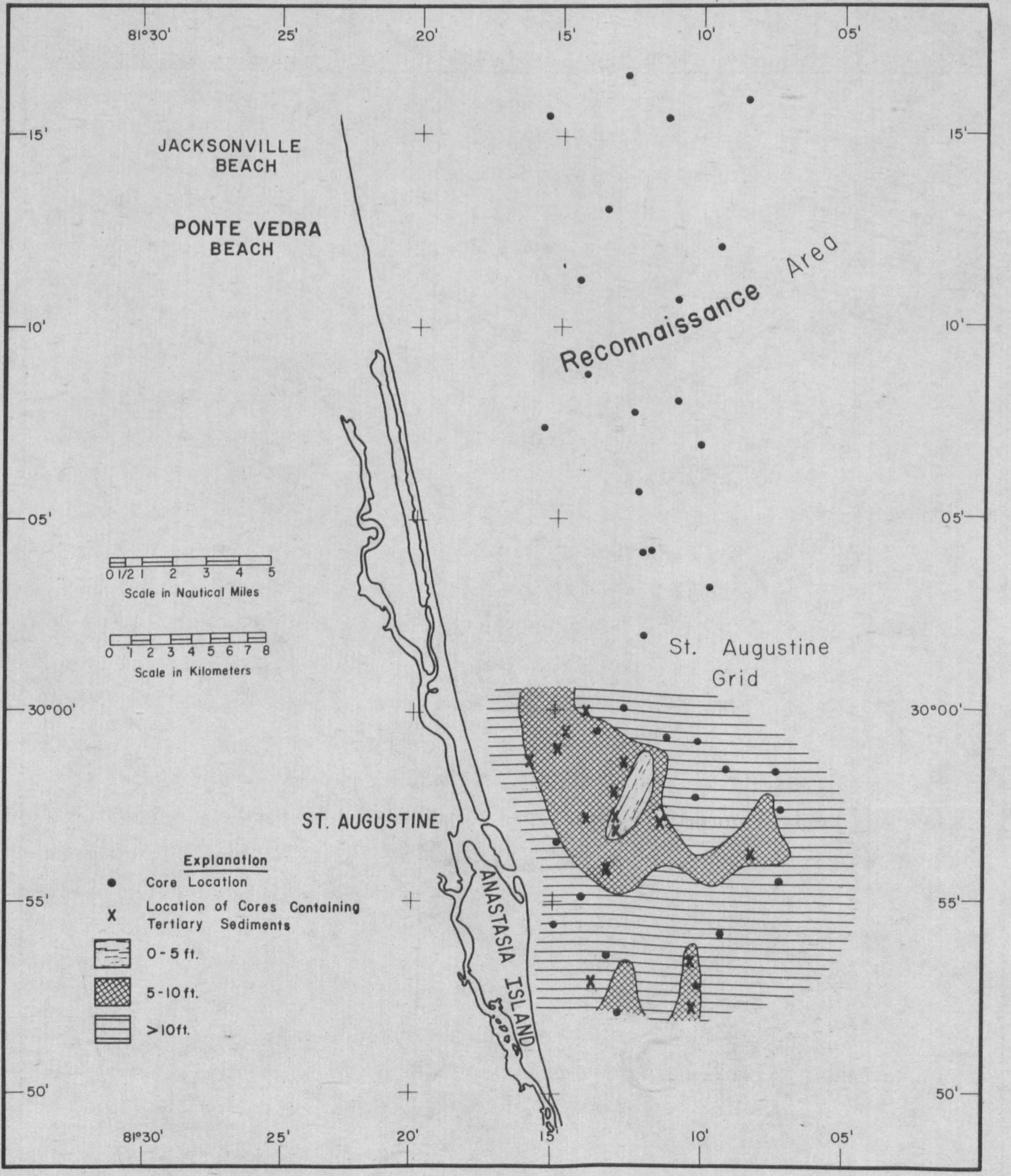

Figure 33. Map of the Jacksonville to St. Augustine area showing relationship between depth to first reflection and locations of cores bearing Tertiary sediments. Depth to first reflector, or overburden thickness, was determined by acoustic data and is indicated by a Zip-a-tone pattern. Note the close association. Acoustic data north of St. Augustine (reconnaissance line) is too sparse to contour. Note the close association in the grid area of cores containing Tertiary material (X's) with acoustic data showing areas of thin (< 10 feet) overburden. Shore-normal lines in the grid area refer to lines in Figure 26. This figure (at same scale) ties to Figure 22.

The reconnaissance line extending from Jacksonville to St. Augustine is characterized by relatively thick sequences (greater than 8 feet) of type A sand. Of the 18 cores from this section, 12 contain type A sand to the bottom. Only sediment types A and F are in this region, and their occurrence is correlative between cores. Older strata occur at or near the surface at several locations in the St. Augustine grid. These deposits include type L and only rarely type M, both of which are more common at Jacksonville and north; and several lithologies which are referred to either as type G or unclassified sediment (U). The unclassified sediments represent many diverse lithologies while type G sediment is typically coarse quartzose-molluskan sands, judged to be Pleistocene in age. Core 129 on line J in Figure 34 shows a thin, poorly indurated calcarenite overlying Tertiary deposits.

(3) St. Augustine to Cape Canaveral. Sediment character changes south of St. Augustine as the surface Quaternary sediments thicken and display facies changes that are quite marked on shore-normal lines but not clearly defined on shore-parallel lines (Figs. 35 and 36). Clayey silt deposits and muddy shell gravels, not present north of St. Augustine, occur nearshore in surface and subsurface units along the reconnaissance line, particularly south of Daytona Beach. Most muds and shell gravels are adjacent to the Mosquito Lagoon barrier and may simply reflect a migration of the lagoon-barrier island complex landward during the last rise in sea level. The relation between selected cores along the reconnaissance line is shown in Figure 35. Along line A–A′ the southernmost near-surface occurrence of Tertiary strata is in core 142. Overlying sediments are very fine to fine silty sands of uncertain origin. Cores not alined in shore-parallel configuration show onshore-offshore facies changes. Nearshore cores at C′, D′, and E′ (Fig. 36) contain buried sands and (bioturbated) muds with deeply weathered shells. These deposits pinch out seaward beneath the surface deposits of clean medium quartz sand. Profile F-F′ is a simplified example of the same trend; shelf sands are replaced landward by older, lagoonal deposits.

Trends in sediment thickness and character along the reconnaissance line, particularly south of Daytona, are linear shore-parallel patterns different from those north of St. Augustine. The patterns are similar to those mapped by Field and Duane (1974) in the Cape Canaveral area.

IV. DISCUSSION

1. Shallow Subbottom Stratigraphy and Structure.

Although stratigraphically logged wells from the coastal zone of northeastern Florida are scarce, a sufficient number exists for tentative correlation between onshore coastal geology and reflection units beneath the inner Continental Shelf (Table 4). Of the five reflection units observed in this study, all but the red unit probably extend under the east Florida landmass where they should be represented in coastal wells.

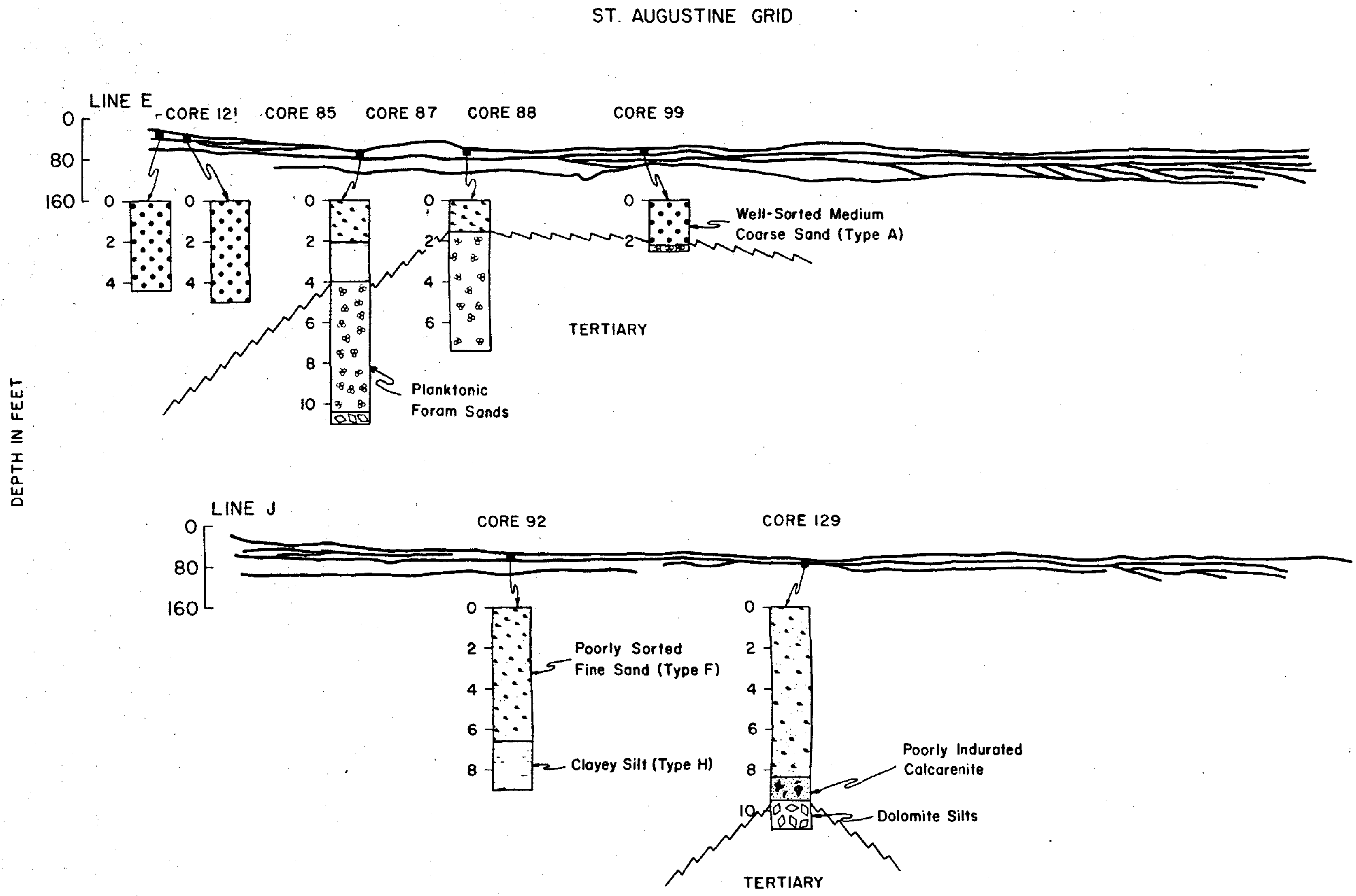

Figure 34. Shallow shelf stratigraphy along lines E and J in the St. Augustine grid (see Fig. 33). Cores are plotted to scale on the reduced seismic profile and expanded below the line to show lithology. Tertiary sediments are correlated on basis of fauna and mineralogy.

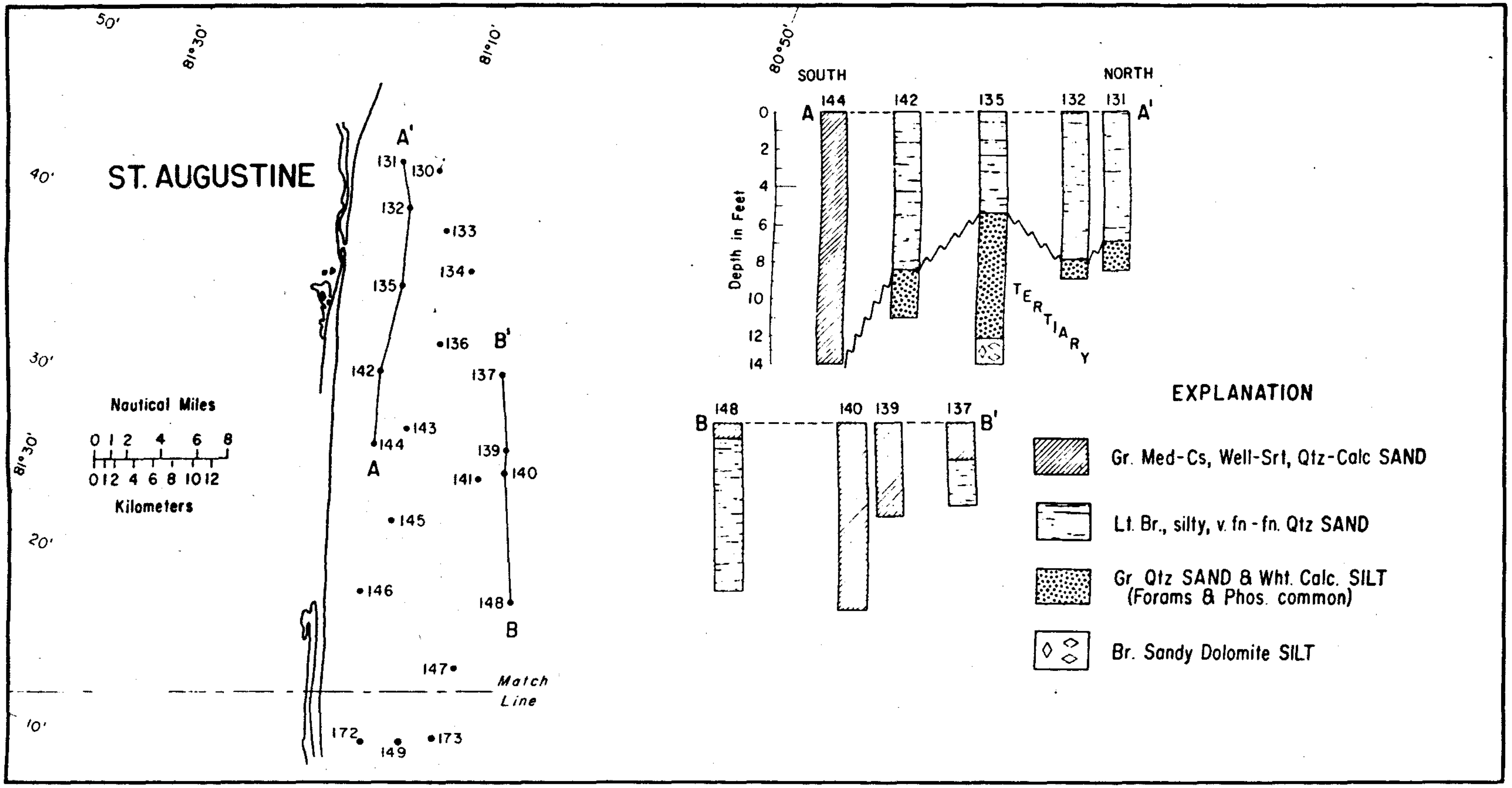

Figure 35. Lithostratigraphic correlations along selected transects between St. Augustine and Daytona Beach.

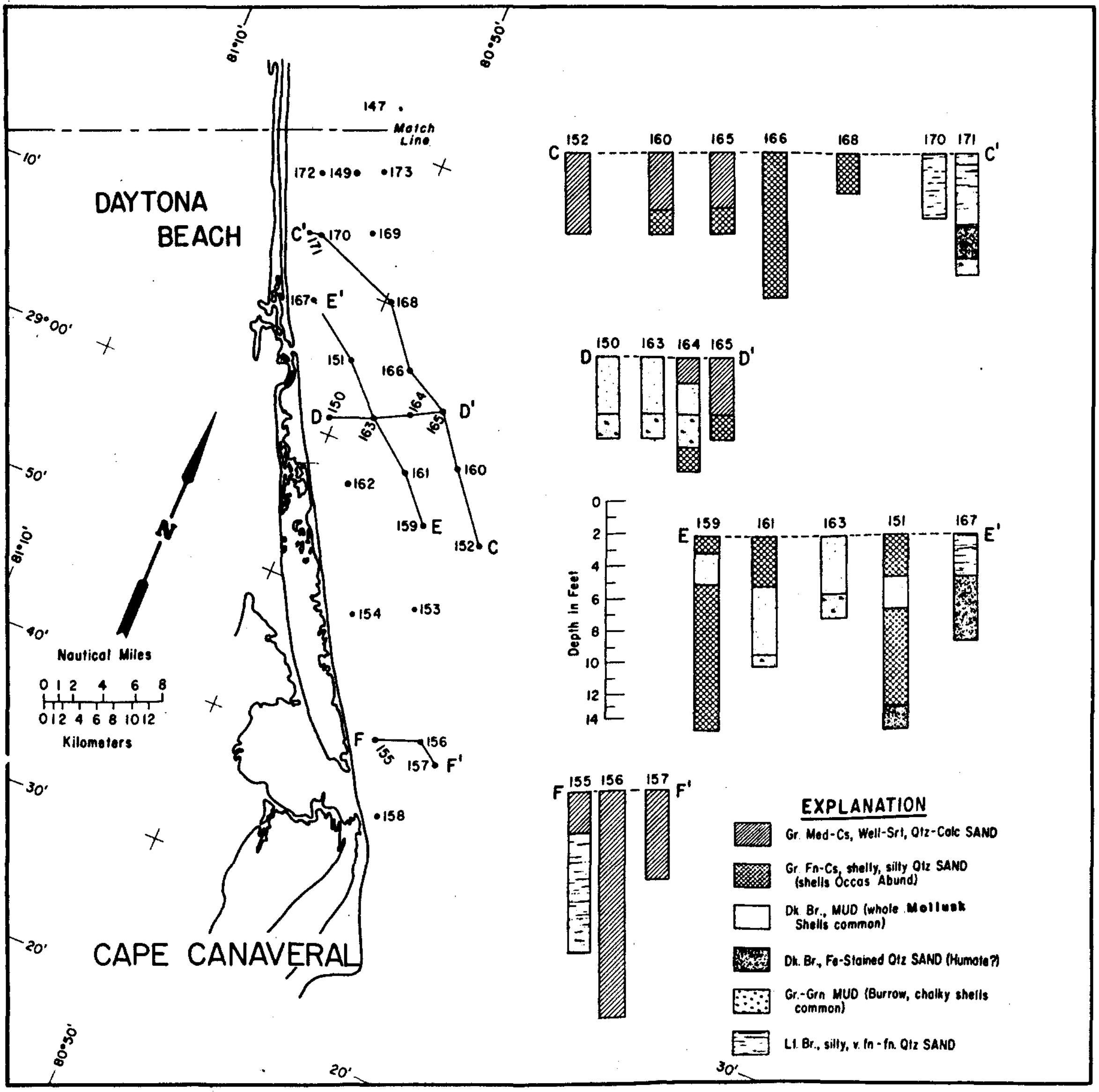

Figure 36. Lithostratigraphic correlations along selected transects between Daytona Beach and Cape Canaveral. Note the shore-normal trends in vertical sediment relationships.

Table 4. Stratigraphic summary of reflection units.

Reflection unit	Sediment	Probable age
A	sand, silt, clay, shells	Pliocene-Pleistocene, Holocene
B	sand, silt	late Miocene
C	clay, sand	Miocene
D	clay, sand	Miocene
E	limestone	Eocene, Oligocene, Miocene

Between Cape Canaveral and Palm Valley (30°10′N.) the green primary reflector correlates closely with elevations in coastal wells on top of the Floridan artesian aquifer (Bermes, 1958; Tarver, 1958; Wyrick, 1960; Brown, et al., 1962). The top of this aquifer is common but not everywhere coincident with the top of the Eocene section.

North of Palm Valley, wells at Jacksonville Beach and Fernandina Beach (Leve, 1961a, b) show the top of the Floridan aquifer lying over 500 feet below mean sea level (MSL) while the green reflector lies under the adjacent shelf no more than 350 feet below MSL (Fig. 15). Reasons for this are not clear; possibly the green surface actually dips northward to over 500 feet below sea level at Jacksonville, but is obscured by an overlapping strong reflector which may appear on seismic reflection records as a direct continuation of the green surface. Alternatively there may be a sharp downward displacement of the green unit between the inshore boundary of the survey area and the onshore wells at Jacksonville and Fernandina.

Faults and solution features occur in Eocene strata underlying the Florida peninsula and it is likely that similar features occur in the green unit; however, there is no clear evidence of either in the seismic reflection profiles. Some small angular irregularities of the green reflectors may result from fault displacement rather than erosion but firm evidence is lacking. If large solution features do exist it is probable that they are either masked by the generally poor reflection returns from below the green reflector or by insufficient acoustic contrast at the boundaries.

The purple reflection unit and the overlying white unit lie at elevations similar to those of coastal wells in units comprising the aquiclude of the Floridan aquifer. These strata are relatively impermeable, and in the coastal zone are generally considered to consist of Miocene beds.

Over the structural high off Daytona Beach the purple and white units and the overlying red unit are missing or too thin to be resolved on available seismic reflection records. The Floridan aquifer thus appears to be breached in this locale as the overlying sediments of the blue reflection unit consist generally of permeable clastics.

The red reflection unit is believed to be confined primarily to the shelf area and not continuous with any widespread deposit under the adjacent landmass. Since this unit is overlain in places by type L sediment of early Pliocene age and underlain by probable middle Miocene strata of the purple and white units it seems likely that this unit is of late Miocene age. The foraminifera in some respects suggest relationship to late Miocene Choctawhatchee Stage fauna but more detailed study is needed to establish any possible relationship.

Sediments in the blue unit overlying the red reflectors are believed to include thin strata of Pliocene, Pleistocene and Holocene age. The entire unit is quite thin, especially in the northern part of the study area where it rarely exceeds 15 feet in thickness; in the south the unit is up to 40 feet thick. Since the surveyed area is displaced eastward toward the south the apparent thickening of this unit may indicate a general downdip increase in thickness rather than "onstrike" southward thickening. JOIDES Hole No. 1 at 81°00'W. off Jacksonville contains about 65 feet of post-Miocene sediment indicating an eastward thickening of the post-Miocene deposits. This post-Miocene section is about 20 feet thicker than the blue reflection unit at a comparable longitude in the southern part of the study area.

A structure contour map on the surface of the Ingles Formation of the Ocala Group (Vernon, 1951) shows that under east Florida, Ocala Group strata rise southward from the Georgia border to a broad truncated high situated westward of Daytona Beach. At the summit of the high Vernon found a closed fold truncated on the west by a fault. He called this feature the Sanford high and hypothesized that before disruption by faulting and erosion the high may once have extended westward across the peninsula. Puri and Vernon (1964) believe that the structural movement which formed the Sanford high took place in early Miocene time.

A comparison between Vernon's (1951) map on the Ingles Formation and the green reflector (Fig. 15) shows similar structural trends with both surfaces rising southward to a broad high near Daytona Beach. This suggests that strata involved in the structural development shown by Vernon's map and by the green reflector are continuous and that the high off Daytona Beach is possibly an eastward prolongation of the Sanford high.

A second prominent feature of the subbottom strata is the abrupt steepening in eastward dip of the green reflector from a slope of about 1 on 400 to 1 on 50 occurring south of the Volusia-Brevard County line (28°37'N.). Presumably this feature is more extensive but lies too far offshore elsewhere in the study area to be intersected by survey lines. However, south of Cape Canaveral the slope appears to extend as far as Fort Pierce (Meisburger and Duane, 1971). Total depth of the steep slope in the green reflector is unknown but it extends from about –180 to –200 feet MLW to at least –450 feet MLW, the maximum depth of coverage of available seismic reflection profiles. Whether this slope is of structural or erosional origin cannot be ascertained from available data.

2. Sources of Inner Shelf Sediments.

a. Surface and Near-Surface Tertiary Deposits. The relative occurrence and abundance of surface and near-surface deposits of Tertiary age on the north Florida inner shelf are of major significance to shallow subshelf stratigraphy. Exposures of these strata at the shelf surface have not been reported previously nor has their proximity to the surface been suspected. This is due in part to the lack of seismic profiling in inner shelf waters and the preponderance of surface-type grab samplers used by investigators for reasons of efficiency and economics. The occurrence of Tertiary-age sedimentary units marked approximately by a widespread, mappable, acoustic reflector and containing white, quartzose-foraminiferal sands and brown quartz-sand dolomite silt, has several marked implications toward interpretation of Holocene coastal retreat and sediment sources.

Both sedimentary units are judged to represent primary deposition, and therefore have not resulted from major reworking and secondary transport. Evidence for this is severalfold as discussed below.

The lower unit (Type M) contains an abundance of well rounded, very fine to fine phosphorite grains and rounded medium quartz grains. The sediments are distinctly bimodal with quartz, phosphorite and occasionally, foraminifera comprising the sand fraction, and dolomite or finely particulate organic matter and unidentifiable degraded carbonate grains comprising the silt fraction.

Dolomite silt grains are wholly intact and lack any evidence of an abrasional history. Degraded grain surfaces occur only in isolated cores, and in those instances there is a noted increase in grain surface irregularity towards the surface, which is interpreted to be the result of *in situ* weathering processes. Studies of sediments obtained from JODIES hole J-1 seaward of the study area showed a generic relationship between dolomite silt clusters and overlying calcareous deposits. A gradual transition between the two sediments exists, with decreases in calcareous fauna accompanied by an increase in similar-sized authigenic dolomite clusters (Schlee and Gerard, 1965). Furthermore, in a study of dolomite sediments offshore of Charlotte Harbor on the gulf coast of Florida, Huang and Goodell (1967) concluded that abraded grain surface characteristics indicated the sediments had been derived from an inland source. In contrast, dolomite grains in the present survey area have clean unaltered rhombohedral surfaces and occur in silt-size friable clusters that suggest a complete absence of transport.

Overlying the dolomite silty sands are type L deposits composed of quartz, phosphorite, and calcium carbonate grains. The calcareous fraction is principally composed of foraminifera and small, largely unidentifiable carbonate fragments. Foraminifera in one representative sample and ostracods in several samples were determined to be Pliocene in age by Dr. Joseph Hazel and Miss Ruth Todd of the U.S. Geological Survey (letter reports to CERC dated 3 and 15 December 1970). Several ages and environments are judged to be represented by type L sediments, Hazel's analysis showing that both early and late Pliocene types were present, and that certain species suggested deeper water than others.

Presence of many planktonic foraminifera in sediments would indicate water deeper than that of the survey area. Similar fauna are presently accumulating in outer shelf and shelf edge (200 to 300 feet below sea level) sediments along the southeastern U.S. continental margin where sediment influx is very low (Milliman, Pilkey, and Ross, 1972).

Based on ostracod species and abundance of planktonic foraminifera it is estimated that the original environment of deposition for most type L sediment was 200 feet deep, or about 120 feet deeper than at present. Onshore marine terraces occur as high as 120 feet (Penholoway Terrace) and the upper two terraces have been assigned a Pliocene age (Alt and Brooks, 1965). This information corroborates, in a general way, a deepwater environment of about 300 feet for a relatively short duration during which time type L sands were deposited.

b. Significance of Mud and Shell Gravels. Sediments with modal sizes larger or smaller than sand (0.63 to 2.0 millimeters; 4.0 to −1.0 phi) are rare on the north Florida inner shelf. In a shallow stratigraphic record of a transgressed shelf, sediments of all sizes are usually present, reflecting the preservation, at least in part, of the highly variable environments. At Cape Canaveral, lagoonal deposits are common in surface and near-surface deposits (Field and Duane, 1974). Adjacent to the barrier island coasts of the middle Atlantic Bight, estuarine and lagoonal facies are commonly present beneath the shelf surface (Duane, et al., 1972; Shideler, et al., 1972; Swift, et al., 1972). In both areas, deposits are typically composed of sandy and clayey silts with occasional channel clays, and admixtures of shell gravel with silt. Peat deposits and organic muds are often present.

The near absence of shallow subsurface muds and shell gravels on the north Florida inner shelf indicates either complete removal of that section of the stratigraphic record or absence of a significant barrier coast during Holocene development. Since extensive removal of back barrier facies has not occurred elsewhere, the latter explanation seems more accurate. Although silt to fine grain deposits and muddy shell gravels occur at St. Augustine and north, their distribution and extent are very limited. Along the reconnaissance line south of St. Augustine these particular lithologies become more abundant. This section of the survey area has a well defined barrier-lagoon configuration (Fig. 35). Mosquito Lagoon is over 26 nautical miles long, approximately 3.5 nautical miles wide and is separated from the ocean by a narrow 0.5 nautical mile barrier. The occurrence of lagoonal sediments (poorly sorted shell gravels and muds bearing lagoonal fauna) at shallow sediment depths on the inner shelf suggests that a barrier analogous to the present one existed during early Holocene at a point seaward of the existing shoreline. Interpretation of the large shoals off Cape Canaveral as remnants of a relict cuspate foreland by Field and Duane (1974) provides supporting information for existence of a barrier-beach ridge complex at this end of the survey region.

c. Generation of Surficial Quartzose Deposits.

(1) Quaternary Fluvial Sources. The dominance of quartz sand in surface and near-surface deposits throughout the study area has been emphasized in this report. Based on earlier works (Gorsline, 1963; Pilkey, 1963; Giles and Pilkey, 1965; Milliman, 1972) the quartz sands of the shelf (Types A and F) and the beach sands have characteristics which indicate an ultimate derivation from the Georgia Piedmont province. These characteristics

are: (a) an unstable heavy mineral assemblage similar to that of Georgia coastal sediments and reflecting a metamorphic-igneous source region, and (b) a fine-grained low carbonate nature suggesting modern fluvial derivation.

The Georgia coastal region is a likely source for the north Florida shelf quartz sands. No large rivers draining Piedmont formation discharge to the Florida Atlantic coast, whereas Georgia contains numerous streams and rivers with headwaters in the Piedmont province carrying sediment to the coast. In particular, the Savannah and Altamaha Rivers, according to Meade (1969), are among the rivers on the east coast highest in suspended sediment discharge.

Since north Florida sands (shelf and beach) are finer and less calcareous than sediment adjacent to and south of Cape Canaveral, investigators have suggested a Georgia fluvial source for "modern" shoreface sands and "relict" inner shelf deposits. Henry and Hoyt (1968) mapped gray fine quartz sands in the nearshore Georgia shelf and ascribed their origin to reworking of coastal sands during the last transgression. Seaward of approximately the –50-foot contour lie coarser iron-stained Pleistocene sands. The sharp break between the two sediment types has been reported by many investigators (Howard, 1972; Pilkey and Frankenberg, 1964) and referred to as the "relict-recent boundary."

Milliman (1972) has characterized the fine sand lying within 4.4 nautical miles off the coast (Type F) as possibly modern fluvial deposits and considered the belt to be continuous between Cape Fear, North Carolina and Cape Canaveral. Seaward of the possibly modern fluvial deposits lie relict shallow water terrigenous deposits. However, nearshore sands off Georgia are classified by Milliman as subarkosic, whereas those off north Florida are orthoquartzitic. Field and Pilkey (1969), also reported similar discrepancies between feldspar values for Georgia shelf and Florida shelf sand. Other mineralogical aspects of the two shelf areas are equally incongruent. Heavy mineral assemblages in Georgia rivers and shelf sands are unstable, i.e., they reflect derivation from Piedmont rocks without having passed through a sedimentary cycle of deposition, lithification, and subsequent erosion. Heavy minerals of Florida shelf sands are both unstable and stable (Pilkey, 1963, 1968) which may indicate different source areas or a single source followed by weathering during lower sea level or resorting. Within a small area north of Cape Canaveral, Tyler (1934) found large variations in mineralogy of surface samples, but gave no explanation. More recently Carver (1971), studied samples along a shore-normal shelf transect off Georgia and noted large variations in mineralogy, particularly hornblendes, which he attributed to differing fluvial sources during the Holocene transgression. These discrepancies in mineralogy (feldspars and heavy minerals) suggest that although Piedmont-draining streams in Georgia may have been the original and perhaps most significant source, other secondary sources have been interjecting material into the inner shelf surficial deposits.

(2) Residual Shelf Contributions. The large extent of surface exposures and near-surface occurrences (less than 10 feet) of Tertiary strata has been well documented in

earlier discussions. Both major sediment types, white foraminiferal sands and brown sand with dolomite silt, comprise at least 50 percent quartz and contain few heavy minerals. The quartz grains are rounded to well rounded and show microscopic solution features on grain surfaces, like grains from the shelf surface.

In many parts of the study area post-Tertiary quartz sands are thin. Contacts between the Tertiary sediments and overlying quartz sand are megascopically both sharp and transitional. Microscopic analysis of transitional intervals in cores shows gradual gradients in grain characteristics.

Subsurface Tertiary deposits (Types L and M) display continuity with overlying sands. Grain surfaces of dolomite rhombs are sharp and well defined below contacts and become increasing degraded up through the transitions. Gradual and increasing surface degradation is traceable in some cores for several feet. This transition exists between type L and type M sediments, and between type M and surface quartz sands where type L is absent. Where type L deposits are present at shallow depth, the contact with overlying quartz is sharp with a fine-grained "soil profile" often lying in between. The base of quartz sands usually contains small white calcareous fragments. The fragments are highly altered and recrystallized from diagenetic effects and cannot be identified by faunal type. Based on color, degree of degradation and alteration, these shell fragments are believed derived from the lower unit.

(3) Shoreface Sands. The entire shoreface in the survey area is mantled by slightly silty fine quartz sand (Type F) which, except for its finer texture, is similar to type A sand. Origin of the fine sand, like that of the coarser shelf facies, is difficult to determine. However, the sand may be derived in part from direct fluvial-littoral transport, and in part from substrate erosion and reworking.

Most cores from the shoreface are uniform in sediment type, but one core encountered Tertiary sediments a few feet down. Thicknesses of the fine quartz sand over Tertiary strata cannot be accurately determined, since few cores penetrated beneath it; the bulk of shoreface cores does not exceed 8 feet in length. The composite information collected in this survey suggests that the shoreface, or at least the upper 10 feet, is an aggrading deposit possibly superimposed in places on a preexisting geomorphic surface.

From St. Augustine northward, and especially north of Jacksonville, the shoreface in most places is a poorly defined irregular slope having a base at about 50 feet below MLW. As a topographic feature in this area the shoreface is difficult to distinguish and is similar in this respect to the Georgia shoreface. This is due in part to the mass of remnant inlet-shoals that have been stranded and redistributed as the coastal sector retreated during the last rise in sea level.

Shallow subsurface structure of the shoreface is variable and can be characterized in two ways. Some areas are underlain by horizontal acoustic reflectors which may indicate either constructional or erosional origin; others by bottom parallel reflectors indicate construction upon a preexisting surface.

Certain aspects of the sediment mineralogy point to a modern depositional origin of type F sand. The sands contain little or no phosphorite, and are micaceous like the Georgia counterpart shoreface sands. The mica content reflects fluvial derivation since both offshore surface sands and subsurface deposits are deficient in this mineral.

Faunal assemblages remain constant throughout shoreface cores indicating continuity of the deposit. The *Elphidium-Ammonia* foraminiferal assemblage indicates an environment with fluctuating temperature, salinity, and turbidity. Although most commonly associated with marginal marine estuaries, lagoons, and semi-enclosed bays, these conditions may also occur in nearshore water off open coasts and where few or no streams discharge in the coastal area. Kohout and Kolipinski (1967) have shown zonation of organisms in Biscayne Bay, Florida, due solely to ground water percolation through the bottom.

Macrofauna of the shoreface are chiefly echinoids and the pelecypods *Mulinia, Anadara*, and *Corbula*, none of which is restricted to a narrow well defined environment (Abbot, 1954; Stanley, 1970). Shells are evenly dispersed throughout the shoreface; shell gravels or hashes were not in any of the cores examined.

3. Origin of Area Beach Sediments.

Areal beach sediments range in size from coarse to fine sand and contain between 2 and 95 percent acid soluble material. These variations in grain size and shell content of beaches between Cape Canaveral and Fernandina result from coastline orientation and exposure, availability of offshore source materials, and local presence of Pleistocene coquina outcrops. Additionally, short-term changes in sediment character are induced by intense periodic storms, tidal fluctuations, and seasonal changes in wave direction.

Location, percent acid soluble material, mean grain size, and sorting are plotted for each of 32 beach samples shown in Figure 37. Each location represents a single sample collected from the swash zone at a specific time; values shown in the figure are not long-term averages. Results shown on the chart are representative of subtle regional trends and overall variation in characteristics of areal beach sands.

Curves for mean sand size and shell content are directly related—nearly every increase in shell content is paralleled by an increase in grain size. This pattern indicates that mean sand size is primarily a function of composition, and this correlation is further reflected by the sorting curve (Fig. 37). Although the sorting curve does not always parallel the other two, decreases in grain size and shell content are frequently marked by a decrease in the standard deviation, indicating better sorting. Such a pattern further demonstrates the influence of shell material in the areal beach sediments—sands containing lesser amounts of shell material are finer and appear to be better sorted than those enriched in biogenic sand. Mollusks, chiefly pelecypods, are the primary contributors of carbonate material, whether derived from recently living fauna or reworked Pleistocene deposits. Whelks, conchs, and other gastropods also contribute a significant amount of shell to beaches. Among the minor components of the carbonate assemblage, the absence of ooids is of particular note. Ooids

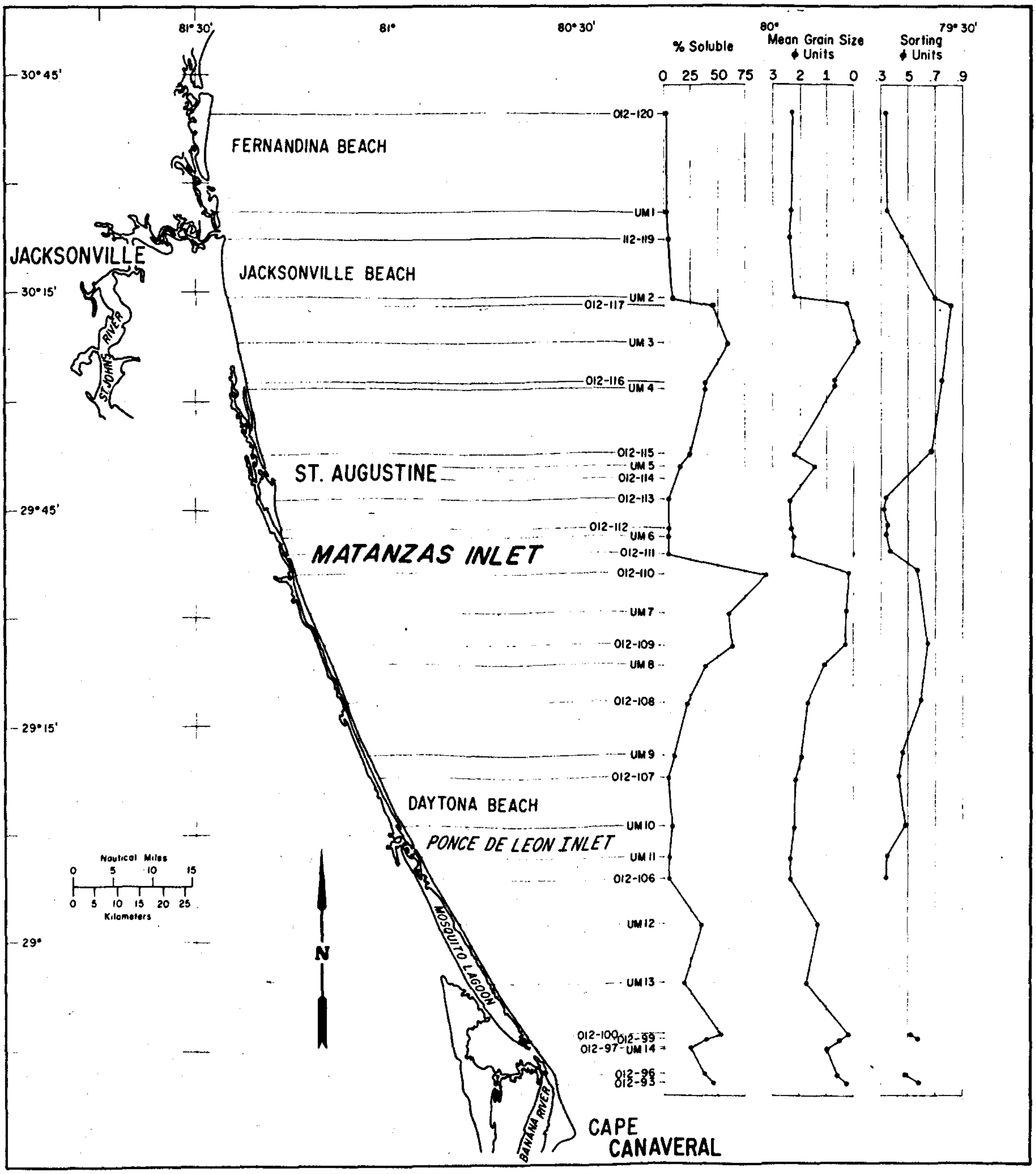

Figure 37. Weight percent at acid soluble material, median grain size, and sorting of sediment samples for east coast beaches of north Florida. Note relationship between acid soluble content, which is predominantly shell, grain size, and sorting.

are present in shelf sands beyond the 60-foot contour (Terlecky, 1967). At Cape Canaveral these ooids are present in both shelf and beach deposits, suggesting that an exchange of material has taken place between the two environments (Pilkey and Field, 1972).

4. Inner Shelf History.

Certain events in the Cenozoic history and evolution of the inner shelf are indicated by data collected for this study. Reflection records yield good evidence of several episodes of erosion and fragmentary evidence of the sedimentary processes and environment controlling deposition of some units. Sediment cores contain much lithologic and faunal data relating to the history and origin of the late Tertiary, Pleistocene, and Holocene section.

Seismic reflection data throughout the area show no evidence of structural deformation or faulting sufficient to reverse stratal positions. Therefore, it is assumed that superposition is valid in establishing the relative ages of reflection and sediment units.

The earliest event recorded in the ICONS survey is erosion of the Ocala Group limestone before deposition of overlying Miocene strata. The erosional interval is inferred from the locally irregular nature of the green reflector in the area where it correlates with the top of the Eocene in onshore wells. This erosional episode probably correlates with the post-Oligocene, pre-Tampa Stage (Miocene) erosion of rocks underlying the Florida peninsula (Puri and Vernon, 1964).

Evidence of probable erosion of unit E can be seen throughout the penetration range of the seismic reflection profiles; thus, assuming that erosion took place in a subaerial or littoral setting, relative subsidence of more than 450 feet has occurred off northeastern Florida since late Oligocene or early Miocene time (about 26 million years B.P.).

Following erosion of E unit, sea level rose and D unit was deposited on the eroded surface. Internal reflection in D unit can be seen only in a small part of the study. Where visible, the secondary reflectors suggest that the unit consists of thin parallel beds of a homogeneous sediment. Such a deposit is usually associated with nonturbulent depositional conditions occurring in deep or protected waters.

The evidence at hand indicates that the D unit was in place before the uplift resulting in the high off Daytona Beach.

Whether the surface of D unit was eroded before deposition of C unit is not known because the contact between these two units is obscure. Later erosion of high standing parts of the unit did apparently occur and is discussed later. The internal bedding pattern of C unit suggests that this deposit may have formed as either a river mouth delta or a tidal platform at the entrance to a large estuary. Subsequently, the unit was planed off by erosion. This erosion surface (white reflector) also transgresses the top of the older D unit where it supplants C unit in the area south of Jacksonville (Fig. 14).

The general smoothness of the white reflector surface and apparent lack of channels incised in underlying units suggest that the surface may have been eroded in a shallow marine setting with little or no subaerial exposure. Since the overlying B unit is believed to be an upper Miocene or lower Pliocene deposit the erosional episode evidenced by the white reflector is probably of Miocene age.

The red reflector has been reached by cores and there is more direct information on the red and the overlying blue reflection units than for deeper strata. The red reflector is underlain sequentially southward by B, D, and E units. It is overlain by Pliocene, Pleistocene, and Holocene sediments. The B reflection unit was deposited on the erosion surface corresponding to the white reflector. Foraminifera in B unit indicate that the deposit was probably lain down in a water depth of 150 feet or greater. The internal reflectors suggest that the deposit prograded eastward for at least 5 nautical miles along a front of over 70 nautical miles forming an initial 5-nautical-mile-wide series of seaward-dipping beds followed by near-horizontal beds. The occurrence of medium to coarse quartz sand and a relatively deepwater (> 150 feet) foraminiferal assemblage suggests deposition near the foot of a prograding inshore terrace rising steeply from the shelf floor. If this explanation is correct B unit must have originally been much thicker than the present remnant.

The surface of B unit may have been eroded before deposition of the type L sediment of early Pliocene age, which overlies it in places; however, the evidence for an unconformity is not clear. Seismic reflection records indicate that in places, the eroded top of B unit is well below the level in which type L sediment was encountered in overlying cores. In the few cores where both type L and type M sediment were recovered the contact between them was a narrow zone containing elements of both sediment types. Changes in fauna and mineralogy suggest that the contact zone could not have been created by unbroken transition from one to another and more likely represents the result of mixing across a boundary marking an erosional hiatus.

If B unit was eroded before deposition of type L sediment the event must have occurred in late Miocene or early Pliocene time. Where B unit is not overlain by Pliocene sediments its surface was probably re-eroded during a period of lower eustatic sea level in Pleistocene time. The red surface is thus a product of more than one erosional episode.

Age of the sediments contained in A reflection unit ranges from probable early Pliocene to Holocene. Type L sediment lithology is the earliest known deposit of the reflection unit and probably originated during a higher relative sea level stand in Pliocene time. Subsequently this deposit was eroded and sediments of Pleistocene and Holocene age were deposited on the eroded surface.

Locally between Holocene-age sediments (Types A and F) and Miocene-Pliocene deposits (Types L and M) there exists a complex group of sediments having widely varying lithologic and faunal characteristics. These deposits are judged to be of Pleistocene age, but possibly they include older material. Many of these sediments can be included with the broadly defined type G sediment which probably comprises several facies and possibly more than one stratigraphic unit.

A few cores recovered atypical sediment of the various unclassified sediments (Type U). Characteristics and fauna of these sediments indicate deposition in a wide variety of environments ranging from marginal marine to mid-shelf. Many may represent remnants of previously extensive Pliocene-Pleistocene deposits largely removed by erosion during low eustatic sea level stands. In some cores the deposits from the area over the Daytona Beach high may be of Miocene age. Since such remnant deposits rarely occur together in the same core, there is little information about relative stratigraphic relationships or history.

Although the Pliocene-Pleistocene history of the inner shelf from ICONS data is fragmentary, some meaningful generalizations can be made. Pleistocene deposits are localized and thin and in many places absent from the inner shelf of north Florida. This contrasts sharply with the thick late Pleistocene sands mapped from Cape Canaveral (Field and Duane, 1974) and farther south (Meisburger and Duane, 1971). The paucity of fluvial and coastal sands south of the large Piedmont-draining Georgia river system has two possible explanations—either the area was one of nondeposition, or original deposits were stripped off by subsequent erosion. Because of the preservation of thick subsurface Pleistocene sands south of the study area (Field and Duane, 1974) and in other parts of the east coast, the latter explanation seems unlikely. It seems more probable that each time the sea transgressed the shelf, the deep stream channels that were cut into the shelf became embayed and began to trap sediment, thereby reducing the detritus supplied to the coastline when the shoreline was farther seaward. This lack of new material resulted in a very thin sediment cover derived principally from erosion of exposed strata.

The most recent event apparent from the north Florida ICONS data is the Holocene transgression beginning about 15,000 years (B.P.) following the termination of the last Pleistocene glacial stage. As the shoreline migrated landward, Pleistocene and Tertiary substrata were reworked to generate thin surficial type A sediment deposits. During the last several thousand years finer type F sediments in the littoral system have been transported seaward mantling the shoreface and the innermost shelf floor. Outside of the littoral and shoreface zones there seems to be little modern sedimentation taking place. Reworking of surface sands of the inner shelf by waves and currents in continuing and possibly significant transportation and redeposition of winnowed fines is occurring.

V. SAND RESOURCES ON THE NORTH FLORIDA INNER SHELF

1. Sand Requirements for the North Florida Coast.

The *National Shoreline Study* (U.S. Army, Corps of Engineers, 1971) lists the northeast coast of Florida as one of four areas within the State where shore erosion problems are serious. Specific areas covered in this study and undergoing sufficient erosion to warrant engineering protective measures are shown in Figure 38. Quantities required for initial restoration and annual nourishment of those areas are cited in Table 5. According to a Beach Erosion Control Study (BEC) for Duval County (U.S. Congress, 1965) the shoreline south of St. Johns River to the county line, a distance of about 10 miles, will require

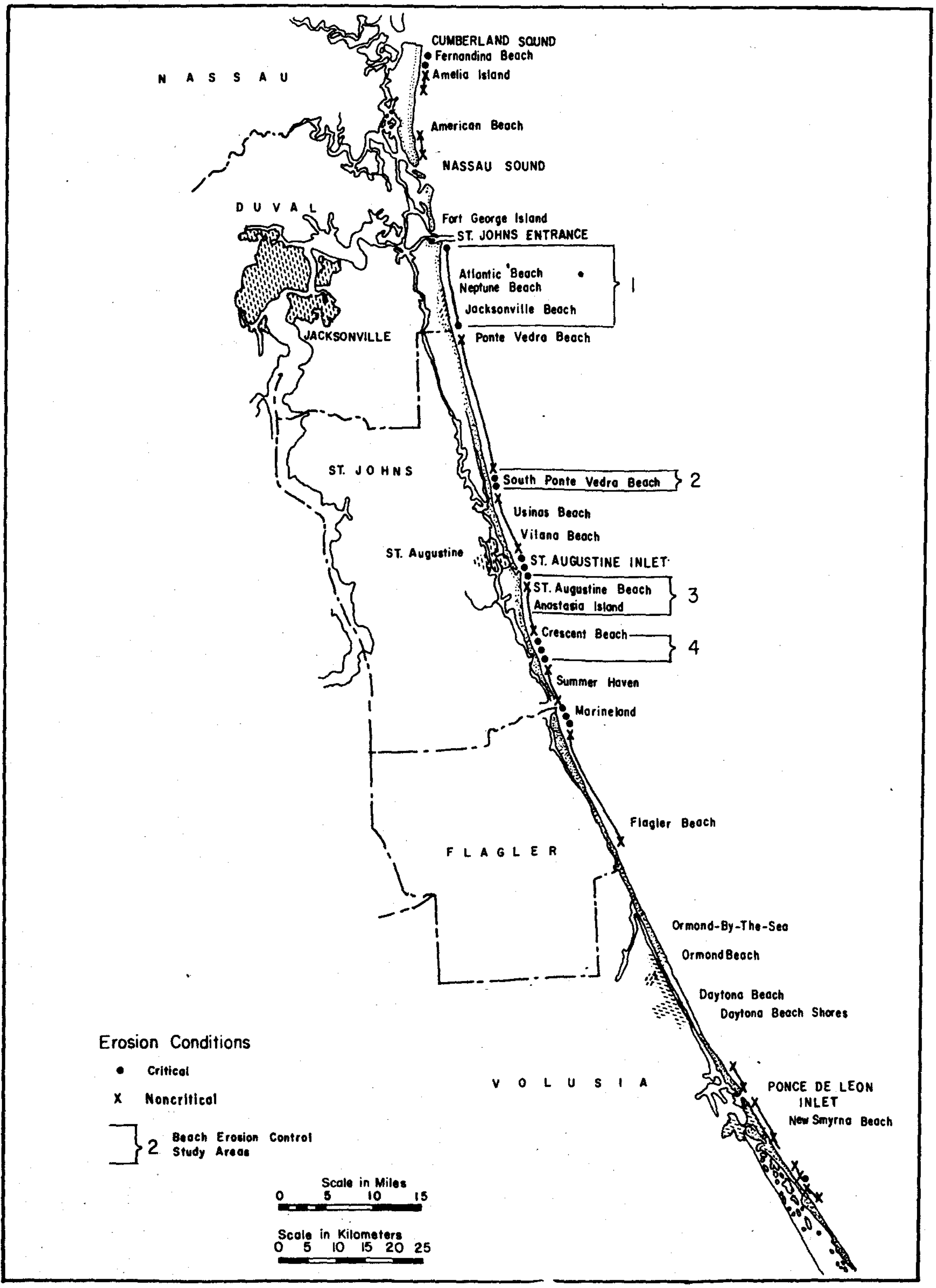

Figure 38. Map of north Florida showing erosion conditions of beaches and areas under study by the U.S. Army Engineer District, Jacksonville, for beach erosion control. Limits of critical and noncritical erosion are from the *National Shoreline Study* (U.S. Army, Corps of Engineers, 1971). Erosion is judged critical if the rate of erosion, considered in conjunction with all other factors, indicates that action to halt erosion may be justified.

Table 5. Areas and estimated quantities required for beach erosion control.[1]

Area	Shoreline length	Initial fill	Nourishment		Initial fill
			Annual	50-Year	+ 50-year nourishment
		$\times 10^6$	$\times 10^6$	$\times 10^6$	$\times 10^6$
Duval County[2]	about 10 miles	3.75	0.26	13.0	16.75
St. Johns County[3]	about 5 miles	3.05	0.56	28.0	31.05
South Ponte Vedra Beach	11,600 feet				
Anastasia Beach	7,600 feet				
Cresent City Beach	7,500 feet				
Total		6.8	0.82	41.0	47.8

1. Cubic yards.
2. Beach Erosion Control Study, Duval County, Florida (U.S. Congress, 1965).
3. Beach Erosion Control Study, St. Johns County, Florida (U.S. Congress, 1966).

3.75×10^6 cubic yards of sand for initial fill and about 0.26×10^6 cubic yards annual nourishment (Table 3). Including initial fill, nearly 16.75×10^6 cubic yards of material will be needed to restore and maintain this area in Duval County for a 50-year period.

Erosion in St. Johns County occurs principally at South Ponte Vedra Beach, St. Augustine Beach, and Crescent City Beach, and approximately 3.5×10^6 cubic yards of sand will be required for initial fill and over 0.5×10^6 cubic yards for yearly maintenance (U.S. Congress, 1966). Over 31.05×10^6 cubic yards will be required for restoration and nourishment of these beaches over a 50-year period.

2. Comparison of Beach and Offshore Sands.

Beach-fill sand, to be well suited for restoration and maintenance should closely match the size distribution of native beach material, be mechanically and chemically stable, and be reasonably free of fines and foreign material (such as sharp coral fragments) which might degrade the quality of the beach for recreational purposes.

Type A deposits occur in a wide range of characteristic sizes, thus reasonably good matches for typical sand on north Florida's Atlantic beaches can be defined. However, deposits suitable for some areas may not occur within economic transport distance of the project site or in the volume required for borrow operations.

Beach samples from along the active profile of the northeast Florida coast range from very fine to very coarse sand; the vast majority of samples are fine sand size, but range from about 0.1 to 0.4 millimeters. Median sieve diameters averaged by profile position for each of three Florida counties are presented in Table 6. Ranges of median diameters are also presented to provide information on between-profile variability. Most anomalously coarse sizes shown on median size range reflect the local occurrence of shell material. Size range of beach samples, taken from several literature sources, is compared to size ranges of offshore type A sands in Figure 39. In general, comparison of ranges of median and mean grain-size values shows that offshore samples are slightly coarser and would probably be well suited

Table 6. Median sieve diameter of composite samples for three north Florida counties by position on profile.

County (median size)	Dune (mm)	Foreshore (mm)	Sea level (mean) (mm)	Low water (mean) (mm)	−3 feet (mm)	−6 feet (mm)	−12 feet (mm)	−18 feet (mm)	−30 feet (mm)
Nassau[1]									
Average	0.20		0.24		0.19	0.18	0.15	0.18	0.15
Range	0.13 to 0.39		0.12 to 0.70		0.10 to 0.51	0.09 to 0.38	0.08 to 0.31	0.11 to 0.44	0.09 to 0.22
Samples	9		10		10	9	10	10	9
Duval[2]									
Average	0.18	0.24			0.52	0.14	0.11	0.10	0.56
Range	0.13 to 0.26	0.16 to 0.66			0.17 to 1.80	0.10 to 0.18	0.07 to 0.16	0.08 to 0.16	0.09 to 2.10
Samples	5	8			5	5	5	7	6
St. Johns[3]									
Average	0.21	0.56		0.44	0.21	0.19	0.17	0.14	0.16
Range	0.16 to 0.26	0.16 to 1.90		0.18 to 1.15	0.15 to 0.38	0.15 to 0.25	0.13 to 0.35	0.08 to 0.25	0.09 to 0.55
Samples	8	15		11	11	11	11	11	11

1. Data from U.S. Congress (1961).
2. Data from U.S. Congress (1963).
3. Data from U.S. Congress (1966).

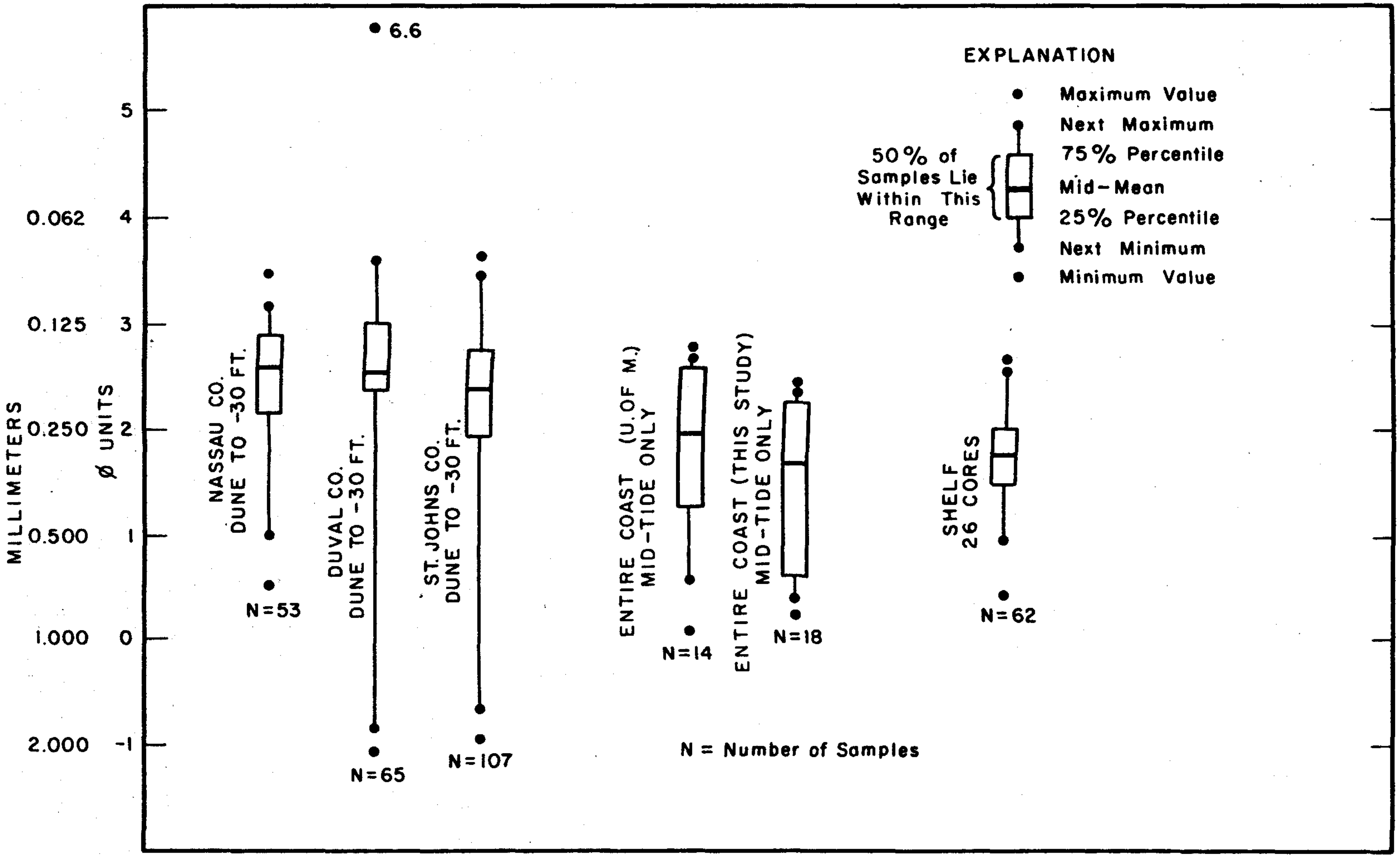

Figure 39. Comparison of the distribution of phi means and phi medians of beach and shelf sands. Samples are plotted by method developed by Professor Tukey, Princeton University. County samples are median grain-size values from sieve analysis; entire beach and offshore samples are mean grain-size values determined by settling velocity.

for beach-fill material. Ranges of medium values are greater for individual county beaches and their overall size is finer than for sample collections from the shelf or mid-tide samples covering the entire study area. This can be partly attributable to the fact that county beach samples range across the beach from the dune to –30 feet and the offshore samples are usually fine and very fine type F sand (Table 4). The beach samples from the entire shoreline are biased toward the coarse side since they were collected only from the mid-tide area. Offshore samples are also biased toward the coarse side since selection was based on their appearance as suitable sand for beach nourishment.

Direct comparison of size data derived from different analysis techniques (settling velocity versus sieve) as in Figure 39 may be made for a general overview. However, comparison of either individual samples or composite values requires that particle-size parameters derived from them be corrected so they are comparable and reproducible by either method. An empirical correction factor for the CERC Rapid Sediment Analyser (RSA) has been determined so that RSA data may be directly equated with sieve data. The equation for conversion is:

$$M_\phi \text{ (sieve)} = 0.157 + 1.1\, M_\phi \text{ (RSA)},$$

where

M_ϕ (sieve) = the mean sieve diameter,
M_ϕ (RSA) = the mean RSA diameter.

If only the median diameter is available, an assumption can be made that the median is an approximation to the mean and differences between the two are insignificant. However, the correction factor was determined empirically for the RSA and therefore cannot reliably be used for other settling tube data.

If differing sets of data are in different units (millimeters and phi), then one set must be converted to conform to the other. It is preferable to transform data to phi (ϕ) values, using the formula:

$$\phi = -\log_2 (d_{mm}),$$

ϕ = diameter in phi units,
d_{mm} = diameter in millimeters.

Data from the native beach (the one to be restored) can be compared directly to data from a potential borrow site by comparison of a composite sample from each area. A composite sample is a single theoretical sample calculated from all samples that statistically represents the spread of mean grain sizes and sorting that is present. Methods of calculating composite values are given by Krumbein (1957). The mean grain size and sorting of the composite samples from the native beach and borrow site can be compared to determine a ratio for calculating the quantity of sand to be dredged to yield a given quantity of sand on the beach. The method for determining the ratio is given by Krumbein and James (1965) and in the *Shore Protection Manual* (U.S. Army, Corps of Engineers, Coastal Engineeing Research Center, 1973).

Factors affecting the quality of a potential borrow site other than the character of included sand are: uniformity of the sand throughout the deposit, accessibility to dredging, proximity to the project site, and thickness of the deposit. Based on these suitability factors the best sediment in the study area is the coarser facies of type A quartz sand. Type A sands are composed predominantly of mechanically and chemically stable quartz particles, are generally free of fines and objectionable inclusions which might degrade the recreational quality of a beach and, being the characteristic surficial deposit, are readily accessible to dredging.

The characteristic thinness of type A surficial sand is its chief potential drawback to exploitation since it limits the most suitable borrow sites to certain locales. These are extensive areas of inner shelf where type A sediment mantles the bottom to only a few feet in thickness, and thus dredging would affect a relatively large area to recover a given volume of sand compared to dredging a thicker deposit. In addition, dredging thin deposits may uncover a different substrate, consequently changing the character of the bottom in the borrow area.

Sediments of silty fine sand (Type F) which characteristically form the surficial deposits of the shoreface and contiguous innermost ramp are considered to be generally unsuited for nourishing north Florida beaches because of their fine size and silt content.

Sediments classed as type G are also considered generally unsuited for beach fill because of the high shell-gravel content, strongly bimodal size characteristics, and apparent nonuniformity of characteristics within deposits. Further, type G sediments were usually found under an overburden of dissimilar material sometimes several feet thick.

Type L sediment is composed of up to 50 percent calcium carbonate in the form of silt-size calcareous grains and sand-size foraminiferal tests. The large content of silt in the high energy beach zone would likely result in excessive loss of fines should this material be placed on a beach.

Exposures and near exposures of type M sand deposits are accessible in places along the northern part of the study area. Available indirect evidence from seismic reflection data indicates that the deposit of type M sediment may be over 50 feet thick in places. Therefore, where deposits are accessible, it should be possible to recover large amounts of sand with a minimal area directly affected by dredging. Size distribution of the sand fraction of type M sediment is within ranges suitable for beach fill in nearby coastal areas. A possible drawback to use of type M sediment is its content of silt-size dolomite crystals or, in places, silt-size particulate organic matter; also the deposit may be lithified below the uppermost section penetrated by cores.

3. Potential Offshore Sand Resources.

a. General. Delineation of sites within the survey area which appear to be most promising for future detailed investigation as potential borrow areas is accomplished by interpretation of data and comparison with geologically analogous areas. Potential borrow sites are shown in Table 7.

Suitable borrow sites are considered to be those with clean quartz sand of a size range compatible with that judged to be suitable for fills on nearby beaches and thick enough so that borrowing operations would affect only a small area.

In general the inshore zone coincident with the surface distribution of type F fine silty sand contains few potential sand sources because of the characteristic fine and frequently silty character of bottom and shallow subbottom sediments in the zone.

Seaward of the fine silty sand areas, there are extensive but discontinuous deposits of type A quartz sand. The quality of type A sand is more favorable, but deposits are commonly thin and in many areas the sand is too fine to be suitable for beach fill.

Linear ridge-like shoals occurring on the inner shelf off Fort Pierce and Cape Canaveral were found to be excellent sources of clean, medium to coarse sand (Meisburger and Duane, 1971; Field and Duane, 1974). Similar linear shoals occur south of Daytona Beach off the study area.

In contrast, topographic highs elsewhere in the study area are large, often flat-topped, masses of irregular outline and low relief. Most of these *bank* shoals are judged to be largely the product of erosion rather than accretion; however, core data show that accumulations of clean type A sand generally occur atop these highs and the sand is likely to be several feet thick in places. Additional detailed surveys on these features may serve to precisely define the character and extent of type A sand.

Very large quantities of fine to coarse quartz sand are believed to be contained in reflection unit B. However, in most places the unit is buried and only readily accessible locally where it outcrops or lies under very shallow overburden. In addition, type M sediment is of doubtful utility as beach replenishment because of the certain qualitative difficulties with this material as discussed previously.

Potential sand sources are identified in Figures 40 through 43. Areas designated A are considered to have the best potential for exploitations as offshore borrow areas. Subareas (within the A areas) that appear to afford the best prospects have also been identified in the figures.

Areas designated B are judged to be possible sources of suitable sand but available data on these areas are too scant for an assessment.

In the Figures 40 and 41, M areas show where the top of the type M sediment layer is accessible either in outcrop or under shallow overburden.

b. Georgia Border through St. Augustine Grid. Fine sediments ranging from clay to clean fine sand cover a zone extending seaward through most of the Fernandina grid and to

Table 7. Summary of potential borrow areas near designated coastal communities.

Location	Area	Volume[1] X 10^6	Significant cores
Fernandina	A1	unknown	194
Fernandina	A2	unknown	76
Nassau sound	A3	unknown	191
Jacksonville	A4	unknown	78, 79, 185
Jacksonville	A5	5.0	48, 65
Mickler Landing	A6	178.0	107, 110, 111, 174, 175, 176
St. Augustine	A7	7.4	123, 125, 127
Fernandina	B1	unknown	2
Fernandina	B2	unknown	11
Fernandina	B3, 4, 5	unknown	none
Nassau Sound	B6, 7	unknown	none
Fernandina	M1	unknown	31, 32, 33
Nassau Sound	M2	unknown	190
Jacksonville	M3	unknown	47, 50, 57, 61, 62, 63, 180
Marineland	A8	39.0	140
Ormond Beach	A9	61.0	147
Ormond Beach	A10	5.0	173
Matanzas Inlet	B8	unknown	133
Flagler Beach	B9	unknown	none
Daytona Beach	B10, 11, 12	unknown	none
Ponce de Leon Inlet	B13	unknown	none
Turtle Mound	B14, 15, 16, 17, 18	unknown	152, 160

1. Cubic yard.

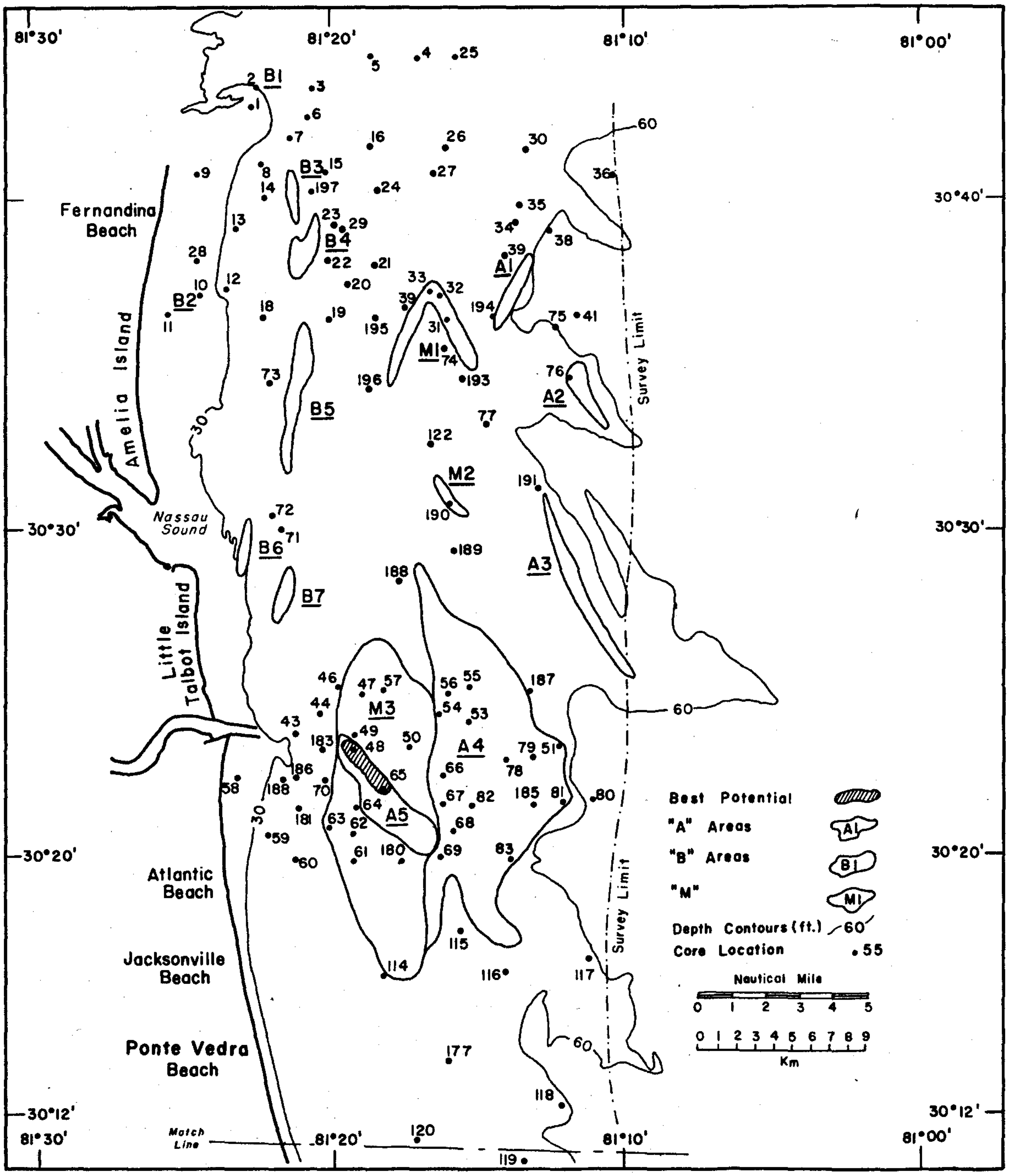

Figure 40. Potential offshore sand borrow areas off the Fernandina-Jacksonville area.

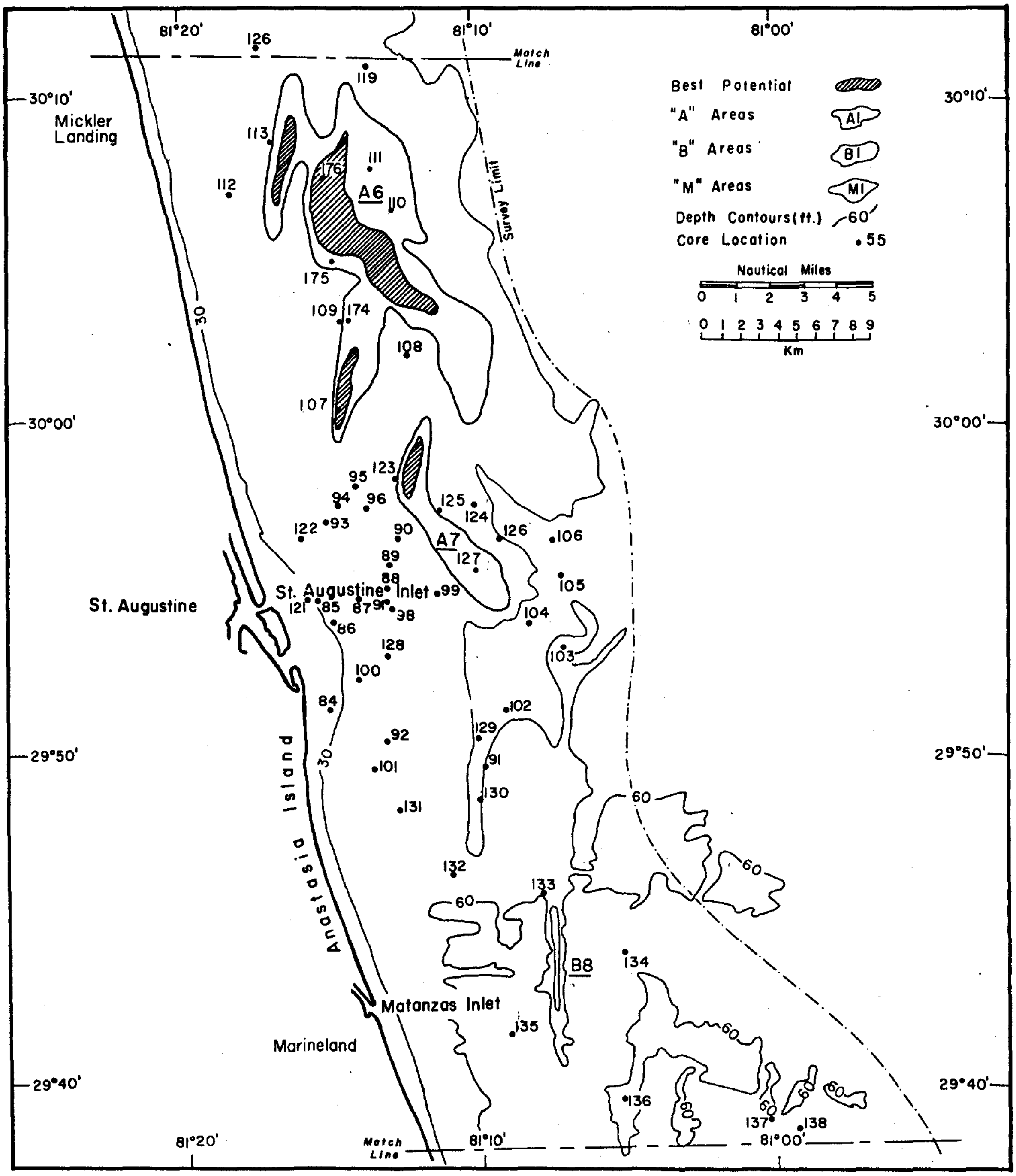

Figure 41. Potential offshore sand borrow areas between the Jacksonville area and Matanzas Inlet.

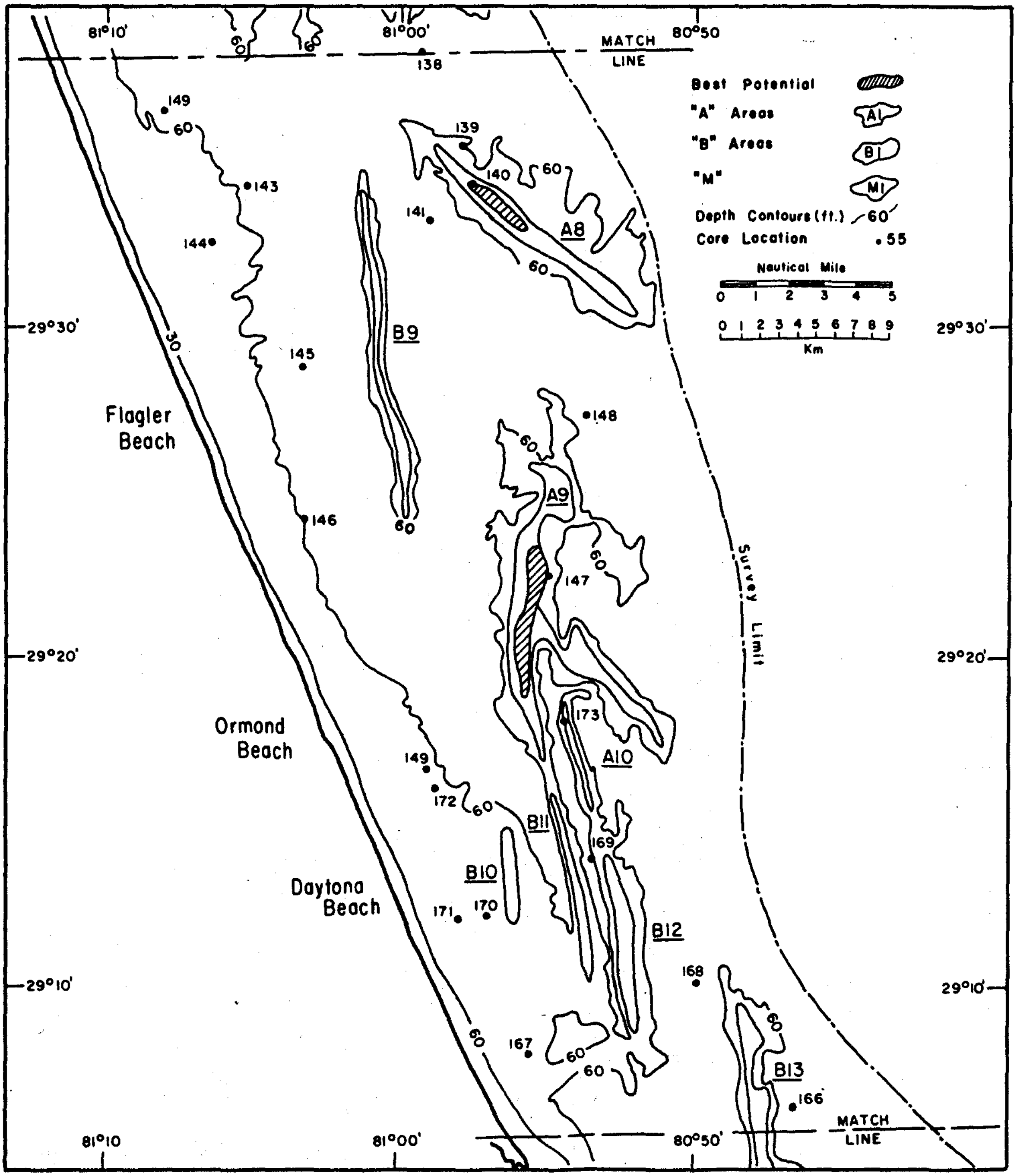

Figure 42. Potential offshore sand borrow areas between Matanzas Inlet and Daytona Beach.

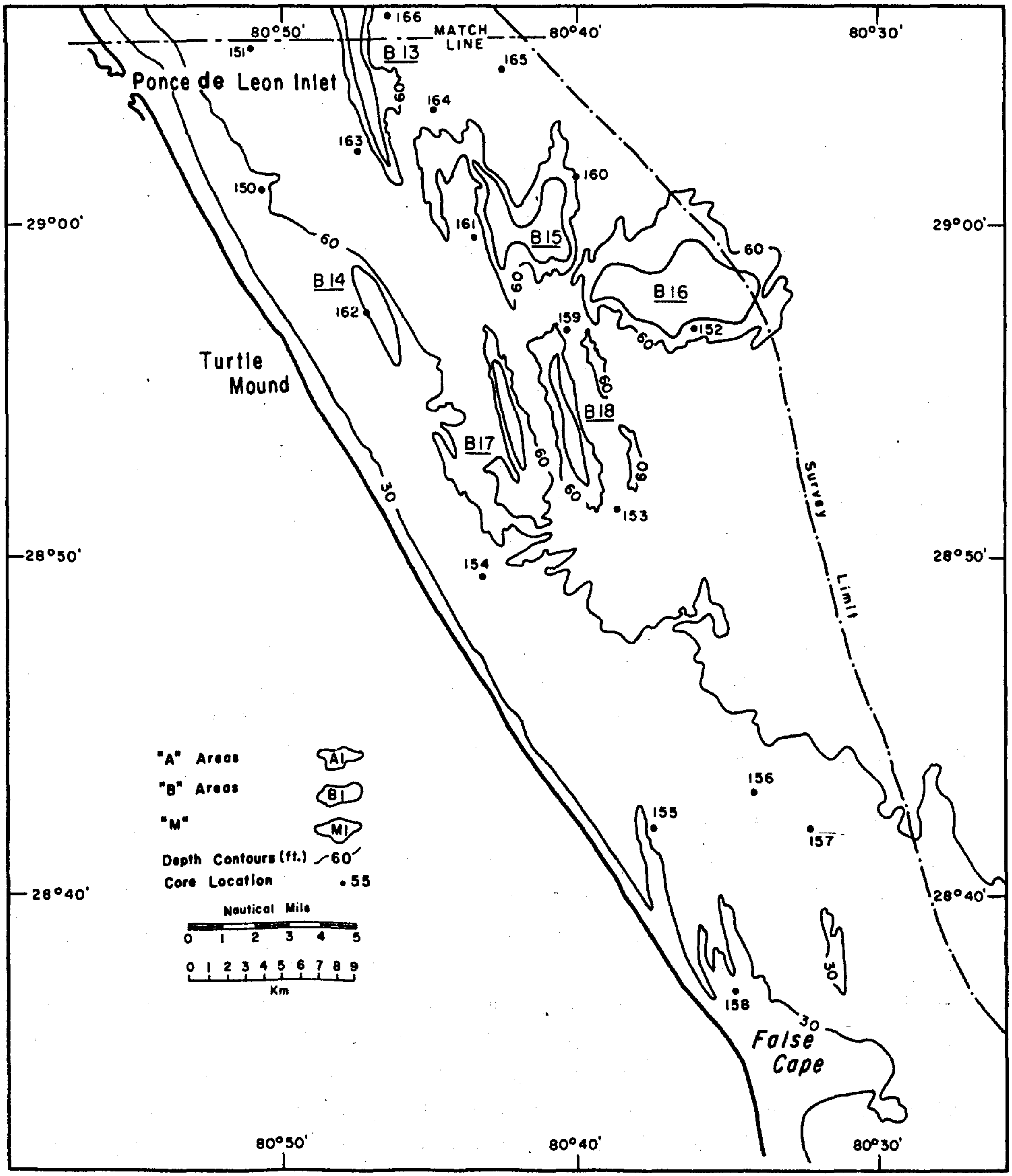

Figure 43. Potential offshore sand borrow areas between Daytona Beach and Cape Canaveral.

the south up to 6 nautical miles seaward of the shoreline (Figs. 40 and 41). This sand is mostly interbedded with clays, particularly in the region north of St. Johns River Entrance. Because of the presence of fine sand and its often silty character, and the common occurrence of clay layers, this zone is unpromising for location of any extensive deposits of clean sand which would be potentially usable for replenishment of nearby beaches. However, some locales within the zone have potential and therefore warrant further investigation. A summary of the more promising locals in the region follows.

(1) Area A-1. This area is a low linear shoal trending northeast. Core 194 near the southwest end recovered 9 feet of clean fine to medium quartz sand with thin layers of varying size. Composite sand borrowed from this site may prove satisfactory for use on nearby beaches. Since the site appears to afford the only reasonable prospects in the Fernandina grid it warrants further investigation.

(2) Area A-2. Core 76 at the northwest edge of this low linear ridge atop a *bank* shoal contains clean quartz sand with a median diameter range of 0.330 to 0.268 millimeters (1.6 to 1.9 phi). Since core 76 was only 3 feet long it is not known if the ridge contains similar material in depth. Seismic evidence suggests that the sand is 10 feet or more thick.

(3) Area A-3. Core 191 at the extreme end of a long low ridge contains suitable sand with a mean diameter of 0.380 millimeters (1.4 phi), in the upper 2 feet. If the ridge is covered by similar material it would provide a usable offshore borrow site but details are lacking. The material in core 191 is fine grained below –2 feet and it is doubtful if any but the surficial material will be suitable.

(4) Area A-4. Cores taken throughout this extensive area off Jacksonville Beach generally contained a thin surficial layer of clean, medium to coarse quartz sand. In general, the upper 2 feet were coarser than deeper material. Suitable borrow sites probably exist at several places within this area; however, indications are that the sand is probably too thin in many places for a desirable borrow site. The best material was contained in cores 78, 79, and 185 in the eastern part of the area. There is not enough information from this area to estimate the volume of suitable sand that may be available, but further study is warranted.

(5) Area A-5. Cores 48 and 65 located over the "ancient channel" of the St. Johns River contained reasonably clean, medium to coarse quartz sand under a shallow overburden of type F sand. This material may represent a deposition in the old channel and further exploration of the channel area outlined in Figure 17 would be warranted, especially since this site is closer to shore than most potential sites in the Fernandina-Jacksonville area. Further exploration would probably be most productive along the central part of the channel area southeastward of core 48; cores to the northwest indicate that the channel in that area is probably filled, by silty sand and clay. There are insufficient data available for a reliable estimate of the sand volume, but there may be over 5.0×10^6 cubic yards of clean sand in the channel deposit.

(6) Area A-6. A large irregular shoal centered 5 to 6 nautical miles offshore between Jacksonville Beach and St. Augustine is judged to be the best prospect in the northern part of the study area. In general, the shoal is of very low relief and nearly flat-topped. Geophysical records indicate the shoal may have formed by accretion, possibly during the latter part of the last transgression. If so, this is an exception as most similar shoals off north Florida appear to be erosional remnants. The few cores from the highest part of the shoal recovered up to 10 feet of clean uniform quartz sand of medium and coarse size. Two small ridge-like features surmounting the shoal and its highest central part are considered the best prospects. If this shoal was formed entirely by accretion, the total volume of sand within the shoal would be approximately 178 $\times$ 10^6 cubic yards. However, the typical bank shoals appear to be largely products of erosion.

(7) Area A-7. This is the only prospective site within the St. Augustine grid. Two cores penetrated a clean medium quartz sand layer 4 to 6 feet thick. A ridge-like feature near core 123 is judged to be the most likely locale for a suitable borrow area. The estimated volume of sand in this ridge is 7.4 $\times$ 10^6 cubic yards.

(8) Area B-1. Core 2 off St. Marys River Entrance at Fernandina contains 5 feet of clean well-sorted fine sand with an average mean diameter of 0.218 millimeters (2.2 phi). The core is 5 feet long and terminates in sand; total depth of the deposit is unknown. The deposit is apparently not extensive as surrounding cores do not contain similar material. The material in this deposit may be related to the nearby inlet.

(9) Area B-2. This area, of unknown extent and depth, is centered on core 11 south of St. Marys River Entrance. The core is 5 feet long and consists of well-sorted, quartz sand of fine to medium size. Core 11 is the shallowest core taken in the Fernandina area (–20 feet MLW) and thus represents an upper shoreface locale which was not sampled elsewhere. The sand deposit may therefore extend laterally along the upper shoreface, but is unlikely to extend any appreciable distance seaward since all cores in the zone immediately seaward of this locale contain fine silty sand.

(10) Areas B-3, B-4, and B-5. Three low, roughly linear shoals lying parallel to shore off Amelia Island may contain thick sand accumulations. No core data are available for these areas; however, if they are composed of the fine silty sand typical of the inshore zone it would not be well suited for beach fill.

Since these shoals are close to shore and would be desirable borrow sites if suitable material were available, they warrant further investigation.

(11) Areas B-6 and B-7. Both of these areas consist of small shoreface-connected linear shoals in the vicinity of Nassau Sound. Elsewhere, most similar shoals have been found to be composed of clean sand. Since there are no cores from these shoals the character and size gradation of the shoal sediment are unknown. Proximity to potential project sites would make these areas desirable borrow sites should they contain suitable material.

(12) Area M-1. Near the southern border of the Fernandina grid is a large triangular-shaped closed depression in which cores indicate the top of the type M sediment layer outcrops or is at shallow depth (< 5 feet) and thus accessible to dredges. Type M sand in cores from this area is generally of coarse texture and has a dolomite silt matrix.

(13) Area M-2. Core 190 is in a small closed depression and contains 11 feet of type M sediment which outcrops at the core site and may be exposed throughout the depression. The core contains an admixture of coarse quartz sand with a dolomite silt matrix.

(14) Area M-3. An extensive area covering a broad, ridge-like feature with subtle topographic expression off Jacksonville appears to be underlain by type M sediment. Cores in this area generally encountered the sediment at –3 feet or less, and outcrops probably occur in many places. An ancient channel bisects the area and along the channel course type M sediment is deeply buried under channel fill. This part of the channel containing the fill may provide suitable sand; the area has been delineated area A-5.

The type M sediment found in area M-3 is composed mostly of medium to coarse quartz sand in a silty matrix consisting of particulate finely divided organic matter or dolomite silt.

c. *St. Augustine Grid to False Cape.* Throughout most of this stretch of coast the shoreface and innermost ramp are mantled by silty fine type F sands (Figs. 41, 42, and 43). Because of the fineness of the characteristic surficial deposits this zone, which extends about 5 nautical miles offshore, is unpromising for potential beach fill material. Farther offshore clean type A quartz sands are common on topographic highs. Elsewhere in the offshore zone the sediment is heterogeneous; fine shelly quartz sand and fine silty sand are particularly common in the surficial layer, and sandy shell hash and clay are common in the shallow subsurface. Near the southern end of the study area surficial sediments are shelly quartz sand and shell hash typical of type A sands in shoals around Cape Canaveral (Field and Duane, 1974).

There are no known exposures of type M sediment in the St. Augustine–False Cape section. Absence of type M material in cores from this area supports seismic reflection evidence that the top of the type M sediment layer is covered by 15 feet or more of overburden south of St. Augustine.

(1) A-8. Clean type A sand over 10 feet thick with mean diameters ranging from 0.287 to 0.308 millimeters (1.7 to 1.8 phi) was recovered by core 140 in the center of this linear shoal (Fig. 40). Prospects for locating suitable borrow areas in this ridge are judged to be very good. If the entire ridge is of suitable material the estimated reserve is 39 $\times 10^6$ cubic yards.

(2) Area A-9. Core 147 in this irregular low relief shoal area contained over 11 feet of clean uniform medium sand with an average mean diameter ranging from 0.287 to 0.308 millimeters (1.7 to 1.8 phi). Suitable borrow areas should exist near core 147 and probably occur throughout the main ridge area; probable reserves of sand are estimated to be 61 $\times 10^6$ cubic yards.

(3) Area A-10. The surface sand in core 173 from this long narrow ridge (Fig. 42) is a clean medium quartz sand ranging from 0.233 to 0.308 millimeters (1.7 to 2.1 phi) mean diameter. Below about –2 feet, similar but slightly silty sand extends to –7 feet. The quality of the material in this area does not appear to be as good as sand in areas A-8 and A-9. The ridge is judged to contain about 5×10^6 cubic yards of sand of which about 1.5×10^6 cubic yards are probably well suited for beach fill.

(4) Area B-8. This area consists of a crook-shaped low ridge. Core 133 near the inshore flank of the ridge contains fine slightly silty sand. It is not known if this sand is typical of the ridge sediments.

(5) Areas B-9, B-10, B-11, B-12, B-13, B-14, B-17, and B-18. Although there are no cores in these linear, roughly north-south trending shoals, they are morphologically similar to linear accretionary shoals off Fort Pierce and Cape Canaveral (and elsewhere on the East Coast Shelf) which are formed of clean medium to coarse sand. Further, three other linear shoals (Areas A-8, A-9, and A-10) near these features were cored and found to contain sand suitable for nourishment and maintenance of beaches within the nearby coastal area. Therefore, it is considered likely that areas B-9, B-14, B-17, and B-18 contain usable sand and further investigation is warranted. The B-11 shoal is a particularly good prospect since it appears continuous with area A-9 where presence of suitable sand is supported by core data.

(6) Areas B-15 and B-16. These two large flat-topped irregular shoals were not cored; however, clean medium sand occurs in cores 160 and 152 at the edge of the shoals. The deposit may be thicker on the shoal proper; if so it would be suitable for borrow sites and would contain large volumes of sand.

VI. SUMMARY

Survey of the north Florida Atlantic inner Continental Shelf was undertaken to obtain data on inner shelf morphology, shallow structure, sediments, and sand resources. During the survey, 1,153 nautical miles of seismic reflection line were run and 197 cores up to 15.5 feet long were collected from the study area.

The Atlantic coast of Florida north of Cape Canaveral is a low coastal plain modified by relict terraces and beach ridges of Pliocene-Pleistocene age. Well developed modern beaches fringe the shoreline throughout the region; lagoons or marshy lowlands commonly lie inland of the beach.

The East Coast Shelf off northern Florida is a submerged coastal plain with a very gentle seaward slope and subdued topography. The most prominent topographic feature of the inner shelf is the shoreface slope which decends to depths of 45 to 55 feet generally within 1.2 nautical miles of shore. Elsewhere the inner shelf contains linear and irregular highs and broad, linear depressions. These features are generally of low relief and many may be related to a relict subaerial drainage system.

A thick section of Cenozoic sedimentary rocks dipping generally eastward underlies the Atlantic coastal zone of northern Florida. The stratigraphy of these rocks is not well known due to a scarcity of outcrops. Major structural features occur near the Georgia border and in the vicinity of Daytona Beach. Eocene rocks underlying the coast are principally limestones. Overlying the Eocene rocks are clastic sediments of heterogeneous lithologic character representing deposits of Miocene, Pliocene-Pleistocene and Holocene ages. The principal artesian aquifer of Florida is largely contained in the permeable Eocene limestones and confined by relatively impermeable Miocene strata.

Beneath the inner shelf floor seismic reflection, profiles show reflectors as deep as –450 feet MLW. Based on primary and secondary reflector patterns the visible section was divided into five reflection units. In the lower part of the section with the two lowermost reflection units, reflectors indicate that the strata are mutually parallel or nearly so. Dip is northward in the northern third of the study area and east to southeast elsewhere. In the upper section primary reflectors dip gently eastward throughout the study area. Numerous secondary reflectors indicate that upper section strata contain internal bedding features and are apparently more heterogeneous and complex than in the lower section. Filled channels incised into the upper section strata are common, especially in the north.

A broad structural high affecting the lower stratigraphic section is centered off Daytona Beach where the crest of the high has been truncated by erosion. Broad gentle undulations and occasional sharp folding can be seen in both lower and upper section strata throughout the study area. Five widespread subbottom reflectors are judged to be erosional surfaces because they truncate internal bedding and structural features, and are time transgressive. These surfaces record episodes of lower relative sea level or subsidence occurring from probable late Eocene to Pleistocene time. Two of these surfaces can be traced throughout the study area.

Correlation of the five reflection units underlying the inner shelf with sparse coastal well data indicates that the lowest unit is probably the subsea extension of the Floridan aquifer and is comprised largely of Ocala Group limestones. The three units overlying the lowermost unit are believed to be of Miocene age. On the basis of core data the uppermost unit is considered to be composed of various beds, lenses, erosional remnants, and channel fill of Pliocene, Pleistocene, and Holocene ages.

Cores penetrating up to 15.5 feet into shallow subbottom strata show that the shelf is covered by thinly bedded sediments ranging in age from late Tertiary to Holocene. The older relict sediments are exposed at the surface where younger layers have been eroded. These sediments are predominantly quartz sands; silt and clay are common in places but are minor lithologies in the regional context. Most of the sediments encountered are classifiable into five broadly defined lithologic types. These lithologics can be related to the morphology and structure of the inner shelf.

The shoreface zone contains a fine to very fine quartz sand. Seaward of the shoreface the inner shelf is mantled by a fine to medium (0.125 to 0.5 millimeters; 2 to 1 phi), well-sorted sand that is well suited for use in beach restoration and nourishment. The sand is predominantly quartz with a small percentage (< 10) of shell fragments, residual phosphorite and accessory detrital minerals, and is commonly less than 10 feet thick. Beneath the surficial deposits, and locally exposed at the surface are Pleistocene shelly quartz sand and Tertiary foraminiferal-rich quartz sands, and dolomitic quartz sands.

Biogenic particles generally comprise less than 20 percent in most sediments of the study area. The main biogenic entities are mollusk shells, echinoid parts, foraminifera and ostracods. Analyses of macrofauna and microfauna indicate that lithologically defined sediment groups are genetically related.

Tertiary sediments bear a microfaunal assemblage indicative of deposition in water much deeper than presently exists in the study area. The terrigenous fraction was probably derived from the southeastern U.S. Piedmont province. Pleistocene deposits are very thin and in most places absent from the shallow subbottom sediment column, indicating this region was starved of sediment influx during repeated transgression and regression of the sea. Evidence from cores indicates that a significant fraction of the inner shelf surficial deposits may have been generated by erosion and reworking of the Tertiary substrate with additional contribution of contemporaneous biogenic material. This evidence consists of the thin nature of the Holocene overburden and the upward decrease in abundance and increase in degradation of diagnostic grains (foraminifer, dolomite) across the Tertiary-Quaternary boundary.

Shoreface and beach sands are judged to be modern active deposits. Since few streams discharge on the north Florida Atlantic coast, beach and nearshore sands are most likely derived from shore erosion and littoral transport of fluvial sand southward from sources along the Georgia coast.

During the next 50 years, 4.78 X 10^6 cubic yards of suitable sand will be needed for restoration and periodic nourishment of beaches along the north Florida Atlantic coast. Favorable conditions exist for obtaining much of this supply from the inner shelf area.

The best sources of sand for beach fill are the fine to coarse quartz sands in the Holocene deposits of the shelf floor area. Thick deposits of this sand, well suited for borrow, are located in several places within the study area; however, not all sites are located near the shoreline. Sediments from areas designated as suitable sites for beach restoration have an average mean grain size of 0.30 millimeters (1.73 phi) and 95 percent of the samples have a mean diameter between 0.50 and 0.177 millimeters (1 and 2.5 phi).

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APPENDIX A

SELECTED GEOPHYSICAL PROFILES

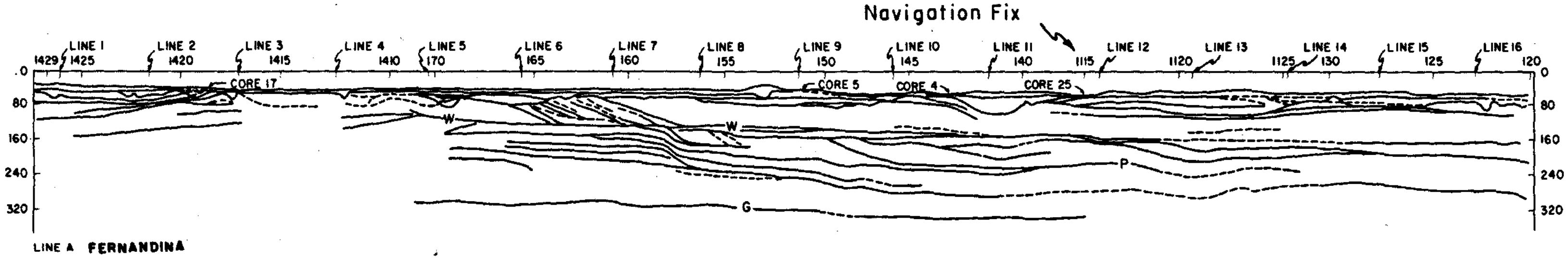
Appendix A contains line profile drawings of selected seismic reflection records from the north Florida area.

Fix numbers and point of crossing lines are plotted along the upper margin of the profile.

The bottom and all subbottom reflectors are delineated and those reflectors mentioned in the text are identified by letter symbols.

All depths are in feet below mean sea level (MSL); and based on an assumed sound velocity of 4,800 feet per second in water and 5,440 feet per second in the subbottom.

Position of lines and fixes are plotted on Figure 2.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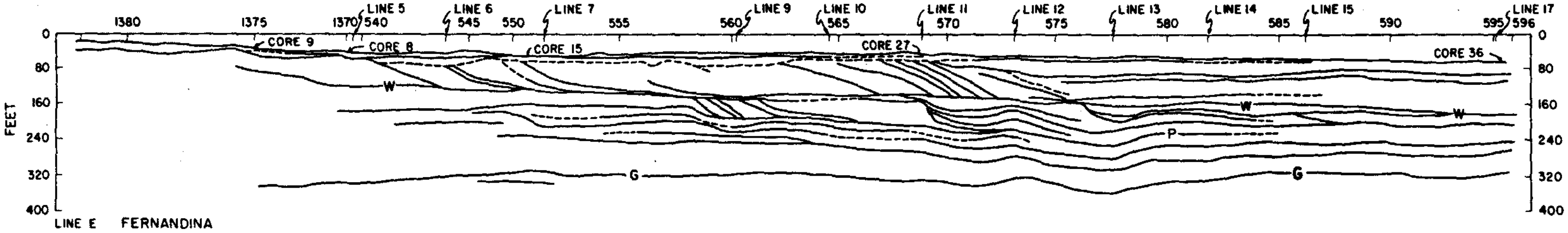
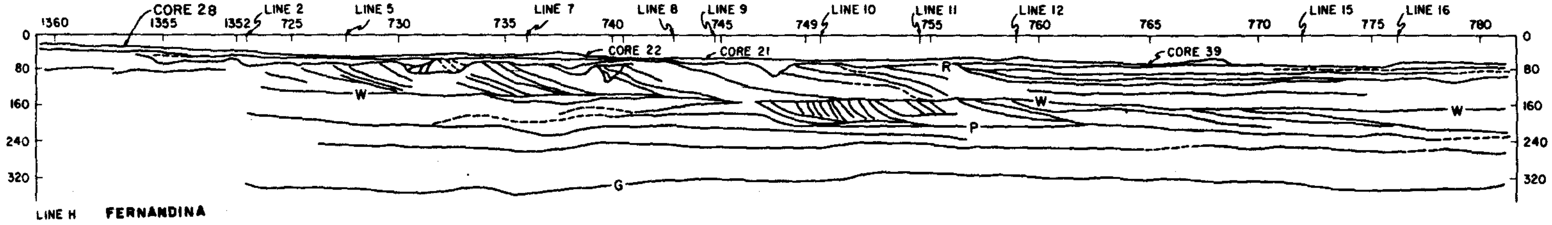
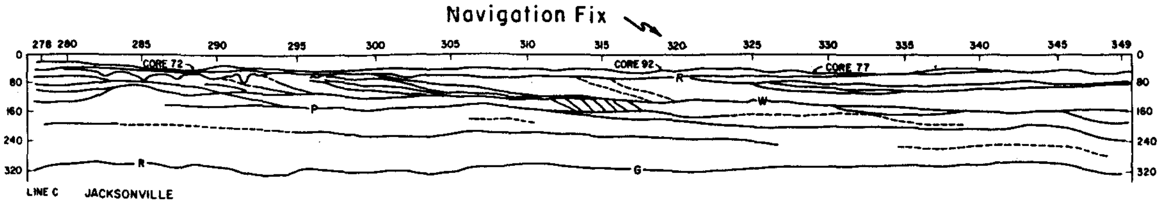
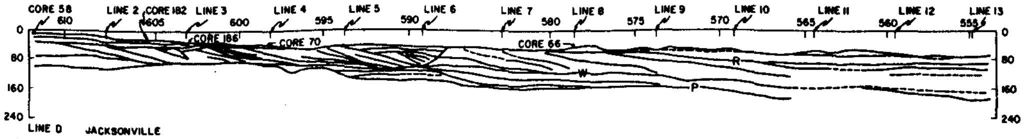
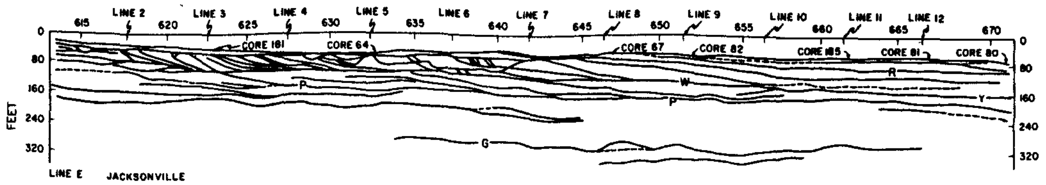
LINE 1
LINE 2
LINE 3
LINE 4
LINE 5
LINE 6
LINE 7
LINE 8
LINE 9
LINE 10
LINE 11
LINE 12
LINE 13
LINE 14
LINE 15
LINE 16
1429
1425
1420
1415
1410
170
165
160
155
150
145
140
1115
1120
1125
130
125
120
0
80
160
240
320
CORE 17
CORE 5
CORE 4
CORE 25
W
P
G
LINE A FERNANDINA

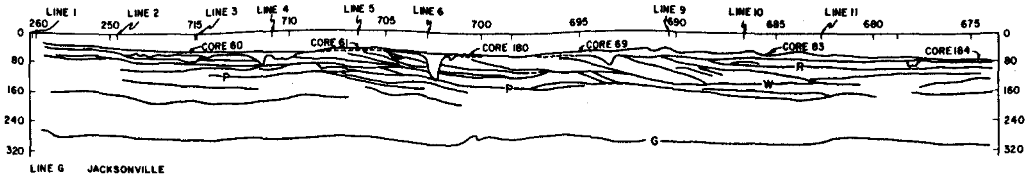

LINE 5
LINE 6
LINE 7
LINE 9
LINE 10
LINE 11
LINE 12
LINE 13
LINE 14
LINE 15
LINE 17
1380
1375
1370
540
545
550
555
560
565
570
575
580
585
590
595
596
0
80
160
240
320
400
FEET
CORE 9
CORE 8
CORE 15
CORE 27
CORE 36
W
P
G
LINE E FERNANDINA

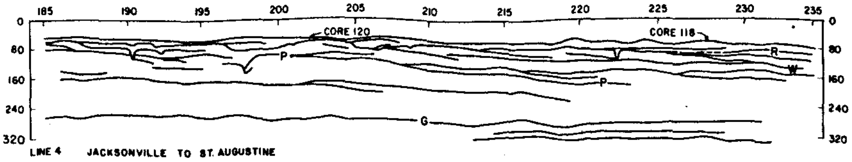

CORE 28
LINE 2
LINE 5
LINE 7
LINE 8
LINE 9
LINE 10
LINE 11
LINE 12
LINE 15
LINE 16
1360
1355
1352
725
730
735
740
745
749
755
760
765
770
775
780
0
80
160
240
320
CORE 22
CORE 21
CORE 39
R
W
P
G
LINE H FERNANDINA

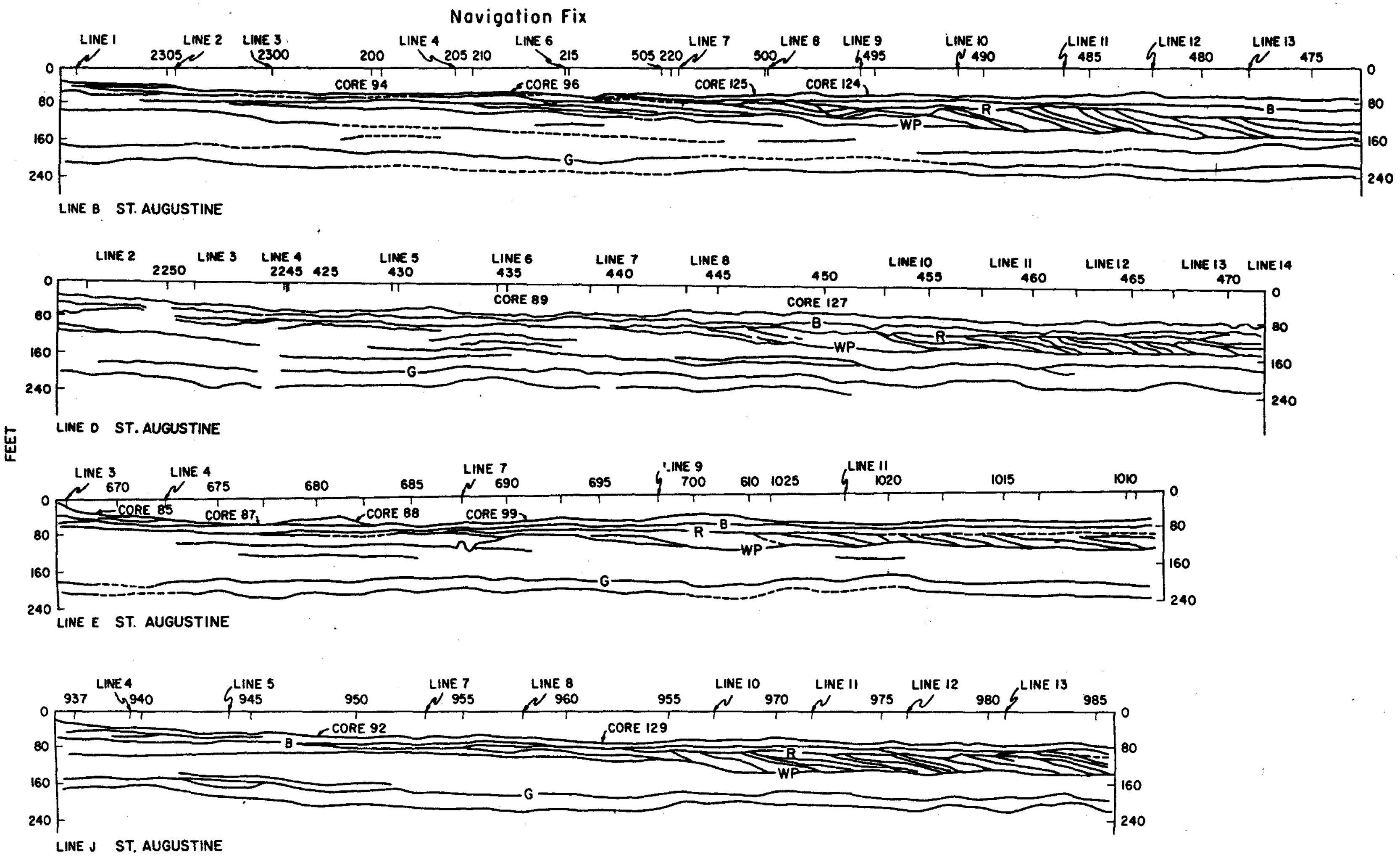

Navigation Fix
278 280 285 290 295 300 305 310 315 320 325 330 335 340 345 349
0 80 160 240 320
CORE 72
CORE 92
CORE 77
R
W
P
G
LINE C JACKSONVILLE


CORE 58
LINE 2
CORE 182
LINE 3
LINE 4
LINE 5
LINE 6
LINE 7
LINE 8
LINE 9
LINE 10
LINE 11
LINE 12
LINE 13
610 605 600 595 590 580 575 570 565 560 555
0 80 160 240
CORE 186
CORE 70
CORE 66
R
W
P
LINE D JACKSONVILLE

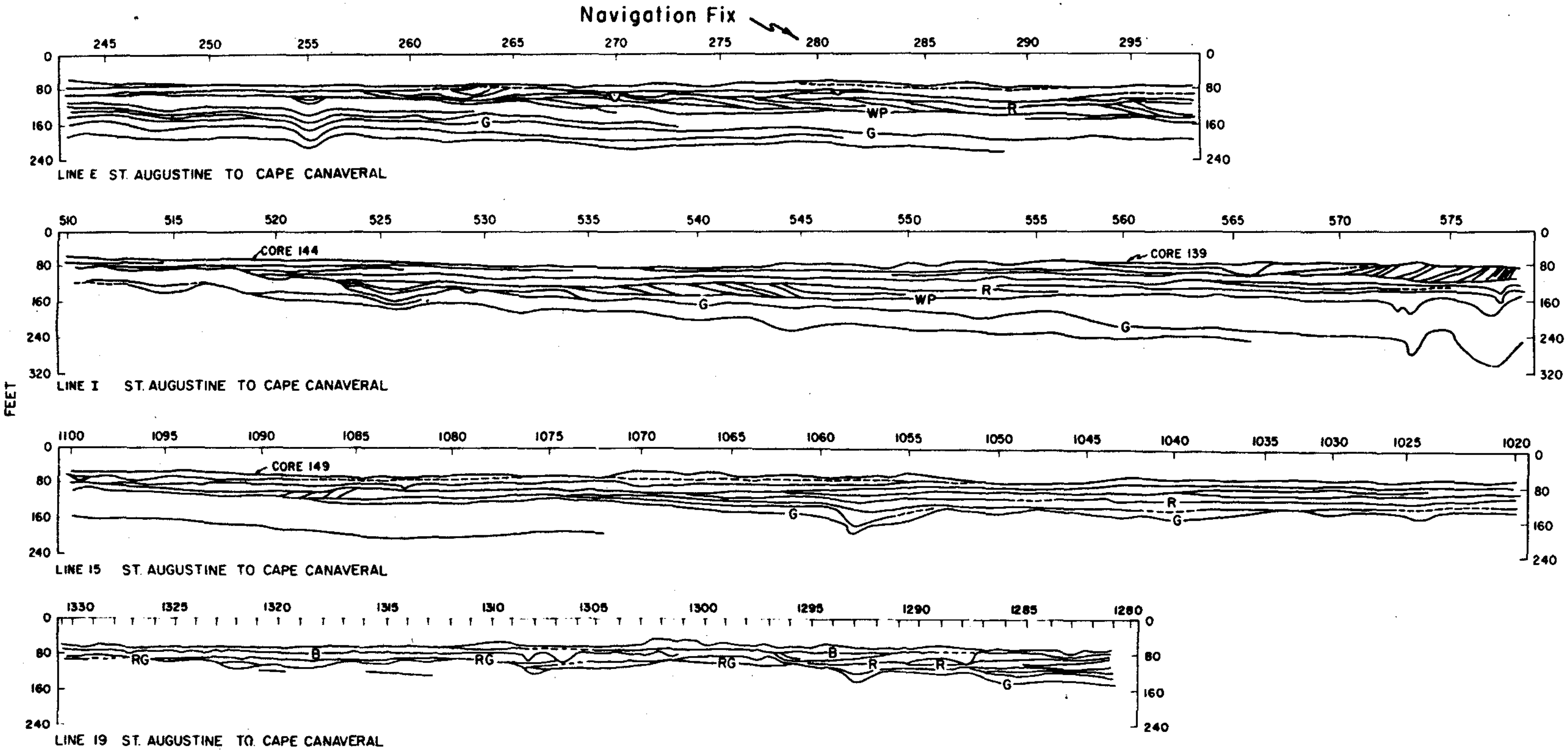

FEET
LINE 2
LINE 3
LINE 4
LINE 5
LINE 6
LINE 7
LINE 8
LINE 9
LINE 10
LINE 11
LINE 12
615 620 625 630 635 640 645 650 655 660 665 670
0 80 160 240 320
CORE 181
CORE 64
CORE 67
CORE 82
CORE 185
CORE 81
CORE 80
R
Y
W
P
G
LINE E JACKSONVILLE

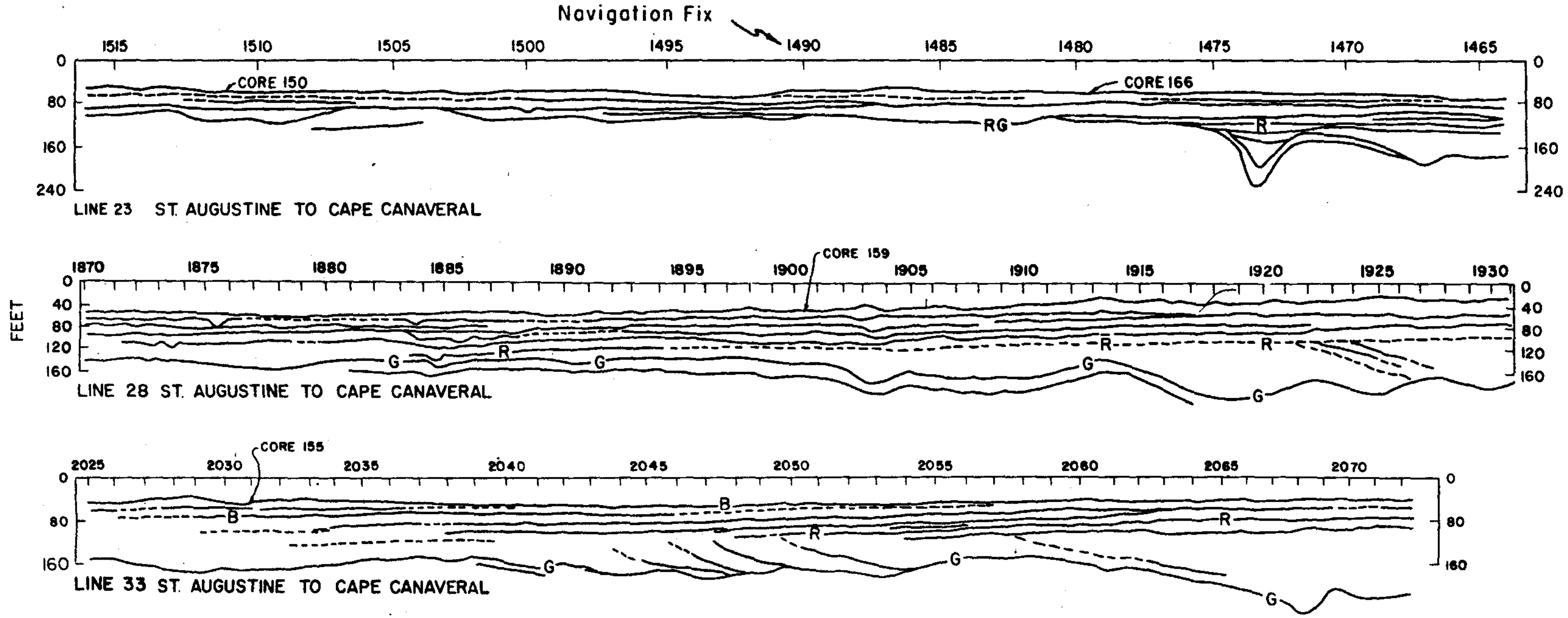

LINE 1
LINE 2
LINE 3
LINE 4
LINE 5
LINE 6
LINE 9
LINE 10
LINE 11
260 250 715 710 705 700 695 690 685 680 675
0 80 160 240 320
CORE 60
CORE 61
CORE 180
CORE 69
CORE 83
CORE 184
R
W
P
G
LINE G JACKSONVILLE


185 190 195 200 205 210 215 220 225 230 235
0 80 160 240 320
CORE 120
CORE 118
R
W
P
G
LINE 4 JACKSONVILLE TO ST. AUGUSTINE



Navigation Fix
FEET
LINE 1
LINE 2
LINE 3
LINE 4
LINE 6
LINE 7
LINE 8
LINE 9
LINE 10
LINE 11
LINE 12
LINE 13
2305
2300
200
205 210
215
505 220
500
495
490
485
480
475
CORE 94
CORE 96
CORE 125
CORE 124
R
B
WP
G
0
80
160
240
LINE B ST. AUGUSTINE
LINE 2
LINE 3
LINE 4
LINE 5
LINE 6
LINE 7
LINE 8
LINE 10
LINE 11
LINE 12
LINE 13
LINE 14
2250
2245 425
430
435
440
445
450
455
460
465
470
CORE 89
CORE 127
B
R
WP
G
LINE D ST. AUGUSTINE
LINE 3
LINE 4
LINE 7
LINE 9
LINE 11
670
675
680
685
690
695
700
610 1025
1020
1015
1010
CORE 85
CORE 87
CORE 88
CORE 99
B
R
WP
G
LINE E ST. AUGUSTINE
LINE 4
LINE 5
LINE 7
LINE 8
LINE 10
LINE 11
LINE 12
LINE 13
937
940
945
950
955
960
955
970
975
980
985
CORE 92
CORE 129
B
R
WP
G
LINE J ST. AUGUSTINE


Navigation Fix
FEET
245 250 255 260 265 270 275 280 285 290 295
0 80 160 240
WP
R
G
LINE E ST. AUGUSTINE TO CAPE CANAVERAL
510 515 520 525 530 535 540 545 550 555 560 565 570 575
0 80 160 240 320
CORE 144
CORE 139
LINE I ST. AUGUSTINE TO CAPE CANAVERAL
1100 1095 1090 1085 1080 1075 1070 1065 1060 1055 1050 1045 1040 1035 1030 1025 1020
CORE 149
LINE 15 ST. AUGUSTINE TO CAPE CANAVERAL
1330 1325 1320 1315 1310 1305 1300 1295 1290 1285 1280
RG
B
LINE 19 ST. AUGUSTINE TO CAPE CANAVERAL


Navigation Fix
1515
1510
1505
1500
1495
1490
1485
1480
1475
1470
1465
0
80
160
240
CORE 150
CORE 166
RG
R
LINE 23 ST. AUGUSTINE TO CAPE CANAVERAL
FEET
1870
1875
1880
1885
1890
1895
1900
1905
1910
1915
1920
1925
1930
0
40
80
120
160
CORE 159
G
R
LINE 28 ST. AUGUSTINE TO CAPE CANAVERAL
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
0
80
160
CORE 155
B
R
G
LINE 33 ST. AUGUSTINE TO CAPE CANAVERAL

APPENDIX B

SIZE DATA OF OFFSHORE CORE SAMPLES DESIGNATED AS SUITABLE MATERIAL FOR BEACH RESTORATION. NORTH FLORIDA

Core	Interval	Median	Mean	Mean	Standard deviation	
	(feet)	(mm)	(phi)	(mm)	(phi)	(mm)
5	top	0.232	2.00	0.251	0.56	1.475
5	–1	0.582	1.05	0.485	0.89	1.854
5	–2	0.248	1.94	0.261	0.58	1.491
48	top	0.497	1.11	0.465	0.76	1.692
48	–4	0.306	1.70	0.308	0.50	1.413
65	–4	0.496	1.19	0.440	0.70	1.625
76	top	0.278	1.90	0.269	0.55	1.465
76	–3	0.345	1.64	0.321	0.67	1.589
78	top	0.497	1.16	0.448	0.64	1.562
78	–1	0.464	1.31	0.402	0.68	1.600
78	–2	0.372	1.46	0.363	0.67	1.587
78	–3	0.348	1.57	0.337	0.65	1.574
78	–4	0.200	2.31	0.202	0.54	1.452
78	–6.5	0.208	2.26	0.209	0.52	1.436
79	top	0.234	2.05	0.241	0.53	1.440
79	–1	0.231	2.11	0.232	0.46	1.378
79	–4	0.200	2.24	0.211	0.49	1.406
107	top	0.254	1.95	0.260	0.45	1.363
107	–1	0.258	1.94	0.260	0.45	1.364
107	–2	0.257	1.97	0.255	0.40	1.318
107	–4	0.245	2.03	0.245	0.40	1.319
107	–6	0.362	1.45	0.366	0.81	1.759
107	–8	0.238	1.93	0.262	0.75	1.681
107	–11	0.201	2.05	0.241	0.90	1.865
109	top	0.300	1.75	0.298	0.48	1.395
109	–2	0.252	1.76	0.296	0.96	1.941
109	–4	0.298	1.73	0.302	1.22	2.337
110	top	0.758	0.42	0.749	0.75	1.682
110	–1	0.488	1.13	0.458	0.80	1.739
110	–3	0.593	0.93	0.523	0.73	1.659
111	top	0.223	2.15	0.225	0.49	1.401
111	top	0.188	2.44	0.184	0.49	1.402
111	–1	0.466	1.27	0.413	0.74	1.672
111	–1	0.459	1.30	0.407	0.75	1.684
111	–3	0.256	1.75	0.298	1.30	2.459

Appendix B—Continued

Core	Interval (feet)	Median (mm)	Mean (phi)	Mean (mm)	Standard deviation (phi)	(mm)
125	top	0.446	1.38	0.385	0.72	1.647
125	–1	0.155	2.62	0.163	0.47	1.390
125	–2	0.153	2.57	0.168	0.55	1.466
127	top	0.269	1.88	0.272	0.42	1.340
127	–2	0.267	1.80	0.286	0.62	1.542
127	–4	0.243	2.02	0.246	0.41	1.325
140	top to –4	0.266	1.84	0.279	0.51	1.420
140	–5 to –9	0.299	1.73	0.302	0.50	1.419
147	–1	0.297	1.73	0.301	0.48	1.396
147	–4	0.282	1.78	0.290	0.54	1.450
147	–8	0.310	1.70	0.308	0.45	1.370
152	top	0.351	1.59	0.332	0.59	1.508
152	–1	0.352	1.49	0.355	0.66	1.576
152	–2	0.282	1.80	0.287	0.57	1.483
152	–3	0.335	1.64	0.322	0.63	1.545
152	–4	0.313	1.78	0.292	0.63	1.544
152	–5	0.248	2.04	0.243	0.66	1.582
160	top	0.315	1.67	0.313	0.56	1.473
160	–1	0.360	1.51	0.351	0.63	1.550
160	–3	0.260	1.95	0.259	0.64	1.559
160	–5	0.491	1.08	0.472	1.04	2.052
173	top	0.289	1.67	0.314	0.50	1.411
173	–2	0.231	2.09	0.234	0.58	1.495
176	top	0.281	1.83	0.280	0.38	1.300
176	–2	0.277	1.87	0.274	0.43	1.344
176	–4	0.301	1.73	0.301	0.44	1.359
183	top	0.261	1.81	0.284	0.93	1.911
183	–1	0.183	2.44	0.185	0.39	1.306
183	–7	0.520	1.11	0.463	0.99	1.989
183	–8	0.452	1.30	0.407	0.70	1.625
191	top to –1	0.384	1.42	0.374	0.71	1.634
191	–3 to –4	0.200	2.29	0.204	0.52	1.437

APPENDIX C

FAUNAL LISTS

The presence of upper Tertiary sediments in outcrop and shallow subcrop under the north Florida Atlantic inner Continental Shelf is of considerable stratigraphic interest. Therefore, more detailed faunal data on these sediments, not discussed in the text, are included in Appendix C.

A typical sample of type L sediment from core 39 at 11.5 feet downhole was submitted to the Paleontology and Stratigraphy Branch, U.S. Geological Survey (USGS) for detailed analysis of the microfauna. This analysis correlates with zone N. 19 of the Neogene planktonic foraminiferal zonation of Banner and Blow (1965) indicating a probable early Pliocene age. The species list for core 36 at 11.5 feet compiled by Miss Ruth Todd, USGS, is presented in Table C-1. Assignment of the stratigraphic range of the sample was based largely on planktonic foraminifera and ostracods.

Dr. J. E. Hazel, USGS, examined the ostracods in sample C-36-11.5 and also analyzed ostracod fauna in several other samples of type L sediment from various parts of the study area. Results of this analysis indicate that deposition of type L sediment occurred under various environmental conditions over a period probably extending from early to late Pliocene.

Table C-2 lists the most common foraminifera occurring in reflection unit B. This list is based on analysis by the authors of available samples containing identifiable remains.

Table C-1. Foraminifera in the White Calcareous Sand

Benthonic	Planktonic
Acervulina inhaerens Schultze	*Globigerina apertura* Cushman
Ammonia beccarii tepida (Cushman)	*Globigerina bulloides* d'Orbigny
Amphistegina sp. (rel. to *A. floridanus* Cushman and Ponton, except smaller)	*Globigerina conglomerata* Schwager?
	Globigerina eggeri Rhumbler
Angulogerina occidentalis (Cushman)	*Globigerina* cf. *inflata* d'Orbigny
Bolivina marginata multicostata Cushman	*Globigerina opima nana* (Bolli)
Buccella sp.	*Globigerina rubescens* Hofker
Bulimina gracilis Cushman = *B. elongata* d'Orbigny	*Globigerinella aequilateralis* (Brady)
Cassidulina sp.	*Globigerinita glutinata* (Egger)
Cibicides lobatulus (Walker and Jacob)	*Globigerinoides obliquus* Bolli
Elphidium advena (Cushman)	*Globigerinoides ruber* (d'Orbigny)
Elphidium incertum (Williamson), juv.	*Globigerinoides sacculifer* (Brady)
Eponides sp.	*Globigerinoides trilobus* (Reuss)
Globulina inaequalis caribaea d'Orbigny	*Globoratalia menardii miocenica* Palmer
Guttulina costatula Galloway and Wissler	*Orbulina universa* d'Orbigny
Guttulina lactea (Walter and Jacob)	*Sphaeroidinella dehiscens immatura* (Cushman)
Hanzawaia concentrica (Cushman)	
Lagena substriata Williamson	
Marginulina sp.	
Nonion grateloupi (d'Orbigny)	
Planulina depressa (d'Orbigny)	
Reussella pulchra Cushman	
Robulus americanus (Cushman), juv.	
Robulus americanus spinosus (Cushman)	
Textularia aff. *warreni* Cushman and Ellisor	
Textularia sp. of Cushman and Ponton, 1932	
Uvigerina auberiana d'Orbigny	

Table C-2. Foraminifera in Reflection Unit B

Benthonic	Planktonic
Angulogerina occidentalis (Cushman)	*Globigerina bulloides* d'Orbigny
Bolivina sp.	*Globigerina juvenillis* Bolli
Buccella mansfieldi (Cushman)	*Globigerinoides* cf. *G. conglobatus* (Brady)
Buccella sp.	*Globigerinoides trilobus* (Reuss)
Bulimina gracilis Cushman	*Globigerinoides obliquus* Bolli
Cancris sagra (d'Orbigny)	*Globigerinoides quadrilobatus quadrilobatus* (d'Orbigny)
Cassidulina crassa d'Orbigny	*Globigerinoides quadrilobatus sacculifer* (Brady)
Cassidulina laevigata d'Orbigny	*Globigerinoides ruber* (d'Orbigny)
Cibicides cf. *C. floridanus* (Cushman)	*Globorotalia acostaensis acostaensis* Blow
Cibicides lobatulus (Walker and Jacob)	*Globorotalia acostaensis humerosa* Takayanagi and Saito
Cibicides cf. *C. mollis* Phleger and Parker	*Globorotalia cultrata* (d'Orbigny)
Diocibicides biserialis Cushman and Valentine	*Globorotalia margaritae* Bolli and Bermudez
Elphidium sp.	*Globoquadrina altispira* Cushman and Jarvis
Globulina inaequalis Reuss	*Hastigerina siphonifera* (d'Orbigny)
Guttulina austriaca d'Orbigny	*Orbulina universa* d'Orbigny
Guttulina costatula Galloway and Wissler	*Sphaeroidinella subdehiscens* Blow
Guttulina palmarae McLean	
Hanzawaia cf. *H.* concentrica (Cushman)	
Lagena clavata (d'Orbigny)	
Lagena cf. *L. costata* (Williamson)	
Lagena substriata Williamson	
Lagena perlucida (Montagu)	
Lagena sp.	
Lenticulina calcar (Linne)	
Lenticulina sp.	
Nodosaria catesbyi d'Orbigny	
Nonion pizarrense Berry	
Nonion grateloupi (d'Orbigny)	
Nonionella auris (d'Orbigny)	
Oolina hexagona (Williamson)	
Pseudopolymorphina rutila (Cushman)	
Reussia spinulosa (Reuss)	
Rosalina floridana Cushman	
Textularia cf. *T. agglutinans* d'Orbigny	
Textularia conica d'Orbigny	
Textularia mayori Cushman	
Uvigerina peregrina Cushman	
Virgulina sp.	

Meisburger, Edward P.
Geomorphology, shallow structure, and sediments of the Florida Inner Continental Shelf, Cape Canaveral to Georgia, by Edward P. Meisburger and Michael E. Field. Fort Belvoir, Va., U.S. Coastal Engineering Research Center, 1975.
119 p. illus. (U.S. Coastal Engineering Research Center. Technical memorandum no. 54).

The inner Continental Shelf off eastern Florida was surveyed to obtain data on bottom morphology and sediments, subbottom structure, and sand deposits suitable for beach restoration and nourishment. Primary survey data consist of 1,153 miles of seismic reflection profiling and 197 sediment cores.

1. Beach nourishment. 2. Continental shelf. 3. Geomorphology. 4. Seismic reflection. 5. Sediments. I. Title. II. Field, Michael E., joint author. (Series)

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