GEOLOGICAL SURVEY OF ALABAMA

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Final Report

GEOLOGIC RESOURCE DELINEATION AND HYDROGRAPHIC CHARACTERIZATION OF AN OFFSHORE SAND RESOURCE SITE FOR USE IN BEACH NOURISHMENT PROJECTS ON DAUPHIN ISLAND, ALABAMA

by

Richard L. Hummell and W. Everett Smith

Prepared by the Geological Survey of Alabama in cooperation with the Department of Geology, University of Alabama, in fulfillment of U.S. Department of the Interior, Minerals Management Service Cooperative Agreement No. 14-35-0001-30781

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CONTENTS

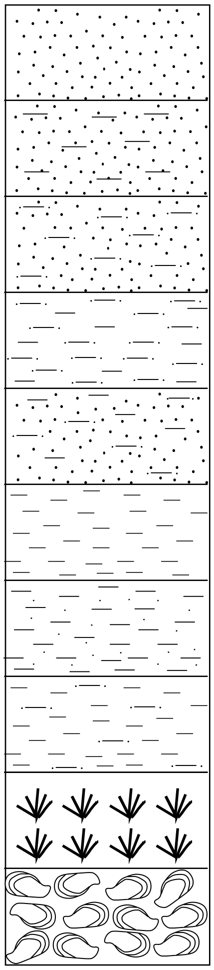
ILLUSTRATIONS

Page

TABLES

EXPLANATION OF PATTERNS AND SYMBOLS

SEDIMENT TYPES



SAND

CLAYEY SAND

SILTY SAND

CLAYEY SILT

SAND-SILT-CLAY

CLAY

SANDY CLAY

SILTY CLAY

PEAT

OYSTER BIOSTROME

ACCESSORIES

- OYSTER SHELL
- ARTICULATED PELCYPOD
- INARTICULATED PELCYPOD
- SHELL FRAGMENT
- PEBBLE
- GRANULE
- NODULE
- PEAT BALL
- ROOTS
- ORGANIC MATTER
- CRAB

SEDIMENTARY STRUCTURES

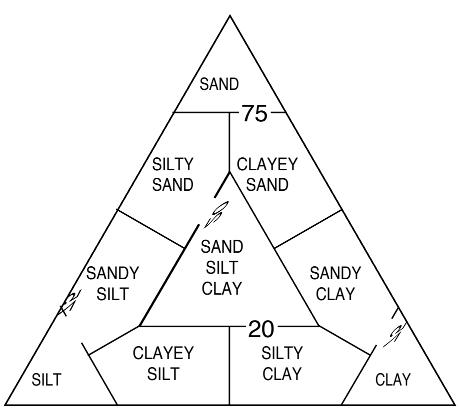
- SAND POCKET
- CLAY POCKET
- CLAYEY SAND POCKET
- SANDY CLAY POCKET
- MUD BURROW
- SAND BURROW
- CLAY DRAPE

SAMPLE INDEX

310 - SEDIMENT SAMPLE

300 - C-14 SAMPLE

SEDIMENT TEXTURE NOMENCLATURE



BIOTURBATION INDEX*

(1) No bioturbation recorded; all original sedimentary structures preserved.
(2) Discrete, isolated trace fossils; up to 10% of original bedding disturbed.
(3) Approximately 10 to 40% of original bedding disturbed. Burrows are generally isolated, but locally overlap.
(4) Last vestiges of bedding discernable; approximately 40 to 60% disturbed. Burrows overlap and are not always well defined.
(5) Bedding is completely disturbed, but burrows are still discrete in places and the fabric is not mixed.
(6) Bedding is nearly or totally homogenized.

*(Droser and Bottjer, 1986)

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EXECUTIVE SUMMARY

Since 1986, the Minerals Management Service of the U. S. Department of Interior has directed the Gulf Task Force, composed of representatives of the states of Alabama, Mississippi, Louisiana, and Texas, to assess the occurrence and economic potential of hard mineral (nonfuel) resources in the Exclusive Economic Zone of those states. Sand and gravel, shell, and heavy minerals were the prominent hard minerals identified in the Gulf of Mexico Exclusive Economic Zone, with sand being identified as the most abundant mineral and having the highest near-term leasing potential.

The primary goal of the present study by the Geological Survey of Alabama and the University of Alabama is to better describe the geometry and granulometry of an area 4 sand resource body delineated by Hummell and Smith (1995). This sand body has near term lease potential for use in beach nourishment projects on Dauphin Island. Evaluation of pre-existing wind, wave, current, tide, and bathymetric data, and previous hydrographic studies form the basis for making recommendations concerning the nature of future computer modeling studies of the physical system associated with the sand resource site and eroding shoreline segments on southeastern Dauphin Island. Additional ground surveys were conducted along southeastern Dauphin Island eroding shoreline segments to document shoreline loss for the 1994-96 period and recalculate the estimated sand required to restore selected segments of shoreline to their 1955 positions. Several forums permitted extensive networking with numerous individuals and agencies as a prelude to making recommendations toward development of a demonstration project that would utilize the sand resource body for beach nourishment projects on Dauphin Island.

Geometric and granulometric details of the area 4 sand resource body were provided by the collection of 10 vibracores and 10 bottom sediment samples. The additional data, in conjunction with data collected by Hummell and Smith (1995), permitted the sand resource body to be modeled with respect to grain size, sedimentary texture, lithofacies patterns, and three-dimensional distribution of sediment type.

Evaluation of the geologic framework of the area 4 sand resource body and vicinity indicates that sediments there consist of Holocene ebb-tidal delta, shelf sand sheet and shelf sand ridge sediments overlying an irregular erosional surface of late Pleistocene-early Holocene age.

Geologic data and resource characterization of the area 4 sand resource body were reevaluated in terms of areal extent and volume of sand, sediment size, and compatibility for beach nourishment in light of the new data collected for the present study. As was concluded by Hummell and Smith (1995), the Graded Shelly Sand Lithofacies sand resource body is deemed to have high potential as a beach nourishment source.

A shelf sand ridge comprised of an estimated 15.5 million cubic yards of the Graded Shelly Sand Lithofacies lie in the east-central portion of the area 4. Geologic data from the present study indicates that that portion of the shelf sand ridge with the highest potential for recoverable sand resources is confined to federal waters some 5 to 7 miles off the southeast coast of Dauphin Island in water depths 40 to 55 feet below sea level. The upper surface of this portion of the ridge is exposed over an area of about 5 square miles of seafloor. It is recommended that a sand recovery project avoid the northeastern end of the sand ridge (roughly the state waters portion) and places where the Graded Shelly Sand Lithofacies is not exposed at the sea floor.

A typical composite stratigraphic sequence of facies for the Graded Shelly Sand Lithofacies sand resource body shows the general trend of the Muddy Shelly Sand Microfacies overlying the pre-Holocene surface which is overlain in turn by the Graded Shelly Sand Lithofacies. Around the margins of the sand resource body, the Graded Shelly Sand Lithofacies interfingers with the Sand-Silt-Clay Microfacies or the Muddy Sand Microfacies. Where these muddy sediments are absent, the sand resource body interfingers with the Muddy Shelly Sand Microfacies.

The ridge thickens down dip (toward the southwest) and its main axis trends northeast-southwest approximately perpendicular to shelf bathymetry. The sediments enclosing the sand ridge contrast lithologically with the ridge which may facilitate locating and following the ridge during a mining operation. Also, this lithologic contrast should facilitate recognition of the contact between the ridge and enclosing sediments in subsurface samples, either on site or in the laboratory.

The Graded Shelly Sand Lithofacies measures up to 11 feet thick at its center and has an average mean grain size, deduced from vibracore sediment samples, of 1.31 phi (medium sand) and average standard deviation of 0.93 phi (moderately sorted). The average major grain size classes for the sand unit are 1.9 percent shell gravel, 95.5 percent sand, 0.6 percent silt, and 1.9 percent clay. Within the resolution of the vibracore and boring data the shelf sand ridge sediments are facies homogeneous and fine-upward. Vibracore sediment samples from the ridge collected in the present study were evaluated with respect to grain size and color and it was determined that these sediments would be compatible with eroding southeastern Dauphin Island shoreline sediments.

Current erosion rates are essentially unchanged from those reported by Parker and others (1993) and Hummell and Smith (1995). The Gulf of Mexico shoreline of southeastern Dauphin Island could be restored to near the 1955 shoreline position by application of about 2.4 million cubic yards of sand. The Graded Shelly Sand Lithofacies unit contains sufficient sand resources (15.5 million cubic yards) to nourish these shoreline segments and provide additional sand for future nourishment projects as the need arises.

Helicopter overflights of coastal Alabama indicate that Hurricane Opal (October 4, 1995) inflicted minimal and localized property damage along the immediate coast. Storm surge combined with storm winds and waves resulted in short term loss of dry beach and the first line of foredunes. The hurricane caused permanent loss of beach at erosion hot spots.

Published regional oceanographic data and studies are available to provide calibration of hydrographic numerical models for simulation of water movement and sediment transport at the sand resource site and along the southeastern shoreline of Dauphin Island. Modeling studies of the physical processes in sand resource target area 4 and eroding shoreline segments on southeastern Dauphin Island would be needed before a definitive determination can be made of the potential impacts of sand dredging and beach replenishment projects. An estimate of the longevity of beach nourished sand and the nature of any future maintenance after initiation of beach replenishment projects appear to depend on these data and studies.

ACKNOWLEDGEMENTS

We would like to thank the staff of the University of Mississippi Marine Minerals Technology Center, Oxford, Mississippi, and especially the crew of the R/V *Kit Jones*, for assistance with marine vibracoring. Likewise, the field logistical assistance received from Mobil Exploration and Producing U.S. Inc. and the use of the Mobil dock on Dauphin Island for embarkation and disembarkation is appreciated.

We are indebted to Sean Patterson, Department of Geology, University of Alabama, for conducting granulometric analyses of vibracore and sea bottom sediment samples, and for his assistance with library research.

We wish to thank Richard Carroll of the Geological Survey of Alabama for assistance with field sampling.

INTRODUCTION

OBJECTIVES

Hard mineral resources in the Exclusive Economic Zone (EEZ) have been the target of much research in recent years due to a growing need to delineate additional supplies of sand and gravel, shell, heavy minerals, phosphates and other economic minerals. In 1986, the U. S. Department of the Interior, Minerals Management Service (MMS) established the Gulf Task Force composed of representatives of Alabama, Mississippi, Louisiana, and Texas to assess the occurrence and economic potential of hard mineral (nonfuel) resources in the EEZ, offshore Alabama, Mississippi, Louisiana, and Texas based on available data. Sand and gravel, shell, and heavy minerals were the prominent hard minerals identified in the Gulf of Mexico

EEZ. Sand was identified as being the most abundant mineral and having the highest near-term leasing potential. Based on these results, ensuing studies by the task force have been directed at characterizing high quality sand deposits for use in beach restoration projects.

In 1993, the Geological Survey of Alabama (GSA) identified and characterized five potential sites of high-quality clean sand deposits in the EEZ, offshore Alabama and determined the development potential for use in beach nourishment of specific eroding shoreline segments in Alabama's coastal area (figs. 1, 2). Characteristics of the offshore sand deposits were compared with competing onshore deposits to identify the most suitable material for use in beach nourishment projects. In addition, a preliminary evaluation of the physical and biological environmental impacts was completed. The Gulf of Mexico shoreline along the southeastern portion of Dauphin Island was determined by GSA to have the highest prioritization of all eroding shoreline segments. One of the five delineated sand resource target areas (area 4) was determined by MMS to be the most economical of the target areas for beach replenishment of these portions of Dauphin Island (fig. 2).

In 1995, the GSA continued the goals of the Gulf Task Force with a study by Hummell and Smith (1995). The primary objective for this study was to better characterize area 4, which appears to have near term lease potential for use in beach nourishment projects on Dauphin Island.

Research by Hummell and Smith (1995) focused on the acquisition of additional data to determine shoreline loss for the period 1985-93 along eroding Dauphin

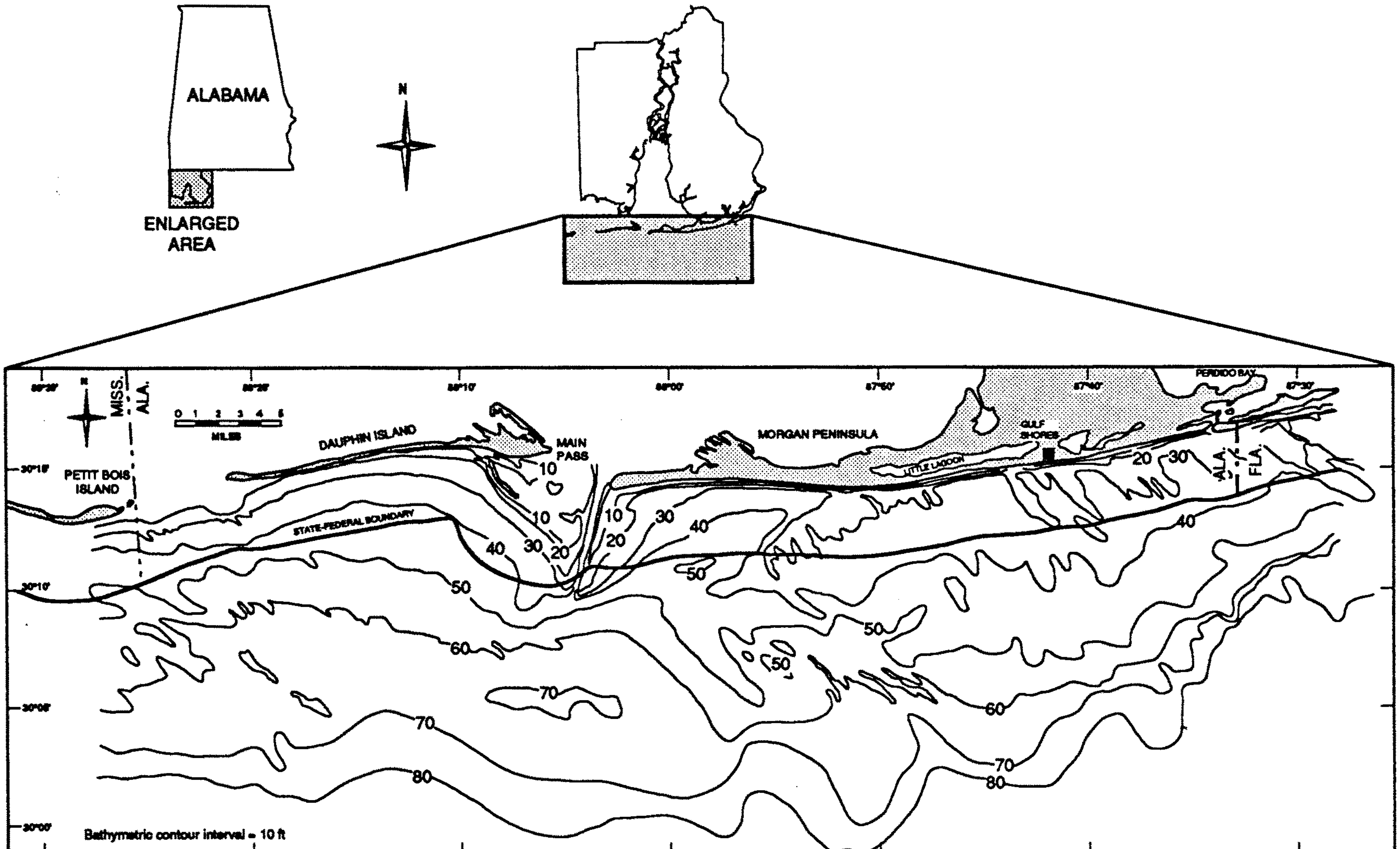


Figure 1.--Map of the Alabama EEZ (modified from Parker and others, 1993)

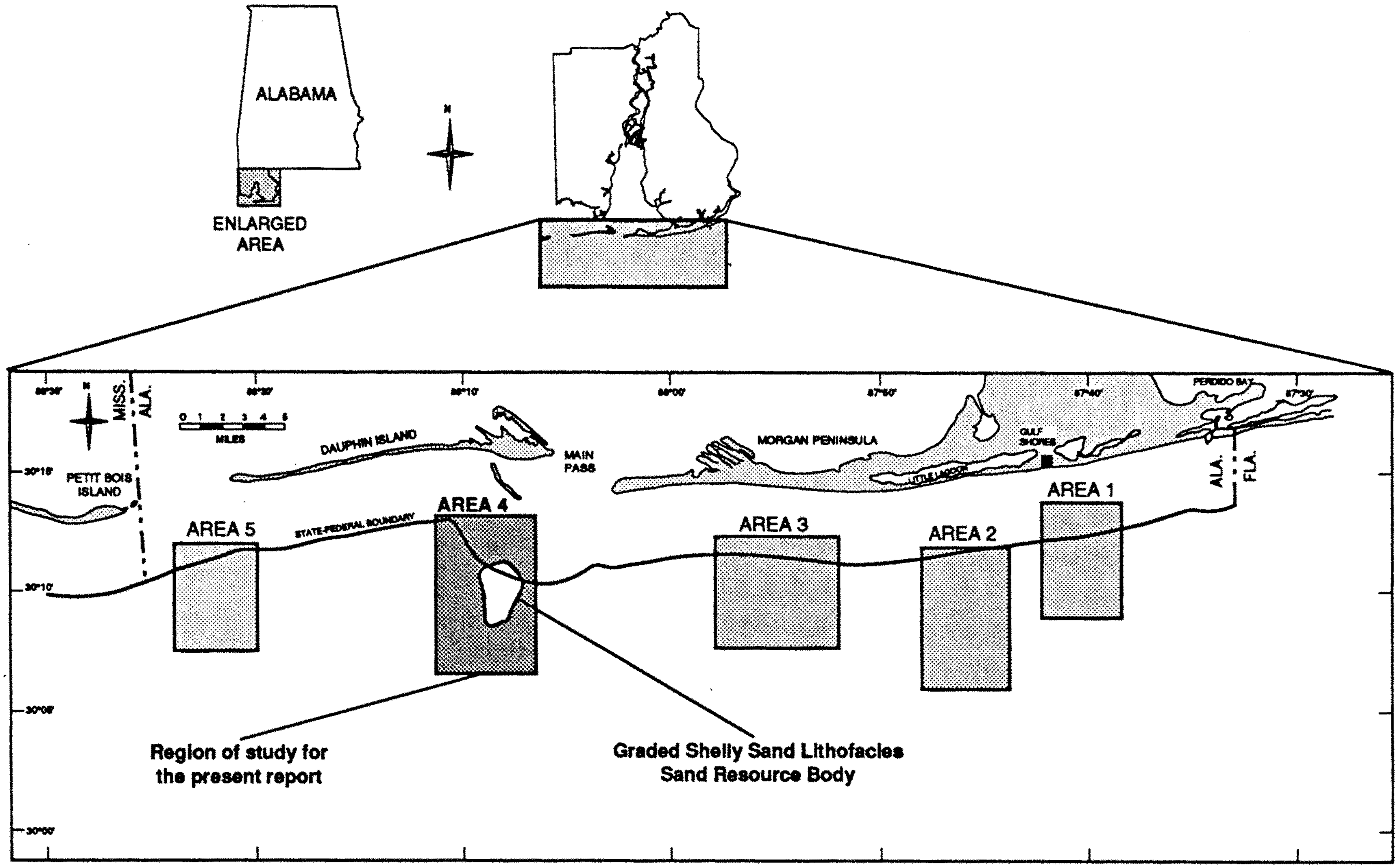


Figure 2.--Index map of EEZ sand resource target areas showing site of the Graded Shelly Sand Lithofacies sand resource body (modified from Parker and others, 1993).

island Gulf of Mexico shoreline segments combined with shoreline loss determinations made by Parker and others (1993) for the period 1955-85, resulted in an estimation of the sand volume required to restore selected segments of Dauphin Island shoreline to their 1955 position.

Parker and others (1993) used only a few vibracores to delineate the distribution and physical characteristics of the sand deposit in area 4. Much of the sand is associated with the distal margin of an ebb-tidal delta of Mobile Bay. Research by the senior author on the ebb-tidal delta (Hummell, 1990) and nearshore Gulf of Mexico (Hummell, 1996), indicates that Holocene sediment geometry in area 4 is related to bathymetry. In addition, ebb-tidal sand bodies (potential target sands) are 'tongue-shaped' or 'sheet-like' deposits interbedded with muddier ebb-tidal delta deposits (Hummell, 1996). Mobile Bay ebb-tidal delta stratigraphy and facies relationships are complex, especially adjacent to the ebb-flood tidal channel and along the distal margin of the delta where ebb-tidal delta deposits interfinger with nearshore Gulf of Mexico shelf sediments (fig. 3) (Hummell, 1996).

In light of these findings, it was necessary to conduct a detailed geological evaluation of area 4 to identify and characterize specific target sand bodies before initiating sand dredging to ensure a cost-effective program. Hummell and Smith (1995) collected additional vibracores and combined this new data with pre-existing vibracores, foundation borings (borings), and seismic data to more accurately describe and delineate the sand resources in area 4.

In addition, Hummell and Smith (1995) developed a more complete evaluation of benthic and nektonic organisms that live in area 4. This information would provide a basis for conducting a detailed sea bottom biological investigation of the target sand bodies to determine the impact dredging activities would have on inhabiting organisms.

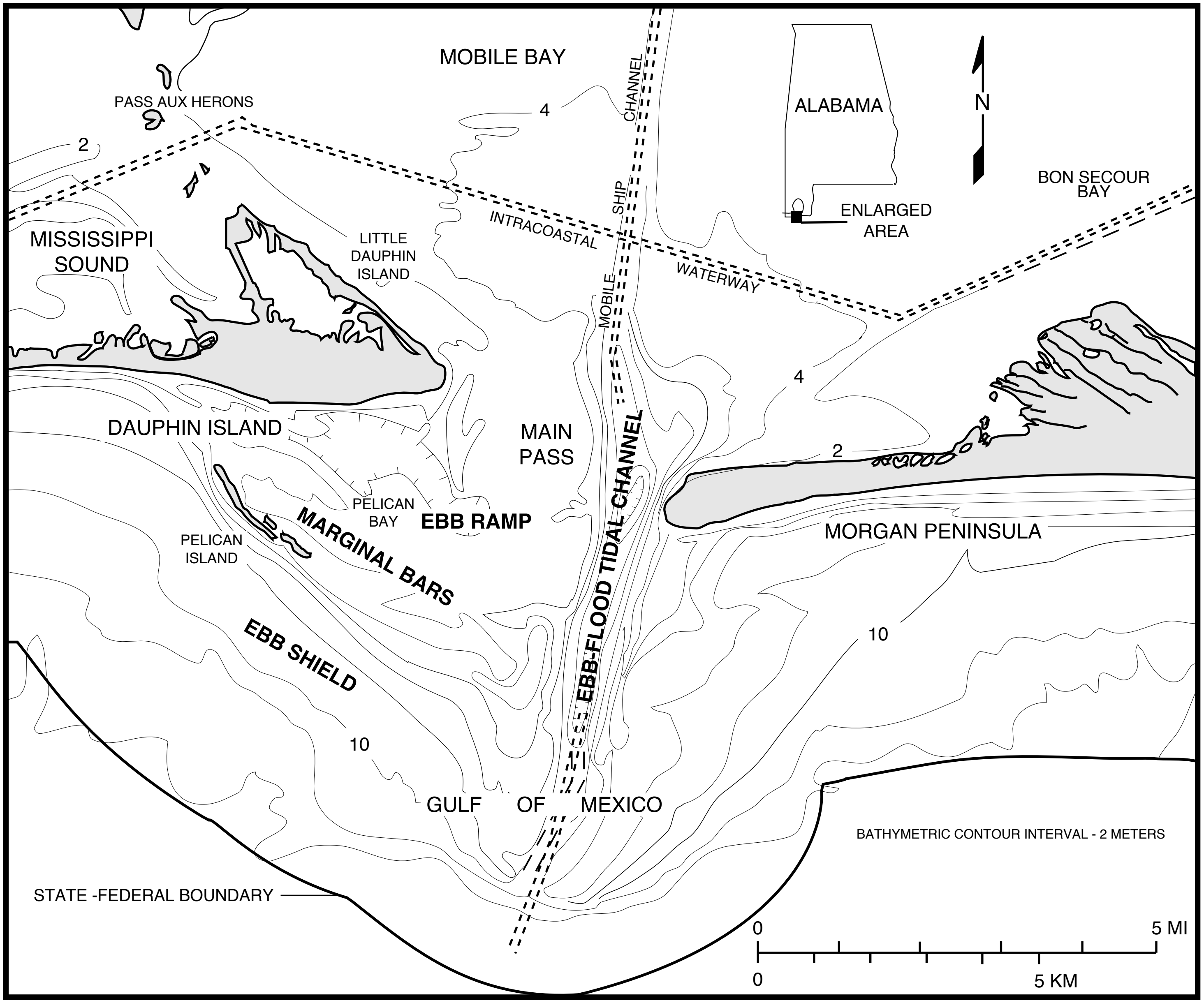


Figure 3.--Geomorphology of the ebb-tidal delta of Mobile Bay (modified from Hummell, 1996).

As a result of their investigation, Hummell and Smith (1995) recommended that before a dredge operation can take place, additional vibracores need to be collected from the sand resource body to better delineate sand body geometry and granulometric homogeneity to ensure a cost-effective program of sand resource recovery. In addition, they recommended that the erosion and sediment transport systems for area 4 and southeastern Dauphin Island shoreline should be computer modeled to predict the possible consequences of mining and application of sand. Also, communication (networking) with local officials, and state and federal agencies with jurisdiction in coastal Alabama is vital to development of recommendations pertinent to a demonstration project, environmental impact study, and a full scale shoreline nourishment project.

The present report is a synthesis of the findings of Hummell and Smith (1995), and new data collected during the present study. The authors consider a synthesized, stand-alone report to be more useable and instructive than two related but separate reports. Included in the present report, are the results of a further investigation of the area 4 sand resource body discovered by Hummell and Smith (1995). In addition, pre-existing wind, wave, current, tide, and bathymetric data was collected and evaluated for the sand resource site and eroding shoreline segments on eastern Dauphin Island. Analysis of these data in conjunction with previous hydrographic studies form the basis for making recommendations concerning the nature of future computer modeling studies of the physical system associated with the sand resource site and eroding shoreline segments on southeastern Dauphin Island. Several forums permitted extensive networking with numerous individuals and agencies as a prelude to making recommendations toward development of a demonstration project that would utilize the sand resources body for beach nourishment projects on Dauphin Island.

TASKS ACCOMPLISHED AND APPROACH FOLLOWED

The objectives of this study were to be accomplished through completion of four tasks designed to better characterize the sand resource body in area 4, which appears to have near term lease potential for use in beach nourishment projects on Dauphin Island; begin networking as a mechanism to involve agencies in the process of developing a recommendation for a demonstration project; and collect and evaluate pre-existing geoscience data to support future computer modeling studies of the physical system associated with the sand resource body and southeastern Dauphin Island. The plan of study was designed to ensure that a coordinated effort was maintained throughout the project that resulted in fulfilling the project objectives and specific identified tasks. These tasks, and the approach utilized for each, include the following:

1. Networking. The approach utilized was to take advantage of several available lines of communication to establish a dialogue with local government, state, and federal agencies concerning past, present, and future work efforts by the GSA and MMS toward a beach nourishment demonstration project for Dauphin Island. This dialogue permitted the exchange of information and ideas between groups addressing Alabama coastal erosion issues. In addition, the networking established a partnership between groups that will ultimately be involved in a Dauphin Island demonstration project.

2. Detailed assessment of the area 4 sand resource body geometry and granulometry was to be accomplished by the acquisition of additional geologic data and further resource evaluation of the sand body. The approach followed was to utilize pre-existing vibracores, borings, seismic data, and prior research findings to guide the collection of a minimum of 10 additional vibracores to more accurately describe the area 4 sand resource body geometry and granulometry to ensure a cost-effective dredging operation. In addition, grain size, percent sand, sand thickness, and aesthetic quality was described to further delineate the resource potential of the sand body. These new data were compared to sediment characteristics of the eroding shoreline segments to check estimated overfill factors and to ensure that the sand resource body does meet volume requirements for replenishment and future maintenance of eroding southeastern Dauphin Island shoreline segments.

3. Detailed assessment of the sedimentary and erosional regimes in the vicinity of the area 4 sand resource body and eroding shoreline segments on southeastern Dauphin Island. Pre-existing wind, wave, current, and tide data along with published hydrographic studies were collected and evaluated for the sand resource body site and for the eroding shoreline segments on southeastern Dauphin Island. Additional ground surveys were conducted along southeastern Dauphin Island eroding shoreline segments to document shoreline loss for the 1994-96 period. This information was used to supplement the existing shoreline loss information compiled in Phase 2 (1955-85) and Phase 3 (1985-94) in estimating sand required to restore selected segments of Dauphin Island shoreline to their 1955 positions. Studies were initiated of the prevailing sedimentary and erosional regimes associated with the site of the sand resource body and southeastern Dauphin Island as a prelude to future computer modeling studies of these regimes.

4. Development of a computer modeling database. Collection and evaluation of pre-existing wind, wave, current, and tide data; published hydrographic studies; utilization of data collected during GSA ground surveys; and information garnered from networking with geologists and engineers was to form the basis for future computer modeling studies of the physical system associated with the sand resource body and southeastern Dauphin Island shoreline.

NETWORKING

COASTAL SHORELINE EROSION TASK FORCE

The legislature of the State of Alabama passed a joint Senate and House Resolution (HJR-324) on June 28, 1995 creating the Alabama Coastal Area Erosion Task Force, which is comprised of various local officials and state and federal agencies. The task force has been charged with the duties of exchanging information and technical results of studies or analysis of shoreline changes, and investigating the feasibility of developing a shoreline management plan for the state. The senior author of this report was the GSA representative in attendance for the approximately bimonthly task force meetings.

The task force has provided a forum to successfully network with Alabama coastal leaders. The task force committee members agree that Alabama's coastal shorelines are valuable to Alabama citizens and the state; coastal Alabama is experiencing significant coastal erosion; it is an appropriate role for state government, in close cooperation with coastal county and municipal governments, to address the coastal erosion issue; and Alabama needs a coastal erosion management plan. Committee members are in agreement that several agencies have partial jurisdiction over the Alabama coast; coordination and cooperation between agencies having coastal responsibilities could be better; there is no one coastal information source for the public; that conflicting answers are given by agencies with coastal jurisdiction; nonconsistent rulings are made by coastal agencies;

and that a coastal erosion management plan (including a post-hurricane plan) needs to be developed. The GSA's coastal research and the sand resources cooperative work effort between the MMS, the University of Alabama (UA), and the GSA represents the technical/scientific component of a beach nourishment program for Dauphin Island.

After examination of coastal management plans for other states, task force members agree that Alabama's coastal management plan would contain elements from all of these plans, but be patterned most closely after Florida's plan.

The Alabama Coastal Area Erosion Task Force is not in favor of creating a new agency of state government with the responsibility of managing coastal erosion. Most local government members of the task force are not supportive of further scientific research studies of Dauphin Island coastal erosion.

The committee has reported to the legislature by letter through the Alabama Department of Community Affairs, Coastal Program Office to develop a coastal management plan. It is further requested that the state's shoreline erosion management effort should continue to be advised by the Alabama Coastal Area Erosion Task Force.

COASTAL ZONE '95

A poster presentation on the GSA's coastal program and cooperative work effort between the MMS, the UA, and the GSA was given at Coastal Zone '95 in Tampa, Florida, on July 20, 1995. Meetings were held during the convention with various State of Alabama and federal agency coastal professionals to discuss beach nourishment projects on Dauphin Island.

1996 NATIONAL CONFERENCE ON BEACH PRESERVATION TECHNOLOGY

The senior author attended the 9th annual National Conference on Beach Preservation Technology in St. Petersburg, Florida, January 24-26, 1996. The theme of this years convention was "The Future of Beach Nourishment?" The meeting provided an opportunity to collect and bring back information on beach nourishment solutions and technology; meet with the nation's top coastal professionals to discuss beach nourishment; report back to the Alabama Coastal Area Erosion Task Force; and apply the acquired knowledge toward development of a recommendation to MMS for a beach nourishment demonstration project on Dauphin Island.

ALABAMA GEOLOGICAL SOCIETY FIELD TRIP

The senior author is co-chairman of the Alabama Geological Society's 33rd annual field trip, *Geological Perspectives on Current Issues in Coastal Alabama*, scheduled to be held June 6-9, 1996. Attendees will be primarily geologists from throughout the southeastern United States.

Coastal Alabama is dominated by several major water bodies, deltas, inlets, and islands that collectively form a complex and dynamic ecosystem. As is true of most coastal margins today, this system is undergoing short term and long term change in an atmosphere of multiple human activities and interests. During the past several years there has been a concentrated geoscientific research effort in Alabama to address coastal issues such as relative sea level rise, shoreline erosion, marsh loss, sand resources, and beach nourishment in order to develop ways of protecting and managing natural resources.

The purpose of the field trip is threefold; first to give participants an opportunity to gain first hand experience with various coastal issues. Second, to permit an examination of modern coastal depositional environments. The third purpose is to demonstrate how coastal issues and modern depositional environments are related to Holocene historic development of coastal Alabama. In addition, Coastal Plain geologists will have a chance to compare notes on modern and Quaternary depositional environments.

As is customary, the field trip will consist of a published field trip guidebook containing invited scholarly papers by working Alabama coastal research professionals and a field trip. The guidebook will cover a spectrum of scientific endeavor, including coastal issues, and recent and on ongoing coastal research in geology, hydrography, and biology. The trip should therefore provide a good sample of the work being done in coastal Alabama.

GEOGRAPHIC SETTING

INTRODUCTION

Area 4 is part of the east Louisiana-Mississippi-Alabama Shelf (fig. 4), a triangular-shaped region that includes parts of offshore Louisiana, Mississippi, Alabama and northwest Florida (Parker, 1990). The shelf extends from the Mississippi River delta eastward to the De Soto Canyon and from the southern shorelines of the Mississippi-Alabama-northeast Florida barrier islands to the 650-foot (ft) (200-meter) isobath (Parker, 1990). Area 4 includes that part of the shelf from Main Pass to just west of Pelican Island and from south of Pelican Island out to about the 60-ft isobath (fig. 5). The narrow shoreface of Dauphin Island forms the northern boundary of the shelf. The break in slope between the shelf and shoreface here occurs at approximately the 19.5-ft isobath. The shoreface gradient south of Dauphin Island is approximately 53 ft per mile (mi) and the shelf gradient from the shoreface of Dauphin Island to the state-federal boundary is approximately 9 ft per mi. The surface within the study area is relatively smooth and featureless interrupted by the broad topographic high representing the ebb-tidal delta of Mobile Bay (fig. 5). Directly north of the study area is Dauphin Island, Pelican Island and two large estuary systems, Mississippi Sound and Mobile Bay.

Dauphin Island is the easternmost island in the Mississippi-Alabama barrier chain that separates Mississippi Sound from the Gulf of Mexico (fig. 6). The island is approximately 15 mi long and varies from 1.6 mi to 0.25 mi wide with elevations on the eastern end of the island generally between 5 and 10 ft, with the exception of an east-west trending coastal sand dune located north of the beach, which rises to as

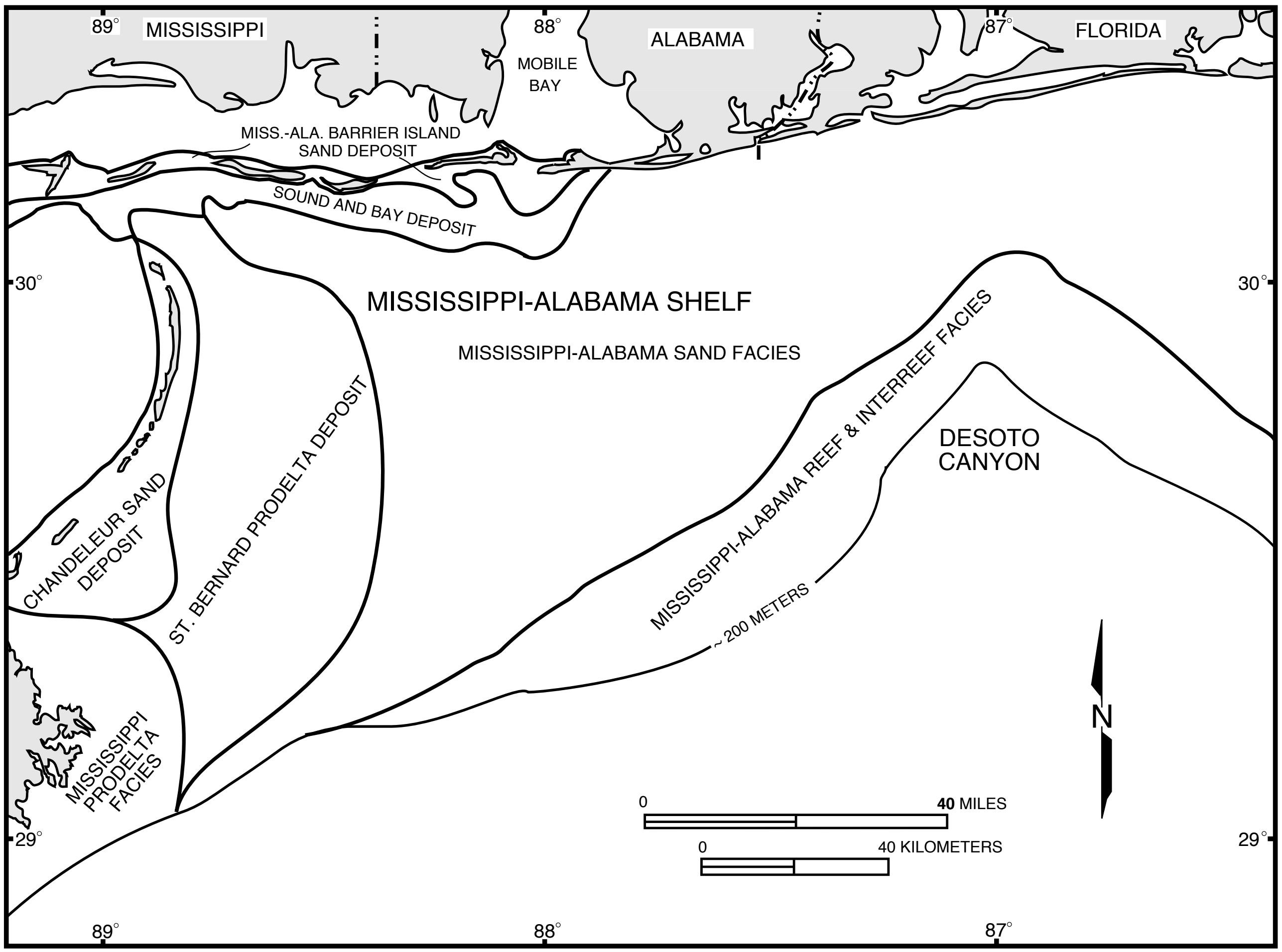


Figure 4.--Sedimentary facies on the Mississippi-Alabama shelf (modified from Ludwick, 1964; Boone, 1973).

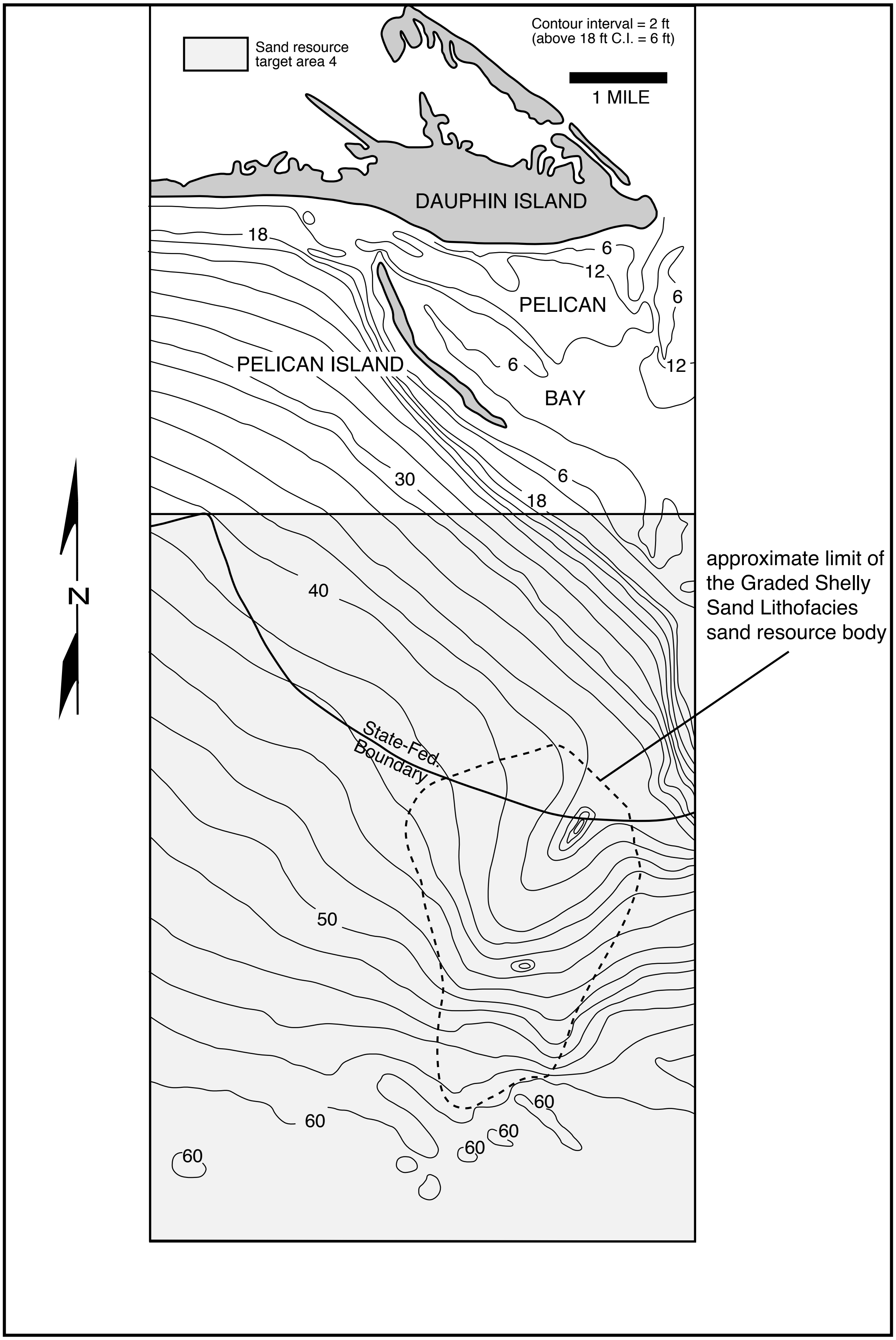


Figure 5.--Map of sand resource target area 4.

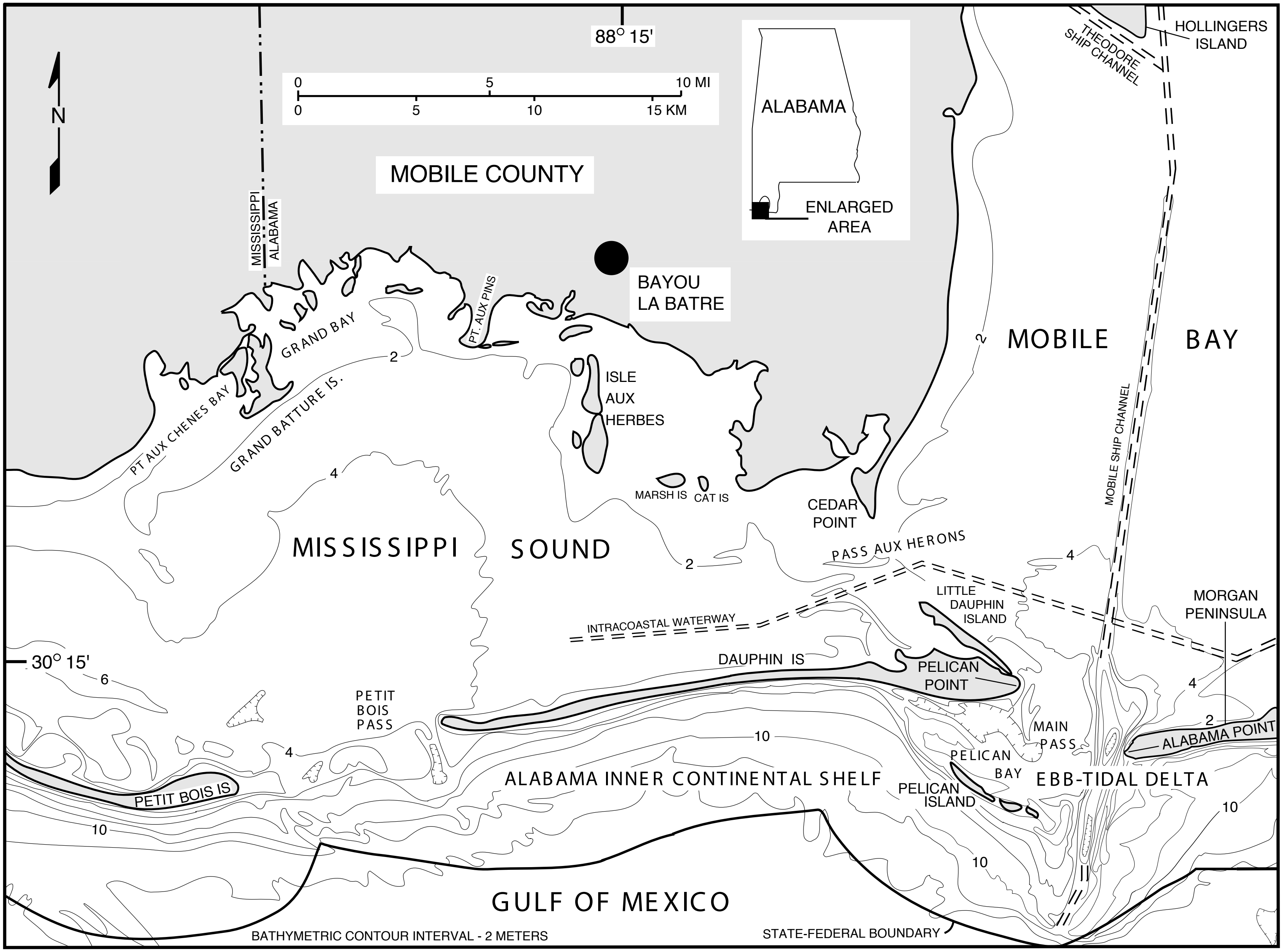


Figure 6.--Map of coastal Alabama showing the west Alabama inner continental shelf (modified from Hummell, 1996).

much as 45 ft. (Hardin and others, 1976). The western three-fourths of the island is a spit where elevations are 5 ft or less except for coastal dunes that may reach a height of up to 10 ft above sea level. Washover and the opening of temporary inlets across the spit part of the island occur as a result of cold air outbreaks, hurricanes, and tropical storms (Hardin and others, 1976; Nummedal and others, 1980).

Little Dauphin Island is a spit extending from the eastern tip of Dauphin Island into Mississippi Sound (fig. 6). The spit measures approximately 2.8 mi long, 0.6 mi wide at its widest point, and has an elevation of less than 5 ft above sea level. Tidal inlets, produced by high energy storm events (hurricanes and tropical storms) have subdivided the spit into a series of islands (Nummedal and others, 1980). Nautical charts show that these inlets have closed, reopened, and changed location over the past two centuries (Hardin and others, 1976; Hummell, 1990).

Main Pass is the 3 mi wide inlet connecting Mobile Bay to the Gulf of Mexico at the southern end of Mobile Bay (fig. 6). An ebb-tidal delta is located at the mouth of Mobile Bay measuring approximately 10 mi wide, and extending approximately 6 mi into the Gulf of Mexico, and has an average water depth of about 10 ft over its top. Its emergent portions consist of numerous shoals and ephemeral islands which enclose Pelican Bay. The ebb-flood tidal channel contains the Mobile Ship Channel, and the tidal channel has been scoured by ebb and flood tidal currents and dredging to depths of 54 to 58 ft (Boone, 1973) (fig. 6). The maximum channel depth is 60 ft due west of Mobile Point (U.S. Department of the Navy, 1986).

Pelican Island, is an emergent part of a northwest-southeast-trending intermittent bar adjacent to the Mobile Ship Channel (figs. 3, 6). This bar continuously changes shape, size, and location as a result of storm events, fair weather waves, and sediment movement within Pelican Bay. In the past, this bar has existed as one or more separate islands. The ephemeral nature of the emergent portions of these bars has led to the use of various names for the islands on maps and in documents produced over the past 400 years. On the latest nautical chart (National Oceanic and Atmospheric Administration (NOAA), 1991b), the emergent, northern part of the bar is labeled "Pelican Island."

BATHYMETRY

The bathymetry of area 4 reflects the presence of the ebb-tidal delta of Mobile Bay (fig. 5). The surface of the inner continental shelf dips gently towards the southwest. The surface in the study area is relatively featureless except where it is disrupted by a northeast-southwest trending ridge lying on the ebb shield of the ebb-tidal delta of Mobile Bay. Water depths range from 6 ft or less in the northeast corner of area 4 to about 60 ft along its southern margin.

CLIMATE AND METEOROLOGY

Coastal Alabama has a humid subtropical climate (Trewartha and Horn, 1980) with an average annual temperature of 68° Fahrenheit (F) and greatest range from a high of 90° F in the summer to 20° F in winter (Vittor, and Associates, 1985). Wind and wave activity is low to moderate along the Alabama coast. Prevailing winds average 8 mi per hour (mph) and are stronger and northerly in the winter and calmer and southerly during the summer (Vittor, and Associates, 1985). Precipitation in the form of rain occurs throughout the year, but is concentrated during summer months due to thunderstorm and tropical storm activity.

The central Gulf of Mexico coast has one of the highest frequencies of hurricane landfall in the United States. From 1871 through 1980 an average of 2.2 tropical storms made landfall along every 11.5 mi stretch of the coast (Neumann and others, 1981). However, the coastal Alabama region escaped a direct hit from a major hurricane for more than 50 years preceding Hurricane Frederic in 1979. Tropical storms are capable of producing heavy rainfall over coastal Alabama. Rainfall amounts of 0.4 to 0.8 ft are not unusual.

TIDES

The astronomical tide along coastal Alabama is diurnal, i.e., with one high and one low tide per day (U.S. Department of the Navy, 1986). During the biweekly neap tide, however, two highs and two lows occur within one day (U.S. Department of the Navy, 1986). The mean tidal range is 1.2 ft at Mobile Point (Crance, 1971), which is classified as microtidal (Hubbard and others, 1979). Mean low water during the winter months ranges from 0.5 to 1.0 ft below that during the summer months (U.S. Army Corps of Engineers, 1979).

WAVES

Wave intensity along coastal Alabama is low to moderate, with periods ranging from 3 to 8 seconds and wave height rarely over 3 ft (Upshaw and others, 1966). This is consistent with the limited flood-tidal delta development landward of the ebb-tidal delta of Mobile Bay. These fair-weather waves are important for longshore transport of sediments in the nearshore zone (Upshaw and others, 1966). Wave approach is predominantly from the southeast. Intense wave activity associated with hurricanes and other storm events help rework shelf sediments (Upshaw and others, 1966; Chermock and others, 1974).

Wave heights in the nearshore area generally are proportional to wind speeds, with wave heights at a minimum during the summer and a maximum during the winter

(Chermock and others, 1974). Chermock and others (1974) state that wave heights of 12 ft occur throughout the year, but heights of 20 ft or greater have been reported in February and October only.

WATER TEMPERATURES

Surface water temperatures of Gulf of Mexico waters seaward of Dauphin Island out to approximately 12 mi offshore reflect fluctuations in air temperatures, ranging from a high of 86° F to a low of 53.6° F (Vittor, and Associates, 1985). Gradual warming of surface waters throughout the spring and early summer months can lead to temperature stratification during the month of July with generally uniform water temperature profiles during October and November (Vittor, and Associates, 1985). In general, water temperature conforms less to air temperature with greater distance from shore and greater depth of the water column (Vittor, and Associates, 1985).

SALINITY

Overall, interactions between Mobile Bay, eastern Mississippi Sound, and the Gulf of Mexico result in dynamic and constantly changing water movement in the nearshore zone. Salinity of continental shelf waters seaward of Dauphin Island is usually highly variable due to low salinity waters discharged from Mobile Bay and eastern Mississippi Sound which are mixed with marine waters of varying salinities (Vittor, and Associates, 1985).

Limited data has prevented determination of any seasonal or annual cycle in nearshore Alabama salinity distribution. In general, steep salinity gradients (e. g. 0 to 36 parts per thousand or ppt) are sometimes observed within a short distance (Vittor, and Associates, 1985). Meteorological events (storms and cold air outbreaks) disrupt seasonal patterns of salinity distribution. During late spring and early summer, low salinity surface water may spread over much of the nearshore continental shelf (Vittor, and Associates, 1985).

HYDROGRAPHIC SETTING

GENERAL HYDROGRAPHY

Numerous small to medium spatial scale and/or short time period studies have been conducted on circulation patterns within coastal Alabama, especially Mobile Bay, employing direct measurement, remote sensing techniques, and computer modeling. Circulation on the continental shelf of the northern Gulf of Mexico is strongly influenced by four factors: open Gulf circulation (e.g., the Loop Current), winds, tides, and freshwater discharge from rivers (Vittor, and Associates, 1985). Secondary factors include the configuration of the coast, bathymetry, and the Coriolis Force.

Sustained winds tend to be the dominant driving force of the circulation on the inner continental shelf (Vittor, and Associates, 1985). In the case of an onshore wind in shallow water, the surface waters will tend to flow with the wind direction while the bottom waters tend to flow offshore following a seaward-directed pressure gradient induced by an elevation of the water level near the coast (Vittor, and Associates, 1985). The presence of other forces, such as a horizontal density gradient, will alter this scheme dramatically (Vittor, and Associates, 1985). If a horizontal density gradient is present in the bottom waters, such that the lighter water lies near the coastline, the density current will oppose and perhaps reverse the effect of an onshore wind on the current field (Vittor, and Associates, 1985). Similarly, offshore winds will drive light (and/or low salinity) surface waters away from the coast, resulting in the upwelling of heavier bottom water (Vittor, and Associates, 1985). The horizontal density gradient which results is confined to the surface layer and directed offshore as a density current (Vittor, and Associates, 1985).

Due to their complexity and seasonal variability, currents on the inner continental shelf are not well described (Vittor, and Associates, 1985). However, general understanding of the overall patterns can be derived from the works of Schroeder (1976), Chuang and others (1982), Kjerfve (1983), and Kjerfve and Sneed (1984).

Drift bottles released during late spring and early summer from a Stage I platform located 12.4 mi offshore from Panama City, Florida, were found primarily along the northwest Florida beaches (Tolbert and Salsman, 1964). However, the recovery zone shifted westward toward Alabama and Mississippi coasts during late summer and early fall, coinciding with the peak frequency in the westward-flowing wind component (Tolbert and Salsman, 1964).

After removal of the tidal current, the influence of wind and horizontal density gradients are of great importance to current structure on the shelf. A strong onshore wind (i.e., from the southeast) results in a transient two-layer flow in the cross-shelf direction (i.e., vertical circulation patterns with onshore flow in the surface waters and offshore flow in the bottom waters) (Vittor, and Associates, 1985). Subsequent to this onshore wind, strong south to southwesterly setting currents persist, establishing a relatively stable flow pattern (Vittor, and Associates,1985).

The shoreline variation in coastal geometry plays a major role in controlling circulation patterns on the shelf (Murray, 1976; Chuang and others, 1982). Variations in frequency response indicate that circulation is strongly affected by the wind duration, density stratification, and coastal geometry (Chuang and others, 1982). In his studies of the influence of wind on shelf circulation, Schroeder (1976, 1977) shows a very close correlation of bottom flow with the Ekman spiral.

Sustained winds tend to be the dominant driving force of the circulation on the inner continental shelf (Vittor, and Associates, 1985). Wind-driven circulation is caused by frictional drag of the air as it passes over the surface of the water (Vittor, and Associates, 1985). In deep water far from coasts, surface currents in the Northern Hemisphere are deflected 45° to the right of the wind direction; this deflection continues to rotate clockwise as depth increases, forming the logarithmic Ekman spiral (Vittor, and Associates, 1985). In shallow waters far from coasts, the same balance of forces produce a deflection to the right, but the angle between wind and surface current is less than 45° (Vittor, and Associates, 1985). In water depths of 5 to 10 meters (m) the maximum deflection with depth is 5 to 10° (Vittor, and Associates, 1985).

Analysis of current data collected 16.1 mi south of Mobile Bay shows the tendency of near-bottom waters to be transported about 90° to the right of sustained wind direction. During July 1976, prevailing winds were to the north and northeast with near-bottom currents to the east and southeast. During November 1976, prevailing winds were to the south with a prevailing near-bottom current direction to the west. Poor correlation between wind and near-bottom current was also noted, which may occur when winds are not of consistent direction or duration to produce a sustained current direction, or when Ekman transport of bottom waters is directed toward a barrier (i.e., shoals or barrier island). This may occur in the study area when northeast, east, or southeast winds tend to move bottom waters shoreward. This shoreward movement is hindered by barrier islands and thus the bottom water will be turned and will flow along the isobaths.

The vertical structure and overall current pattern along the nearshore area of Mississippi Sound and Alabama is considered a two-season event with transitional periods (Kjerfve and Sneed, 1984). Winter, with frequent energetic storms and low freshwater imput, is characterized by a well-mixed water column. The regional winter current pattern is dominated by alongshore currents flowing to the west in response to the strong offshore-directed mean winds (Schroeder and others, 1985) (fig. 7). In spring, increased freshwater runoff, coupled with a reduction in mixing energy as a result of fewer and less intense storms, results in the development of a partially stratified water column. Once initiated, stratification is maintained through the summer by solar heating of the surface waters and a further reduction of storm-derived mixing. With the reversal and reduction in strength of the prevailing winds to onshore conditions, the regional circulation can reverse to exhibit alongshore movement towards the east (Schroeder and others, 1987) (fig. 7). Peak current speeds for either flow direction exceed 1 ft per second (fps) (Dinnell, 1988).

Kjerfve and Sneed (1984) further document the seasonal differences in oceanographic conditions in the study area during a one-year investigation (1980-81) offshore of coastal Mississippi and Alabama, based on three 45-day deployment periods at eight current meter stations (surface and bottom) (fig. 8). The mean currents for each of the three current meter deployments, indicated in figure 8 as mean vectors, have different overall current characteristics. During

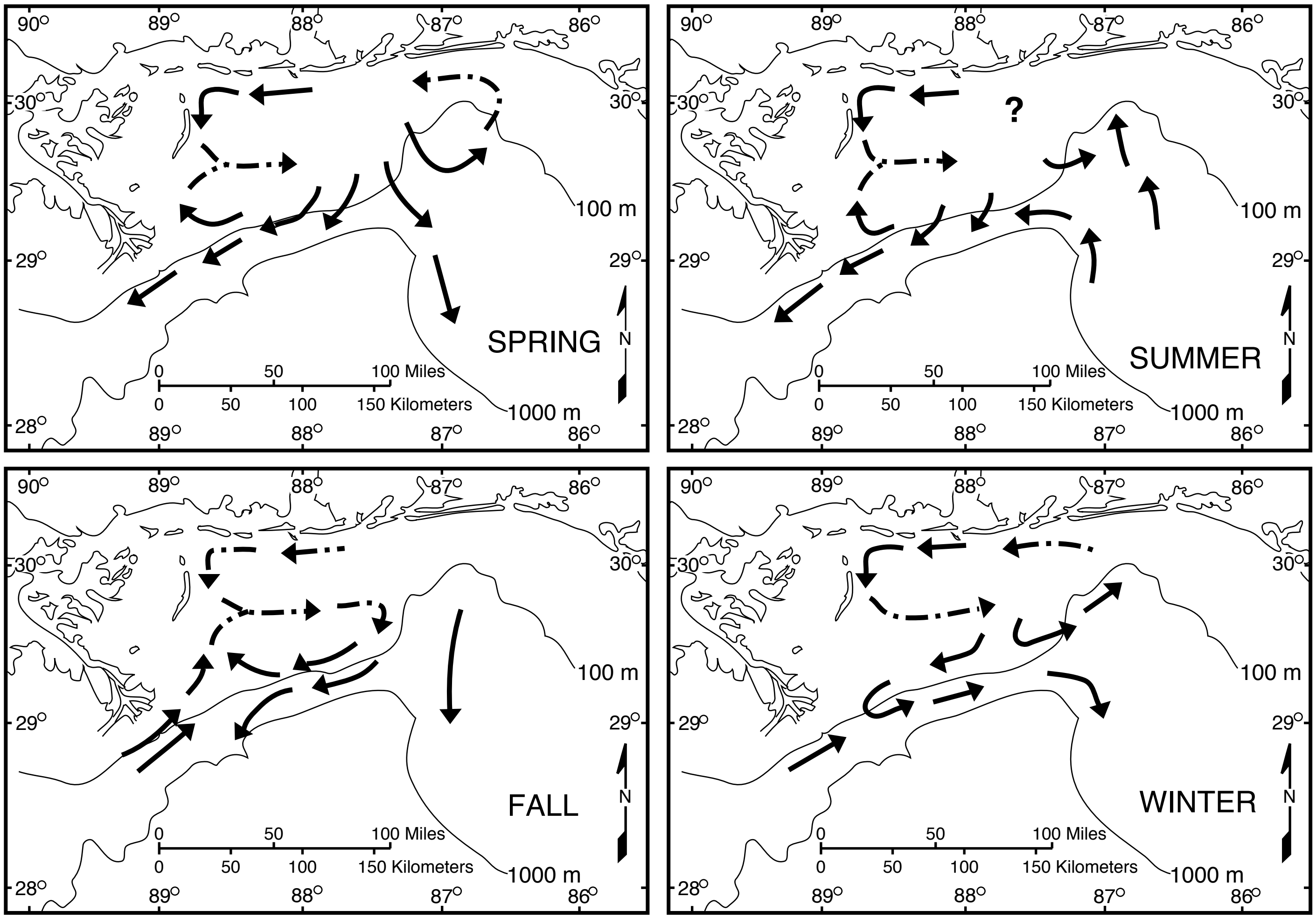


Figure 7.--Circulation patterns on the east Louisiana-Mississippi-Alabama continental shelf (modified from Parker, 1990).

NOV. 1, 1980 - JAN. 9, 1981

MAR. 21 - MAY 23, 1981

JUL. 18 - SEPT. 16, 1981

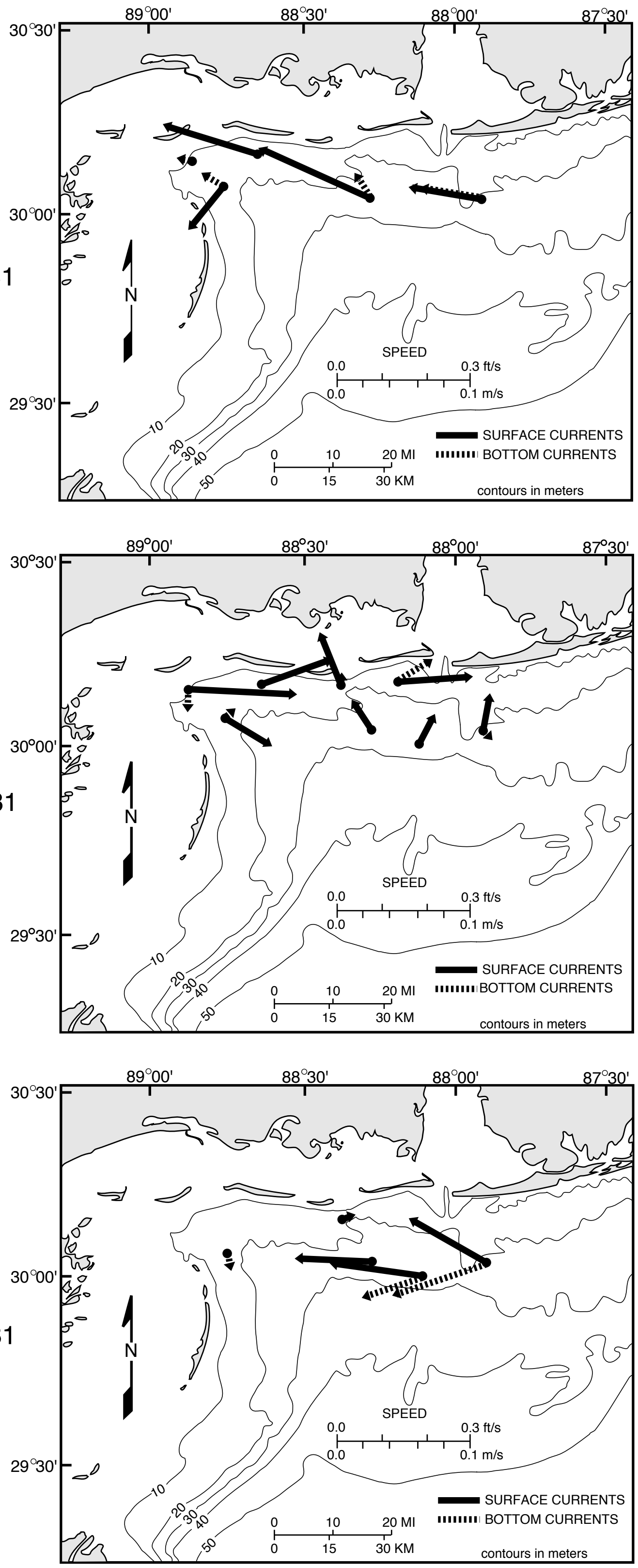


Figure 8.--Mean current velocities on the East Louisiana-Mississippi-Alabama inner continental shelf (modified from Parker, 1990).

the November 1980 - January 1981 deployment (A), mean surface flow was towards the west with bottom currents flowing north and west away from the barrier islands. During the March-May 1981 deployment (B), surface currents were largely to the east with bottom currents to the north at six of the eight stations. During the July-September 1981 deployment (C), both surface and bottom currents were largely directed towards the west.

Although tidal currents are considered the most energetic currents observed on the shallow shelf, Kjerfve and Sneed (1984) concur that nontidal wind-induced circulation is the principal driving force of low frequency circulation. In an attempt to generalize predictions of surface and bottom flow directions based on meteorological and current data of Schroeder (1976, 1977), TerEco (1979) constructed probable current regimes on the shallow Mississippi-Alabama shelf during specified sustained wind conditions. The circulation patterns as shown do not take into account open Gulf of Mexico influence, density currents, or storm conditions.

With sustained winds from the west, northwest, north, or northeast, the estimated average near-bottom current speed as measured at Anderson Reef in 20-m water depths is 20 centimeters per second (cps) and the maximum sustained hourly speed is 46 cps (TerEco, 1979). During northeast winds there is a tendency for bottom water to move shoreward; however, bottom topography causes this portion of the flow to turn westerly along the shelf.

When winds are sustained from the southeast, south, southwest, or west, the estimated average near-bottom current speed is 26 cps and the maximum sustained hourly speed is 60 cps. During periods of sustained southeast winds, bottom water tends to move shoreward; however, bottom topography probably causes that portion of the flow to turn eastward.

Sustained winds from the northeast, east, or southeast yield an estimated average near-bottom current speed of 26 cps and a maximum sustained hourly speed of 60 cps. Under these wind conditions there may be a tendency for bottom and surface waters to flow shoreward, resulting in an accumulation of water along the coast. The accumulated water will generally inhibit further shoreward movement and may result in bottom transport parallel to shore in the direction of the wind. If winds are sufficiently strong, this accumulated water along the coast may force bottom water away from shore.

SEDIMENT TRANSPORT

Along the seaward sides of Dauphin Island and Morgan Peninsula, longshore currents have the most apparent affect on the transport of sediment (Parker, 1990). Longshore currents typically move east to west at rates of 1.6 to 4.4 fps and on incoming tides may increase to 4.4 to 8.8 fps (Foxworth and others, 1962). Sustained northwestern or western winds may cause temporary reversals in the longshore current direction. On the average, 3-day sustained eastward winds are required to reverse the longshore current direction (Abston and others, 1987).

Wind, waves, tides, and currents are the dominant factors controlling water movement within the study area. As a result, these factors are important in sediment transport. In the estuarine systems, tides are the major influence on circulation and sediment transport. Ebb tides disperse tons of fine-grained, suspended sediment through the tidal passes and onto the adjacent shelf. Much of this material is deposited directly southwest of the tidal passes in elongate lenses due to longshore currents. Flood tides, which generally produce weaker currents than ebb tides, inhibit transport of sediment from the estuaries to the shelf. Sustained southerly or southeasterly winds suppress ebb tides while enhancing flood tides, which decreases the transport of suspended sediment load to the shelf. Conversely, northerly winds and high river discharge increase ebb tidal flow and elevate the amount of suspended sediment being transported to the shelf. Within the narrow tidal inlet passes, tidal currents are elevated and fine-grained sediment is winnowed out. As a result, fine- to medium-grained sand occurs in Petit Bois Pass, Main Pass, and Perdido Pass. The amount of bedload coming out of the bays is difficult to quantify; thus, data concerning volume of bedload are not available. Transport of bedload from Mobile Bay is evidenced by a large ebb-tidal delta occurring south of Main Pass.

Tides have little affect on sediment movement on the shelf; however, they may influence sedimentation as they accelerate crossing the shelf (Upshaw and others, 1966). Longshore currents transport sediment along the seaward coasts of the barrier islands. Wave and current activity is primarily responsible for sedimentation on the shelf. Under normal conditions in the study area, waves and currents can move fine- to medium-grained sand in water depths of 20 m; however, little or no net horizontal displacement occurs (Dinnell, 1988). Hurricanes produce waves and currents strong enough to disturb sediments on the outer shelf. Near the shelf edge, sediments are disturbed about once every 5 years (Upshaw and others, 1966).

The amount of sediment entrained in the littoral system along the Mississippi-Alabama barrier islands is not known with confidence. However, Garcia (1977) determined that the total net littoral transport at Dauphin Island to be about 196,000 cubic yards (yd^3) per year. This agrees well with the U. S. Army Corps of Engineers (1995) estimate of 200,105 yd^3 per year at Perdido Pass and

212,111 yd^3 per year (U.S. Army Corps of Engineers, 1984) estimate for Petit Bois Island.

DIRECT MEASUREMENT MODELS

Seim and others (1987) collected hourly water level and current data from Mississippi Sound, Mobile Bay, and adjacent Gulf of Mexico for the period April 1980 to October 1981. The current data was obtained from 29 stations and the data is summarized in figure 9. In the figure, the arrow length gives the mean surface major axis current amplitude and arrow orientation gives the direction at maximum flood tide. Gulf of Mexico flood tide surface waters flow in a generally northern direction at speeds of several centimeters per second, accelerating to reach tens of centimeters per second where water flow is channelized in inlets. Flood tide surface currents in the sand resource site are estimated to average north-northeast at 8 cps.

The low frequency current variability on the Alabama continental shelf was examined by Chuang and others (1982) from three years (1976, 1978, and 1979) of summer current, sea level, and meteorological records. The current meter mooring was located about 16.1 mi south of the east end of Dauphin Island in about 25 m of water. The latitude-longitude coordinates place the mooring about 6 mi south of area 4. The current meter was set at a 1-hour sampling interval and placed 5 m above the sea bottom. Cross-shelf currents (northward) averaged about 2 cps for the three year period with the strongest currents only about 5 cps. Alongshore currents (westward) averaged about 5 cps for the same time period with the strongest currents about 15 cps.

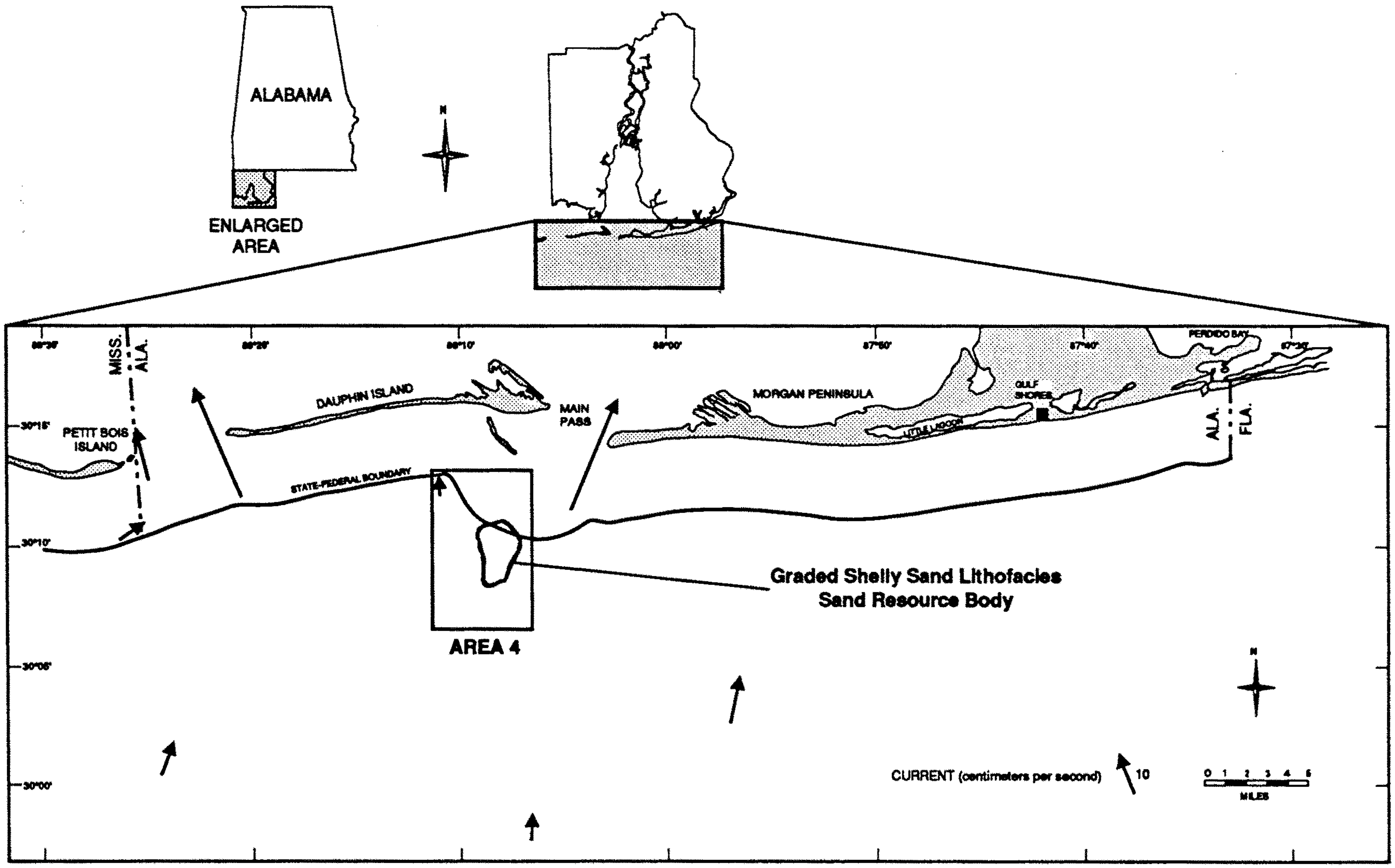


Figure 9.--Index map of the Alabama inner continental shelf showing site of the Graded Shelly Sand Lithofacies sand resource body and currents. Arrow length represents surface major current amplitude and orientation gives direction at maximum flood tide (modified from Seim and others, 1987).

SATELLITE AND AREAL PHOTOGRAPHY MODELS

Remotely-senced suspended sediment data in coastal regions is a useful tracer for studies of estuarine circulation and estuarine-shelf exchange. However, very few of these studies have addressed Alabama inner continental shelf circulation using remote sensing. Satellite imagery has been used to describe estuarine-shelf response to cold-air outbreaks (Schroeder and others, 1985) and Mobile Bay discharge sediment plume morphology (Abston and others, 1987; Stumpf and Pennock, 1989; Stumpf and Gelfenbaum, 1990). Regional estuarine-shelf exchange is important to an understanding of the general physical circulation and, consequently, transport of suspended sediment (Schroeder and Wiseman, 1986; Wiseman, 1986; Abston and others, 1987; Wiseman and others, 1988).

Abston and others (1987) used Landsat imagery for the years 1973 to 1983 to provide scenes of Mobile Bay sediment plume morphology that can be correlated with coastal processes occurring at the time of the image. Mobile Bay sediment plumes introduce a significant amount of suspended sediment to the inner continental shelf of Alabama and Mississippi. The plumes may extend along the inner continental shelf 22 mi east and west of Main Pass and offshore as far as 30 mi (Abston and others, 1987). Reworking of sediment as a result of normal wave activity is limited to the very nearshore area. Transport of sediment from Mobile Bay onto and across the shelf, under normal conditions, is due primarily to tidal flushing and longshore currents. Wind wave resuspension of both estuarine and shallow shelf sediments occurs during cold-air outbreaks, from November through April (Schroeder and others, 1985). Hurricanes and tropical storms, with higher wave activity, are important factors in the reworking of shelf sediments.

They defined four morphological types of Mobile Bay sediment plumes. Measurable parameters of plume morphology are area, length, width, and orientation which were correlated with environmental forcing parameters (river discharge, the time elapsed since the last high tide, predicted tidal range, and wind speed and direction). An increase in plume area is generally correlated with higher river discharge. Daily tides initially flush turbid water from Mobile Bay onto the shelf. Although the tidal range, to a large extent, determines the volume of water introduced to the shelf, the plume area determined by imagery appears influenced more by the time since the last high tide. Once the plume is on the shelf, its orientation and dispersal pattern is influenced by surface currents and local wind. Plume orientation seems dependant on alongshore current direction. Deflection of plumes is usually westward, corresponding to the mean westward flow of the inner shelf, but sufficient eastward winds may reverse the inner shelf currents and deflect plumes eastward. Plume size is also affected by an Ekman transport that is related to alongshore wind directions. Water is forced offshore as winds blow to the east; winds to the west force water toward shore. Plumes are dispersed and carried seaward as winds blow to the east and confined to the inner shelf area as winds blow to the west. Generally, high values of river discharge, tidal range, and time since the last high tide, along with winds to the east or southeast, produces the most favorable conditions for the development of large plumes.

Dinnel and others (1990) quantified the relationships between Mobile Bay sediment plume morphology and environmental forcing parameters discussed by Abston and others (1987). Dinnel and others (1990) used correlation and regression analyses to determine statistical relationships between plume morphology and environmental forcing. They found that plume morphology, defined by area, length, and width, are primarily related to river discharge with modulating effects due to the tides. Up to a certain level of river discharge, 4,500 cubic meters per second, plume size is directly related to tide phase, i.e. the longer the tide has ebbed, the larger the plume. Above this level the river discharge dominates the plume size. Yet, even at times of large river discharge, the tidal range and phase modifies the plume size.

Local winds, either across or alongshore do not seem to be significantly related to plume size. Yet, the alongshore winds, are well correlated with the orientation of the discharge plume. The direction of the alongshore currents is related to the wind direction, so the orientation of the discharge plumes are thought to be a result of advection by the local current, an indirect result of the alongshore winds, as well as a result of direct momentum transfer from the wind.

COMPUTER MODELS

Numerical models for simulation of Mobile Bay system waters have undergone rapid development in the last ten years. Both improved model-formulation techniques and improved digital-computer capabilities have stimulated the increased use of, and confidence in, these models. The first-generation hydrodynamic models (e.g., April and Hill, 1974; April and Liu, 1975; April and Ng, 1976a, 1976b) were restricted to a constant spatial step size and fairly simple boundary conditions. For example, finite difference cells were either land or water with no provisions for "drying" or "flooding" of cells during the modeling process. Second-generation hydrodynamic models (e.g., April and others, 1975; April and Hu, 1979; Raney and others, 1984) introduced improved boundary conditions for the finite difference cells, including an inundation capability. Sub-grid features also allowed a description of a geometric feature smaller than the selected grid size. For example, a sand bar, smaller than a grid cell, might be represented by a sub-grid barrier restricting flow through one or both faces of the cell. Current-state-of-the-art third-generation hydrodynamic models (e.g., Raney, 1984, 1985; Raney and Youngblood, 1987) introduced a variable spatial grid capability allowing a smaller spatial step, where required, for proper resolution of physical detail.

It is important to recognize that numerical modeling of hydrodynamic systems is not an academic exercise with little relationship to the physical world. Any computer model will provide an investigator with an answer to a question. However, the numerical hydrodynamic model, when properly applied and verified, is an extremely powerful predictive tool and a viable, cost effective alternative to physical (scale) modeling or extensive oceanographic data collection.

In order to establish representative monthly salinity and velocity distributions in Mobile Bay, Raney and others (1989a) applied a two-dimensional-depth-averaged finite difference numerical model with average monthly boundary conditions. The numerical model was previously calibrated and verified using surface elevations, velocity, and salinities (Raney and others, 1989a). Average monthly tidal regimes, winds and fresh water inflow were collected from the literature and provided by the Mobile District, Corps of Engineers. These average monthly values allow the establishment of required boundary conditions for the numerical model.

For each month of the year, a set of reasonable initial conditions was established and a 24-hour cycle of tide and river inflow boundary conditions was applied to the numerical model (Raney and others, 1989a). The long-term monthly average wind speed and direction was held constant in both magnitude and direction. The numerical model was run for a total of three cycles (72 hours). The first two cycles were used to establish essentially repetitive conditions in Mobile Bay with results presented for hours 48 through 72 of the numerical simulation. Raney and others (1989a) representative velocity plots are presented at hourly intervals for each month of the year. The salinity contours are presented in a separate report (Raney and others, 1989b).

The numerical model results appear to be generally consistent with available data (Schroeder, 1976; Bault, 1972) for Mobile Bay. The movement of high salinity water up the main channel is very apparent in the monthly salinity contours. Figure 10 shows the 60 hours (ebb tide) and 72 hours (flood tide) for the months of January and July in the Gulf of Mexico southeast of Main Pass (Raney and others, 1989a).

SURFACE SEDIMENTS OF AREA 4 AND VICINITY

GRAIN SIZE

The Mobile-Tensaw River system drains approximately 34,600 square miles (mi^2) in the states of Alabama, Georgia, and Mississippi (Mettee and others, 1989). These areas include terrains of the Appalachian Valley and Ridge, Plateau, Piedmont, and Gulf Coastal Plain (fig. 11). The entrained sediments of this stream system, therefore, have been derived from sedimentary, igneous, and metamorphic lithologies.

The Valley and Ridge and Plateau areas include sequences of Paleozoic clastic sediments, such as sandstone,shale, conglomerate and carbonate rocks, which are in part chert-bearing. Lithologies of the Piedmont area include granite and granite gneiss, quartzite, schist and other metamorphic lithologies.

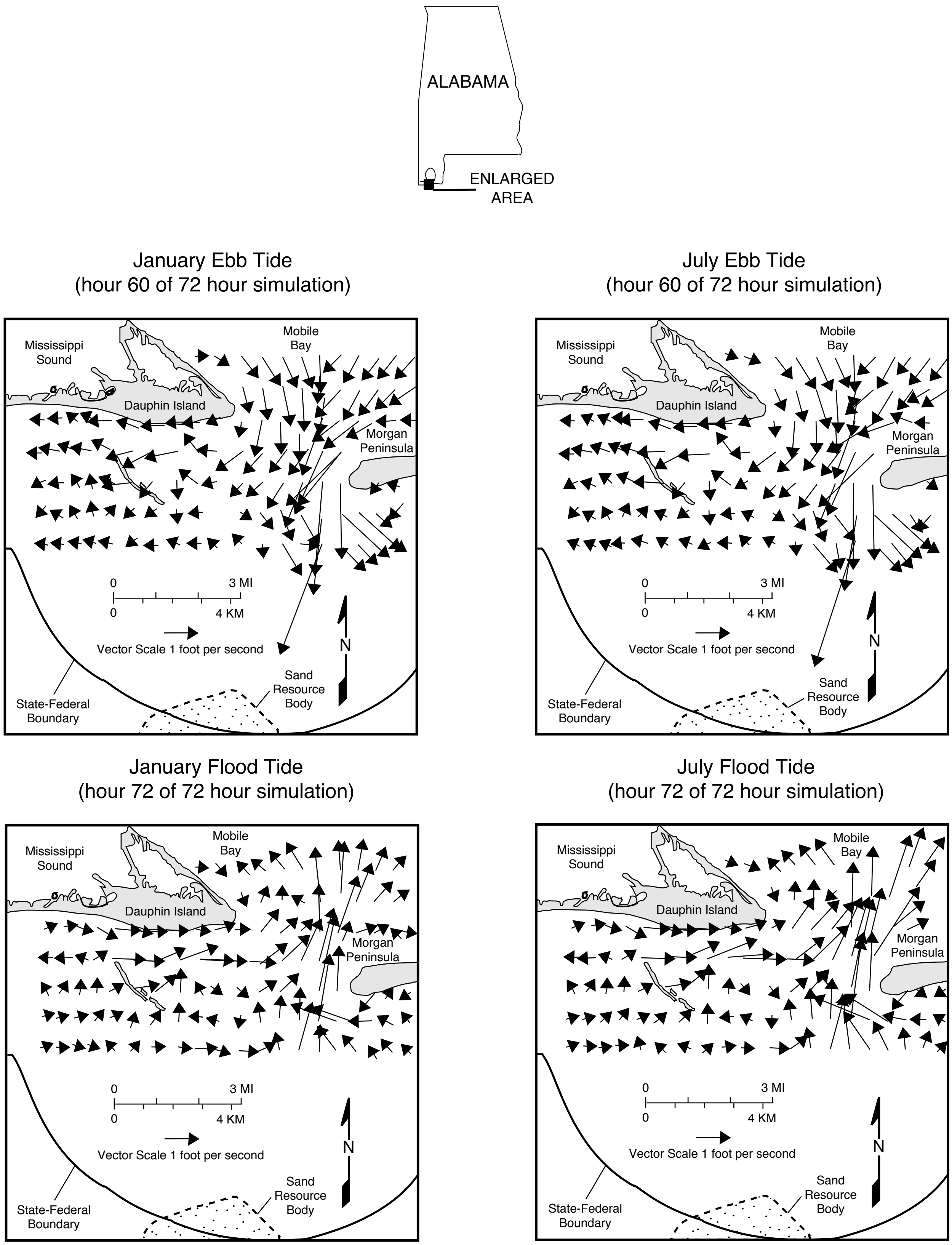


Figure 10.--Maps showing surface water velocity vectors generated by a two-dimensional, depth-averaged finite difference numerical model of average monthly conditions for January and July (modified from Raney and others, 1989).

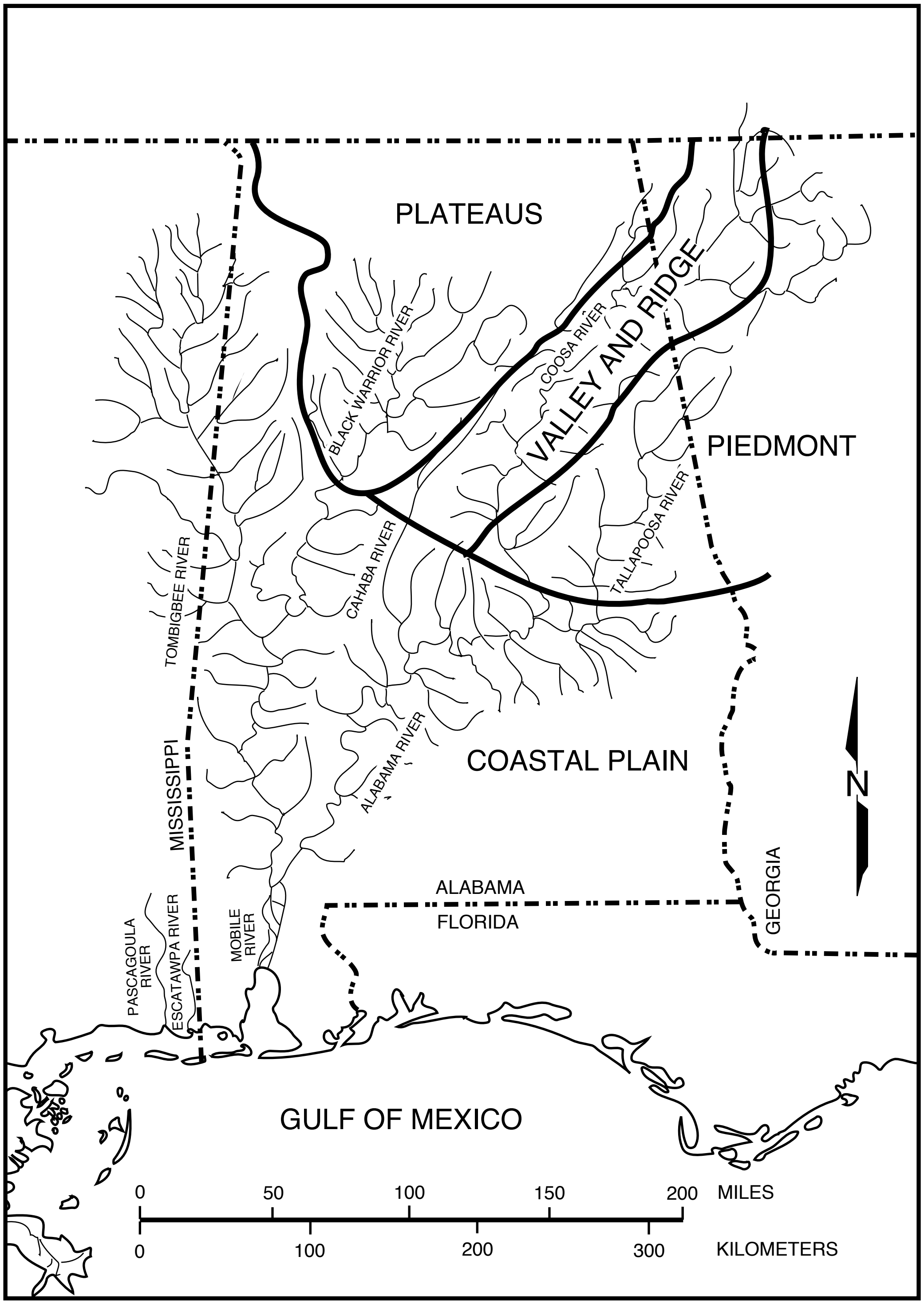


Figure 11.--Mobile River drainage basin (modified from Hardin and others, 1976).

Coastal plain areas include sediments derived primarily from the valley and Ridge and igneous and metamorphic areas.

The major lithologic contributions to fluvial deposits, and ultimately to Gulf sediments from the above described areas, include gravel, sand, silt and clay-sized quartz, quartzite, and chert. In addition, many accessory minerals, such as zircon, rutile, tourmaline, kyanite, ilmenite, monazite, garnet, hornblende, and others, are derived from these areas and ultimately become minor constituents of Gulf sediments. The Coastal Plain area consists of poorly consolidated sedimentary rocks which are derived, in part, from the Valley and Ridge and Piedmont terrains. Erosion of this area contributes sand, clay, gravel, and detrital heavy minerals to the fluvial deposits. Mobile Bay and eastern Mississippi Sound are filled with sediments consisting of fluvial, marine, estuarine, and deltaic clay, silt, sand, and gravel.

The Mississippi-Alabama shelf is part of a triangular-shaped region that includes parts of offshore Louisiana, Mississippi, Alabama, and westernmost Florida (fig. 4). Ludwick (1964) divided the Mississippi-Alabama shelf into six facies (fig. 4). Area 4 lies in the nearshore fine-grained facies which is comprised of sand, muddy sand, sandy mud, and mud (fig. 4). These sediments are deposited at water depths generally less than 60 ft and in a zone about 7 mi wide.

Prior to the study by Hummell and Smith (1995) a current surface sediment texture map was not available for area 4. Published granulometric data from bottom samples collected within the study area are widely scattered in the literature, differ widely in collection dates, are site specific, differ widely in the nature of the project, methods used and the form of presentation of the data in a report, and are largely qualitative. The most recent surface sediment texture map that includes area 4 is from 1984 (U.S. Army Corps of Engineers, 1984) (fig. 12). Parker and others (1993) constructed a surface sediment texture map for the Alabama EEZ utilizing the

U.S. Army Corps of Engineers (1984) map and data from several sources. Granulometric analysis of bottom samples collected from area 4 by Hummell and Smith (1995) and the present study indicates that the U.S. Army Corps of Engineers (1984) map better reflects surface sediment texture in area 4 and vicinity.

Sediment types displayed on the U.S. Army Corps of Engineers (1984) sea bottom sediment distribution map for the Alabama inner continental shelf (fig. 12) occur in an approximately east-west belt of sand encompassing Dauphin and Little Dauphin Islands, Main Pass, and Morgan Peninsula. This belt occurs between the Mobile Bay clays and silts and the ebb-tidal delta clays and silts. Narrow, east-west oriented zones of silty clay lie just south of Dauphin Island. Area 4 surface sediments consist of mostly silty sand with a patch of sand/silt/clay in the central portion of the study area. Sand covers the sea bottom surface in the northeastern portion of area 4.

Geographic variation in sea bottom sediment type is subject to prevailing hydrologic and oceanographic conditions (many of which show distinct seasonal variation), which on the Alabama inner continental shelf constantly rework and redistribute surficial sediments. Heterogeneity of nearshore sediments is attributed to Holocene transgression, variation in local bathymetry, changes in sediment transport pathways, reworking by wave activity, and sedimentation associated with sediment plumes emanating from Mobile Bay (Swift and others, 1971; Pyle and others, 1975). Tidal inflow and outflow through Main Pass redistributes estuarine sediments in the southern half of Mobile Bay and transports fines out of Mobile Bay. Most of the sediment exiting Mobile Bay is deposited south to west of the Main Pass, in response to the predominant westward directed littoral drift, forming an ebb-tidal delta (U.S.

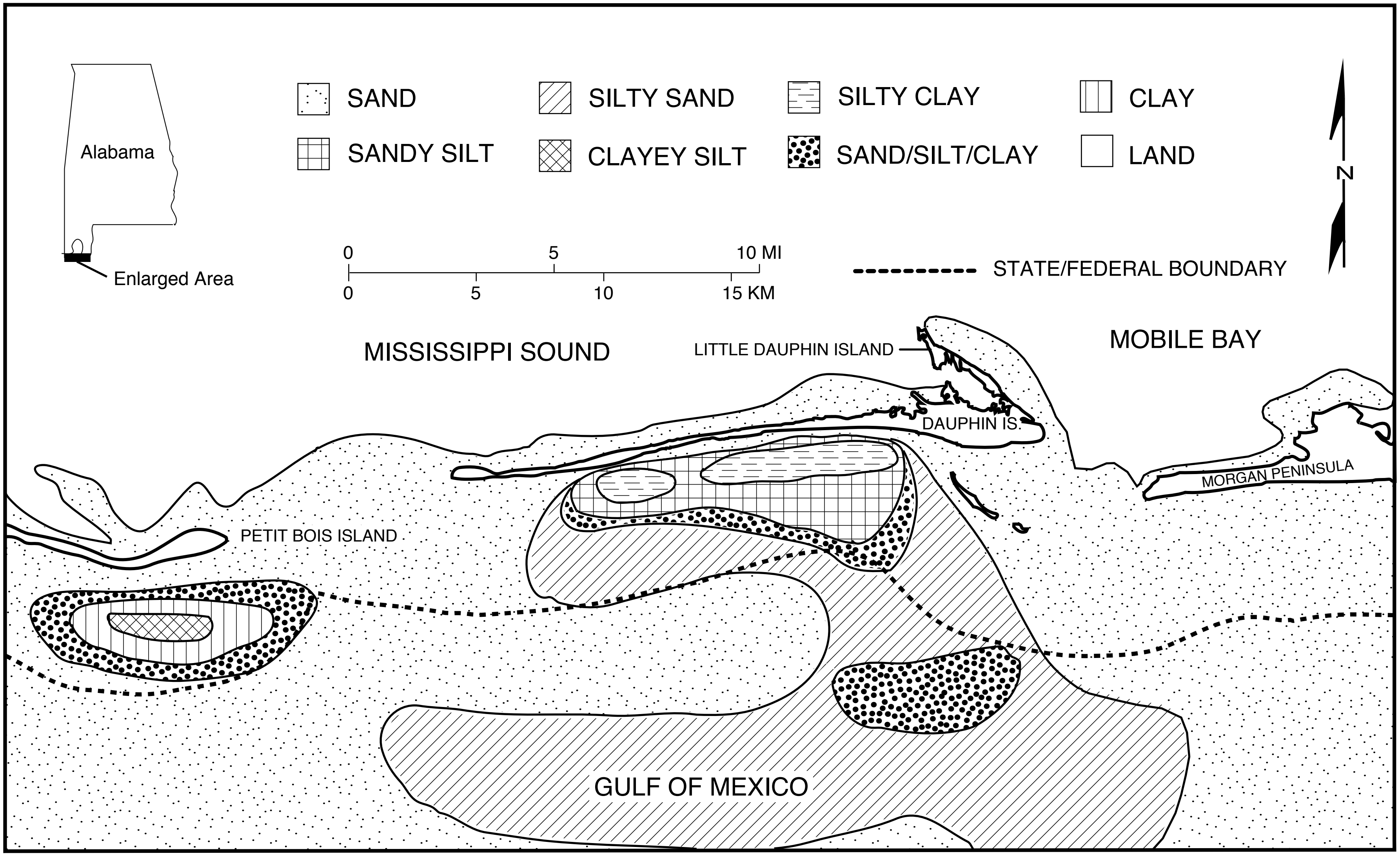


Figure 12.--Sediment distribution in the west Alabama inner continental shelf (modified from U.S. Army Corps of Engineers, 1984).

Army Corps of Engineers, 1979). During summer months, some of the sediment fines move eastward in response to an eastward component of the longshore drift (U.S. Army Corps of Engineers, 1979).

Average sea bottom sediment grain size gradually decreases both landward and seaward of the strandline. Deposition of sand from ebb-tidal sediment plumes occurs seaward of the tidal inlet on the ebb ramp, with clays and silts being deposited on the shelf seaward of the ebb shield (figs. 3 and 12). Flood-tidal currents carry shelf sands landward of the strandline, and these mix with clays and silts in southern Mobile Bay. This sea bottom sediment distribution is similar to that of the ebb-tidal delta of North Edisto Inlet, South Carolina, which was described by Imperato and others (1988).

HEAVY MINERALS

Foxworth and others (1962) studied the heavy mineral assemblage of the Mississippi-Alabama barrier islands and found that island sediments contained a tourmaline-kyanite suite of heavy minerals. This suite falls in the eastern Gulf of Mexico heavy mineral province which is characterized by a relatively high content of ilmenite, staurolite, kyanite, zircon, tourmaline, and stillimanite, and by low percentages of magnetitie, amphiboles, and pyroxenes (Hsu, 1960; Van Andel and Poole, 1960; Doyle and Sparks, 1980). The barrier island sands are thought to have been derived from erosion of pre-Holocene coastal plain sediments and reworking of Pleistocene inner continental shelf alluvial deposits (Rucker and Snowden, 1989). Concentrations of heavy minerals occur as thin laminae to medium beds in back barrier beaches and coastal eolian dunes. Foxworth and others (1962) proposed that longshore currents, waves, and tides move heavy minerals onshore, while storm waves, winds, and rain runoff concentrate these minerals into layers.

Upshaw and others (1966) found concentrations of heavy minerals greater than 4 percent in Petit Bois Pass surficial sediments. Studies by Stow and others (1975), Drummond and Stow (1979), and Woolsey (1984), found heavy mineral concentrations of up to 2.4 percent in surficial shoreface sediments off the west end of Dauphin Island and in Pelican Bay. Stow and others (1975) suggested that these shore-parallel elongated heavy mineral concentrations are a result of a combination of longshore transport and wave action. The ultimate source of heavy minerals for Dauphin Island and nearshore Alabama inner continental shelf sediments is the igneous-metamorphic complex of the southern Appalachian Mountains.

CLAY MINERALS AND CARBONATE

On the shelf, smectite and kaolinite are the predominant clay minerals, with illite present in smaller quantities (Doyle and Sparks, 1980). Smectite, which is characteristic of the Mississippi River and Mobile-Tensaw River systems, is predominant on the continental shelf. Smectite increases while kaolinite decreases offshore, over most of the continental shelf south of the study area (Doyle and Sparks, 1980).

Surficial shelf sediments are comprised mostly of sand to clay-sized terrigenous quartz with less than 25 percent carbonates (Vittor, and Associates, 1985). Ryan and Goodell (1972) found that carbonate percentages were due to the presence of whole and disarticulated bivalve shells and that most of the gravel-sized clasts were composed of shell debris. Carbonate content increases southwest of Main Pass (Ryan and Goodell, 1972).

REGIONAL GEOLOGY

INTRODUCTION

Several studies of Pleistocene and Holocene stratigraphy and geologic history of the west Alabama inner continental shelf provide an improved understanding of the Quaternary development of this region.

PREVIOUS INVESTIGATIONS

Utilizing borings in the Louisiana, Mississippi, and Alabama portions of Mississippi Sound, Mississippi and Alabama barrier islands, and Mississippi mainland coastline, Otvos (1975, 1976, 1982, 1985, 1986) in a series of reports described the coastal geology of eastern Louisiana, Mississippi, and Alabama. He defined several informal formations of late Pleistocene age, thought to have been deposited during the Sangamon (about 120,000 years before present or b.p.). The "Prairie formation" represents alluvial facies, the "Biloxi formation," inner shelf to estuarine facies, and the "Gulfport formation," barrier island facies (Otvos, 1986). He grouped sediments that lie between the Citronelle Formation or Miocene deposits and the "Biloxi formation" and "Prairie formation," and called them earlier Pleistocene alluvial sediments (Otvos, 1976, 1986). In coastal Louisiana, Mississippi, and Alabama Otvos (1986) described some early or mid-Wisconsin fluvial and nearshore deposits and above them, sediments deposited in association with the late Pleistocene-Holocene transgression.

Otvos (1985, 1986) used benthic foraminifera recovered from the drill holes to map seven Holocene and Pleistocene biotopes for coastal Louisiana, Mississippi, and Alabama. He relied in large part on biotopes to define late Pleistocene formations.

Brande (1983) studied the Holocene stratigraphy of Mississippi Sound, Mobile Bay, and the Alabama inner continental shelf east of Mobile Point. High resolution, shallow seismic data were obtained by him in cooperation with the U.S. Geological Survey from a seismic cruise run in coastal Alabama in 1980. During 1981 and 1982, he collected 21 vibracores in Mobile Bay. He used the seismic records to develop a generalized seismic stratigraphy for Mobile Bay. Brande (1983) used the vibracores to describe the near surface sediments and stratigraphy and ground truth the seismic stratigraphy.

An approximately 5 mi long segment of one of Brande's (1983) seismic records passes through the eastern side of Main Pass and out into the Gulf of Mexico east of Mobile Point. A lithostratigraphic cross section was constructed by Hummell (1990) based on analysis of a paper copy of this seismic line. In the same report Hummell (1990) utilized boring descriptions from the U.S. Army Corps of Engineers (1985) and Exxon Company, U.S.A. (1986) to construct north-south and east-west lithostratigraphic cross sections for Main Pass, the ebb-tidal delta of Mobile Bay, and the Alabama inner continental shelf.

Parker (1990) assessed the nonhydrocarbon mineral resources in the Alabama state waters and federal waters areas in offshore Alabama. He used boring descriptions from Exxon Company, U.S.A. (1986) to prepare cross sections showing sediment texture distribution in the shallow subsurface of the west Alabama inner continental shelf for the purpose of evaluating sand resource potential in this area.

Parker and others (1993) carried out work, the primary objective of which, was to augment and complete regional reconnaissance work on EEZ sand resources in the Alabama state waters and federal waters areas in offshore Alabama. The study identified five offshore target areas as being best suited as a sand resource for use in beach nourishment projects on Dauphin Island.

Hummell (1996) studied the geologic factors and related natural processes involved in the development of the west Alabama inner continental shelf from Petit Bois Pass to Alabama Point and from Dauphin Island south to the State - Federal Line. Vibracores, borings, drill holes, and seismic records were utilized to show that the sediment column in his study area contains a Holocene transgressive marine fill sequence deposited on a late Pleistocene-early Holocene unconformity formed by erosion of estuarine and fluvial-deltaic deposits determined to be of late Pleistocene age or older.

Hummell and Smith (1995) evaluated the geologic framework of area 4 and found that sediments there consist of Holocene ebb-tidal delta, shelf sand sheet and shelf sand ridge sediments overlying an irregular erosional surface of late Pleistocene-early Holocene age. Six lithofacies comprised of seven microfacies were delineated based on sediment characterization, spatial extent, and environment of deposition; of these, the Graded Shelly Sand Lithofacies was deemed to have highest potential as a beach nourishment source.

A shelf sand ridge/sand sheet comprised of Graded Shelly Sand Lithofacies was discovered by Hummell and Smith (1995) in the east-central portion of the study area. The upper surface of this sand body is exposed over about 8 mi^2 of seafloor in water depths ranging from 30 to 60 ft. The sand unit measures up to 11 ft thick at its center and has granulometric characteristics compatible with eroding southeastern Dauphin Island shoreline sediments.

PRE-HOLOCENE AND HOLOCENE GEOLOGIC HISTORY

GEOMORPHOLOGY

Sedimentary deposits preserved in present day Mobile Bay and Mississippi Sound record Holocene sea level rise over the last 6,000 to 7,000 years (Hummell and Parker 1995a, 1995b). Information on the earlier Holocene transgressive history of coastal Alabama is derived from sediments on the continental shelf (Hummell, 1996). Radiometric dates and sea level curves from Hummell (1996) indicate that in the Holocene, area 4 was inundated during a period from approximately 10,000 to 9,000 years before present (b.p.).

Today, Mississippi Sound is separated from the Gulf of Mexico by Dauphin Island. Petit Bois Pass and Main Pass permit exchange of water and sediments between Mississippi Sound and Mobile Bay and the Gulf of Mexico, respectively. Area 4 occupies a portion of the distal margin of the ebb-tidal delta of Mobile Bay.

As a result of the study by Hummell (1996), it is clear that the geomorphology of the west Alabama inner continental shelf has changed substantially from what we see today. Prior to Holocene transgressive inundation, the area that is the present day Alabama inner continental shelf was occupied mostly by marsh, coastal plain terrestrial forests, and fluvial-deltaic systems. Relief of this area before drowning may have been low except, possibly along part of the shoreface zone of Dauphin Island and along a barrier complex a few miles to the east of Dauphin Island (Hummell, 1996). It is possible that an escarpment has been present along the Mississippi-Alabama barrier island system since the late Pleistocene (Smith, 1988; Randolph A. McBride, oral communication). As a result, a prominent slope possibly separated the gently sloping terrane of the study area from that of the lowland area occupied by present day Mississippi Sound.

With relative rise in sea level during the Holocene the generally low relief of the study area allowed the shoreline to rapidly transgress northward across the land surface (Smith 1986, 1988; Hummell, 1996). This caused the shelf occupying ancestral Escatawpa and Mobile-Tensaw fluvial-deltaic systems to retreat relatively rapidly into what is now Mississippi Sound and Mobile Bay, respectively. The transgressing seas would have reworked and redistributed the terrigenous sediments on the shelf through wave action and coastal currents, partially or completely destroying pre-Holocene geomorphologic features (Ludwick, 1964; Kindinger and others, 1982; Kindinger, 1988; Kindinger and others, 1994). Sediments directly underlying the thin Holocene cover on the Alabama inner continental shelf are comprised mostly of relict fluvial-deltaic sediments deposited during the latest sea level low stand which ended about 15,000 to 18,000 years b.p. (Smith, 1988; Lockwood and McGregor, 1988).

During Holocene transgressive inundation of the Alabama inner continental shelf, up until the late stages of inundation of present day Mississippi Sound, only the eastern end of Dauphin Island may have existed as an emergent barrier island (Hummell, 1996). Mississippi Sound, therefore, may have been largely open to the Gulf of Mexico throughout most of middle to late Holocene permitting marine sands to be transported into Mississippi Sound (Hummell, 1996).

The ebb-tidal delta of Mobile Bay appears to have developed late in the inundation history of the Alabama inner continental shelf. Formation of the longshore drift system along the southern margin of Dauphin Island and a decrease in the rate of sea level rise about 4,500 years b.p., not only facilitated barrier island development, but it probably initiated ebb-tidal delta growth at the mouth of Mobile Bay (Hummell, 1996). A north-south oriented paleobathymetric high extending south from Pelican Point and the Mobile-Tensaw alluvial valley seems to have confined growth of the ebb-tidal delta to the western side of Main Pass and south of Dauphin Island (Hummell, 1996). Ebb-tidal delta growth by vertical accretion and progradation continued throughout the late Holocene (Hummell, 1996).

HOLOCENE GEOLOGIC HISTORY

Vibracores, borings, drill holes, and radiometric age dates of organic remains collected from the west Alabama inner continental shelf by Hummell (1996) reveal a Holocene transgressive marine fill sequence overlying estuarine and fluvial-deltaic deposits of at least in part Pleistocene age. A southward dipping, late Pleistocene-early Holocene unconformity (last transgressive surface) was formed by erosion of these estuarine and fluvial-deltaic deposits during late Pleistocene and early Holocene regression and sea level lowstand. This unconformable surface extends throughout Mobile Bay and Mississippi Sound (Hummell and Parker, 1995a, 1995b) and is interpreted as the "Biloxi formation" (Otvos, 1986). Subsequently, roughly north-south oriented networks of channels were incised into these deposits south of present day Dauphin Island (ancestral Escatawpa fluvial-deltaic system) and Main Pass (Mobile-Tensaw fluvial-deltaic system) (Hummell, 1996).

The eastern fourth of Dauphin Island is comprised of a barrier island sand deposit that has been interpreted as the Pleistocene "Gulfport formation" (Otvos,

1986) which unconformably overlies the "Biloxi formation" (Hummell, 1996). This portion of Dauphin Island may have acted as a barrier island nucleus for later development of the rest of present day Dauphin Island and as a partial sediment dam for open bay facies mud deposition in Mobile Bay during the Holocene (Hummell and Parker, 1995a, 1995b; Hummell, 1996). The Holocene section of the western three-fourths of Dauphin Island is underlain by the marsh and alluvial sediments of the Pleistocene "Prairie formation" which appears to unconformably overlie the "Biloxi formation" and "Gulfport formation" (Otvos, 1986).

Holocene sediments onlap the margins of "Gulfport formation" sediments of Dauphin Island and therefore thicken rapidly in a seaward direction away from the eastern fourth of Dauphin Island (Hummell, 1996). The Holocene sequence measures the greatest in the ebb ramp of the ebb-tidal delta of Mobile Bay and in the Mobile-Tensaw alluvial valley (Hummell, 1996).

Sea level began to rise about 15,000 to 18,000 years b.p. and flooded the present day west Alabama inner continental shelf between 10,000 and 6,000 years b.p. depositing shelf, open bay (and shelf mud equivalent), and ebb-tidal delta sediments over late Pleistocene estuarine and fluvial-deltaic deposits (Hummell, 1996). As mentioned previously, the rate of sea level rise slowed about 4,500 years b.p. and established a shoreline position along the eastern fourth of Dauphin Island a few miles seaward of the present day shoreline. The decrease in the rate of sea level rise and the formation of the longshore drift system along the southern margin of Dauphin Island caused late Holocene barrier island development through vertical accretion to produce present day Dauphin and Little Dauphin Islands and initiated and promoted ebb-tidal delta growth through vertical accretion and progradation.

Sea level rise resulting in flooding of the remainder of the present day west Alabama inner continental shelf fostered deposition of mostly shelf, open bay (and shelf mud equivalent), and ebb-tidal delta sediments. This continued uninterrupted throughout the late Holocene and continues today. The gradual deepening of the waters on the shelf in the late Holocene caused very little shoreward migration of facies which is consistent with the shoreline position at that time and initiation of barrier island and ebb-tidal delta sedimentation resulting in the facies distribution pattern seen today on the shelf today.

The western three-fourths of Dauphin Island may not have acted as an effective barrier to sediment and water exchange between the Gulf of Mexico and Mississippi Sound until the late Holocene (Hummell and Parker, 1995a, 1995b; Hummell, 1996). The presence of the ebb-tidal delta as a sediment sink and the gradual restriction to the transport of sediments from Mississippi Sound and Mobile Bay out on to the present day inner continental shelf during the Holocene, resulted in sediment starvation (thin Holocene section) in the southwestern portion of the area 4 (Hummell, 1996).

SUBSURFACE GEOLOGY

The Alabama continental shelf consists of a massive section of Mesozoic and Cenozoic age terrigenous clastic and carbonate sediments which attain thicknesses of over 24,000 ft (Raymond and others, 1988). The Mesozoic section is over 15,000 ft thick and is comprised of terrigenous rocks interbedded with carbonate, anhydrite, and salt units that overlie metamorphic and igneous rocks (Murray, 1961; Mancini and Payton, 1981; Tolson and others, 1983; Raymond and others, 1988). The Mesozoic rocks are overlain by nearly 6,000 ft of Cenozoic sediment consisting of terrigenous marine sediments interbedded with carbonates (Murray, 1961;

Raymond, 1985; Mancini and Tew, 1988; Raymond and others, 1988). Upper Cenozoic sediments consist of fluvial, fluvial-deltaic, estuarine, and coastal deposits of Pleistocene and Holocene age (Carlston, 1950). Quaternary development of the offshore Alabama continental shelf is related to multiple transgressions and regressions of the sea caused by worldwide changes in glacial-eustatic sea level fluctuations (Ludwick, 1964; Kindinger and others, 1982; Suter and others, 1985; Kindinger, 1988; McFarlan and LeRoy, 1988; Kindinger and others, 1989; Kindinger and others, 1994).

Present day offshore Alabama continental shelf seafloor topography and sediment distribution are the result of a combination of deltaic progradation, regression with concomitant dissection of the exposed shelf by ancient fluvial systems associated with the late Wisconsin sea level fall and reworking by coastal processes during Holocene sea level rise (Ludwick, 1964; Kindinger and others, 1982; Kindinger, 1988). During late Wisconsin continental glaciation, sea level falls, fluvial systems were incised into the continental shelf, and nearshore environments were extended seaward, ultimately culminating in the deposition of deltas at the seaward margin (Suter and others, 1985; Kindinger and others, 1989; Kindinger and others, 1994).

During regression associated with the late Wisconsin sea level fall, Mesozoic and Cenozoic Gulf of Mexico Coastal Plain sediments were exposed on the shelf and eroded by fluvial systems that developed on the broad, low lying plain (Kindinger and others, 1989; Kindinger and others, 1994). Marine, coastal, and fluvial environments prograded seaward until sea level reached a maximum lowstand approximately 400 ft below its present level (Milliman and Emery, 1968).

During Holocene sea level rise beginning 15,000 to 18,000 years b.p., fluvial-deltaic lowstand deposits were reworked resulting in the winnowing out of the finer material, fluvial systems were submerged and filled, and eventually a sea level high stand was reached (Suter and others, 1985; Kindinger and others, 1989; Kindinger and others, 1994). Coleman and others (1990) suggest that the transgression is continuing today. Sediments underlying the thin Holocene sedimentary cover consist of relict or "palimpsest" (Swift, 1976) fluvial sands and gravels that were deposited during the latest low sea level stand which ended about 125,000 to 18,000 years b.p. (Smith, 1986; Lockwood and McGregor, 1988).

Dauphin Island possibly formed by Holocene beach ridge, shoal, and spit aggadation around a Pleistocene age core that served as a barrier island nuclei (Otvos, 1979, 1985). This pre-Holocene core ("Gulfport formation") consists of semi-consolidated, limonitic, and humate-impregnated sands and silty sands which underlies Holocene beach ridge and eolian deposits of the eastern fourth of present day Dauphin Island (Otvos, 1979). Hummell (1996) indicates that there are exposures of pre-Holocene sediments ("Gulfport formation") underlying the Holocene veneer along the southeastern shoreline of Dauphin Island and on Dauphin Island itself. Holocene deposits of the western three-fourths of Dauphin Island overlie pre-Holocene sandy mud marsh sediments classified as "Prairie formation" (Otvos, 1986). It is thought that present day Dauphin Island, like most Mississippi and Florida barrier islands, began to form at a time marked by a slowing in the rate of Holocene sea level rise or 3,000 to 4,000 years b.p. (Otvos, 1979; Davis and Klay, 1989; Donoghue, 1989; Stapor and others, 1991).

DATABASE AND METHODOLOGY

ERODING SHORELINE CHARACTERIZATION

Identification of Alabama Gulf of Mexico shoreline showing significant erosion in recent years was accomplished by reviewing the available data pertaining to historical and current erosional-accretionary trends on Alabama's Gulf of Mexico shoreline, by reviewing tentative results of ongoing GSA studies of Alabama Gulf of Mexico shoreline dynamics, and by study of aerial photographs. Parker and others (1993) utilized aerial photographs of 1955 (U.S. Department of Agriculture Commodity Stabilization Service) for Mobile County, and U. S. Geological Survey 1985 aerial photographs of coastal Mobile County to delineate potential restoration and nourishment areas on Dauphin Island Gulf of Mexico shoreline.

The aerial photographs for 1955 and 1985 are of slightly different scales, requiring rectification of measurement data taken from the two sets of photographs. For studies of Dauphin Island Gulf of Mexico shoreline leading to estimation of sand volumes required to achieve a shoreline position of 1955, overlays of the shoreline were made for the two sets of photographs. The 1955 shoreline overlay was then rectified to the scale of the 1985 photograph. Based on the information conveyed by the composited overlays, shoreline areas showing significant erosion for the 1955-85 period were identified.

The estimates made by Hummell and Smith (1995) for the 1985-95 period were based on erosion rates calculated from beach profile data for the period 1989-94. Although there have been some variability in erosion rates between the two periods, estimates of sand loss based on ground surveys for approximately 6 years of the 10 year period 1985-95 represent greater accuracy than estimates that could have been derived through other methods (Hummell and Smith, 1995).

During the present study, additional ground surveys were conducted along southeastern Dauphin Island eroding shoreline segments to document shoreline loss for the 1994-1996 period. This information was used to supplement the existing shoreline loss information compiled in Phase 2 (1955-1985) and Phase 3 (1985-1994) in estimating sand required to restore selected segments of Dauphin Island shoreline to their 1955 positions.

BATHYMETRY OF ALABAMA EEZ

Area 4 bathymetry was described by Parker and others (1993) (fig. 5). The bathymetric data used to prepare the bathymetric map were derived from NOAA nautical charts Nos. 11373, 11376, and 11382 (NOAA, 1991a, 1991b, 1991c). Soundings from each of these charts were plotted on a single base map and contoured at 2 ft intervals. A review of historic nautical charts of this area indicates that bathymetry data on the maps are a collection of many years of data with only certain areas having been recently updated. These data were the best available and are probably adequate for describing the general seafloor morphology of the study area. Bathymetric readings taken at vibracore sites were recorded and compared with existing data. It was obvious from this comparison that some discrepancies are present in some areas and that modification of the seafloor has taken place since bathymetric data were collected in these areas. However, a comparison of recent nautical charts with the historical charts shows that large scale morphologic features such as shoals and large sand ridges have been present in approximately the same location. New data are needed to determine the degree of seafloor modification in this area since initial bathymetric measurements were made.

GEOLOGIC FRAMEWORK AND LITHOFACIES: VIBRACORES, BORINGS AND SEDIMENT SAMPLES

Existing data compiled by Parker and others (1993) and Hummell and Smith (1995) for the area 4 sand resource body were reexamined and a determination was made concerning the need for additional subsurface information to further delineate sand body geometry and granulometry. It was determined that further vibracoring and sea bottom sampling was necessary to provide the level of detail required for a cost effective and efficient sand recovery operation.

Pre-existing sediment cores for area 4 consist of three vibracores from Parker and others (1993), and 15 vibracores and seven borings from Hummell and Smith (1995) (tables 1 and 2). The locations of these borings are shown on figure 13. Table 2 contains information about the length, location, and water depth of each boring. A columnar section illustration for each boring appears in Appendix A (figs. A-1 to A-7).

Based on pre-existing data, vibracores were sited in the sand resource body where they would be most useful for further delineation of sand body geometry and granulometry. Ten vibracores were collected within the sand resource body and vicinity during August 9 and 10, 1995. The vibracores were collected in water depths ranging from 35.4 to 50.2 ft and from 4.5 to 8 mi offshore. The vibracores ranged from 7.4 to 19.5 ft long and totaled 157.6 ft of core. The vibracore locations are shown on figure 9. Table 1 contains information about the length, location, and water depth of each vibracore. A columnar section illustration for each vibracore appears in Appendix A (figs. A-8 to A-35).

Table 1.--Summary of information pertaining to vibracores.

Core Number	Core length (feet)	Elevation above sea level (feet)	Loran-W	Loran-Y	Latitude	Longitude
SR-46*	12.2	-46.2	12690	47070	30 10" 40"	88 09' 06"
SR-47*	16.6	-54	12690.3	47059.9	30 08" 17"	88 08' 58"
SR-48*	4.9	-66	12689.9	47049.9	30 05" 59"	88 08' 55"
SR-60**	17.8	-39.3	12700.4	47072.6	30 11' 24"	88 08' 06"
SR-61**	20.4	-47.7	12699.5	47065.5	30 09' 48"	88 08' 06"
SR-62**	16.7	-54.6	12704.1	47059	30 08' 18"	88 07' 36"
SR-63**	8.4	-64.4	12689.2	47052.5	30 06' 42'	88 09' 00"
SR-64**	11.4	-64.2	12701.8	47051.1	30 06' 24"	88 07' 42"
SR-65**	7.7	-71.3	12709.3	47047.4	30 05' 30"	88 06' 54"
SR-66**	16	-64.4	12714.8	47050.8	30 06' 18"	88 06' 24"
SR-67**	16.1	-49.6	12719	47057.3	30 07' 48"	88 06' 12"
SR-68**	10	-39.9	12724.6	47062.9	30 09' 06"	88 05' 36"
SR-69**	17.8	-37.8	12714.9	47072.4	30 12' 06"	88 05' 39"
SR-70**	19.2	-36.7	12734.8	47066.3	30 09' 54"	88 04' 36"
SR-71**	19.6	-45.5	12738.8	47061.3	30 08' 42"	88 04' 12"
SR-72**	19	-58.4	12734.1	47056.6	30 07' 36"	88 04' 36"
SR-73**	10.9	-64.5	12733.1	47051	30 06' 18"	88 04' 42"
SR-74**	19.6	-68.6	12730.1	47047.6	30 05' 30"	88 05' 00"
SR-75	20	-36.2	12724	47069.4	30 10' 46"	88 05' 42"
SR-76	16.7	-35.4	12729.9	47067.6	30 10' 19"	88 05' 06"
SR-77	19.9	-37.5	12730.3	47065	30 09' 42"	88 05' 02"
SR-78	19.8	-37.7	12723.6	47066.4	30 10' 03'	88 05' 42"
SR-79	8.3	-43	12712	47062.4	30 09' 08"	88 07' 47"
SR-80	9.1	-39.1	12719.7	47060.7	30 08' 11"	88 06' 23"
SR-81	18.1	-36.4	12714.2	47058.1	30 08' 08"	88 06' 32"
SR-82	17.8	-50.2	12724.1	47057.3	30 07' 55"	88 05' 34"
SR-83	18.8	-45.2	12726.4	47059.6	30 08' 28"	88 05' 21"
SR-84	16	-41.1	12729.3	47062.5	30 09' 23"	88 05' 16"

* from Parker and others (1993); ** from Hummell and Smith (1995)

Table 2.--Summary of information pertaining to foundation borings.

Source*	Foundation Boring or Drill Hole Number	Elevation above sea level (feet)	Total Depth (feet)	Latitude	Longitude
Exxon	84-1114, B-1	-70	356	30 17' 07"	88 11' 29"
Exxon	85-1119, B-2	-37	254	30 17" 07"	88 11' 29"
Exxon	0184-1015, B-1	-52	350	30 17' 07"	88 11' 29"
Exxon	0201-1071-3	-42	278	30 11' 50"	88 08' 46"
Exxon	1188-1314, B-III-1	-34	32	30 10' 05"	88 04' 53"
Exxon	1188-1314, B-III-2	-30	31	30 08' 55"	88 04' 20"
Exxon	1188-1314, D-3A	-39	251.5	30 11' 18"	88 06' 48"

* Exxon Company U.S.A.

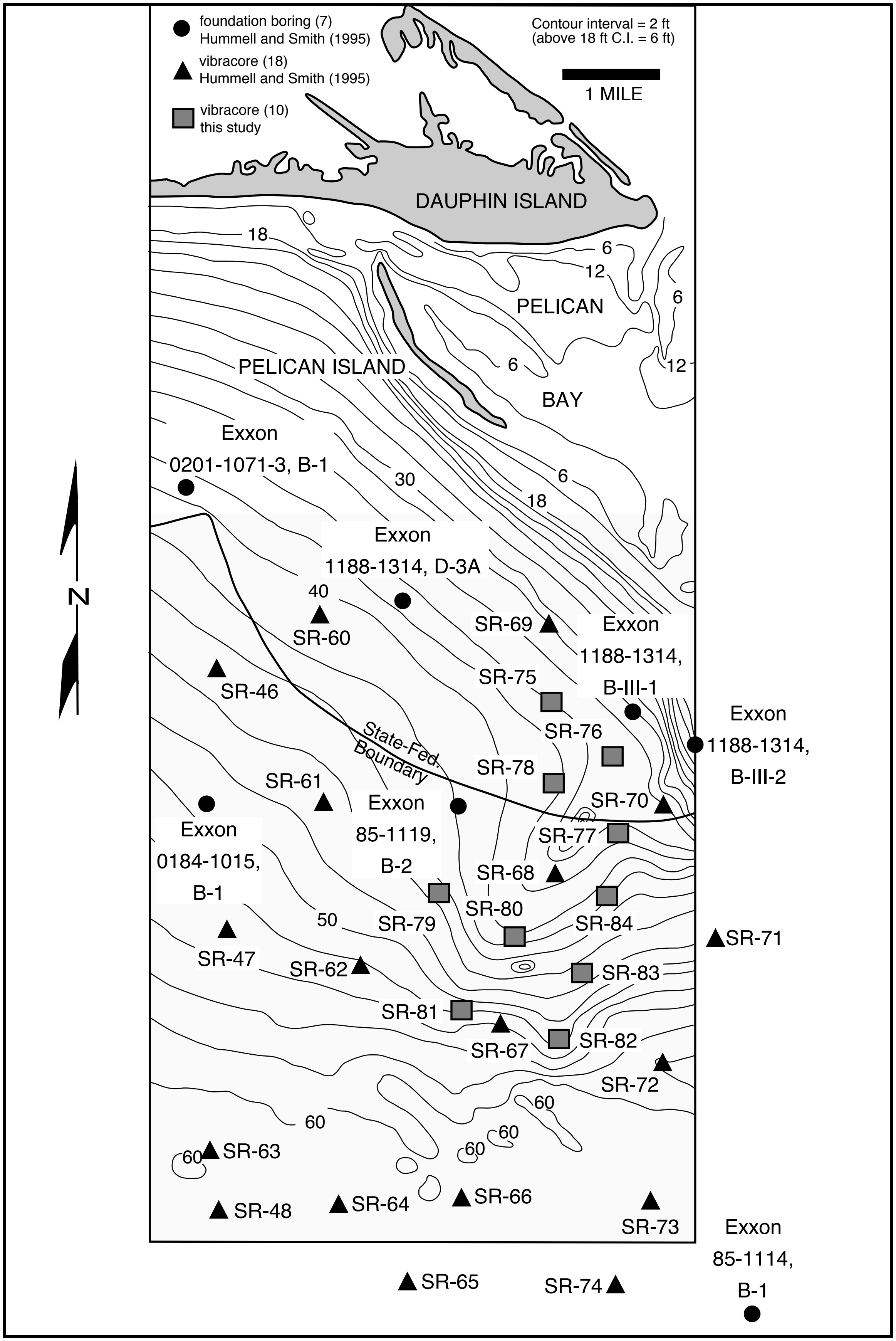


Figure 13.--Map of sand resource target area 4 showing location of vibracores and foundation borings (modified from Hummell and Smith, 1995).

Vibracoring is a technique used to collect relatively undisturbed cores in unconsolidated sediments. The vibracores for this project were collected aboard the R/V *Kit Jones* from the Marine Minerals Technology Center, in Biloxi, Mississippi. The vibracoring system employed in this study consisted of a 25 ft tower that served as a guide for a pneumatic vibrator that drove the core tube into the sediment. A 20 ft long, 3 inch (in) diameter aluminum core tube was used which yielded a maximum core length of approximately 19 ft. Prior to submerging the coring apparatus, the core tube was filled with air which allowed for better penetration. The core was driven into the sediment to the maximum core length or until refusal. After coring ceased, pressure was released and the core tube was allowed to fill with water to provide a suction and prevent loss of the core during extraction. The cores were extracted using a hydraulic winch and the "A-frame" rigging at the stern of the boat. On deck, the cores were cut into 5 ft sections, capped, and stored on board until the vessel came ashore. The core sections were then transported to the laboratory for storage, splitting, and analysis. Navigation aboard the vessel was by Geographic Positioning System.

The major steps involved in the laboratory analysis of the vibracores are presented in figure 14. The vibracore was first clamped into a wooden trough device and split longitudinally using a hand-held router equipped with a high speed steel router bit. After making two length-parallel cuts, a knife was run lengthwise down the core tube dividing the core into halves. Once all sections of a core had been cut, both halves of the core were assembled on a platform for photographing. Thirty five mm color slides were made of each core.

After photography, both halves of the core were described with regards to texture, sedimentary structures, facies, grain size characteristics, facies thickness, and color. Characteristics of each core were entered on data sheets

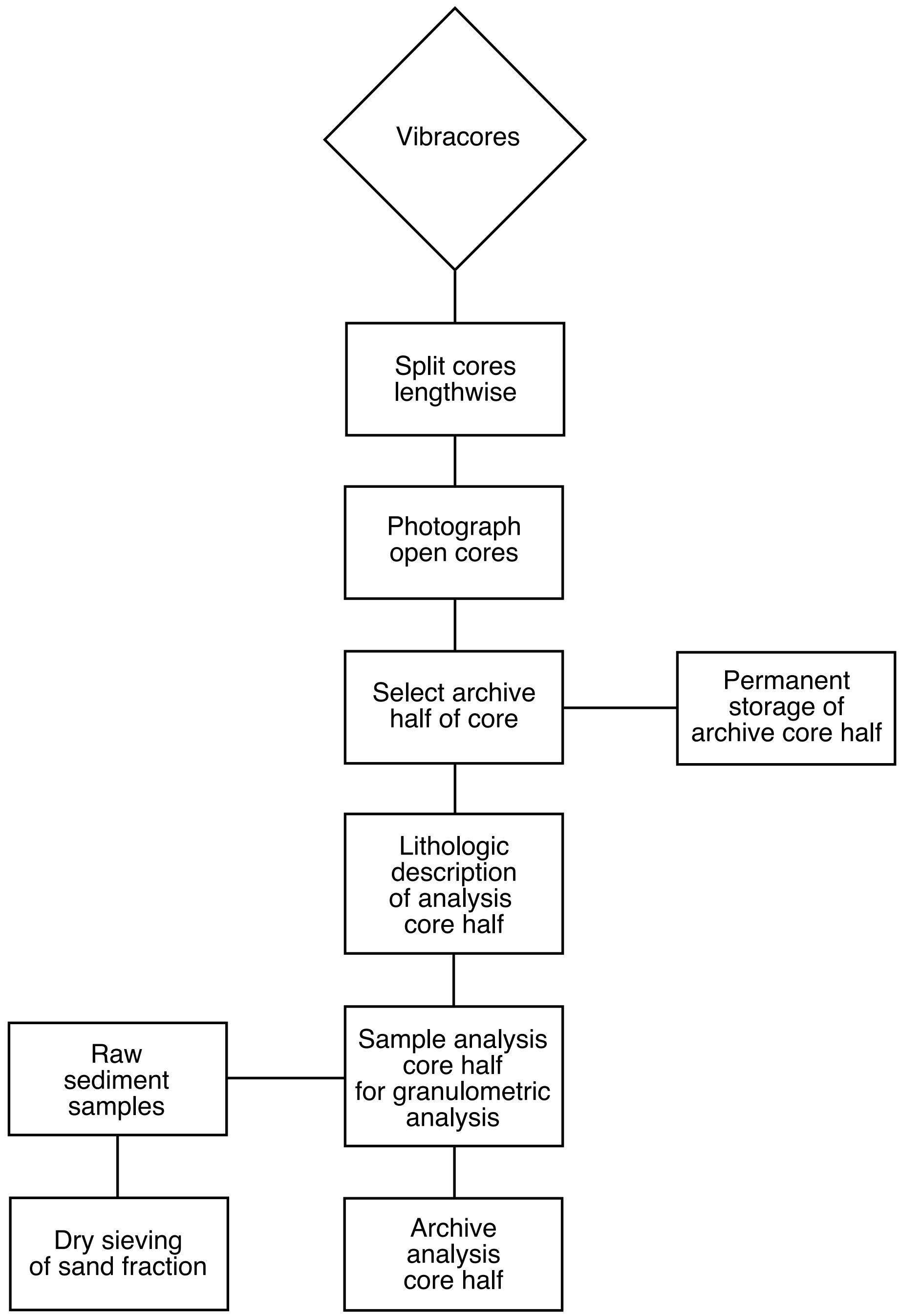


Figure 14.--Flow chart for the laboratory processing of vibracores (modified from Hummell and Smith, 1995).

and then into a computer database. The most intact core half was selected, placed in a plastic sleeve, and archived. The remaining half was processed for granulometry and radiocarbon dating materials when present. Samples were taken on the average every 1 ft or less as needed to characterize lithologic units. After sampling, the processed half was discarded. Organic samples, when encountered, were collected and archived for future radiocarbon dating.

It was found that the physical and chemical properties of the clay minerals in the borings were altered due to oxidation, dehydration, chemical reactions between connate seawater and clay minerals, anaerobic bacterial activity, and chemical reaction between the aluminum core barrel and enclosing sediments. In addition, all of the boring samples were stored in a warm environment that resulted in extensive mold and mildew growth. Particle size analysis by hydrometer conducted on fine-grained samples would therefore result in imprecise and inaccurate measurements. Grain-size characteristics of fine-grained sediment samples was determined by microscopic examination.

Coarse-grained samples from borings suffered from mold and mildew growth, semilithification due to chemical reaction between connate marine water and steel tops of sample containers, and improper subsampling techniques by previous researchers. Particle-size characteristics of these coarse-grained sediment samples was determined by microscopic examination.

Bottom sediment samples were subjected to granulometric analysis by hydrometer and dry sieving. Each sample was washed with deionized water prior to analysis to remove saltwater. This process aided in dispersing the clays during the hydrometer process, since ions in seawater can cause flocculation. The samples were wet sieved through a 63 micron sieve which separated the mud and sand fractions. The mud fraction (finer than 4.0 phi) (Ø) was analyzed using standard hydrometer procedures following Lewis (1984) to determine the percentage of silt and clay. The sand fraction was oven dried at 80° Centigrade to prevent aggregation. A 35 to 60 gram (g) sample was mechanically sieved through stainless steel wire mesh sieves ranging in size from -2.00 Ø (pebble) to 4.0 Ø (very fine sand) at a 0.25 Ø interval. Each sieve fraction was weighed on a top pan Sartorius electronic digital balance to an accuracy of ± 0.001 g, the units used by the balance.

Granulometric analysis was conducted on selected vibracore sediment samples from the sand resource body. As with the sea bottom sediment samples, the sand body samples were washed with deionized water prior to analysis to remove saltwater. However, the sand body samples did not contain enough mud to warrant hydrometer analysis. In this case the samples were oven dried and then mechanically sieved.

The raw data resulting from hydrometer and sieve work were entered into a computer spread sheet to determine the percentages of gravel, sand, silt, and clay for each sample processed. Individual weights for each size fraction were entered into a computer program designed to calculate the first four moments (mean, sorting, skewness, and kurtosis) and produce a histogram and cumulative frequency curve.

Some samples had sand fractions weighing less than 35 g. The probability that a small sample would yield unreproducible results is significant; thus a mode for the sand fraction was estimated for selected samples weighing less than 35 g. This estimate was determined by examining the grain size properties of the sand fractions in samples within the same vibracore. Half the weight of the sand in these samples was placed in the mode with the other half being distributed around the mode (0.25 Ø above and below) to determine the whole sample moment measures.

Lithofacies and their subdivisions, microfacies, were determined for each sedimentary unit using grain size data, sediment texture, and other lithologic characteristics following Parker and others (1993), and Hummell and Smith (1995). The stratigraphic distribution of each microfacies was determined by construction of a series of cross sections, tables and sediment distribution maps.

AREA 4 SAND RESOURCE BODY

Hummell and Smith (1995) used vibracores, borings, and bottom samples to delineate and characterize sand deposits within area 4 resulting in the discovery of a sand resource body with the potential to provide material for beach nourishment projects. Detailed laboratory analyses were performed on bottom, vibracore, and boring sediment samples to determine grain size characteristics and aesthetic quality. From this information, it was concluded by Hummell and Smith (1995) that the sand in the resource body met the specifications of beach sand quality and volume for use in nourishment of eroding Dauphin Island shoreline. The vibracores and bottom samples collected for the present study were also evaluated for grain size characteristics and aesthetic quality.

The sediment sample grain size distribution was divided into shell gravel, sand and shell gravel, sand, silt, and clay. Sediment types on the surface sediment texture map were classified according to the ternary diagram on the explanation page at the front of the report. The area 4 structure contour map of the top of the pre-Holocene, Holocene isopach map, and surface sediment distribution map prepared by Hummell and Smith (1995) were updated using information derived from the analysis of vibracores and bottom sediment samples collected for the present study. Geologic cross sections by Hummell and Smith (1995) showing shallow sedimentary deposits in area 4 were recast to reflect the new information provided by the ten vibracores collected for the present study.

RESOURCE POTENTIAL ANALYSIS

The sediment character of the sand resource body described by Hummell and Smith (1995) and further delineated in this study, was evaluated based on grain size and aesthetic quality to determine the suitability of a deposit for use as beach nourishment material for any of the identified eroding southeastern Dauphin Island Gulf of Mexico shoreline segments. When considering a potential deposit for use in beach nourishment, it is important to calculate an overfill factor to determine the amount material required to restore the beach. James (1975) and Hobson (1977) explained methods of comparing the grain size characteristics of native beach sediment with borrow material using mean grain size and sorting. An overfill factor was determined to account for winnowing processes that affect borrow material placed on the beach. The overfill factor is an estimate of the amount of borrow material required to produce 1 unit volume of native beach material. Aesthetic quality was determined by comparing the color of dry samples of offshore sediment with the beach sediment. The overfill factor calculated by Hummell and Smith (1995) is reevaluated in the present report in light of the new information collected by the present study.

REASSESSMENT OF ERODING COASTAL SHORELINE

SEDIMENT AND SHORELINE CHARACTER

Parker and others (1993) made an assessment of the southeastern shoreline of Dauphin Island to identify and prioritize shoreline characterized by significant erosion that might be mitigated by the application of restorative and nourishment sand obtained from Gulf of Mexico offshore areas. This shoreline was reassessed by Hummell and Smith (1995) and in the present study. It is concluded that the erosional/accretionary regime present along the southeastern shoreline of Dauphin Island has remained unchanged since the study by Hummell and Smith (1995). The prioritization scheme of Parker and others (1993) has also remained unchanged. Ground surveys that included surveyed beach profiles and examination of beach sediments were conducted at southeastern Dauphin Island shoreline monitoring stations for the present study. Current erosion rates are essentially unchanged from those calculated by Parker and others (1993), and Hummell and Smith (1995). Southeastern Dauphin Island beach sediment sample descriptions by Parker and others (1993) were checked using new samples collected for the present study. Sedimentary characteristics of these beach samples were found to be in substantial agreement with that reported by Parker and others (1993).

This past Fall, Hurricane Opal (October 4, 1995) devastated portions of the Florida panhandle coast. Ground surveys and a two-day helicopter overflight of coastal Alabama were scheduled several weeks in advance of the birth of Hurricane Opal for a project unrelated to the present study. By shear coincidence, the surveys and helicopter overflight took place approximately one week after Hurricane Opal impacted the northeastern Gulf of Mexico coast. The field work provided an opportunity to assess the impact of Hurricane Opal on the Alabama coast.

In general, property damage along the immediate coast caused by the hurricane was minimal and localized. An 8 to 10 ft high storm surge combined with storm winds and waves resulted in short term loss (estimated several month recovery period) of tens of feet of dry beach. These storm conditions also resulted in the loss of the first line of foredunes (estimated one year recovery period). Sand from the beach shoreface and foredunes were transported inland by overwash or offshore to the longshore bar system. Except for some permanent loss of beach at erosion hot spots, the beach and eolian dunes should recover to their approximate pre-hurricane state. Alabama state agencies and municipal governments in cooperation with federal agencies have been working on post-storm rehabilitation of the beach/dune system to assist nature in its post-storm coastal recovery process.

ESTIMATED SAND REQUIREMENTS

Parker and others (1993) determined the character of the erosion that has occurred on the southeastern Dauphin Island Gulf of Mexico shoreline since 1955. Hummell and Smith (1995) included estimation of sand volumes necessary to restore southeastern Dauphin Island Gulf of Mexico beaches (fig. 15) eroded during the 10 year period 1985-95. These data were intended to supplement previously derived estimates by Parker and others (1993) of the sand volume required to restore southeastern Dauphin Island beaches eroded during the 30 year period 1955-85. Ground surveys conducted for the present study have provided information to update the estimates of sand volumes required to restore and stabilize southeastern Dauphin Island eroding shoreline

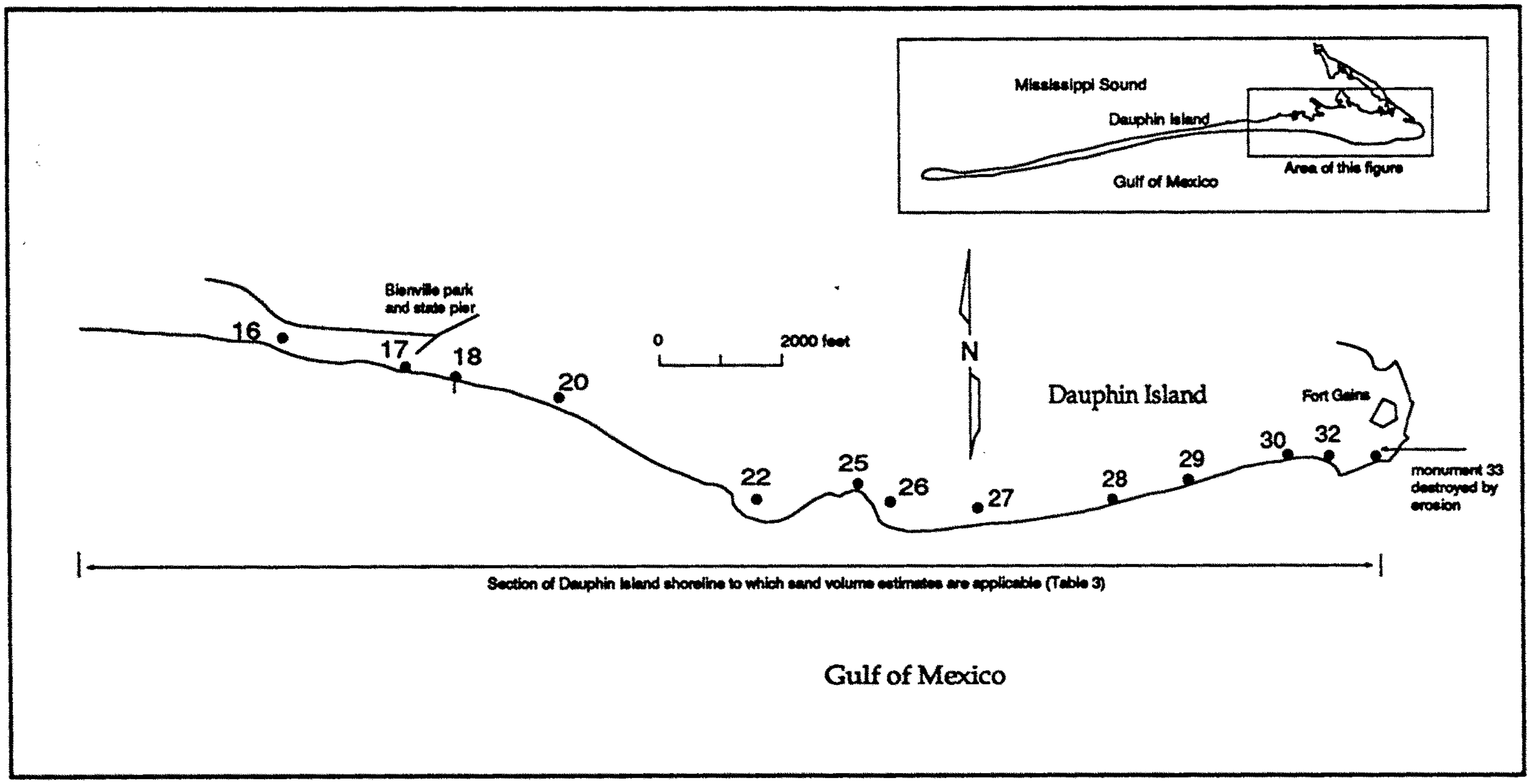


Figure 15.--Dauphin Island Gulf of Mexico shoreline to which sand volume estimates are applicable. Numbered black circles indicate locations of Geological Survey of Alabama beach profile stations used to estimate shoreline erosion rates (modified from Hummell and Smith, 1995).

segments delineated by Parker and others (1993). Table 3 summarizes these updated estimated sand volumes which contain a calculated overfill factor of 20 percent.

GEOLOGIC FRAMEWORK OF THE AREA 4 SAND RESOURCE BODY AND VICINITY

Hummell and Smith (1995) evaluated area 4 of the Alabama EEZ for its sand resource potential. They documented the geologic framework and lithofacies patterns of this area and delineated a sand resource body that has sand resource potential. The GSA recommended to MMS that additional surface and subsurface information be collected to more completely document sand body geometry and granulometry. The MMS directed the GSA in the present study to collect ten new vibracores and bottom samples from the sand resource body and vicinity to define sand body geometry and composition in greater detail. This portion of the study completed task 2 of the project.

LITHOFACIES OF THE AREA 4 SAND RESOURCE BODY AND VICINITY

A lithofacies is a lateral, traceable subdivision of a stratigraphic unit that may be distinguished from adjacent subdivisions on the basis of lithology (Moore, 1949). All characteristics of lithology may be utilized, including the composition, grain size, sedimentary texture and fabric, sedimentary structures, color, biota, and lateral or vertical variation of the unit.

Utilizing these criteria, Parker and others (1993) delineated six separate lithofacies for the Alabama EEZ utilizing 59 vibracores and 59 surface sediment

Table 3.--Estimated volumes (cubic yards) of sand required to restore and stablize (overfill by 20 percent) sand eroded from southeastern Dauphin Island shoreline segments (modified from Hummell and Smith, 1995).

For restoration and stabilization of sand eroded from beaches during the period 1955-85 (data from previous estimates)	1,853,000
For restoration and stabilization of sand eroded from beaches during the period 1985-95 (data from the present study)....................	572,000
For beach restoration and stabilization to 1955 positions	2,425,000

samples. These were subdivided into 13 discrete microfacies (e.g., Wilson, 1975), lithologic units with very similar characteristics that, presumably, formed under nearly identical conditions. These lithofacies and the microfacies for each include the Graded Shelly Sand Lithofacies; the Clean Sand Lithofacies (including the Orthoquartzite Microfacies, the Echinoid Sand Microfacies, the Shelly Sand Lithofacies, and the Sand with Mud Burrows Microfacies); the Dirty Sand Lithofacies (including the Muddy Sand Microfacies and the Muddy Shelly Sand Microfacies); the Biogenic Sediment Lithofacies (including the Oyster Biostrome Microfacies and the Peat Microfacies); the Muddy Sediment Lithofacies (including the Silty/Clayey Sand Microfacies, the Sand-Silt-Clay Microfacies, and the Mud-Sand Interbeds Microfacies); and the Pre-Holocene Lithofacies.

The sediments obtained by Hummell and Smith (1995) from the vibracores, borings, and surface sediment samples in area 4 were also divided into a series of lithofacies. Hummell and Smith (1995) found that the lithofacies classification scheme of Parker and others (1993) agreed well with those lithologic units encountered in area 4 and lithofacies defined by Hummell (1996) in his study of the geologic framework of nearshore Alabama Gulf of Mexico waters.

The lithofacies defined for area 4 by Hummell and Smith (1995) include the Graded Shelly Sand Lithofacies; the Clean Sand Lithofacies (the Orthoquartzite Microfacies); the Dirty Sand Lithofacies (the Muddy Sand Microfacies and the Muddy Shelly Sand Microfacies); the Biogenic Sediment Lithofacies (the Peat Microfacies); the Muddy Sediment Lithofacies (the Silty/Clayey Sand Microfacies, the Sand-Silt-Clay Microfacies, and the Sand-Mud Interbeds Microfacies); and the Pre-Holocene Lithofacies. The other lithofacies defined by Parker and others (1993) were not found to occur in area 4 vibracores and borings used by Hummell and Smith (1995). Lithologic units encountered by vibracores and surface sediment samples in the present study can be classified within the lithofacies defined by Hummell and Smith (1995).

Hummell and Smith (1995) determined that the sand resource body is comprised of the Graded Shelly Sand Lithofacies. Granulometric analysis was conducted on sediment samples from vibracores collected for the present study that penetrated the sand body. These data were pooled with the granulometric data obtained by Hummell and Smith (1995). The pooled grain size characteristics for the sand body are listed in table 4. Table 5 displays the distribution of facies thickness by vibracore for the vibracores collected in the present study. Figures 16, 17, and 18 show the geographic distribution of mean grain size within the sand resource body at depths of 0.1, 0.9 and 2.1 m below the sediment-water interface, respectively.

GRADED SHELLY SAND LITHOFACIES

The sand resource body is comprised of the Graded Shelly Sand Lithofacies. Hummell and Smith (1995) granulometrically analyzed 8 vibracore subsamples of the Graded Shelly Sand Lithofacies; the present study providing an additional 15 subsamples of this lithofacies for grain size analysis (table 4). One of the objectives of the present study is to collect additional vibracores from the sand resource body to better define the bodies geometry and internal granulometry. This targeted approach over the area 4-wide systematic approach of Hummell and Smith's (1995) accounts for the higher frequency percent of lithofacies occurrence in the vibracores collected in the present study (47.5 ft, or 29.6 percent of total core length) versus the vibracores collected by Hummell and Smith (1995) (57.3 ft, or 12 percent of total core length) (table 5).

Table 4.--Grain size characteristics of the Graded Shelly Sand Lithofacies.

	Mean grain size in Phi (Ø)			Standard deviation in Phi (Ø)			Gravel in percent			Sand/gravel in percent			Silt in percent			Clay in percent			Number of samples	Facies thick-ness in feet
Facies	Mini-mum	Aver-age	Maxi-mum	Mini-mum	Aver-age	Maxi-mum	Mini-mum	Aver-age	Maxi-mum	Mini-mum	Aver-age	Maxi-mum	Mini-mum	Aver-age	Maxi-mum	Mini-mum	Aver-age	Maxi-mum		
Graded shelly sand*	2.30	1.31	0.29	0.39	0.93	1.66	0.1	1.93	21.8	93.2	97.4	99.3	0.2	0.6	1.4	0.3	1.93	6	23	104.5

* includes granulometric data from Hummell and Smith (1995)

Table 5.--Facies distribution by vibracore.

Facies	Vibracore number SR-75	SR-76	SR-77	SR-78	SR-79	SR-80	SR-81	SR-82	SR-83	SR-84	Total length in feet	Percent of total core length	
Sands											150		94
Clean sands													
Orthoquartzite													
Graded shelly sand			0.5	0.5	0.2	8.8	13	8.1	7.4	8.7	47.2	29.6	29.6
Dirty sands											102.8		64.5
Muddy sand	6.4	5.7	10.3	10		0.5	0.8	4.6	5.5	3.2	47	29.5	
Muddy shelly sand	9.9	10.2	8.4	4.6	7.3		3.6	4.2	6.2	1.4	55.8	35	
Biogenic sediments													
Peat													
Muddy sediments											5.9		3.7
Silty/clayey sands													
Sand-silt-clay													
Mud-sand interbeds	1.7	1		3.2							5.9	3.7	
Pre-Holocene	1.3			1.4			0.7	0.2			3.6	2.3	2.3

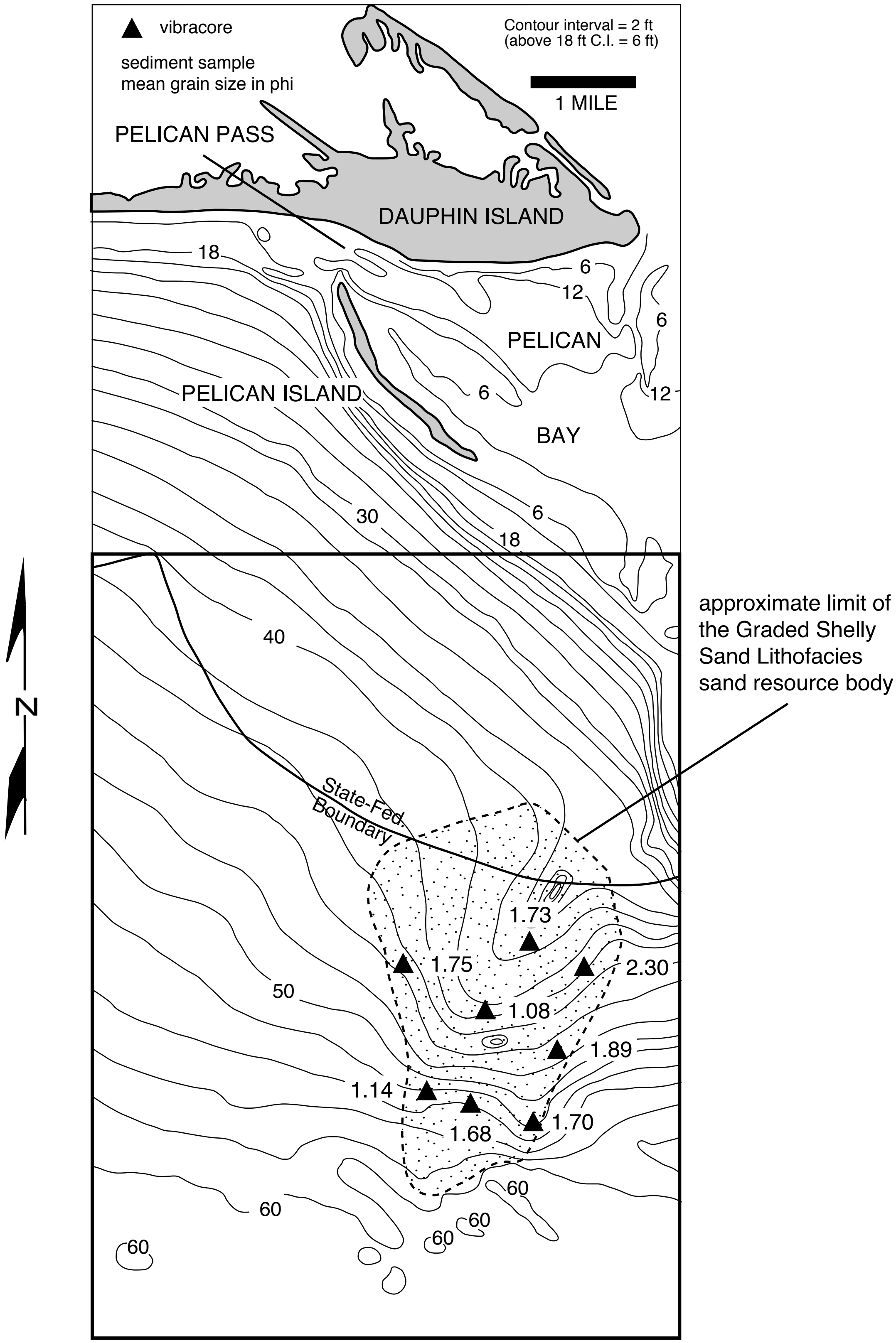


Figure 16.--Map of mean grain size of Graded Shelly Sand Lithofacies vibracore sediment samples 0.1 meter below the sediment-water interface.

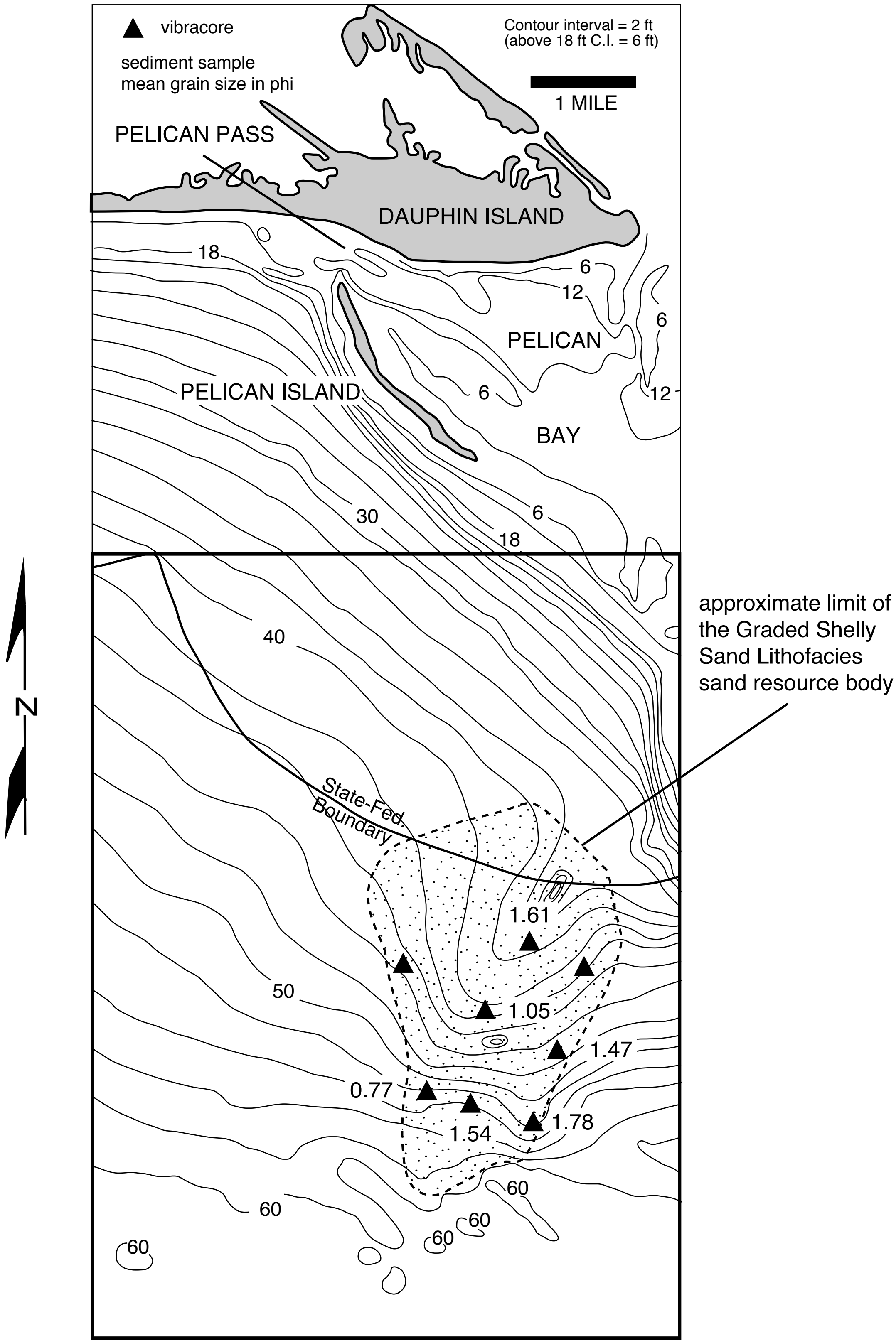


Figure 17.--Map of mean grain size of Graded Shelly Sand Lithofacies vibracore sediment samples 0.9 meter below the sediment-water interface.

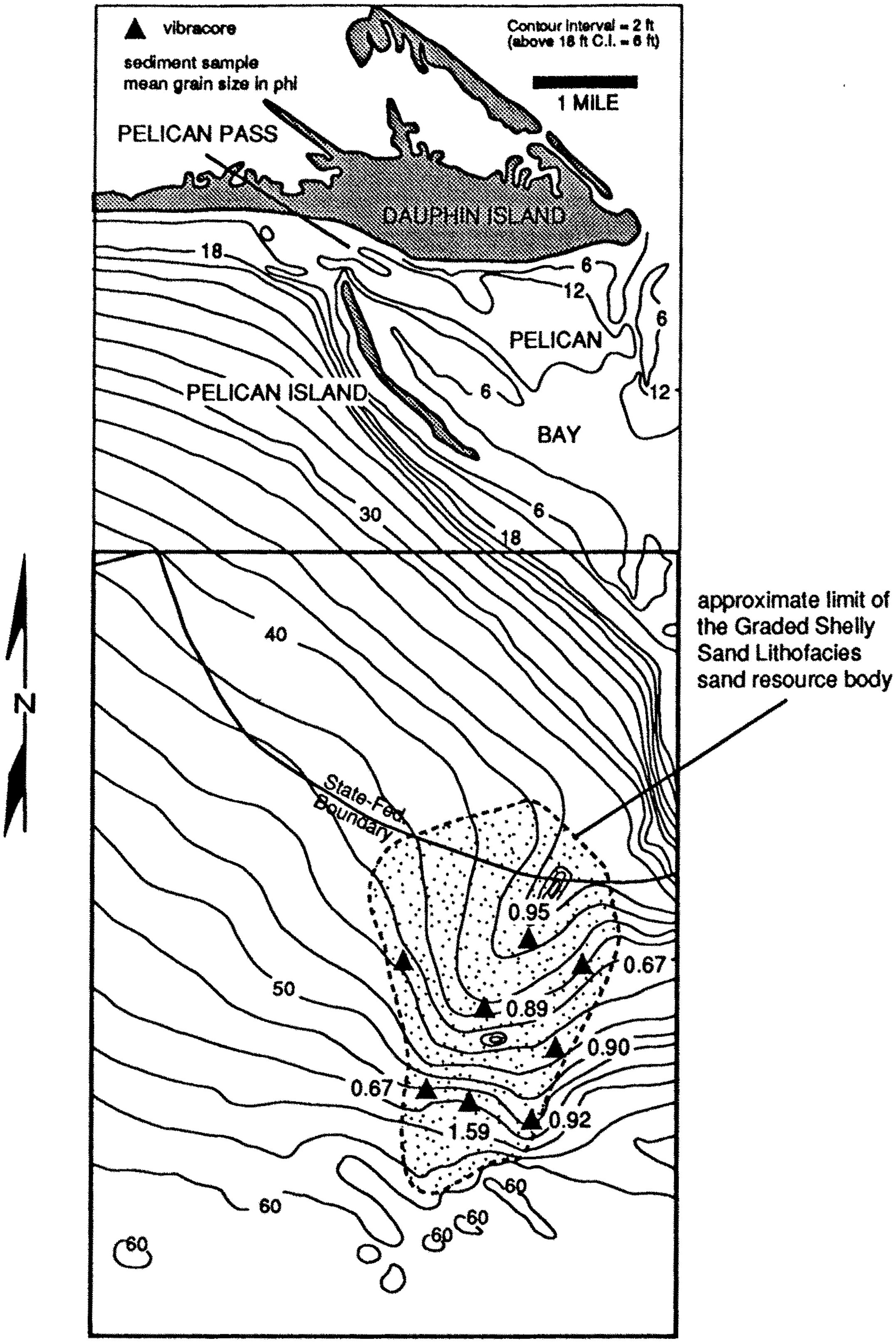


Figure 18.--Map of mean grain size of Graded Shelly Sand Lithofacies vibracore sediment samples 2.1 meters below the sediment-water interface.

This lithofacies is represented in the vibracores by a fining-upwards graded sequence of shell and clean sand. Generally, the Graded Shelly Sand Lithofacies in area 4 show a sharp to relatively sharp base. Parker and others (1993) reported instances of basal mud clasts interpreted as rip-ups of the underlying sediments during high-energy erosive events. This was not observed in any of the vibracores or borings described by Hummell and Smith (1995) nor vibracores from the present study. The basal portions of the units are the coarsest parts, with shell content distributed evenly throughout the unit. The fining-upward texture of the facies is due primarily to a decrease in mean quartz clast and shell particle sizes rather than an upward decrease in relative shell abundance. The basal portion of the graded shelly sand lithofacies in vibracores collected from the northeast-southwest oriented crestline of the sand resource body, such as vibracores SR-68 and SR-80, is a densely packed shell bed as described by Kidwell and Holland (1991). This basal unit is chaotic, with random shell orientations; upwards, the shell fragments are more subhorizontal. The facies in these vibracores reflect storm event reworking of the upper surface of the sand resource body. The facies appears to be massive (as shown in vibracores SR-67, SR-68, and SR-80) and seems to thin rapidly towards the margin of the sand body where the facies pinches out or interfingers with other facies.

The stratigraphically lower portions of the facies may contain muddy sand pockets. Also, the facies may show an occasional, vertically oriented, mud-filled burrow throughout the unit.

Average mean grain size for the graded shelly sand lithofacies is 1.31 Ø (medium sand, table 4); the range for mean grain size is from 0.29 Ø (coarse sand) to 2.30 Ø (fine sand). The average standard deviation for the graded shelly sand samples is 0.93 Ø (moderately sorted); values for standard deviation range from 0.39 Ø (well sorted) to 1.66 Ø (poorly sorted). Overall, the facies represents the coarsest average mean grain size, and the best sorting among all facies (Hummell and Smith, 1995). The inferred origin of these units is rapid deposition of resuspended sediment during storms; this may lead to poor sorting among basal, coarse portions, as material of a wide range of sizes is quickly dumped (Aigner, 1985; Hayes, 1967; Morton, 1981) .

Sediment coarser than 4 Ø (i.e., sand and gravel) (table 4), is by far the dominant constituent of the facies, on average making up 97.4 percent of the unit. The range of values for this material is quite low, 93.2 percent to 99.3 percent. This coarse material comprises two primary components: Quartz-rich sand and shell hash. The quartz-rich sand is a clean, rounded, white to clear, fine to medium quartz sand with minor amounts of feldspars (especially orthoclase, albite and oligoclase), calcite, muscovite and various heavy minerals, among other constituents (Fairbank, 1962; Goldstein, 1942; Griffin, 1962). Parker (1989) showed that the sand-sized component may contain up to approximately 20 percent carbonate in the form of comminuted and juvenile shell material. The gravel-sized component, virtually all shell material, makes up an average of 1.9 percent of the sediment weight. Range for the gravel component is from 0.1 to 21.8 percent. Some samples, especially at the base of the units, contain a preponderance of very coarse (a few inches) whole shells and major fragments (e.g., the shell gravels); other samples, especially those near the tops of the units, may contain only fine shell material. The shell material is composed of a variable mixture of original colored to blackened, discolored shell material that ranges from whole shells and major fragments to small shells and shell fragments. The average sand content would therefore be calculated as 95.5 percent for the lithofacies.

Silt (4 to 8 Ø) is rare in all samples, with a mean of 0.6 percent and a range from 0.2 to 1.4 percent. Likewise, clay content (greater than 8 Ø) is extremely low, with a mean of 1.9 percent and a range of 0.3 to 6.0 percent. Therefore, both mean grain size and sorting values effectively represent the sand and shell gravel components only, with only very secondary influence from the fine-grained components. This lithofacies has very good potential as a source of material for beach replenishment projects.

The fining-upward nature and basal coarsening of the Graded Shelly Sand Lithofacies is shown by comparison of figures 16, 17, and 18. The average mean grain size for vibracore sediment samples that occur at 0.1 m (figure 16) is 1.66 Ø (medium sand). For sample suites that occur at 0.9 (figure 17) and 2.1 m (figure 18), the average mean grain size is 1.37 Ø (medium sand) and 0.94 Ø (coarse sand), respectively.

In addition to a fining-upward trend, sediments comprising the sand resource body would be expected to fine away from the major northeast-southwest oriented axis of the sand body toward its margins where muddy facies are present. The mean grain size data displayed in figures 16, 17, and 18 are too few and variable to show any geographic fining trends by horizon.

CLEAN SAND LITHOFACIES

ORTHOQUARTZITE MICROFACIES

The Clean Sand Lithofacies was not penetrated by vibracores collected in the present study. In area 4, this facies is represented by 0.6 ft of the Orthoquartize Microfacies in vibracore SR-48 which was collected by Parker and others (1993).

Parker and others (1993) described the Orthoquartzite Microfacies in the Alabama EEZ as a clean sand, composed almost completely of quartz grains. It includes very little coarse or fine-grained material. In their study, seventeen samples were analyzed from this microfacies; it comprised 65.1 ft of core material, or 11.0 percent of total core length. Some units possessed layers and/or pockets of increased shell content and there may be an upwards increase in shell content (Parker and others, 1993). The shells are always sand supported. Occasional mud filled burrows are present. Most units have sharp to fairly sharp bases.

The microfacies in vibracore SR-48 is a muddy sand with occasional shell fragments and a gradational lower contact (Parker and others, 1993). Mean grain size for the microfacies in vibracore SR-48 is 2.43 Ø (fine sand), with a standard deviation of 0.93 Ø (moderately sorted). Shell gravel is absent from the microfacies in vibracore SR-48. Sand content is 93.5 percent and silt and clay are 2.4 and 4.1 percent, respectively.

According to Parker and others (1993), shell material is a mixture of mollusc and echinoderm shell fragments, with varying degrees of discoloration. There are relatively few whole shells or large fragments.

The Echinoid Sand Microfacies, the Shelly Sand Microfacies, and the Sand with Mud Burrows Microfacies are absent in the vibracores and borings studied from area 4.

DIRTY SAND LITHOFACIES

As was found in area 4 (Hummell and Smith, 1995), the Dirty Sand Lithofacies is the most common lithofacies analyzed in the present study (102.8 ft of core, or

64.5 percent of core length, table 5). In area 4 it consists of two microfacies: The Muddy Sand Microfacies, and the Muddy Shelly Sand Microfacies. While these share some grain size characteristics, they differ in texture, fabric and other aspects; thus these characteristics will be discussed separately for each.

As determined by Hummell and Smith (1995), mean grain size for the Dirty Sand Lithofacies averages 2.41 Ø (fine sand), with a range from 1.65 Ø (medium sand) to 3.11 Ø (very fine sand). This lithofacies is considerably finer-grained than the Graded Shelly Sand Lithofacies. Average standard deviation for the lithofacies is 1.58 Ø (poorly sorted); sorting ranges from 1.11 Ø (moderately sorted) to 1.99 Ø (poorly sorted) (Hummell and Smith, 1995). Again, these values are much higher than for the Graded Shelly Sand Lithofacies, indicating incorporation of much more fine-grained material in these sediments.

Hummell and Smith (1995) determined that the sand/shell gravel content averages 85.0 percent, with a range from 74.7 to 94.0 percent. They found that shell gravel averages 1.6 percent for this lithofacies, with a range of 0.0 to 8.5 percent. The Dirty Sand Lithofacies averages 83.4 percent sand (Hummell and Smith, 1995).

Silt and clay are significant constituents of sediments from this lithofacies. Silt content averages 6.7 percent, with a range from 2.3 to 12.2 percent (Hummell and Smith, 1995). This average is an order of magnitude higher than for the Graded Shelly Sand Lithofacies. Hummell and Smith (1995) determined that the clay content averages 8.2 percent, with a range of 2.3 to 13.5 percent. This average is 6 to 7 times higher than for the Graded Shelly Sand Lithofacies.

MUDDY SAND MICROFACIES

In area 4, Hummell and Smith (1995) found that the Muddy Sand Microfacies is the least common microfacies of the Dirty Sand Lithofacies. This determination is in agreement with the findings from the present study (47.0 ft of core, or 29.5 percent of total core length, table 5).

This microfacies is composed of a mud-rich sand that is rarely interbedded, but often is highly mottled due to poorly preserved burrowing, with a bioturbation index up to 5 (Droser and Bottjer, 1986). The burrows may be sand filled or mud filled. The units generally contain scarce to abundant shells or shell fragments, but may have a few shells concentrated at the base, or may contain occasional wood fragments. Mud pockets rarely occur. Bases of the units may be gradational or sharp. Units are generally stratigraphically low, often close to or overlying the Pre-Holocene Lithofacies. The microfacies is generally sheet shaped and laterally continuous, and is best developed towards the margins of area 4. The microfacies is usually associated stratigraphically with other mud-rich lithofacies and microfacies, such as the Muddy Sediments Lithofacies.

Hummell and Smith (1995) report that the average mean grain size is 2.47 Ø (fine sand). They go on to state that the range of mean grain sizes for samples from this microfacies is from 1.93 Ø (medium sand) to 3.11 Ø (very fine sand). Both end members of this range are much finer-grained than comparable values for any other sand microfacies. Average standard deviation for this microfacies is 1.43 Ø (poorly sorted); the range is from 1.11 to 1.72 Ø (poorly sorted) (Hummell and Smith, 1995). Except for the Graded Shelly Sand Lithofacies, this sediment type has on average the best sorting of any other lithofacies or microfacies.

Hummell and Smith (1995) found that sand/shell gravel is the dominant grain size class, representing 86.5 percent of the microfacies on average. The range of values is from 77.2 to 94.0 percent (Hummell and Smith, 1995). The average value represents a lower sand/shell gravel content than any other sand microfacies. Shell gravel content is low, 0.8 percent on average, with a range from 0.0 to a maximum of 2.7 percent (Hummell and Smith, 1995). This maximum value is lower than the maximum value for any other sand microfacies. Hummell and Smith (1995) determined that the sand size fraction on average represented 85.7 percent of the unit; among the sand microfacies, only the Muddy Shelly Sand Microfacies contains less sand.

This microfacies contains a relatively high component of silt and clay. Among sand microfacies, it contains on average the second highest average amount of silt (5.8 percent), with a range for samples of 2.3 to 9.3 percent (Hummell and Smith, 1995). Clay content averages 8.0 percent, with a range from 2.3 to 13.5 percent (Hummell and Smith, 1995). This is the highest clay content of any sand microfacies.

MUDDY SHELLY SAND MICROFACIES

The Muddy Shelly Sand Microfacies is common in area 4 (Hummell and Smith, 1995) and at the site of the sand resource body, representing 55.8 ft of the vibracores collected in the present study (35.0 percent of total core collected, table 5).

There are few primary sedimentary structures visible in this microfacies; the unit is a homogeneous muddy sand containing common to abundant molluscan

Shells (whole, articulated, and single valves) and shell fragments in a sand supported fabric. Echinoid fragments are scarce. The units can contain sand-filled burrows or rarely, mud-filled burrows. Shells are usually distributed in a chaotic to subhorizontal orientation, but can occur as shelly pockets or as shell lags. Wood fragments rarely occur in this microfacies.

The microfacies is massive, laterally continuous, and often exposed at the surface in area 4. Unit contacts are mostly sharp, but can be gradational. The microfacies is associated stratigraphically with the Muddy Sediments and the Graded Shelly Sand Lithofacies.

Hummell and Smith (1995) report that the average mean grain size for the microfacies is 2.40 Ø (fine sand), with a range from 1.65 Ø (medium sand) to 2.98 Ø (fine sand). It is therefore much coarser on average than the Muddy Sand Microfacies due to its higher shell content. They determined that the average standard deviation for the microfacies is 1.70 Ø (poorly sorted), with a range in values from 1.31 Ø (moderately sorted) to 1.99 Ø (poorly sorted). Based on the average value, this is the most poorly sorted of the sand microfacies.

Sand/shell gravel content is the dominant size class, comprising on average 84.7 percent of the unit (Hummell and Smith, 1995). This is the second lowest average among the sand microfacies. The range of values is from 74.7 to 91.2 percent (Hummell and Smith, 1995); this wide range in values indicates relative diversity in sediment type due to differences in shell content. Hummell and Smith (1995) state that the shell gravel content averages 1.8 percent, with a range from 0.1 to 8.5 percent. This microfacies has the second highest average shell gravel content after the Graded Shelly Sand Lithofacies. The average sand fraction for this sediment type would be 82.9 percent (Hummell and Smith, 1995), the lowest sand concentration for any sand microfacies.

Silt and clay are both common constituents of this microfacies. Silt makes up on average 6.9 percent of the unit, with a range from 4.0 percent to 12.2 percent (Hummell and Smith, 1995). Thus, this is the most silt-rich of any sand microfacies. Hummell and Smith (1995) determined that the clay content on average is 8.3 percent, with a range of 3.7 to 13.1 percent. Again, this is the most clay-rich of any sand microfacies.

BIOGENIC SEDIMENTS LITHOFACIES

Biogenic sediments are produced by the production of sedimentary particles by the physiological activities of organisms, either plant or animal (Grabau, 1924). Parker and others (1993) defined two biogenic microfacies for the Alabama EEZ: The Oyster Biostrome Microfacies, and the Peat Microfacies. Only the Peat Microfacies occurred in the area 4 vibracores and borings (Hummell and Smith, 1995). Neither microfacies was sampled by the vibracores from the present study.

PEAT MICROFACIES

Hummell and Smith (1995) found that in area 4 the Peat Microfacies made up a total of 0.8 ft of core length (0.2 percent of total core length). They described this microfacies as composed of brown terrestrial plant debris in a muddy or sandy mud matrix. These beds have been interpreted as marsh deposits (Kraft, 1971; Fletcher and others, 1990) and have been described throughout coastal Alabama (Hummell and Parker, 1995a, 1995b; Hummell, 1996). Peat layers are 1.5 to 4 in thick, and are often interbedded with either very thin beds of clay or sand. These units may directly or closely overlie the pre-Holocene unconformity surface and frequently denote the top of the Pre-Holocene Lithofacies (Hummell and Parker, 1995a, 1995b; Hummell, 1996). Rhizoliths (preserved root traces) may extend down into the underlying unit. Peat beds may be disrupted by burrows.

MUDDY SEDIMENT LITHOFACIES

The Muddy Sediment Lithofacies is a common lithofacies in area 4 (Hummell and Smith, 1995). However, this facies is rare at the site of the sand resource body where it comprises 5.9 ft of core, or 3.7 percent of total recovered core (table 5). In area 4 this lithofacies is composed of three separate microfacies: The Silty/Clayey Sand Microfacies; Sand-Silt-Clay Microfacies; and Mud-Sand Interbed Microfacies. Lithologic characteristics for each of these will be described separately.

Hummell and Smith (1995) determined that the Muddy Sediment Lithofacies has an average mean grain size of 3.86 Ø (very fine sand), with a range from 1.72 Ø (medium sand) to 5.40 Ø (medium silt). It is therefore by far the finest-grained lithofacies encountered in area 4. The average standard deviation for the facies is 1.49 Ø (poorly sorted); values range from 1.13 Ø (moderately sorted) to 2.01 Ø (very poorly sorted) (Hummell and Smith, 1995).

This facies has, by far, the lowest sand/shell gravel component of any lithofacies analyzed, 54.6 percent (Hummell and Smith, 1995). Hummell and Smith (1995) report that the range of values is 21.6 to 87.7 percent. Shell gravel content is also by far the lowest of any facies, with an average of 0.6 percent and a range of 0 to 5.3 percent (Hummell and Smith, 1995). Sand content, therefore, would be on average 54.0 percent (Hummell and Smith, 1995), again the lowest of all the lithofacies.

Not surprisingly, fine-grained sediment was found by Hummell and Smith (1995) to be very abundant in the lithofacies. They determined that the silt content averaged 21.5 percent, with a range of 5.5 to 38.8 percent, the highest of any lithofacies. Clay content was also the highest of any lithofacies, with an average of 23.9 percent and a range of 6.8 to 33.4 percent (Hummell and Smith, 1995).

SILTY/CLAYEY SAND MICROFACIES

The Silty/Clayey Sand Microfacies was found by Hummell and Smith (1995) to be uncommon in the vibracores and borings from area 4, representing 5.6 ft of core (1.2 percent of total core length). None of the vibracores collected in the present study encountered this microfacies.

Deposits of this microfacies occasionally contain primary sedimentary structures, such as mud and sand laminae. Additionally, mud drapes or clay balls may be present. Most units are structureless. The lower contact may be sharp or gradational. Occasional shell fragments are encountered. Bioturbation is present, including sand-filled burrows and mud-filled burrows.

Parker and others (1993) found that the average mean grain size of the Silty/Clayey Sand Microfacies is small in comparison to most sampled microfacies from the Alabama EEZ, with an average of 3.36 Ø (very fine sand), and a range from 2.74 Ø (fine sand) to 3.81 Ø (very fine sand). They noted that the average is the finest grain size for any microfacies except the Sand-Silt-Clay Microfacies. The standard deviation for the microfacies averages 1.56 Ø (poorly sorted), with a range from 1.27 Ø (poorly sorted) to 2.06 Ø (very poorly sorted) (Parker and others, 1993). They determined that the lack of better sorting is due to the presence of abundant fine-grained material in the unit.

Parker and others (1993) stated that the sand/shell gravel content is very low, with an average of 67.9 percent and a range from 57.2 to 77.1 percent. This is lower than any microfacies other than those from the Muddy Sediment Lithofacies. Shell gravel content was also low, with an average of 1.1 percent and a range from 0.0 to 4.6 percent (Parker and others, 1993). This average was found to be as low as any microfacies not in the Muddy Sediment Lithofacies. The average sand content was 66.8 percent, again much lower than any microfacies from another lithofacies (Parker and others, 1993).

Silt and clay content was found by Parker and others (1993) to be high. Silt averaging 18.1 percent of the microfacies, with a range from 10.5 to 25.9 percent (Parker and others, 1993). This was a higher average than any microfacies except the Sand-Silt-Clay Microfacies. Clay content was also quite high in their samples, with an average of 14.0 percent and a range from 3.5 to 26.4 percent.

SAND-SILT-CLAY MICROFACIES

The Sand-Silt-Clay Microfacies was determined by Hummell and Smith (1995) to be the most abundant microfacies in the Muddy Sediments Lithofacies in area 4, representing 87.1 ft of core (18.3 percent of total core). However, this microfacies did not occur within any of the vibracores collected for the present study from the site of the sand resource body.

This microfacies is variable in character; mostly unstructured, displays sheet shaped geometry, can be massive, and ranging from clay to muddy sand. The microfacies can occur at most any stratigraphic position and appears to be associated with both mud-rich and sand-rich lithofacies. Typically, the microfacies is a sandy mud with common to abundant sand-filled burrows throughout. Often the unit contains an occasional shell or wood fragment. Rarely are the units laminated, contain shelly pockets, or mud-filled burrows. Where the Peat Microfacies or abundant wood fragments are present, they are often stratigraphically overlain directly by the Sand-Silt-Clay Microfacies. Bases may be gradational to fairly sharp.

This is by far the finest-grained microfacies analyzed by Hummell and Smith (1995), with an average mean grain size of 4.61 Ø (coarse silt), and a range of values from 3.23 Ø (very fine sand) to 5.40 Ø (medium silt). The average is considerably finer than the next finest-grained microfacies (a difference of 0.75 Ø) (Hummell and Smith, 1995). The average standard deviation of grain size is 1.46 Ø (poorly sorted), with a range from 1.35 Ø (moderately sorted) to 1.74 Ø (poorly sorted) (Hummell and Smith, 1995). The poor sorting is partly due to the lack of coarse shell gravel in the microfacies.

This microfacies does not have a dominance of sand/shell gravel; it is the only microfacies that does not. Hummell and Smith (1995) did not find any shell gravel in any sample in this microfacies. Sand content averages 40.0 percent and ranges from 21.6 to 55.7 percent (Hummell and Smith, 1995).

Hummell and Smith (1995) determined that silt and clay are each as dominant in this facies as is sand/shell gravel. They found that the silt content averages 29.4 percent, with a range from 19.5 to 38.8 percent. This is by far the most silt content of any microfacies. Clay content averages 30.6 percent, with a range from 24.8 to 33.4 percent (Hummell and Smith, 1995). This is also by far the most clay-rich microfacies.

MUD-SAND INTERBEDS MICROFACIES

Hummell and Smith (1995) discovered that the Mud-Sand Interbeds Microfacies is common in area 4; it is represented by 69.3 ft of core (14.5 percent of total core length). In the current study, this microfacies is rare in occurrence, accounting for 5.9 ft of core, or 3.7 percent of total core length (table 5).

This microfacies contains interbedded very thin sand and mud laminae. These discrete units are thicker than the laminations sometimes seen in the Sand-Silt-Clay Microfacies. There are occasional small shell fragments, mud-filled burrows, and shelly pockets throughout. Sand-filled burrows are common. Unit contacts are sharp or gradational. The microfacies is usually found low stratigraphically, and often occurs as the basal Holocene, lying unconformably above the Pre-Holocene Lithofacies. The Mud-Sand Interbeds Microfacies displays sheet-like geometry, is somewhat laterally continuous, and occasionally massive. This microfacies was mapped by Hummell (1996) as undifferentiated ebb-tidal delta lithofacies in his Holocene geologic framework investigation of Alabama Gulf of Mexico waters. As was found by Hummell (1996), Hummell and Smith (1995), and in the present study, this microfacies is best developed in the Holocene sediment column of area 4 at the distal margins of the ebb-tidal delta of Mobile Bay.

Hummell and Smith (1995) report that the average mean grain size for this microfacies is 2.81 Ø (fine sand), with a range from 1.72 Ø (medium sand) to 3.71 Ø (very fine sand). This is the coarsest of any of the Muddy Sediment microfacies (Hummell and Smith, 1995). Nonetheless, it is still 0.34 Ø smaller than the finest-grained microfacies from any of the other lithofacies described by Hummell and Smith (1995). Standard deviation of grain size averages 1.50 Ø (poorly sorted), with a range from 1.13 Ø (moderately sorted) to 2.01 Ø (very poorly sorted)

(Hummell and Smith, 1995). Only one microfacies, the Muddy Shelly Sand Microfacies, has a higher average standard deviation.

The percent sand/shell gravel size fraction is low for this microfacies, representing only 75.1 percent on average, with a range from 68.8 to 87.7 percent (Hummell and Smith, 1995). Only the Sand-Silt-Clay Microfacies contains a lower percentage. Hummell and Smith (1995) show that shell gravel content is very low, with an average of 0.6 percent and a range of 0.0 to 5.3 percent. This is the lowest average and range of any microfacies in area 4. Total sand content for the microfacies would therefore average 74.9 percent, the second lowest sand fraction after the Sand-Silt-Clay Microfacies (Hummell and Smith, 1995).

Silt and clay are both major components of the Mud-Sand Interbeds Microfacies. Silt averages 10.4 percent, with a range from 5.5 to 13.9 percent, while clay content averages 14.6 percent, with a range from 6.8 to 21.7 percent (Hummell and Smith, 1995). Only the Sand-Silt-Clay Microfacies has a higher average clay content.

PRE-HOLOCENE LITHOFACIES

The Pre-Holocene Lithofacies was represented by a minimum of 3.6 ft of core (2.3 percent of total core length, table 5); the facies was not analyzed for grain size data, as it is too consolidated to be utilized as a possible source of beach replenishment materials.

In coastal Alabama, there is an extensive unconformity, interpreted as a late Pleistocene-early Holocene transgressive surface, at the base of the Holocene transgressive tract sediments that is recognizable from several criteria, not all of which are present at any one locality. The unconformable surface and underlying pre-Holocene sediments have been extensively studied by Hummell and Parker (1995a, 1995b), and Hummell (1996). These studies determined that the pre-Holocene consists chiefly of estuarine, fluvial-deltaic, and barrier island sediments, that are at least in part of late Pleistocene age. Because all of this material has not been dated the term pre-Holocene is used as a relative age for all sediment below the shallowest unconformity (Hummell and Parker, 1995a, 1995b, Hummell, 1996).

Pre-Holocene deposits in coastal Alabama are characterized by stiff, oxidized clay-rich sediment in shades of bright yellowish orange, brown, gray, and greenish gray or unconsolidated, sands, muddy sands, and gravelly sands in light shades of gray, olive, brown, orange, and white (Hummell, 1996). The unconformity is easily identifiable in vibracores and on most seismic records from Mobile Bay, Mississippi Sound, and the Gulf of Mexico. The pre-Holocene sediment in coastal Alabama generally displays characteristics of paleosols in the upper 3 ft of the deposit that indicate subaerial exposure (Hummell, 1996). This oxidized zone is absent in the pre-Holocene sediments sampled by borings and vibracores collected within the Mobile-Tensaw alluvial system (Hummell and Parker, 1995a, 1995b, Hummell, 1996). Either water was always present in the alluvial valley, thereby preventing subaerial exposure, or these sediments were quickly buried, avoiding significant weathering, or the oxidized zone was cut through and removed by fluvial activity (McFarland and LeRoy, 1988). The top of the pre-Holocene in Mobile Bay, Mississippi Sound, and the west Alabama inner continental shelf shows evidence of being bored by marine organisms during flooding of the unconformable surface by Holocene transgression.

Area 4 vibracores and borings show that the pre-Holocene sediment immediately exposed below the late Pleistocene-early Holocene unconformity or main Holocene transgressive surface appears to represent estuarine (mostly open bay and marsh), except in the vicinity of the Mobile-Tensaw alluvial channel in the eastern part of the study area where fluvial-deltaic sediments are exposed (Hummell, 1996).

Estuarine units are comprised of a variety of sediment types including clay, clayey silt, silt, sandy mud, and sandy silt. Beds are mostly unstructured, with bioturbation measuring between 5 and 6 (Droser and Bottjer, 1986). Shells, peat, roots, and plant material are common throughout the estuarine pre-Holocene deposits. Bioturbation of pre-Holocene estuarine deposits results in sediment being reworked into the overlying Holocene sediments.

Pre-Holocene, moderately to poorly sorted, muddy sands, sands and gravelly sands that directly underlie the unconformity in the Mobile-Tensaw alluvial valley are interpreted as representing fluvial facies (McFarlan and LeRoy, 1988). These sediments are characterized by a lack of shells and the presence of sand-sized muscovite, heavy minerals, and pebble to granule-sized rocks. Associated with fluvial sediments are semi-consolidated sandy clay and sandy muds that are frequently laminated. These beds have a bioturbation of 5 to 6 (Droser and Bottjer, 1986) and contain isolated sand-filled burrows, sand-sized muscovite, heavy minerals, and an occasional shell or shell fragment. These sediments resemble ebb-tidal delta facies sediments in part and bay head delta front facies deposits (Coleman and Wright, 1975). High sedimentation rates keep bioturbation to a minimum, thus preserving sedimentary structures.

LITHOFACIES DISCUSSION

The lithofacies present in area 4 show great variation in their sedimentological characteristics. They range from almost pure quartz sands (Clean Sand Lithofacies) to sandy mud units (Muddy Sediments Lithofacies) to indurated, eroded Cenozoic sedimentary rocks (Pre-Holocene Lithofacies). Likewise, the seven microfacies that make up these lithofacies are equally diverse, although the microfacies that comprise a lithofacies are similar.

Based on their composition, grain size, and color, some lithofacies would make appropriate beach replenishment materials, while others are definitely inappropriate. Hummell and Smith (1995) determined that the Graded Shelly Sand Lithofacies would make an excellent source of Dauphin Island shoreline nourishment sand. This facies is present in area 4 as a massive, shelly sand deposit, most of the upper surface of which is exposed at the seafloor.

Based on the results from the present study of the Graded Shelly Sand Lithofacies sand resource body described by Hummell and Smith (1996), the sand body remains an excellent source of Dauphin Island shoreline nourishment sand. Granulometric analysis by Hummell and Smith (1995) and the present study of Graded Shelly Sand Lithofacies vibracore sediment samples show that the sand resource body maintains its lithologic integrity throughout.

SPATIAL DISTRIBUTION OF FACIES

In order to make any mining operation of the Graded Shelly Sand Lithofacies sand resource body as cost effective as possible, it is essential to describe sand body geometry and overburden. Figure 19 is a surface facies

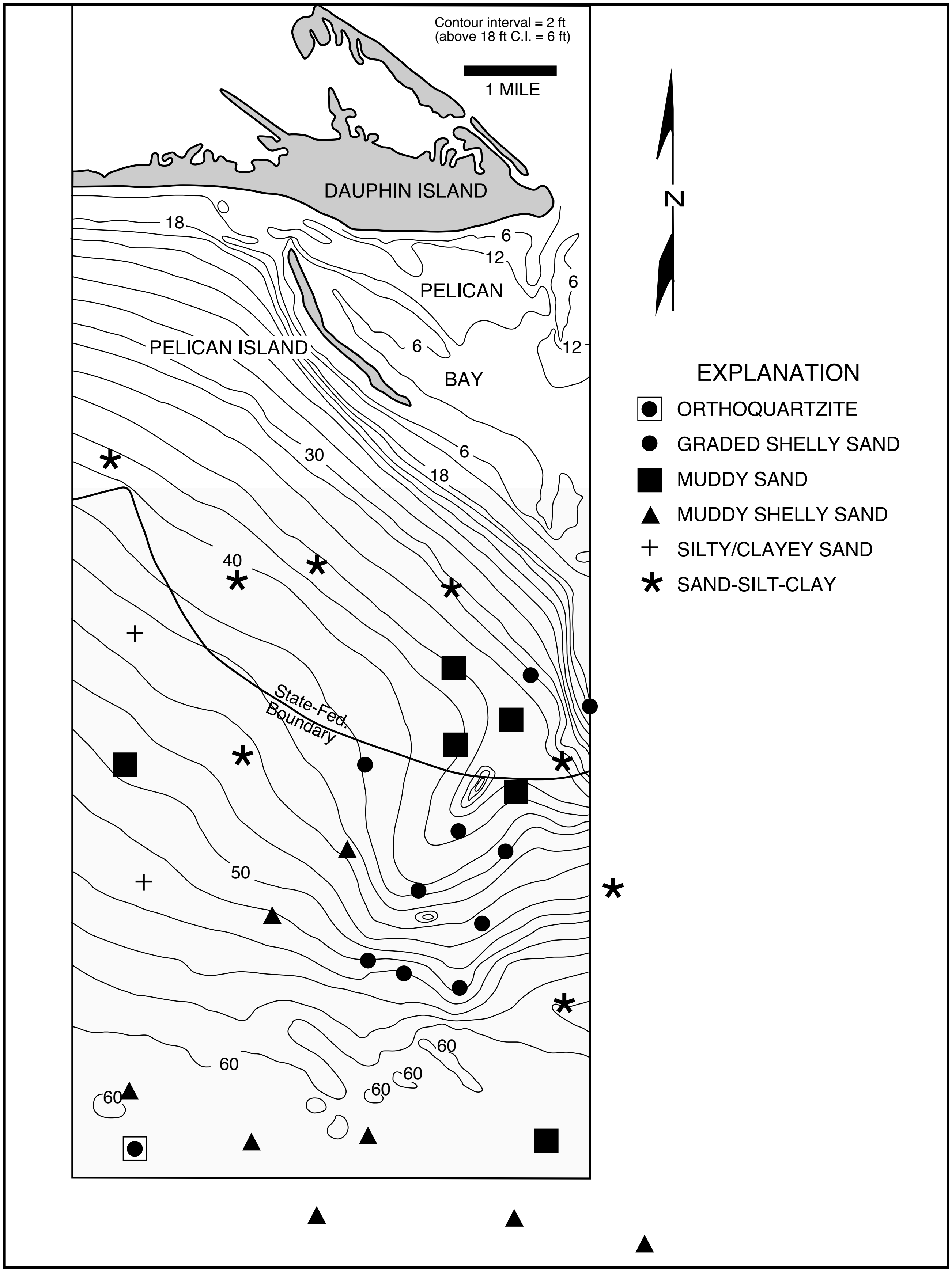


Figure 19.--Surface facies distribution in sand resource target area 4 (modified from Hummell and Smith, 1995).

distribution map for area 4 that shows the microfacies on the seafloor at each vibracore locality. Figure 20 is a map of the distribution of surface sediment texture in area 4.

SURFICIAL DISTRIBUTION OF MICROFACIES

Hummell and Smith (1995) found that six facies occur today at the sediment surface in area 4. Data from the present study has restricted the geographic distribution of the Graded Shelly Sand Lithofacies to mostly the east central portion of area 4 (fig. 19). The Sand-Silt-Clay Microfacies is distributed primarily in the northern half of the area 4 (fig. 19). The Muddy Shelly Sand Microfacies covers much of the southern half of area 4 (fig. 19). The Silty/Clayey Sand Microfacies, the Muddy Sand Microfacies, and the Orthoquartzite Microfacies occur at locations scattered across area 4 (fig. 19).

The distribution pattern of the Graded Shelly Sand Lithofacies can also be seen on figure 20, which shows surface sediment type based on grain size only. The distribution of the Graded Shelly Sand Lithofacies at the sediment-water interface stands out from the muddy sands that cover most of the remainder of area 4.

Geographic variation in sea bottom sediment type in area 4 is subject to prevailing hydrologic and oceanographic conditions (many of which show distinct seasonal variation), which constantly rework and redistribute surficial sediments. Heterogeneity of nearshore sediments is attributed to Holocene transgression, variation in local bathymetry, changes in sediment transport pathways, reworking by wave activity, and sedimentation associated with sediment plumes emanating from Mobile Bay (Swift and others, 1971; Pyle and others, 1975; Abston and others, 1987; Wiseman and others, 1988; Chuang

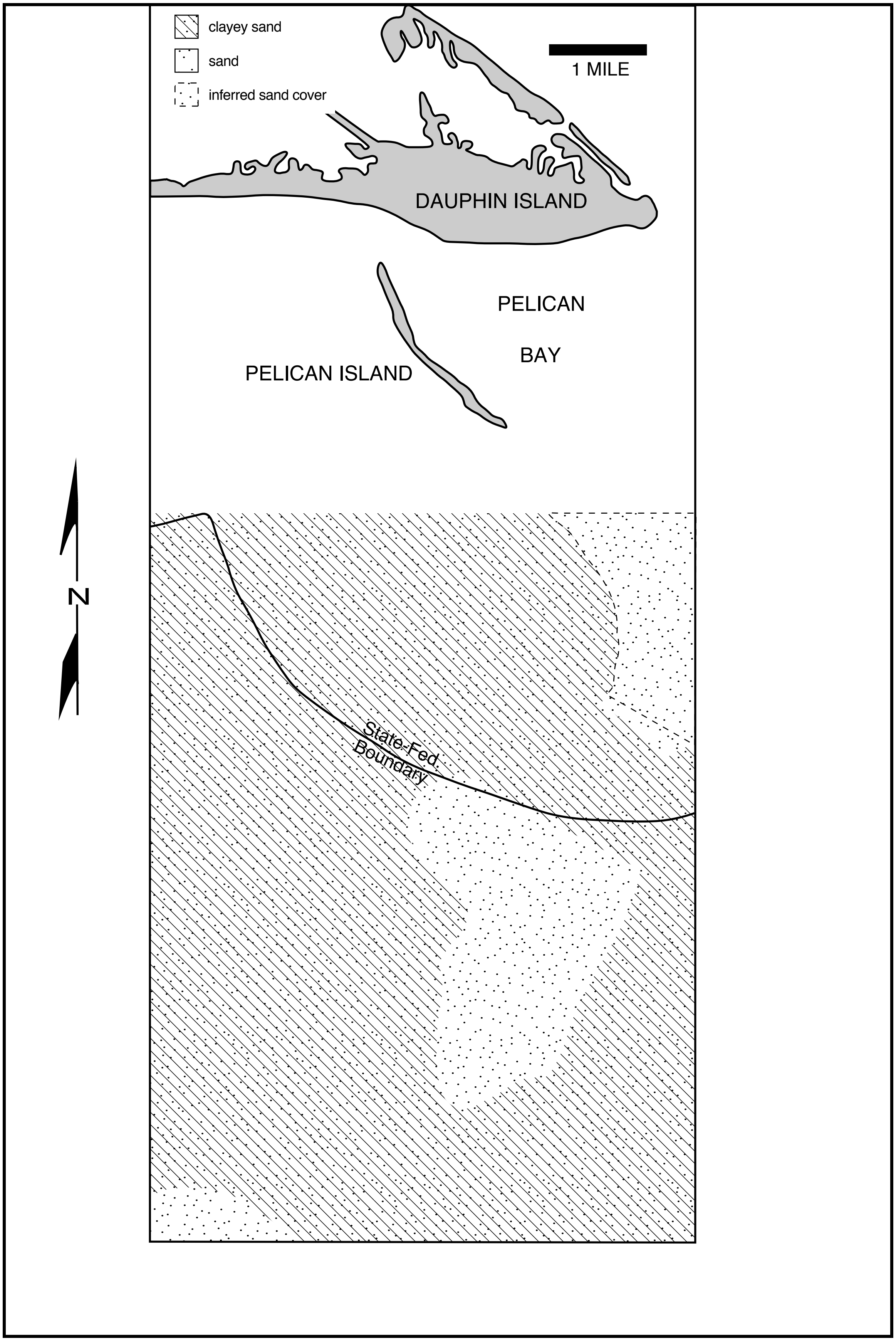


Figure 20.--Map of sand resource target area 4 showing surface sediment texture (modified from Hummell and Smith, 1995).

and others, 1982). Tidal inflow and outflow through Main Pass redistributes estuarine sediments in the southern half of Mobile Bay and transports fines out of Mobile Bay. Most of the sediment exiting Mobile Bay is deposited south to west of Main Pass, in response to the predominant westward directed littoral drift, forming an ebb-tidal delta (U.S. Army Corps of Engineers, 1979). During summer months, some of the fines move eastward in response to an eastward component of the longshore drift (U.S. Army Corps of Engineers, 1979). Deposition of sand from ebb-tidal sediment plumes occurs seaward of Main Pass on the ebb ramp, with clays and silts being deposited on the shelf seaward of the ebb shield which includes area 4 (figs. 3 and 20).

It should be pointed out that despite the homogeneity of facies and sediment texture at the sea bottom, the small scale distribution of the facies is very patchy (Parker and others, 1993). It is expected that in area 4, utilizing a sampling net finer than that used by Hummell and Smith (1995) and in the present study, there will be variability in facies distribution. This patchiness may be the result of the interplay between relict sediment distribution, present topography and hydrodynamics, and local differences in shell content. Present knowledge of topography and circulation is not sufficiently advanced to definitely predict facies patterns on a small scale.

VERTICAL FACIES SEQUENCES AND INFERRED ENVIRONMENTS OF DEPOSITION

Determining the vertical facies pattern is essential in describing the sedimentary history of an area, and therefore is useful in predicting facies distributions in other, unsampled portions of the area. Additionally, by delineating the facies that envelop the Graded Shelly Sand Lithofacies sand resource body, the depth of overburden can be determined and predictions can be made about the subsurface sand body distribution; both of these enhance economic evaluations of proposed mining activities.

Parker and others (1993) and Hummell and Smith (1995) utilized the characteristics of the lithofacies and microfacies together with their vertical patterns to determine the conditions under which the sediments were deposited. Also, Hummell and Smith (1995) developed a typical composite stratigraphic sequence of facies for area 4 (fig. 21). The additional vibracores collected for the present study permit the construction of a typical composite stratigraphic sequence of facies for the Graded Shelly Sand Lithofacies sand resource body (fig. 22). It shows the general trend of the Muddy Shelly Sand Microfacies (Shelf Sand Sheet Depositional Environment) overlying the pre-Holocene surface (fig. 22). In area 4, the Pre-Holocene Lithofacies represents mostly an estuarine depositional environment. Pre-Holocene age sandy sediments, primarily those encountered along the eastern margin of area 4, are interpreted as facies of the Fluvial Depositional Environment (Hummell, 1996).

The Muddy Shelly Sand Microfacies is overlain by the Graded Shelly Sand Lithofacies (Shelf Sand Ridge Depositional Environment) (fig. 22). Around the margins of the sand resource body, the Graded Shelly Sand Lithofacies interfingers with the Sand-Silt-Clay Microfacies (Shelf Mud/Ebb-Tidal Delta Depositional Environment) or the Muddy Sand Microfacies (Ebb-Tidal Delta Depositional Environment) (fig. 22). Where these muddy sediments are absent, the sand resource body interfingers with the Muddy Shelly Sand Microfacies.

Examination of the vibracores and cross sections indicates that a relationship exists between overburden and the sand resource body. Places where substantial overburden (the Sand-Silt-Clay Microfacies, the Muddy Sand Microfacies, or Muddy Shelly Sand Microfacies) exists, the sand resource body

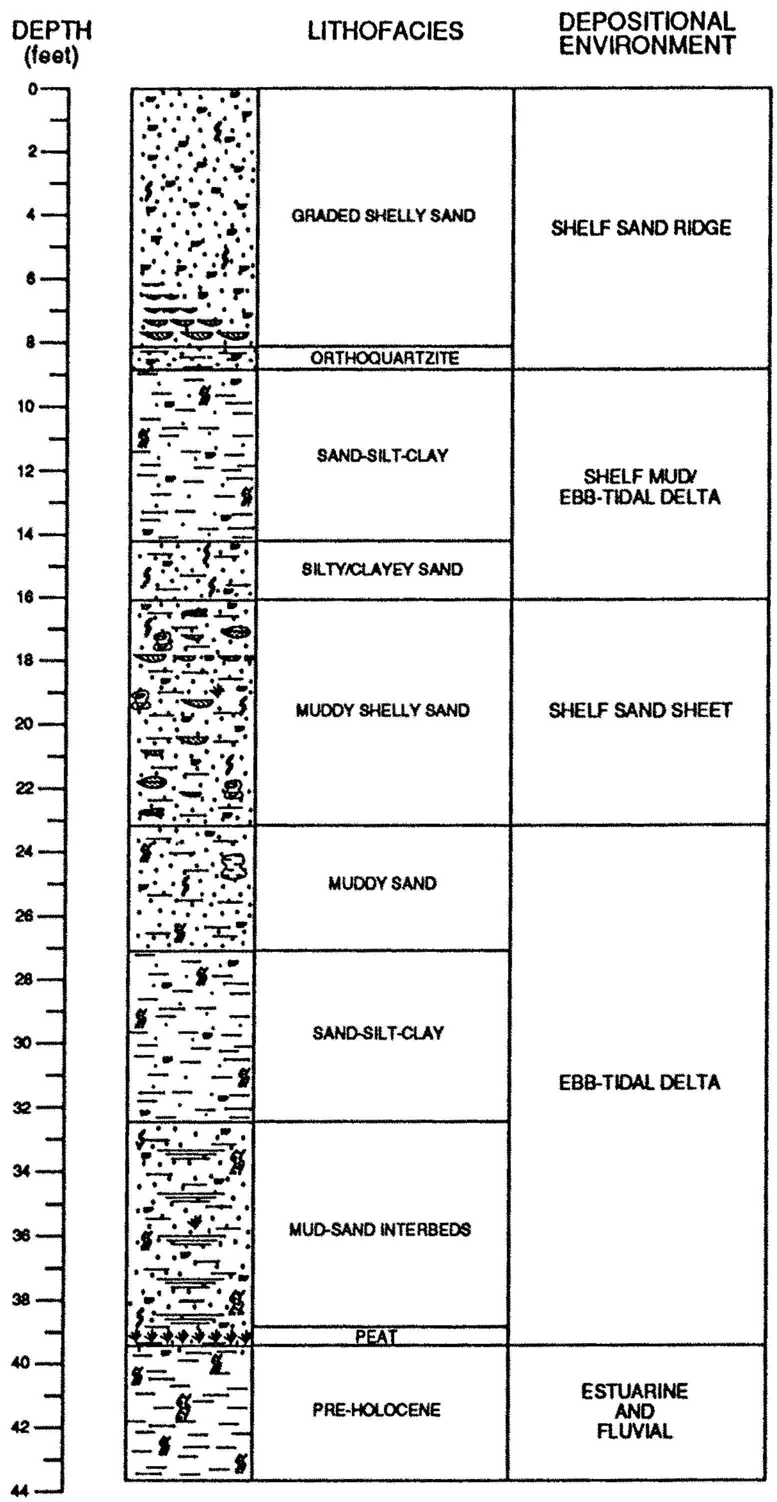


Figure 21.--Generalized stratigraphic sequence of sand resource target Area 4 (modified from Hummell and Smith, 1995).

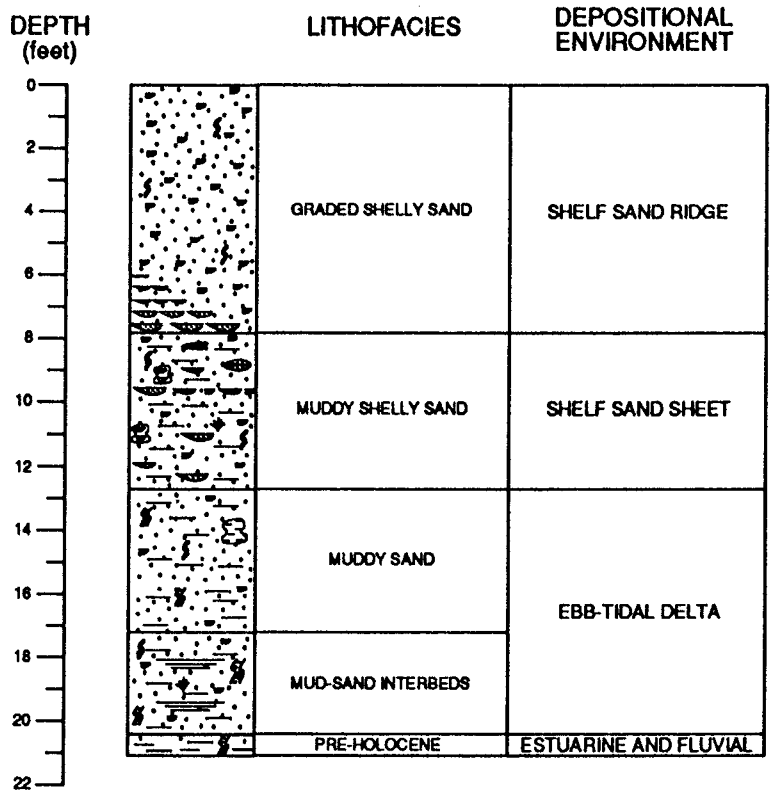


Figure 22.--Generalized stratigraphic sequence of the Graded Shelly Sand Lithofacies sand resource body.

(the Graded Shelly Sand Lithofacies) is generally thin. Therefore, a sand mining operation should avoid portions of the sand body overlain by muddy sediments.

Holocene microfacies from this study formed in four major depositional environments. Much of the inner shelf portion of the Alabama EEZ today represents a Shelf Sand Sheet Depositional Environment (Parker and others, 1993). This depositional environment represents widespread deposition of presumably reworked palimpsest clean sands (but see Swift and others, 1971) following transgression (review in Johnson, 1978; also see Ludwick, 1964, and Parker and others, 1993).

In area 4, the Shelf Sand Sheet Depositional Environment is present exclusively as the Muddy Shelly Sand Microfacies. Here it is a massive, laterally persistent, molluscan-rich, muddy sand. The preservation of articulated bivalves, abundance and pristine condition of the molluscan and echinoid hard parts, and development on the southwestern flanks of the ebb-tidal delta of Mobile Bay (in an area of active sedimentation associated with organic-rich sediment plumes emanating from Mobile Bay) suggest that this is an area of high biological productivity.

This microfacies laterally grades into the Ebb-Tidal Delta Depositional Environment, or engulfs the Shelf Sand Ridge Depositional Environment. The sand in this environment may be reworked either by high energy storm events, or by background (nonstorm) currents and bioturbation (Parker and others, 1993).

Embedded in the Shelf Sand Sheet is the Sand Ridge Depositional Environment, which includes both the ridge crest and inter-ridge trough subenvironments (Caston, 1972; Stubblefield and Swift, 1976). The oblique-to-shoreline sand ridges are capped by mobile sands that are well above storm wave base (Parker and others, 1993). They are capped by coarse-grained deposits that may well be locally moved by interstorm shelf currents (Parker and others, 1993). The inter-ridge troughs are the site of much quieter water deposition of fines between storms, and may receive coarse washovers during storms.

This depositional environment is manifested as the surficial sand sheet facies (McBride and others, 1991; Hummell, 1996) in Alabama Gulf of Mexico waters. Here deposits interpreted as this facies are widespread, massive, and take on a sheet-like geometry (Hummell, 1996). The shallow water and high wave energy promotes a sheet over ridge geometry.

Main Pass is classified as an ebb-type tidal inlet because of the presence of a prominent ebb-tidal delta seaward of the inlet (Hubbard and others, 1979). In addition, Main Pass would be classified as tide-dominated due to its well developed ebb-tidal delta, poorly developed flood-tidal delta, and deep central channel through which tidal currents flow flanked by channel margin bars (Pelican Island and associated submerged shoals) (Hubbard and others, 1979) (fig. 3). Although ebb-tidal deltas are common along barrier island coasts of the Gulf of Mexico and western Atlantic Ocean, their sedimentary processes, stratigraphy, and facies are not well understood. The internal structure of the deltas results from the interaction between tidal currents and waves. Tidal deltas vary greatly in their characteristics, due chiefly to the magnitude of the tidal range (Israel and others, 1987) and the types of depositional environments bordering the inlet (for example, lagoon or estuary).

Hummell (1990, 1996) studied the Holocene stratigraphy of the ebb-tidal delta of Mobile Bay. Internally, the delta is comprised of clay, silt, sand, and gravel, represented in a wide variety of sediment texture types. These sediments are distributed in lensoid and tabular bodies of varying thickness and mostly limited lateral extent. Estuarine and inner continental shelf sedimentary deposits extensively interfinger with ebb-tidal delta deposits (Hummell, 1996). The lithologic and stratigraphic complexity results from the interplay between waves, tides, freshwater discharge events, and shelf currents and the variety of sediment grain-sizes available. The combination of sediments and processes produce shoals, sand waves, dunes, and ripples and a complex water circulation pattern (Hummell, 1996). This results in sediment texture heterogeneity in surficial sediments of the ebb-tidal delta and ultimately, sediment texture and bed geometry heterogeneity of the ebb-tidal delta sedimentary deposit.

Some researchers (Friedman and Sanders, 1978; Reineck and Singh, 1986; Sha, 1989) have chosen not to subdivide ebb-tidal delta deposits into facies while others have tried to group lithostratigraphic units into distal or proximal-tidal delta facies (Hennessy and Zarillo, 1987; Israel and others, 1987). Hummell (1996) choose not to subdivide ebb-tidal deposits as additional closely spaced vibracores and detailed granulometric analysis would be needed to adequately define ebb-tidal delta of Mobile Bay subfacies and understand their genetic interrelationships.

The complex stratigraphic relationships between lithologic units that was seen in the ebb-tidal delta of Mobile Bay study by Hummell (1996) become better resolved as these units are traced into area 4. Some of the lithofacies defined and mapped by Parker and others (1993) in the Alabama EEZ, and interpreted by them as the Bay/Lagoon Depositional Environment are seen in area 4. Although, their lithofacies and microfacies classification applies well to area 4, the facies are better characterized if they are assigned to the Ebb-Tidal Depositional Environment rather than the Bay/Lagoon Depositional Environment. Parker and others (1993) had to develop a depositional environmental classification that applied to a broad region of the Alabama EEZ, rather than, in the case of Hummell and Smith (1995) and the present study, a scheme that applies locally. In addition, Parker and others

(1993) could not benefit from the findings by Hummell and Smith (1995) and Hummell (1996) which enable ebb-tidal delta, shelf mud, and estuarine lithologic units to be traced from their origin in State of Alabama waters out into federal waters.

The Ebb-Tidal Delta Depositional Environment includes the Sand-Silt-Clay Microfacies, the Silty/Clayey Sand Microfacies, the Muddy Sand Microfacies, the Mud-Sand Interbeds Microfacies, and the Peat Microfacies. Lithologic units mapped in the subsurface of the ebb-tidal delta of Mobile Bay by Hummell (1996) appear to be correlatable with area 4 subsurface lithologic units mapped by Hummell and Smith (1995) and in the present study. These units and their facies assignments are therefore classified in the present study as Ebb-Tidal Delta Depositional Environments.

The Ebb-Tidal Delta Depositional Environment partly consists of older sediments that formed during Holocene transgression of the EEZ (e.g., Bridges, 1975). It may include restricted circulation (e.g., variable, lower salinity and water energy) deposits typical of bays and lagoons, including bay muds, silty sands, nearshore interbedded sands and muds, oyster reefs, and bay margin peat deposits (Parker and others, 1993; Hummell, 1996). Additionally, it may include mixed transitional mud and sand units formed on the open shelf during early stages of transgression (Parker and others, 1993).

Shelf mud (Hummell, 1996) which lithologically and genetically appears to be equivalent to open bay facies (Brande, 1983; Fletcher and others, 1990; Hummell and Parker, 1995a, 1995b; Hummell, 1996) of coastal Alabama presently occupies most of the northern two-thirds of area 4 and is mapped in the present study as Sand-Silt-Clay Microfacies. It is equivalent to facies 1 (lagoon) of McBride and others (1991). Located below normal wave base, the open bay facies is deposited in protected areas west of the ebb-tidal delta of Mobile Bay and in the deeper waters of Pelican Bay (Hummell, 1996). Fine-grained sediment plumes emanating primarily from Mobile Bay move out onto the Alabama inner continental shelf and are usually carried westward by longshore drift (Hummell, 1996). Much of the plume suspended sediment is being deposited on the shelf down drift of the ebb-tidal delta of Mobile Bay and in federal waters off of Main Pass (Hummell, 1996).

The muddy sediments protruding from Mobile Bay out onto the inner continental shelf are properly referred to as open bay facies along with other shallow subsurface sedimentary deposits that clearly were deposited in an estuary (Hummell, 1996). This working definition of open bay facies is difficult to apply in the subsurface where lack of lateral continuity of lithologic units makes it difficult to distinguish between a mud unit deposited on the continental shelf in which the sediment source was an estuary and a mud unit extending out of an estuary onto a continental shelf. Unfortunately, mud units deposited in both settings appear indistinguishable in borings and vibracores (Parker and others, 1993; Hummell, 1996). Genetically, both types of units are related in that the constituent fine-grained sediments were derived from Mobile Bay. More work and data are needed to properly classify these shelf muds. The term 'shelf mud' appears to be used as a popular inclusive label for muddy continental shelf sediment of varying origins. To minimize confusion and communicate the relationship between open bay facies sediments and shelf muds, those fine-grained sediments that occur on the continental shelf that appear identical to open bay muds except they are not deposited in an estuarine setting will be referred to as shelf muds equivalent to open bay facies (Hummell, 1996).

Lithologic units interpreted as shelf muds and open bay facies appear at the sediment-water interface and in the subsurface of the ebb-tidal delta of Mobile Bay (Hummell, 1996). At the surface and in the subsurface of Alabama state waters the lithologic units of both facies thin toward the southwest (Hummell, 1996). In the subsurface, these units pinch out into ebb-tidal delta deposits along the northern margin of area 4. At the surface, open bay facies does not appear to extend into area 4. The shelf muds (Sand-Silt-Clay Microfacies) enter area 4 and continue to thin in a southwestern direction, finally pinching out in the south-central part of area 4.

On the Alabama inner continental shelf, the pre-Holocene sediments represent a variety of marine and nonmarine depositional environments (Parker and others, 1993; Hummell, 1996). In area 4, the pre-Holocene is interpreted as belonging estuarine and fluvial depositional environments.

Hummell and Smith (1995) determined the rank order of lithofacies and microfacies in vertical sequence for the sediment column in area 4 (fig. 21). They found that some facies are present throughout the area and others are only present in the absence of another. In ascending order the facies are the Pre-Holocene Lithofacies; the Mud-Sand Interbeds Microfacies or the Sand-Silt-Clay Microfacies (either or neither of which may contain the Peat Microfacies); the Muddy Sand Microfacies; the Muddy Shelly Sand Microfacies; the Graded Shelly Sand Lithofacies, the Orthoquartzite Microfacies, the Sand-Silt-Clay Microfacies or the Silty/Clayey Sand Microfacies (Hummell and Smith, 1995).

The Sand-Mud Interbeds Microfacies is not exposed at the sediment-water interface in area 4, but is most commonly seen near the bottom of vibracores and borings associated with other muddy units, especially the Sand-Silt-Clay Microfacies (Hummell and Smith, 1995). The Sand-Silt-Clay Microfacies occurs in the absence of the Sand-Mud Interbeds Microfacies and visa-versa. The Sand-Mud Interbeds

Microfacies most likely represent a shallow water, fluvial-deltaic environment (Hummell, 1996).

The Sand-Silt-Clay Microfacies appears to have formed in a variety of low energy settings. Most commonly this microfacies is found in a protected, shallow water marine setting (shelf mud and open bay deposition southwest of Main Pass today) or a protected, shallow water, ebb-tidal delta setting (Pelican Bay and vicinity today) (Hummell, 1996).

The Peat Microfacies formed in quiet marshy environments, either low salinity estuarine intertidal salt marshes or nonmarine palustrine wetlands (Cowardin and others, 1979). In coastal Alabama these Holocene age peat deposits are associated with paleotopographic highs on the late Pleistocene-early Holocene unconformable surface (last transgressive surface) (Hummell and Parker, 1995a, 1995b; Hummell, 1996). Therefore, they are seen in area 4 associated with the Sand-Mud Interbed Microfacies, the Sand-Silt-Clay Microfacies, and the Pre-Holocene Lithofacies (Hummell and Smith, 1995).

The Muddy Sand Microfacies formed in an ebb-tidal delta setting (Hummell and Smith, 1995). Vibracores, borings, and bottom sediment samples collected by Hummell (1996) in Pelican Bay suggest that sediments interpreted as this microfacies are being deposited there today.

The Muddy Shelly Sand Microfacies likely form both in the Sand Ridge Depositional Environment, especially on the flanks to troughs, and on the Shelf Sand Sheet (Parker and others, 1993). Sedimentary deposits of this microfacies occur throughout area 4 and Parker and others (1993) report the occurrence of this microfacies at vibracore locations just east of Main Pass on the eastern inner continental shelf. This microfacies likely forms in inner continental shelf areas of muddy sand deposition where nutrients associated with fine-grained sediments promote invertebrate productivity. Also, the slow winnowing of these units by waves or currents, produce a sand with an enhanced shelly concentration (Parker and others, 1993).

The Silty/Clayey Sand Microfacies was deposited in the Ebb-Tidal Delta Depositional Environment and is found exposed at the sediment-water interface in vibracores along the west-central margin of area 4 (Hummell and Smith, 1995). It is associated with the Sand-Silt-Clay Microfacies in the upper part of the sediment column. Sedimentary deposits interpreted as Silty/Clayey Sand Microfacies appear to have formed under environmental conditions similar to the Sand-Silt-Clay Microfacies (a protected, shallow water marine setting or a protected, shallow water, ebb-tidal delta setting). In area 4 this microfacies is present in the absence of the Graded Shelly Sand Lithofacies, Orthoquartzite Microfacies, or Sand-Silt-Clay Microfacies (Hummell and Smith, 1995).

The Graded Shelly Sand Lithofacies is inferred to represent shelf storm deposits of the Sand Ridge and Shelf Sand Sheet Depositional Environments (Parker and others, 1993). Its graded nature, sharp base, and variable thickness are typical of tempestites (Aigner, 1985). In area 4 it overlies the Muddy Shelly Sand Microfacies.

Orthoquartzite Microfacies forms primarily in the Shelf Sand Sheet Depositional Environment, and may extend onto the Sand Ridges (Parker and others, 1993). This microfacies is exposed at the sediment-water interface in the extreme southwestern corner of area 4. Parker and others (1993) consider this facies to be the reworked, winnowed upper portion of underlying lithologic units representing various facies.

SUBSURFACE CROSS-SECTION INTERPRETATIONS

The focus of the current study is to define in greater detail the Graded Shelly Sand Lithofacies sand resource body through the collection of additional vibracores. Hummell and Smith (1995) produced a series of geologic cross sections through area 4 showing the subsurface distribution of facies and the sand resource body. These cross sections have been updated in the present study to include the new information provided by the additional vibracores. In addition, new cross sections have been constructed for the sand resource body and vicinity.

In the present report a labeling scheme has been employed to minimize any potential confusion between these updated cross sections, the new cross sections, and the original cross sections of Hummell and Smith (1995). Cross sections A-A' and I-I' of Hummell and Smith (1995), although useful for characterizing the subsurface facies distribution in area 4, are not retained in the present report as they are too far away to pertain to the sand resource body. To alert the reader, those cross sections from Hummell and Smith (1995) that have been modified carry a double letter label (e.g. BB-BB'). New cross sections constructed for the present report carry a single letter label that continues the lettering sequence started by Hummell and Smith (1995). Figure 23 is a map that shows the location of each of the twelve cross sections through the sand resource body and vicinity. Figures 24 through 35 are geologic cross sections that show subsurface distribution of each facies.

The series of geological cross sections (figs. 24 through 35) show trends in subsurface lithofacies and microfacies distributions in both dip-trending and strike-trending directions (fig. 23) to facilitate determination of lateral variability patterns for the facies. These facies are physically grouped in a Holocene age,

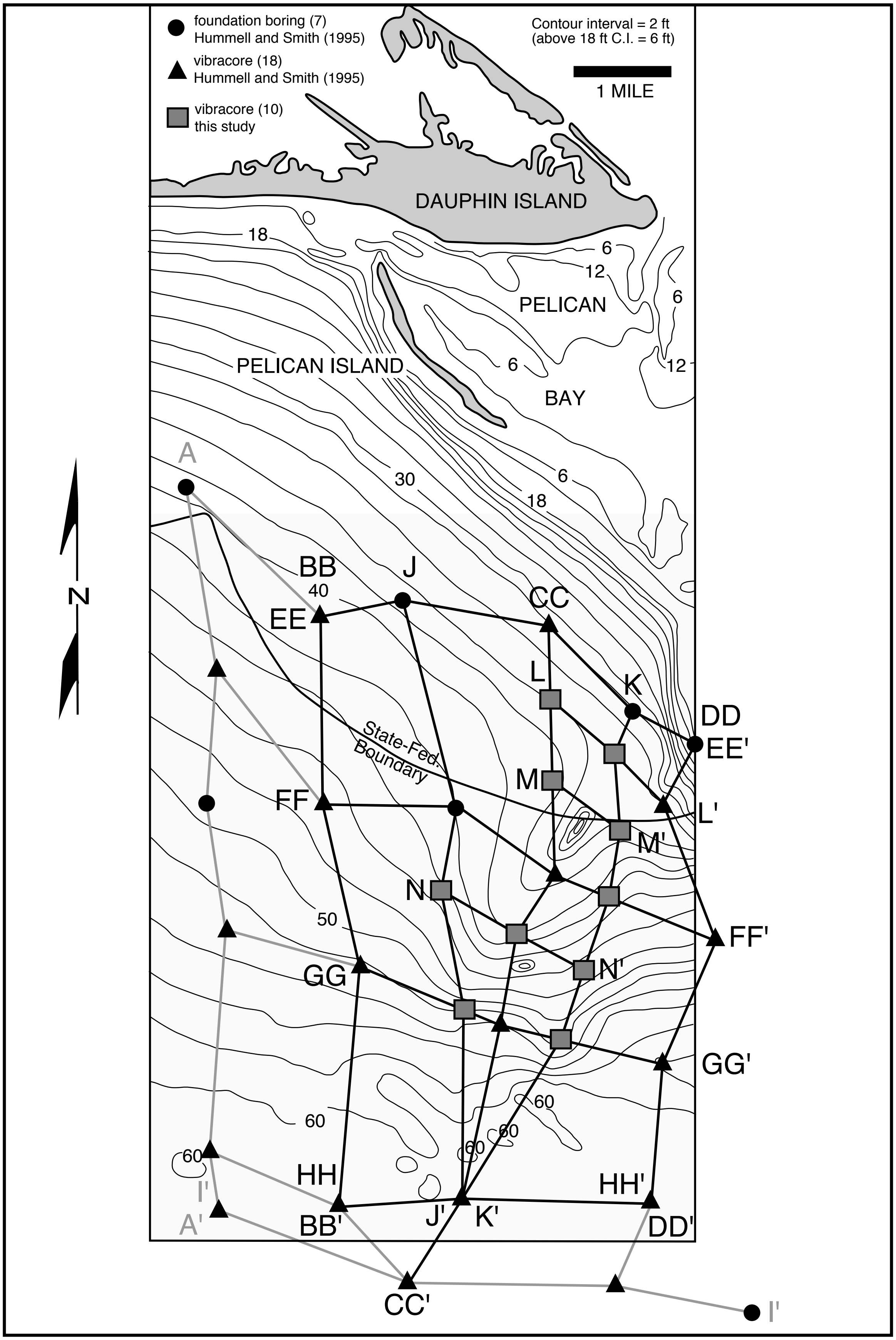


Figure 23.--Map of sand resource target area 4 showing location of vibracores, foundation borings, and cross sections (modified from Hummell and Smith, 1995).

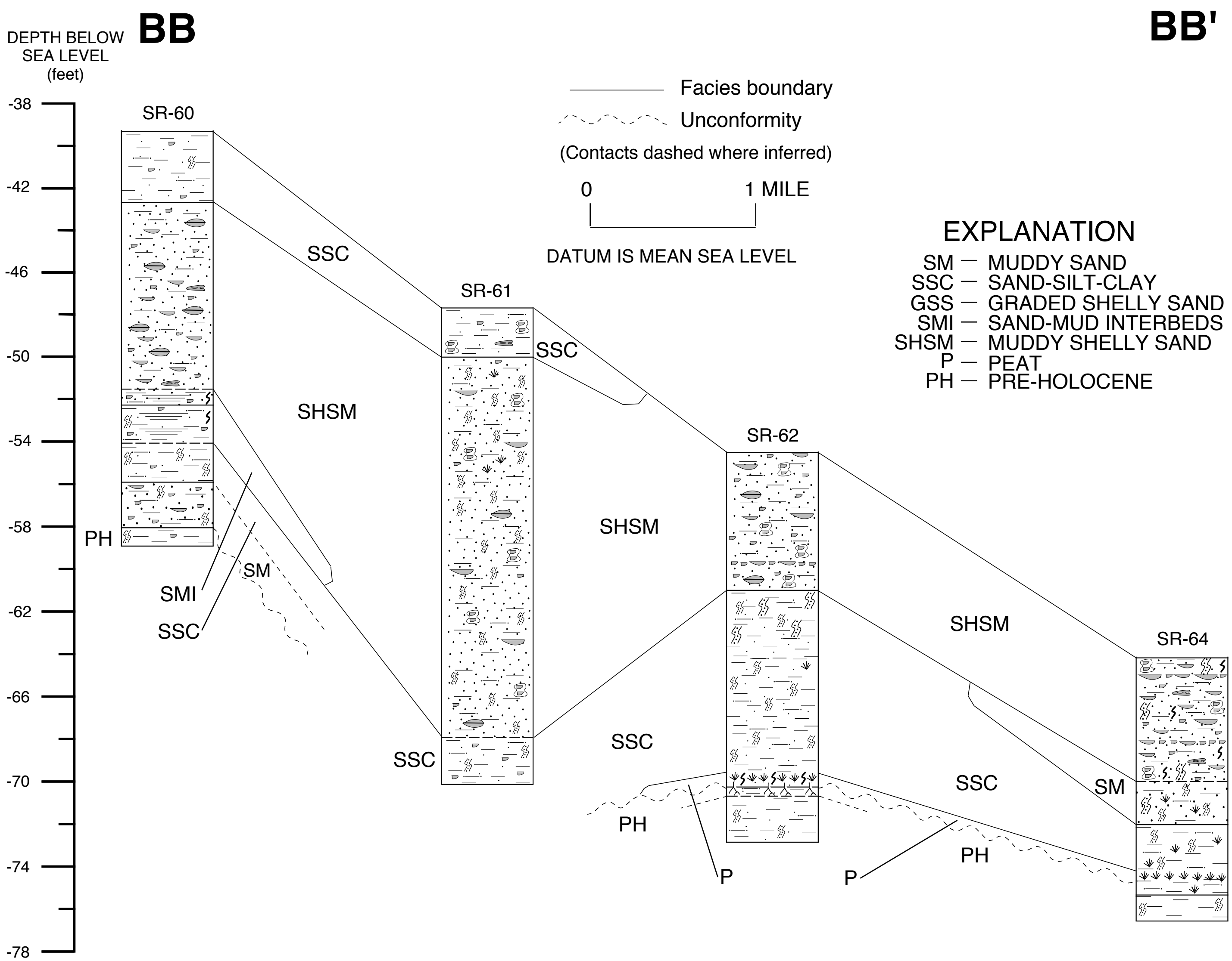


Figure 24.--Cross section BB-BB' (see figure 23 for cross section location) (modified from Hummell and Smith, 1995).

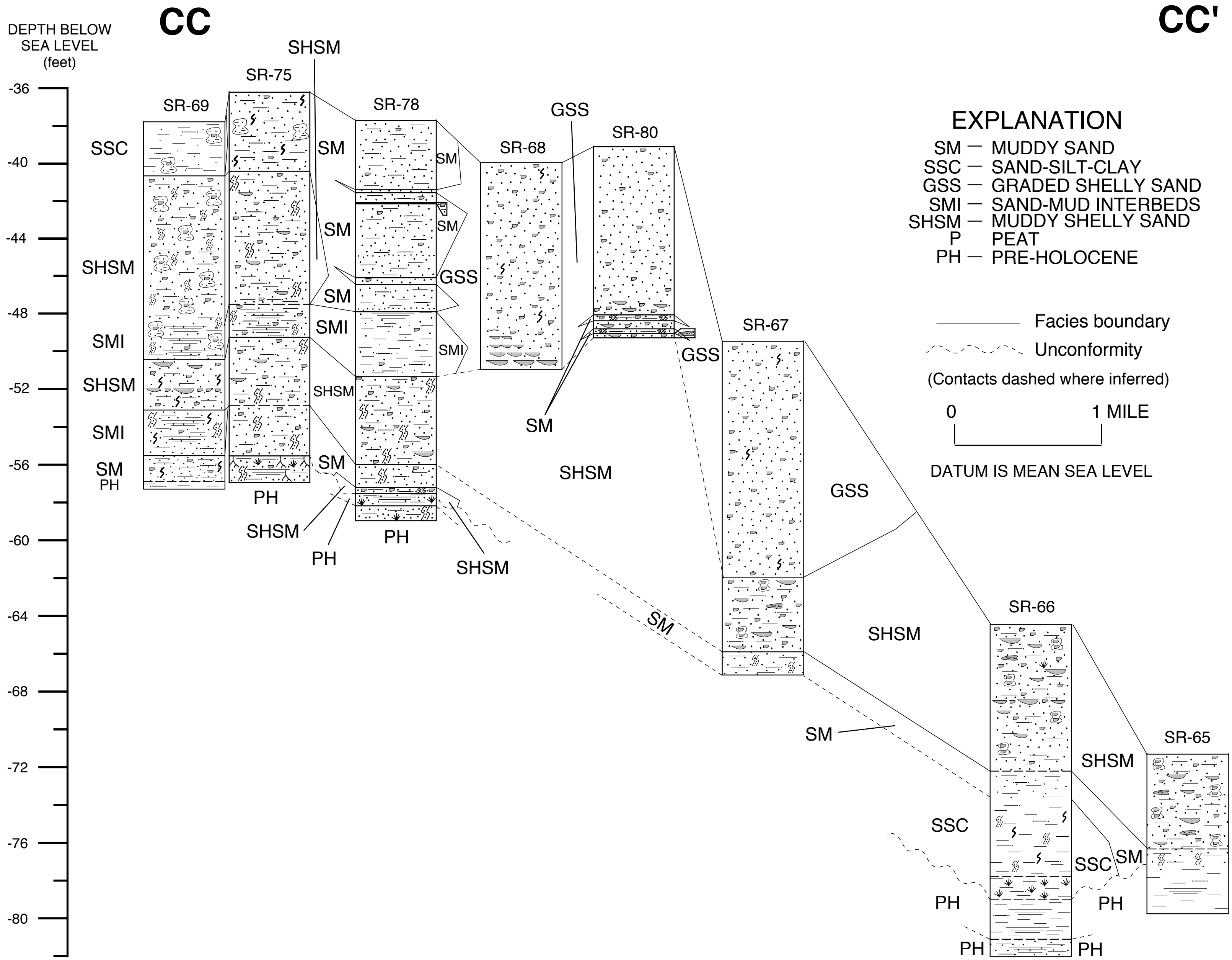


Figure 25.--Cross section CC-CC' (see figure 23 for cross section location) (modified from Hummell and Smith, 1995).

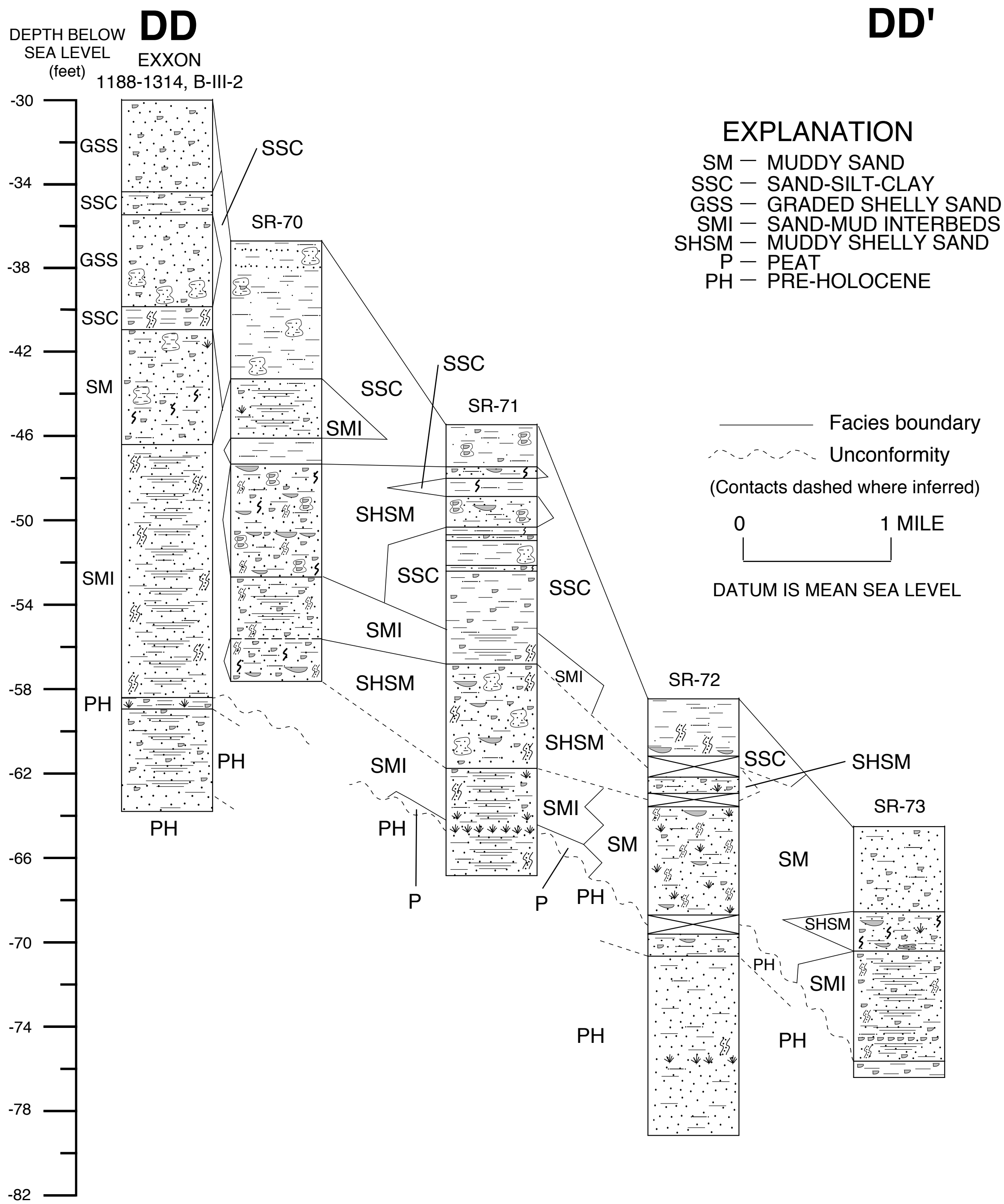


Figure 26.--Cross section DD-DD' (see figure 23 for cross section location) (modified from Hummell and Smith, 1995).

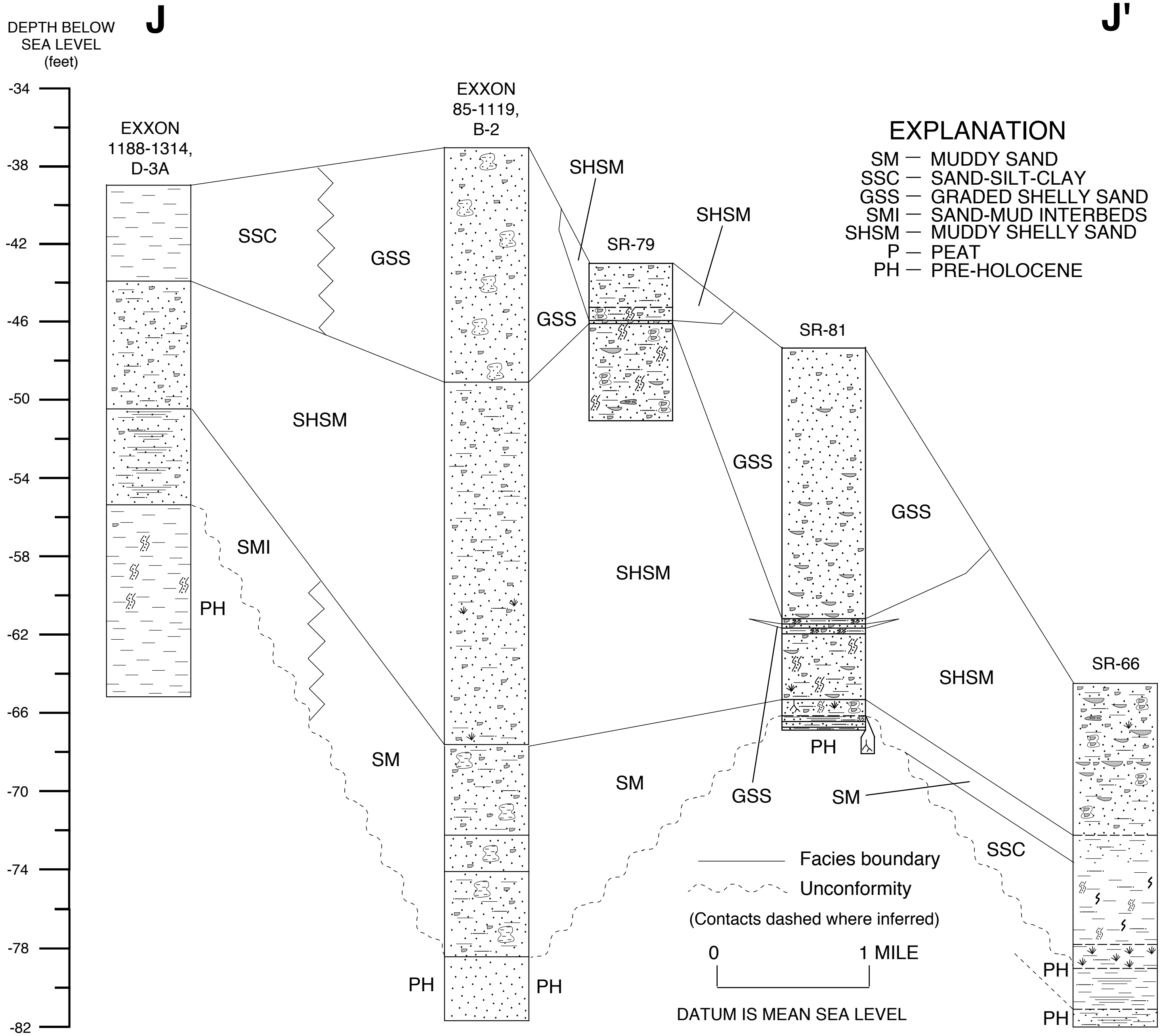


Figure 27.--Cross section J-J' (see figure 23 for cross section location).

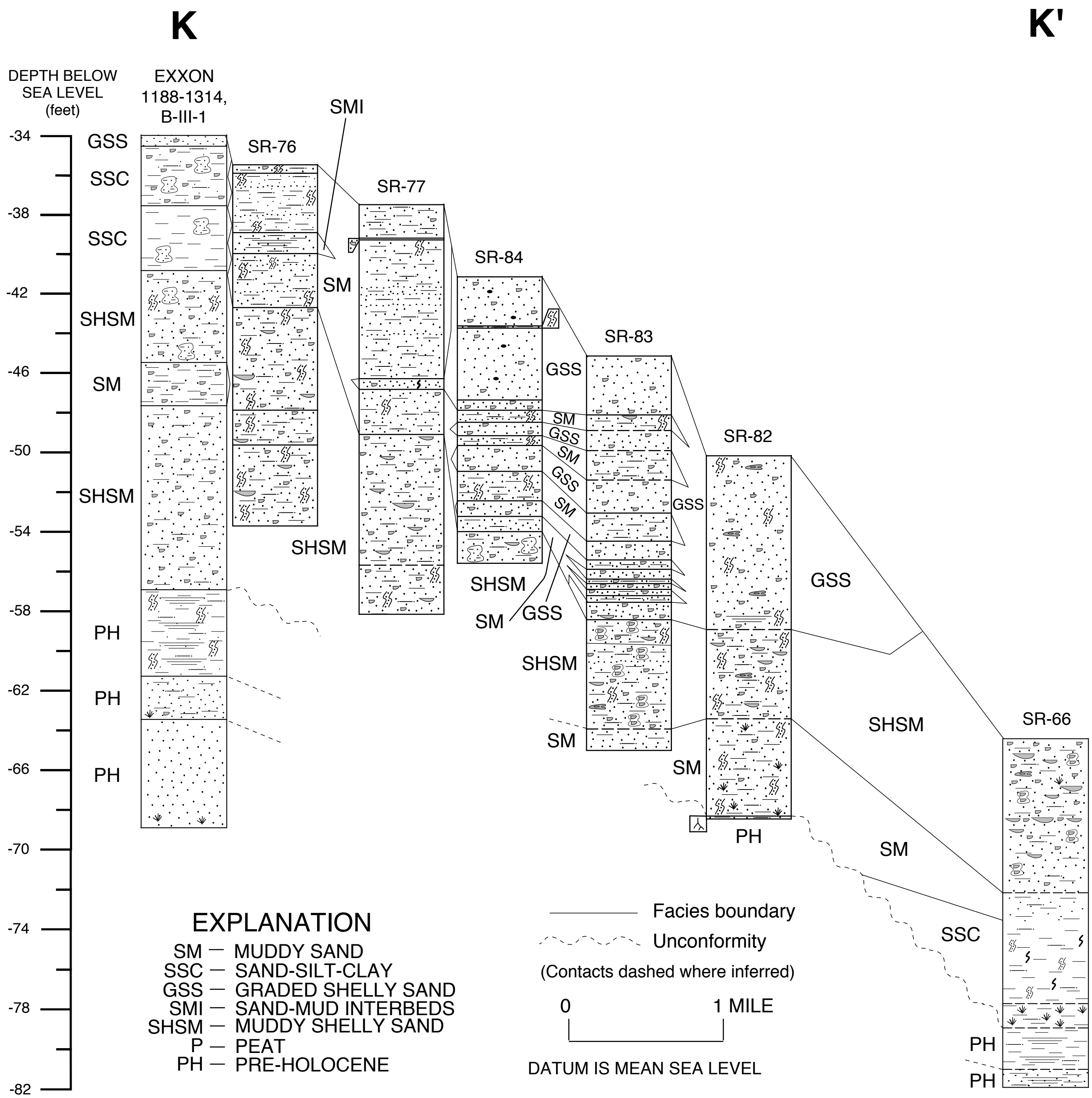
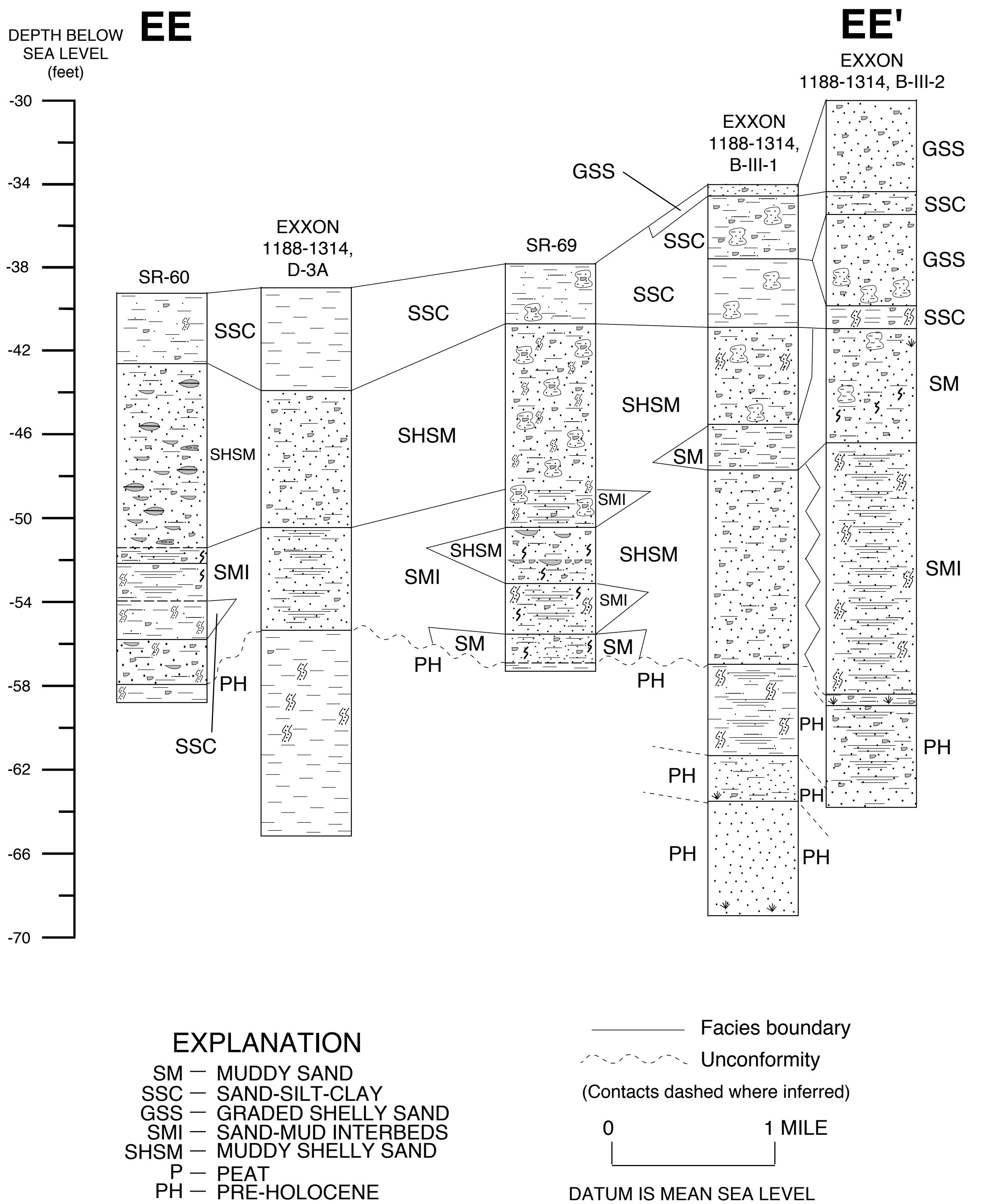


Figure 28.--Cross section K-K' (see figure 23 for cross section location).



EXPLANATION

SM — MUDDY SAND
SSC — SAND-SILT-CLAY
GSS — GRADED SHELLY SAND
SMI — SAND-MUD INTERBEDS
SHSM — MUDDY SHELLY SAND
P — PEAT
PH — PRE-HOLOCENE

Figure 29.--Cross section EE-EE' (see figure 23 for cross section location) (modified from Hummell and Smith, 1995).

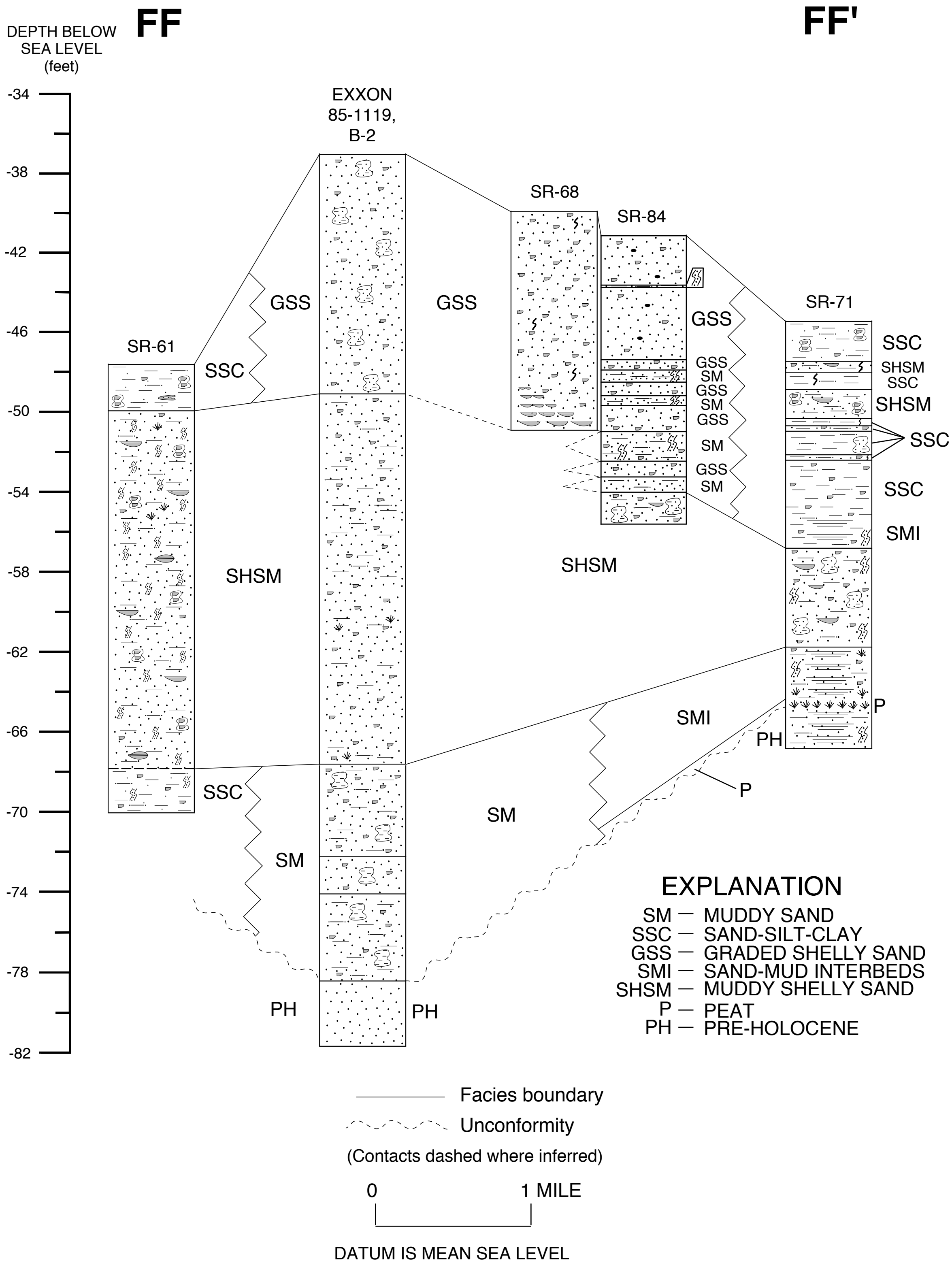


Figure 30.--Cross section FF-FF' (see figure 23 for cross section location) (modified from Hummell and Smith, 1995).

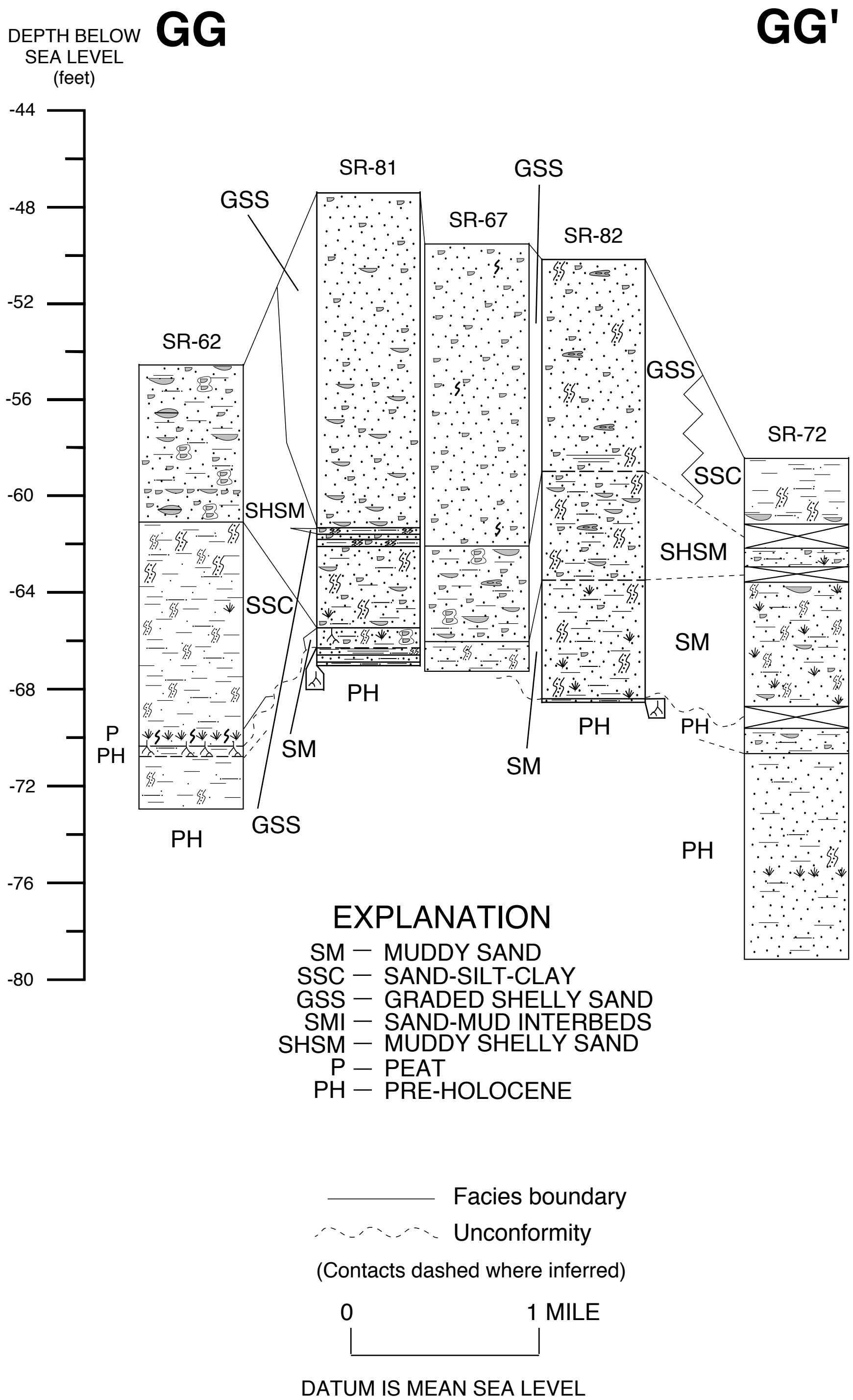


Figure 31.--Cross section GG-GG' (see figure 23 for cross section location) (modified by Hummell and Smith, 1995).

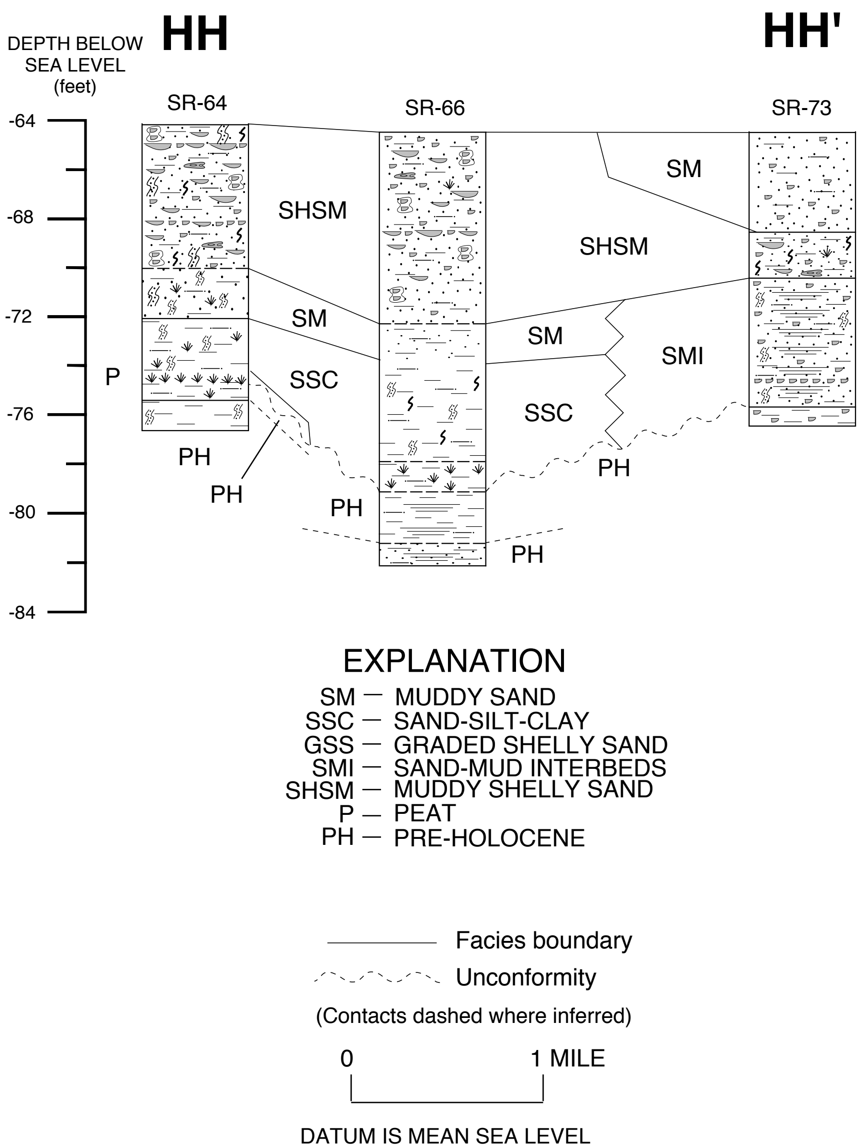
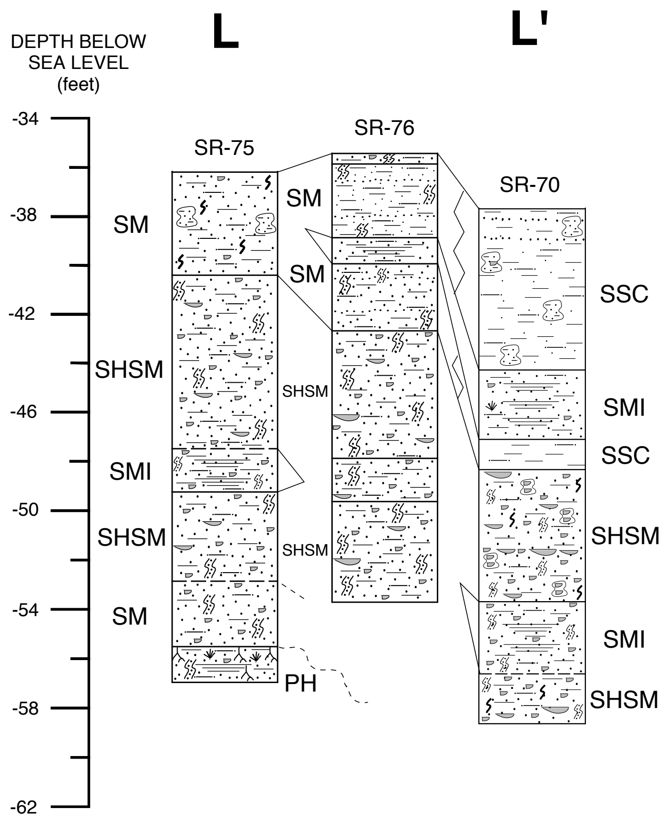


Figure 32.--Cross section HH-HH' (see figure 23 for cross section location) (modified from Hummell and Smith, 1995).



EXPLANATION

SM — MUDDY SAND
SSC — SAND-SILT-CLAY
GSS — GRADED SHELLY SAND
SMI — SAND-MUD INTERBEDS
SHSM — MUDDY SHELLY SAND
P — PEAT
PH — PRE-HOLOCENE

Facies boundary
Unconformity
(Contacts dashed where inferred)

0 1 MILE

DATUM IS MEAN SEA LEVEL

Figure 33.--Cross section L-L' (see figure 23 for cross section location).

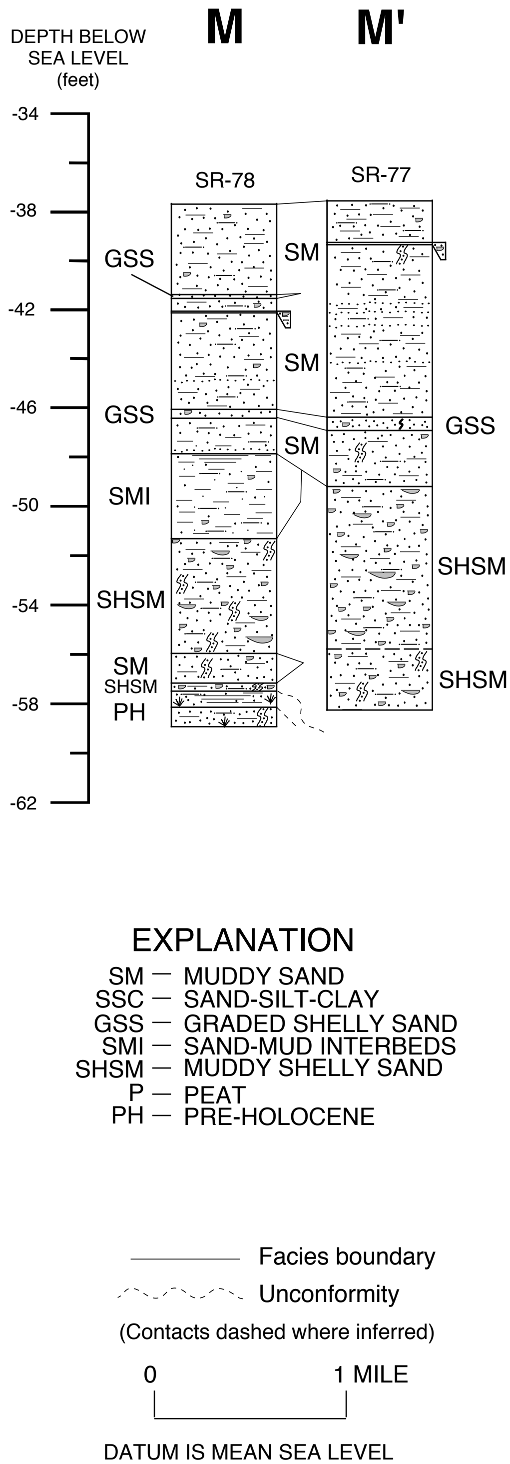
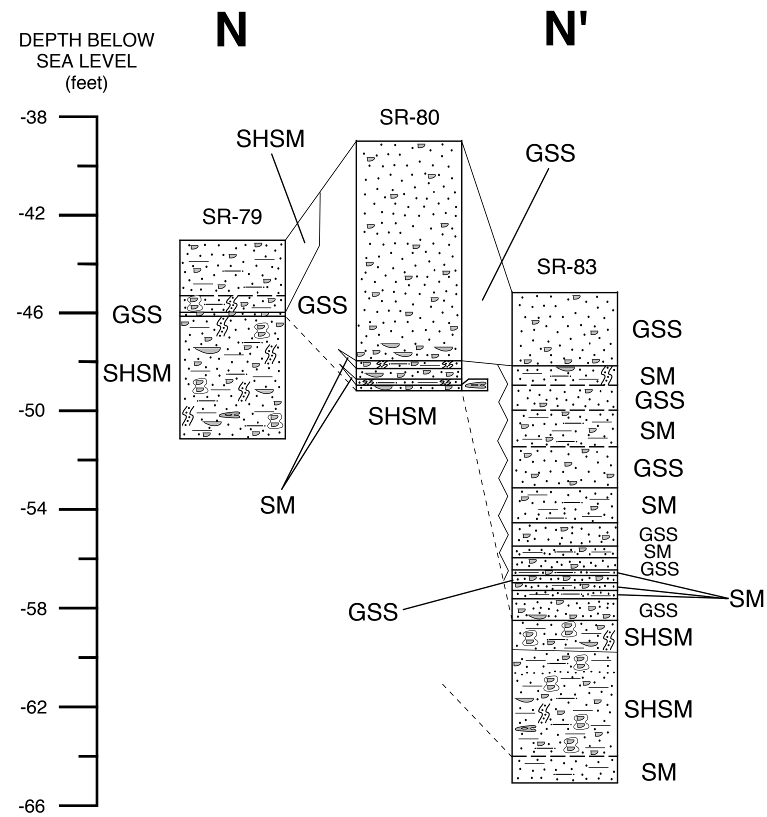


Figure 34.--Cross section M-M' (see figure 23 for cross section location).



EXPLANATION

SM — MUDDY SAND
SSC — SAND-SILT-CLAY
GSS — GRADED SHELLY SAND
SMI — SAND-MUD INTERBEDS
SHSM — MUDDY SHELLY SAND
P — PEAT
PH — PRE-HOLOCENE

Facies boundary
Unconformity
(Contacts dashed where inferred)

0 1 MILE

DATUM IS MEAN SEA LEVEL

Figure 35.--Cross section N-N' (see figure 23 for cross section location).

transgressive sedimentary package and a pre-Holocene age sediment package separated by a time transgressive, unconformable surface.

HOLOCENE AND PRE-HOLOCENE SEDIMENT PACKAGES

Sediments can be grouped into two major sequences that are separated by a type 1 unconformity (Van Wagoner and others, 1988), the major late Pleistocene-early Holocene low stand erosional surface (Brande, 1983; Kindinger, 1988; Reed, 1988; Kindinger and others, 1989; McBride and others, 1991; Parker and Hummell, 1992; Hummell and Parker, 1995a, 1995b; Hummell, 1996). This transgressive surface is readily recognized on seismic lines as well as in vibracores, borings and drill holes, underlying all of Mobile Bay, Mississippi Sound, and the Alabama inner continental shelf. On seismic records, the reflective transgressive surface represents a significant change in lithology and density (velocity) between the unconsolidated surficial middle to late Holocene sediments and the underlying much more consolidated pre-Holocene deposits (Hummell and Parker, 1995a, 1995b; Hummell, 1996). This surface represents a time-transgressive Holocene marine flooding surface (the time of most recent marine inundation) and as such there may well be early Holocene age nonmarine to deltaic sediments below the surface in some updip areas.

The late Pleistocene-early Holocene unconformable surface in coastal Alabama has been mapped by Otvos (1976), Parker and others (1993), Hummell and Parker (1995a, 1995b), Hummell and Smith (1995), and Hummell (1996). The unconformity is characterized by significant relief due to stream erosion associated with sea level fall. Evidence of subaerial exposure along this eroded surface is seen in sediments from vibracores and borings which penetrated the unconformity. Channel-fill deposits associated with late eustatic sea level fall or early rise are classified as a "low stand wedge" (Van Wagoner and others, 1988). These deposits are apparent within the stream channels along the unconformity seen on the seismic records from Mobile Bay and Mississippi Sound (Hummell and Parker, 1995a, 1995b). Overlying these sediments are Holocene age transgressive deposits.

Area 4 seismic data consists of unpublished seismic records collected by L. R. Bartek, Geology Department, UA, and his graduate students (Hummell and Smith, 1995). They found that those portions of the seismic records that pass through area 4 and vicinity are poor in quality, due mostly to the presence of gasified surficial sediments which disrupt the seismic pulse and return signal.

Hummell and Smith (1995) used vibracores and borings that penetrated the late Pleistocene-early Holocene unconformable surface to produce a map showing depths to this surface in feet below sea level. Data from vibracores collected in the present study were used to update the map from Hummell and Smith (1995) (fig. 36). Hummell (1996) produced a structure contour map of the surface in state waters of the west Alabama inner continental shelf. Hummell and Smith (1995) extended his map to include area 4. Data from vibracores of the present study were added to the map from Hummell and Smith (1995) (fig. 37). The structure contour map of the late Pleistocene-early Holocene unconformity shows that the unconformity generally slopes down toward the south and toward the Mobile-Tensaw alluvial valley. This surface is distorted by topographic highs and lows that are associated with erosional remnants and fluvial channels, respectively. The unconformable surface appears to contain an east-west trending topographic high in the central portion of area 4 (fig. 37). The location of the channel network representing the ancestral Escatawpa fluvial-deltaic system is defined by the contour lines in the vicinity of the middle

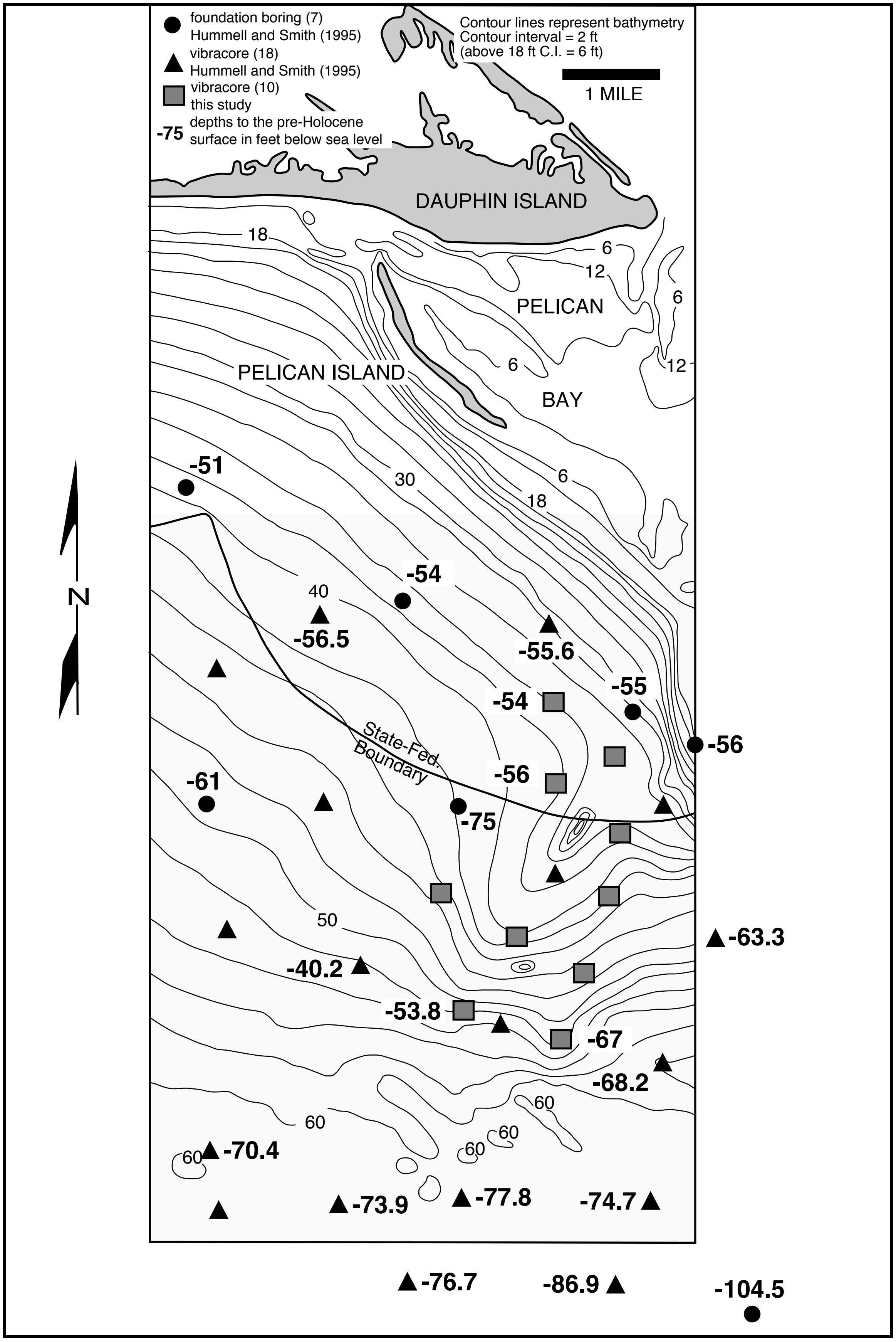


Figure 36.--Map of sand resource target area 4 showing depths to pre-Holocene surface (modified from Hummell and Smith, 1995).

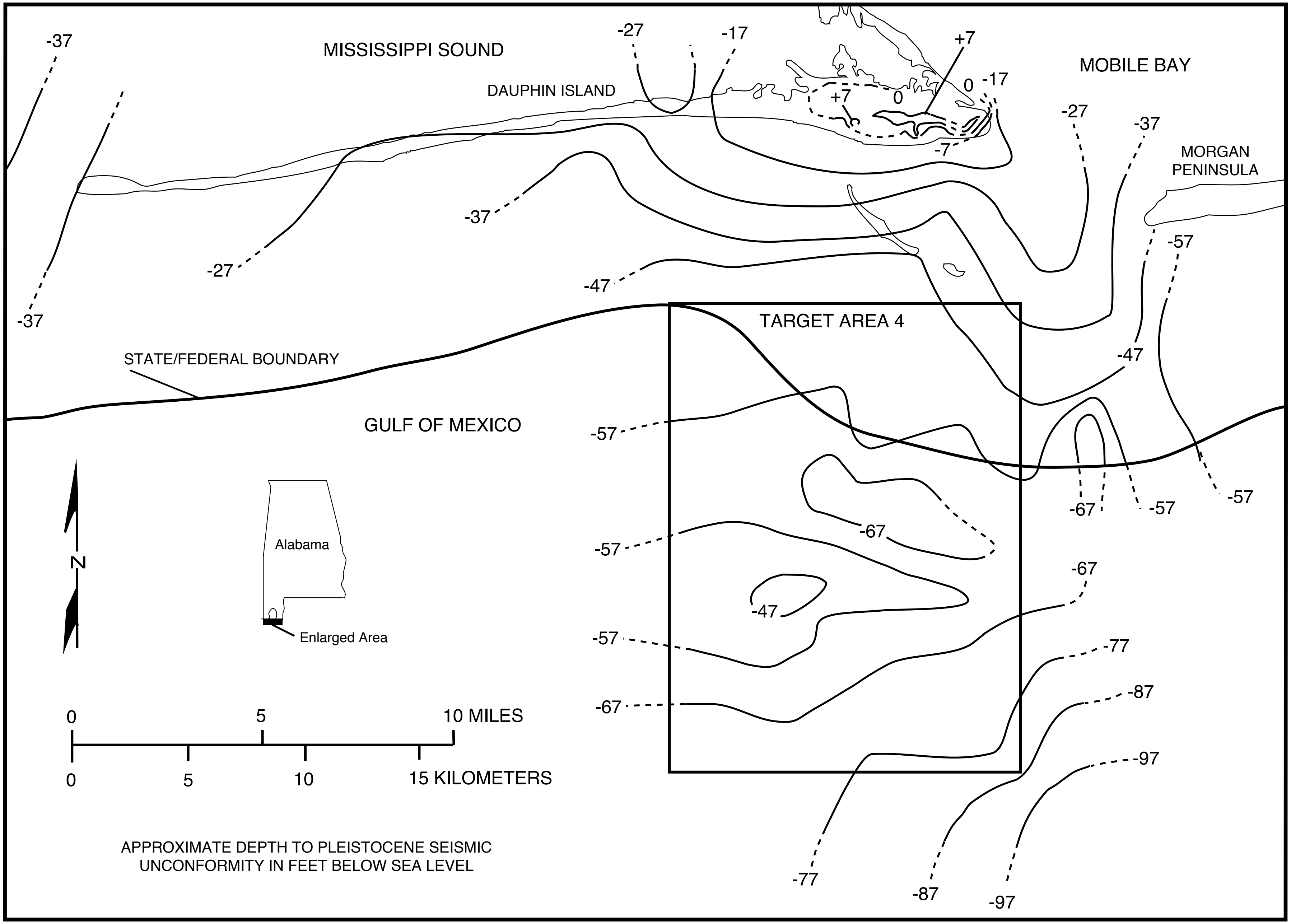


Figure 37.--Structure contour map of the Pleistocene-Holocene unconformity in the west Alabama inner continental shelf (modified from Hummell and others, 1993).

of Dauphin Island (fig. 37) (Hummell, 1996). The channel network does not appear to extend into area 4 and therefore probably lay to the northwest.

Figure 38 shows the total thickness of Holocene sediments measured in the vibracores and borings from Hummell and Smith (1995) which includes data gleaned from vibracores collected in the present study. Figure 39 is an isopach map of the Holocene sediments in area 4 updated from that produced by Hummell and Smith (1995). The Holocene depocenter lay in the central portion of the study area (fig. 39) and fills a paleotopographic low on the northeast side of a paleotopographic high (fig. 39). There appears to be another Holocene depocenter southeast of the study area (fig. 39).

DIP DIRECTION FACIES DISTRIBUTION

Holocene thickness and facies trends for the Graded Shelly Sand Lithofacies sand resource body and vicinity are portrayed in twelve cross sections (five dip-trending and seven strike-trending), taken together, form a grid with cells measuring between 0.5 and 2 mi on a side. The cross sections from the area 4 indicate that the late Pleistocene-early Holocene unconformity deepens toward the south and towards the Mobile-Tensaw alluvial valley in the eastern side of the study area.

In general, inner shelf Holocene sediments thicken toward the center of area 4 and Holocene sediments attain their greatest thickness along the eastern margin of the study area where the cross section lines encounter the largely infilled Mobile-Tensaw alluvial valley. Holocene deposits are thinnest in the southwestern corner of the study area (edge of the ebb-tidal delta of Mobile Bay).

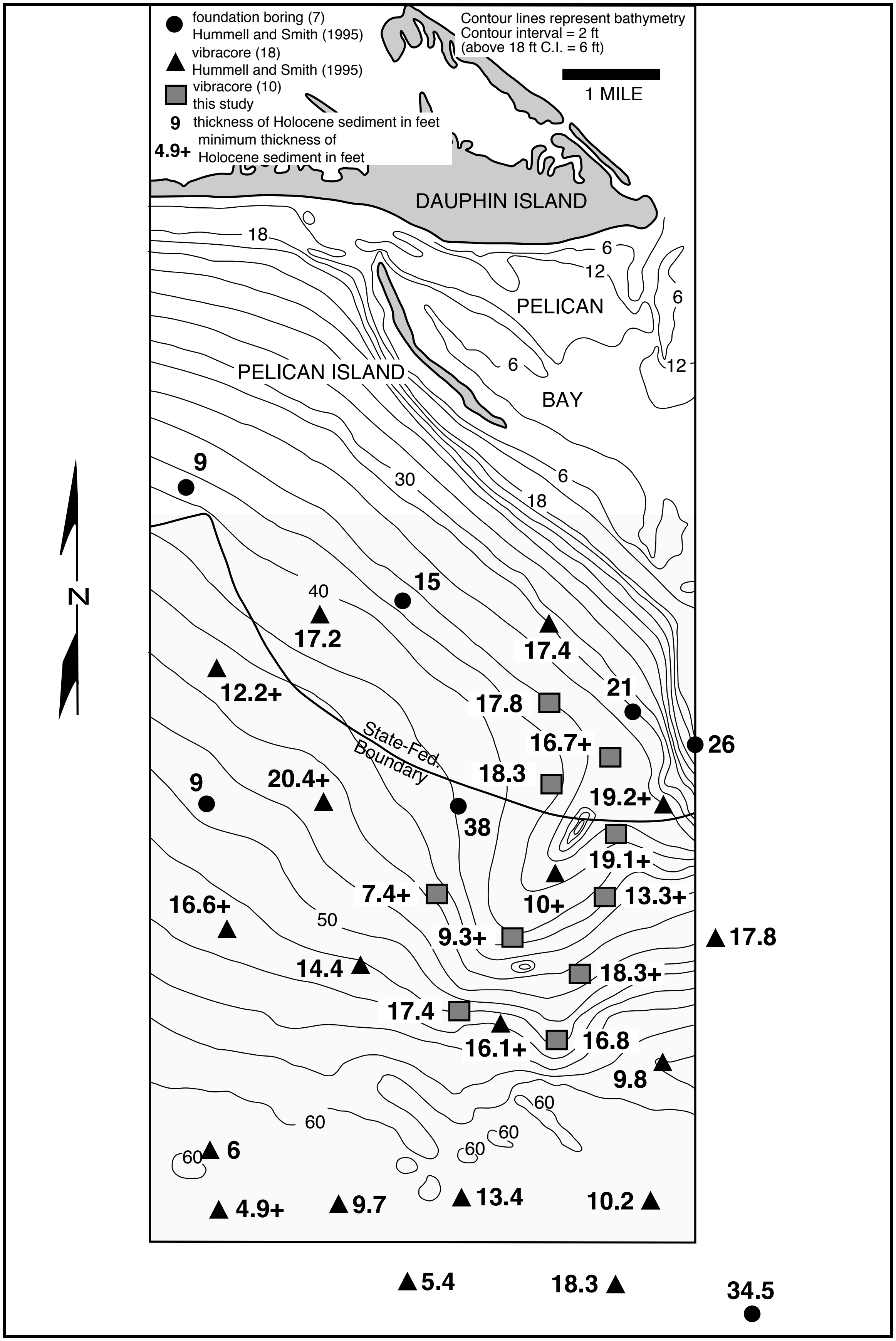


Figure 38.--Map of sand resource target area 4 showing thickness of Holocene sediments (modified from Hummell and Smith, 1995).

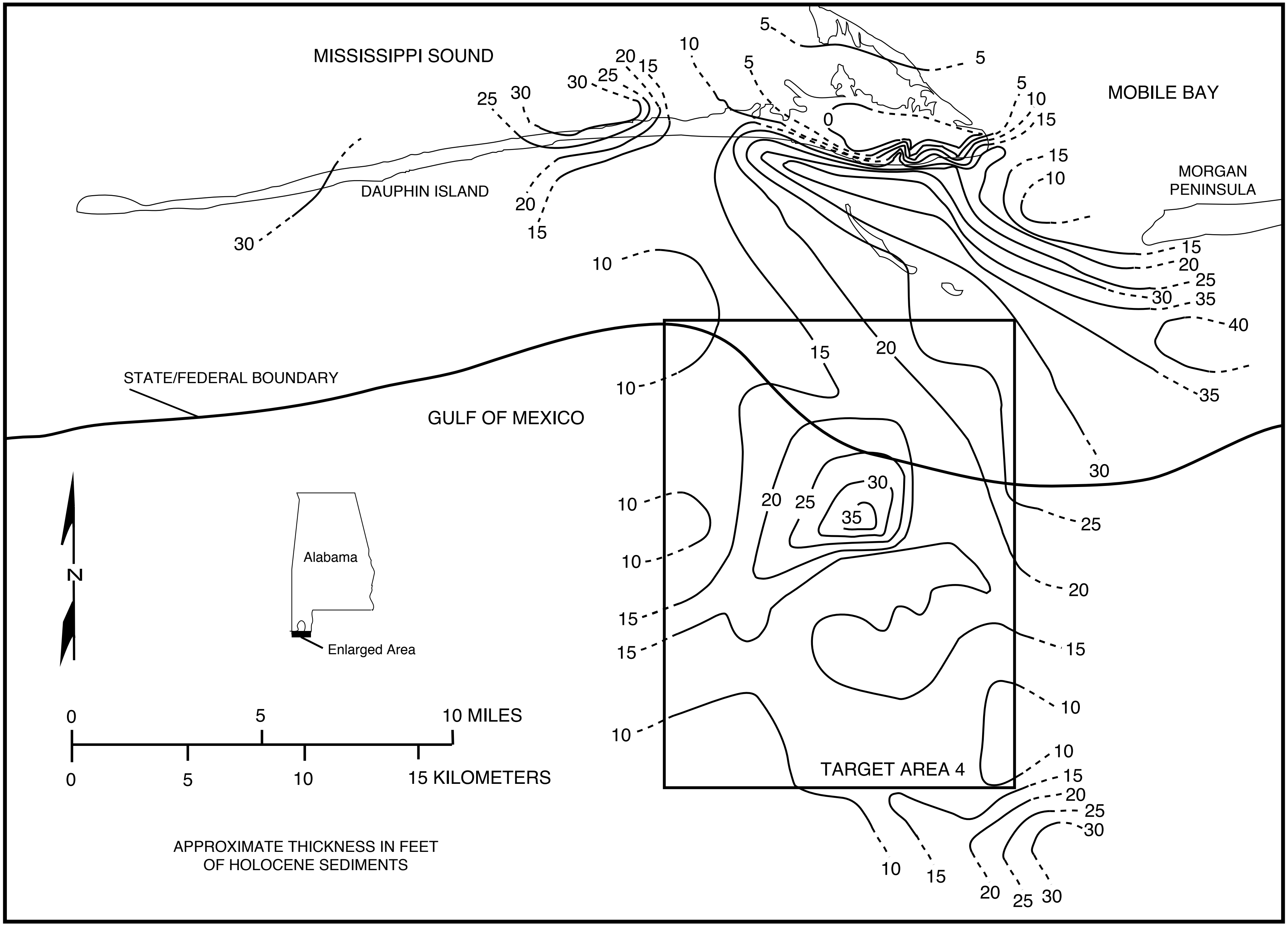


Figure 39.--Isopach map of Holocene sediments in the west Alabama inner continental shelf (modified from Hummell and others, 1993).

None of the vibracores or borings collected by Hummell and Smith (1995) nor the vibracores from the present study appear to have unquestionably encountered any fluvial-deltaic paleochannels. These channels have been mapped in Mobile Bay (Hummell and Parker, 1995a), Mississippi Sound (Hummell and Parker, 1995b), and on the Alabama continental shelf south and southwest of area 4 (Vittor, and Associates, 1985; Kindinger, 1988; Parker, 1990). These channels no doubt exist within area 4, but without seismic data it is not feasible to describe subsurface geometry of the late Pleistocene-early Holocene unconformable surface in detail, map channels incised into the unconformable surface, or check stratigraphic correlations based on vibracores and borings.

Unlike the top of the pre-Holocene sampled by vibracores in Mobile Bay (Hummell and Parker, 1995a) and Mississippi Sound (Hummell and Parker, 1995b), there is a noticeable lack of paleosol development, rooted zones, marsh deposits, peat, and wood associated with the top of the pre-Holocene within area 4 (where sampled by vibracores and borings) (Hummell and Smith, 1995; this study). This was also noted by Hummell (1996) in his study of the west Alabama inner continental shelf. It seems likely that marsh and terrestrial vegetation would have colonized newly exposed continental shelf produced by the last Pleistocene regression of the sea and subsequent low stand. Perhaps fluvial-deltaic sedimentation and erosion on the shelf during this time did not allow extensive areas of vegetation cover to develop or subsequent Holocene transgression of the sea could have destroyed or obscured much of the evidence for vegetation.

Cross section A-A' which extends north-south along the western margin of area 4 was constructed by Hummell and Smith (1995). As mentioned previously, this cross section is too remote from the sand resource body to provide any detailed information about sand body geometry or granulometry, one of the objectives of the present study. Therefore, the cross section A-A' is not included in the present report.

Cross section BB-BB' (fig. 24) stretches approximately north-south through the west-central portion of area 4. This cross section is modified from cross section B-B' constructed by Hummell and Smith (1995) by the deletion of vibracore SR-65 from the southern endpoint of cross section B-B'. The Pre-Holocene Lithofacies at the late Pleistocene-early Holocene unconformable surface along the cross section line consist of clay to sandy mud. The Holocene section thickens and lithologic units become massive along this string of vibracores (fig. 24). The basal Holocene here is dominated by a bed of the Sand-Silt-Clay Microfacies which interbeds with the Muddy Sand and the Sand-Mud Interbeds Microfacies deposits at cross section endpoints. Beds of the Peat Microfacies were encountered in vibracores SR-62 and SR-64 on a broad paleotopographic high in the central portion of area 4 (figs. 37 and 24). The majority of the sediment column along cross section BB-BB' is comprised of the Muddy Shelly Sand Microfacies (fig. 24). A sheet of the Sand-Silt-Clay Microfacies caps the Muddy Shelly Sand Microfacies along the northern segment of the cross section. Both microfacies tend to thin toward the south along the cross section.

Cross section CC-CC' (fig. 25) of the east-central portion of area 4, shows a relatively thick Holocene sedimentary deposit overlying pre-Holocene clays and muds. Cross section C-C' of Hummell and Smith (1995) has been updated by the addition of vibracores SR-75, SR-78, and SR-80 to produce cross section CC-CC' (fig. 25). The basal Holocene in this north-south oriented cross section, is composed of thin beds of various muddy microfacies (fig. 25). As in cross section BB-BB' (fig. 24), much of the remainder of the preserved Holocene shown by cross section CC-

CC' is composed of a thick unit of the Muddy Shelly Sand Microfacies. Embedded within the Muddy Shelly Sand Microfacies and exposed at the sediment-water interface is a massive deposit of the Graded Shelly Sand Lithofacies (fig. 25). This lithofacies interfingers with beds of the Muddy Sand and the Sand-Mud Interbeds Microfacies at the northern end of the cross section.

Cross section DD-DD' (fig. 26) is oriented north-south along the eastern margin of area 4. Vibracore SR-74 has been deleted from the southern endpoint of cross section D-D' of Hummell and Smith (1995). The Holocene section thickens where vibracores and boring encounter the proximal portion (ebb ramp) of the ebb-tidal delta of Mobile Bay and the western side of the Mobile-Tensaw alluvial channel (Hummell, 1996) (fig. 26). In both cases, lithologic units become thinner, less laterally continuous, and the stratigraphic relationships between them become complex (fig. 26).

The northeastern margin of the Graded Shelly Sand Lithofacies sand resource body interfingers with the Sand-Silt-Clay Microfacies, as portrayed at the northern end of cross section DD-DD' (fig. 26). It is recommended that any sand mining project avoid the northeastern margin of the sand resource body, as it would be difficult to follow a given clean sand bed. In addition, a mining operation in this portion of the sand resource body would be expected to encounter diminishing returns as the individual sand beds being mined would tend to quickly thin or pinch out.

The Pre-Holocene Lithofacies along cross section DD-DD' (fig. 26) is preserved as mud and muddy sand units. The late Pleistocene-early Holocene unconformable surface has an apparent dip along the cross section toward the southeast and probably steeply dips into the axis of the Mobile-Tensaw alluvial channel just east of the cross section.

The cross section (fig. 26) portrays a stratigraphically complex Holocene sediment package comprised almost exclusively of lithologic units of muddy microfacies. Beds of the Graded Shelly Sand Lithofacies are interlaid with the Sand-Silt-Clay Microfacies at the north end point of cross section DD-DD'. It appears that the Graded Shelly Sand Lithofacies becomes laterally gradational with the shelf sand sheet facies of Hummell (1996) toward the northeast, outside of area 4. In general, the Sand-Mud Interbeds Microfacies occurs low in the sediment column along the cross section with the Muddy Sand and the Muddy Shelly Sand Microfacies occurring toward the middle portion of the column (fig. 26). The Sand-Silt-Clay Microfacies comprises the top of the sediment column along the northern two-thirds of cross section DD-DD'.

Cross section J-J' (fig. 27) is oriented north-south along the western margin of the sand resource body. The cross section is similar to cross section BB-BB' (fig. 24) in that both lines cut through the topographic high and lows in the late Pleistocene-early Holocene unconformable surface shown in figure 37. Lithologic units filling the topographic lows are relatively thick muddy facies. The Muddy Shelly Sand Microfacies is massive as in cross section BB-BB' (figs. 24 and 27). The Graded Shelly Sand Lithofacies sand resource body is almost completely separated into two pieces by the Muddy Shelly Sand Microfacies that occurs at vibracore SR-79 (fig. 27). The vibracore and boring database does not provide the resolution needed to determine the stratigraphic relationship between the Sand-Silt-Clay Microfacies and the Muddy Shelly Sand Microfacies at the northern end of cross section J-J' (fig. 27).

Cross section K-K' (fig. 28) traces a northeast-southwest path along the eastern margin of the Graded Shelly Sand Lithofacies sand resource body. The cross section displays several noteworthy features about sand body geometry. The northeastern endpoint of the cross section K-K' portrays the minimal sand resource potential of the northeastern margin of the sand resource body. Comparison of cross sections CC-CC', J-J', and K-K' (figs. 25, 27, and 28, respectively) show a general southwestward thickening of the Graded Shelly Sand Lithofacies sand resource body. Cross section K-K' shows the fine-scale interfingering between the sand resource body and adjacent facies at vibracores SR-77, SR-84, and SR-83 (fig. 28). This type of interfingering is characteristic of the margin of the sand resource body.

STRIKE DIRECTION FACIES DISTRIBUTION

The remaining seven cross sections are oriented either northwest-southeast (cross sections EE-EE', FF-FF', GG-GG', L-L', M-M', and N-N') or east-west (H-H') across the Graded Shelly Sand Lithofacies sand resource body and vicinity (fig. 23). Cross section EE-EE' (figs. 23 and 29) lay along the northern margin of the sand resource body. Foundation boring Exxon 0201-1071-3, B-1 was deleted from cross section E-E' of Hummell and Smith (1995). Cross section EE-EE' illustrates the thickening of Holocene sediments toward the Mobile-Tensaw alluvial valley and increased complexity of the stratigraphic relationships between lithologic units. The top of the pre-Holocene is picked above a collection of clay, sandy mud, and muddy sand beds. The late Pleistocene-early Holocene unconformable surface dips gently toward the southeast. Basal lithologic units of the Holocene are interpreted as the Sand-Mud Interbeds, the Sand-Silt-Clay, and Muddy sand Microfacies (fig. 29). These units interfinger with a relatively thick unit of the Muddy Shelly Sand Microfacies that dominates the middle portion of the sediment column along the cross section line (fig. 29). The sequence of sediments are capped by a thin, laterally continuous bed of the Sand-Silt-Clay Microfacies which interfingers with the Graded Shelly Sand Lithofacies at the southeastern end of the cross section (fig. 29).

Cross section FF-FF' (figs. 23 and 30) illustrates the shallow sediment column across the central portion of the Graded Shelly Sand Lithofacies sand resource body. Vibracore SR-46 has been deleted from the northwestern endpoint of cross section F-F' from Hummell and Smith (1995) and vibracore SR-84 has been added (fig. 30). There are several noteworthy features shown by cross section FF-FF'. Based on the vibracores and borings from Hummell and Smith (1995) and this study, the Holocene sediment package in area 4 reaches its maximum thickness along this cross section. In addition, the cross section portrays the internal structure of the Holocene depocenter in the central portion of area 4 (figs. 39 and 30). Based on the findings of Hummell and Smith (1995) and this study, the Graded Shelly Sand Lithofacies sand resource body can be visualized as situated on top of a relatively massive unit of the Muddy Shelly Sand Microfacies with fine-scale lateral interfingering with mostly the Sand-silt-clay Microfacies. This concept is illustrated in cross section FF-FF' (fig. 30).

The late Pliestocene-early Holocene unconformable surface expresses the paleotopographic low noted on the structure contour map (fig. 37). The Pre-Holocene Lithofacies is represented by sand and muddy sand units (fig. 30). Infilling the low are Holocene age units of the Sand-Silt-Clay, the Sand-Mud Interbeds, and the Silty/Clayey Sand Microfacies which are overlain by a thick deposit of the Muddy Shelly Sand Microfacies (fig. 30). This deposit interfingers with other muddy microfacies at cross section endpoints (fig. 30). A bed of the Peat Microfacies occurs near the base of the Holocene section in vibracore SR-71 (fig. 30). The Holocene sediment column is capped by a layer of the Graded Shelly Sand Lithofacies which grades laterally into a relatively thin sheet of the Sand-Silt-Clay Microfacies (fig. 30). The deposit of the Graded Shelly Sand Lithofaces forms a bathymetric high on the seafloor (fig. 5).

The shallow sediment column across the southwestern portion of the Graded Shelly Sand Lithofacies sand resource body is shown in cross section GG-GG' (fig. 23 and 31). Vibracore SR-47 has been eliminated and vibracores SR-81 and SR-82 have been added to cross section G-G' from Hummell and Smith (1995). Here, the Holocene section begins to thin toward the southern flank of the Holocene depocenter (fig. 39). Muddy sands and sandy muds comprise the top of the pre-Holocene along the cross section line. A bed of the Peat Microfacies with an underlying root zone was encountered vibracore SR-62 (fig. 31). The basal Holocene is comprised of beds of the Sand-Silt-Clay, the Muddy Sand, and the Sand-Mud Interbeds Microfacies (fig. 31). As in cross sections EE-EE' and FF-FF', a conspicuous bed of the Muddy Shelly Sand Microfacies is present dominating the middle and upper portions of the Holocene sedimentary deposit (fig. 31). A surficial unit of the Graded Shelly Sand Lithofacies sand resource body interfingers with beds of the Muddy Shelly Sand and the Sand-Silt-Clay Microfacies (fig. 31). Cross section GG-GG' (fig. 31) is located at the southwestern margin of the sand resource body; a place where the body thickens (see cross sections CC-CC', J-J', and K-K'; figs. 25, 27, and 28, respectively). The Graded Shelly Sand Lithofacies unit forms a positive relief feature on the seafloor.

Farther seaward of cross section GG-GG', along the southern margin of area 4, is cross section HH-HH' (figs. 23 and 32). The original cross section of Hummell and Smith (1995), H-H', was modified by the removal of vibracore SR-63 from the western end of the cross section (fig. 32). Here, the seafloor is flat and featureless along the path of the cross section. The Holocene section thins toward the edge of the ebb-tidal delta of Mobile Bay (fig. 32). The Pre-Holocene Lithofacies sampled by the vibracores are mostly planar bedded mud, clay, or sandy mud units. The late Pleistocene-early Holocene unconformable surface dips from the east and west toward the center of the cross section (fig. 32). The lower half of the Holocene sedimentary deposit include beds of the Sand-Silt-Clay, the Muddy Sand, and the Sand-Mud Interbeds Microfacies (fig. 32). A unit of the Muddy Shelly Sand Microfacies and some of the Muddy Sand Microfacies comprise the upper half of the preserved Holocene sedimentary deposit (fig. 32).

Cross section I-I' of Hummell and Smith (1995) lay mostly outside of the southern boundary of area 4 and distal from the Graded Shelly Sand Lithofacies sand resource body. Because it does not add any information about the sand resource body it is not included in this report.

Cross section L-L' (figs. 23 and 33) is alined northwest-southeast through the northeastern margin of Graded Shelly Sand Lithofacies sand resource body. The cross section illustrates a portion of the Holocene sediment column that separates the main sand resource body to the southwest from the minimal Graded Shelly Sand Lithofacies deposits of the northeastern portion of the sand resource body (fig. 33). The cross section also exemplifies the thickening of Holocene sediments towards the Mobile-Tensaw alluvial valley and increased complexity of the stratigraphic relationships between lithologic units.

The Pre-Holocene Lithofacies encountered here consists of muddy sand beds at vibracore SR-75 (fig. 33). The Holocene sediment column here is comprised by what is interpreted as ebb-tidal delta muddy sand, sandy mud, and sand of the Sand-Mud Interbeds and Muddy Sand Microfacies (fig. 33). The Holocene sediment fill contains a unit of the Muddy Shelly Sand Microfacies which is overlain by beds of the Sand-Mud Interbeds, the Muddy Sand, and the Sand-Silt-Clay Microfacies (fig. 33).

Cross section M-M' (figs. 23 and 34), shows thin beds of the Graded Shelly Sand Lithofacies interfingering with relatively thick beds of the Muddy Sand Microfacies. As mentioned previously, it would not be cost effective to recover sand resources here in the northeastern margin of the sand resource body as the Graded Shelly Sand Lithofacies beds are thin and the muddy sand overburden is thick.

The late Pleistocene-early Holocene unconformable surface dips steeply from west to east along the cross section line into the Mobile-Tensaw alluvial valley (fig. 34). The Pre-Holocene Lithofacies encountered here consists of muddy sand beds at vibracore SR-78 (fig. 34). The sediment package between the sand resource body and the Pre-Holocene Lithofacies consists of a relatively thick bed of the Muddy Shelly Sand Microfacies which interfingers with thinner beds of the Sand-Mud Interbeds and Muddy Sand Microfacies (fig. 34).

Cross section N-N' (figs. 23 and 35) is the last of the twelve cross sections through the Graded Shelly Sand Lithofacies sand resource body and vicinity. The cross section trends northwest-southeast through the south-central portion of the sand resource body. Here the Holocene stratigraphic section includes the Graded Shelly Sand Lithofacies which is underlain by mostly the Muddy Shelly Sand Microfacies (fig. 35). At the southeastern endpoint of the cross section the sand resource body complexly interfingers with thin beds of the Muddy Sand Microfacies demarking the sand resource body margin (fig. 35).

To summarize, the structure contour map (fig. 37) shows a paleotopographic low in the central portion of area 4 which served as a site of mostly ebb tidal delta, shelf sand sheet, and shelf sand ridge sedimentation during primarily the middle to late Holocene (Hummell, 1996) (fig. 39). It can be concluded from examination of the twelve cross sections that microfacies of the Ebb-Tidal Delta Depositional

Environment form the basal Holocene in area 4. A massive unit of the Muddy Shelly Sand Microfacies formed in the Shelf Sand Sheet Depositional Environment overlies the ebb-tidal delta deposits. A unit of the Graded Shelly Sand Lithofacies (sand resource body) that formed in the Shelf Sand Ridge Depositional Environment is imbedded in the upper part of the Muddy Shelly Sand Microfacies. The sand resource body displays fine-scale lateral interfingering at its margin with ebb-tidal delta microfacies, the Muddy Shelly Sand Microfacies, and nearshore, shallow water facies (shelf mud, open bay, and surficial sand sheet) of Hummell (1996). The sand resource body thickens down dip (toward the southwest). The main axis of the sand resource body trends northeast-southwest approximately perpendicular to shelf bathymetry. Most of the volume of the sand resource body lies in federal waters, confined to the south-central portion of the Graded Shelly Sand Lithofacies. Thin beds of the Graded Shelly Sand Lithofacies occur at the margins and northeastern end of the sand resource body. These beds are exposed at the sea floor or, more commonly, buried beneath muddy sediments. These thin beds of the Graded Shelly Sand Lithofacies would not be cost effective to mine in a sand resource recovery project. It is recommended that such a project avoid the northeastern end of the sand resource body (roughly the state waters portion) and places where the Graded Shelly Sand Lithofacies is not exposed at the sea floor. Following this methodology may eliminate the cost of overburden removal in any mining project.

SHELF SAND RIDGES

The Alabama EEZ contains an abundance of shelf sand ridges that generally are elongate in a northwest-southeast direction diagonally from the shoreline (Parker and others, 1993). The ridges are rare on the western half of the Alabama inner continental shelf due to the muddy sediment input from the Mobile-Tensaw River system and the St. Bernard Delta onto the shelf (Parker and others, 1993).

The ridges are found most commonly in water depths of less than 50 ft, although they are found in all water depths on the inner shelf portion of the Alabama EEZ (Parker and others, 1993). Many are attached to the shoreline and can display local topographic reliefs greater than 12 ft (Parker and others, 1993).

In general, sediments in the inter-ridge swales are mud-rich, whereas the ridge crest and upper flanks are comprised of clean or coarse-grained higher energy sediments; often the ridges are capped by a thick sequence of coarse stacked Graded Shelly Sands, Echinoid Sand, or Shelly Sand facies deposits (Parker and others, 1993). This may relate to higher ambient wave intensity on the shallow ridge crests (especially during storms), thus much more frequent sediment movement and winnowing, than in the more quiescent swales (Swift and others, 1973). Given the microtidal regime of the Alabama EEZ, the shelf sand ridges found there are assumed to be dominantly storm wave in origin (Parker and others, 1993).

The surficial unit comprised of the Graded Shelly Sand Lithofacies seen in the cross sections from area 4 is interpreted to be a Holocene age shelf sand ridge. The lithology, internal morphological characteristics, unit geometry, size, bathymetric relief, and associated facies of the sand body are compatible with Alabama EEZ shelf sand ridges.

OVERALL LITHOFACIES PATTERNS

Hummell and Smith (1995) investigated the three dimensional facies patterns in area 4 and concluded that sediments of possible use in beach nourishment were restricted to the clean shelly sands that comprise the Graded Shelly Sand Lithofacies. The present study delineated the details of sand body geometry and internal granulometry. That portion of the sand resource body with the highest mining potential has been defined above. In addition, the relationship between the margin of the sand resource body and surrounding lithologic units (including overburden) has been defined as a result of the present study. Within the resolution of the vibracore and boring data the sand resource body is granulometrically (and facies) homogeneous.

Two observations made by Hummell and Smith (1995) that relate to the mechanics of mining the sand resource body have been upheld by the results of the present study. The sediments enclosing the sand body contrast lithologically with the sand body which may facilitate locating and following the sand body during a mining operation. Also, this lithologic contrast should facilitate recognition of the contact between the sand body and enclosing sediments in subsurface samples, either on site or in the laboratory. That portion of the sand resource body that should be the focus of a mining operation is located 5 to 7 mi off the southeast coast of Dauphin Island, is exposed at the surface over an area of 5 mi^2, and is located in water depths from approximately 40 to 55 ft below sea level.

SAND BODY RESOURCE POTENTIAL

THE GRADED SHELLY SAND LITHOFACIES

Hummell and Smith (1995) determined the resource potential of the Graded Shelly Sand Lithofacies and onshore sand deposits by comparing the sediment character of these deposits with the native sediment occurring on each of the eroding southeastern Dauphin Island shoreline segments. The additional granulometric data collected in the present study upholds their view that the Graded Shelly Sand Lithofacies compares favorably with the characteristics of sediment samples collected from eroding southeastern Dauphin Island shoreline segments and analyzed by Parker and others (1993).

Using the additional vibracores from this study, it is estimated that the portion of Graded Shelly Sand Lithofacies sand resource body showing the highest mining potential contains approximately 15.5 million yd^3 of sediment. Hummell and Smith (1995) estimated that 2.4 million yd^3 of sand would be required to restore the southeastern Dauphin Island shoreline to its 1955 position. Present day shoreline studies indicate that this figure is still an accurate estimate. Therefore, the Graded Shelly Sand Lithofacies sand resource body can provide enough sand to restore Dauphin Island beach segments and permit future nourishment as the need arises.

SUMMARY AND CONCLUSIONS

The objectives of this study were accomplished through the completion of the four tasks outlined in the "Introduction". These further evaluated the sand resource potential of area 4 for use as beach nourishment on eroding southeastern Dauphin Island shoreline segments. The specific outcomes for these tasks include:

1. Networking was initiated as a mechanism to involve agencies in the process of developing a recommendation for a demonstration project. This task was accomplished by attendance of meetings of the Alabama Coastal Area Erosion Task Force, Coastal Zone '95, and the 9th Annual National Conference on Beach Preservation Technology.

2. A d**etailed assessment of the area 4 sand resource body geometry and granulometry was accomplished by the acquisition of addit**ional geologic data. These data was used to conduct a further resource **evaluation** of the sand body**.** Hummell and Smith (1995) determined that the sediments in area 4 consist of Holocene marine sediments overlying an irregular erosional surface of late Pleistocene-early Holocene age. The Holocene sediments consist of mud and muddy sand ebb-tidal delta and shelf sediments; and shelf sand ridge sands. In addition, Hummell and Smith (1995) delineated a sand resource body comprised of the Graded Shelly Sand Lithofacies located in the east-central portion of area 4. In the present study, the collection of 10 vibracores and 10 sea bottom sediment samples showed that most of the upper surface of the sand body is exposed at the seafloor over an area of 5 mi^2 and that most of the sand body lay in federal waters some 5 to 7 mi off the southeast coast of Dauphin Island in water depths 40 to 55 ft below sea level. The sand resource body displays fine-scale lateral interfingering at its margin with ebb-tidal delta microfacies, the Muddy Shelly Sand Microfacies, and nearshore, shallow water facies (shelf mud, open bay, and surficial sand sheet) of Hummell (1996). The sand resource body thickens down dip (toward the southwest) and the main axis of the sand resource body trends northeast-southwest approximately perpendicular to shelf bathymetry. It is recommended that a sand recovery project avoid the northeastern end of the sand resource body (roughly the

state waters portion) and places where the Graded Shelly Sand Lithofacies is not exposed at the sea floor. The sediments enclosing the sand body contrast lithologically with the sand body which may facilitate locating and following the sand body during a mining operation. Also, this lithologic contrast should facilitate recognition of the contact between the sand body and enclosing sediments in subsurface samples, either on site or in the laboratory. Within the resolution of the vibracore and boring data the sand resource body is granulometrically (and facies) homogeneous and compatible with eroding southeastern Dauphin Island shoreline sediments. It is estimated that the portion of Graded Shelly Sand Lithofacies sand resource body showing the highest mining potential contains approximately 15.5 million yd^3 of sediment; enough sand to restore Dauphin Island beach segments to its 1955 position and permit future nourishment as the need arises.

3. An a**ssessment of the sedimentary and erosional regimes in the vicinity of the area 4 sand resource body and eroding shoreline segments on southeastern Dauphin Island** was accomplished by synthesis of published hydrographic studies. Pre-existing wind wave, current, and tide data along with additional ground surveys were conducted along southeastern Dauphin Island eroding shoreline segments to document shoreline loss for the 1994-1996 period. This information was used to supplement the existing shoreline loss information compiled in Phase 2 (1955-1985) and Phase 3 (1985-1994) in estimating sand required to restore selected segments of Dauphin Island shoreline to their 1955 positions. Current erosion rates and sedimentary characteristics of southeastern Dauphin Island beach sediment samples are essentially unchanged from those reported by Parker and others (1993), and Hummell and Smith (1995). Helicopter overflights of coastal Alabama indicate that Hurricane Opal (October 4, 1995) inflicted minimal and localized property damage along the immediate coast. An 8 to

10 ft high storm surge combined with storm winds and waves resulted in short term loss (estimated several month recovery period) of tens of feet of dry beach. These storm conditions also resulted in the loss of the first line of foredunes (estimated one year recovery period). Sand from the beach shoreface and foredunes were transported inland by overwash or offshore to the longshore bar system. Except for some permanent loss of beach at erosion hot spots, the beach and eolian dunes should recover to their approximate pre-hurricane state. The currently eroding Gulf of Mexico shoreline areas of southeastern Dauphin Island could be restored approximately to their 1955 shoreline position by application of about 2.4 million yd^3 sand. The Graded Shelly Sand Lithofacies sand unit in area 4 contains sufficient sand resources (15.5 million yd^3) to nourish these shoreline segments and provide additional sand for future nourishment projects as the need arises.

4. **Development** of a computer modeling database was initiated by collection and evaluation of pre-existing wind wave, current, and tide data; published hydrographic studies; utilization of data collected during GSA ground surveys; and information garnered from networking with geologists and engineers.

This study has identified a clean sand source in area 4 that appears to hold sufficient reserves of appropriate sand resource material for nourishment of eroding southeastern Dauphin Island shoreline segments. As a result of this study it can be concluded that if care is taken to avoid man-made structures and the U.S. Army Corps of Engineers berm study area, the sand body identified in area 4 may be utilized as a sand resource. However, before a dredge operation can take place the erosion and sediment transport systems for area 4 and southeastern Dauphin Island shoreline should be modeled to predict the possible consequences of mining and application of sand. Modeling studies would be needed to estimate the longevity of beach nourished sand and the nature of any future maintenance after initiation of beach replenishment projects.

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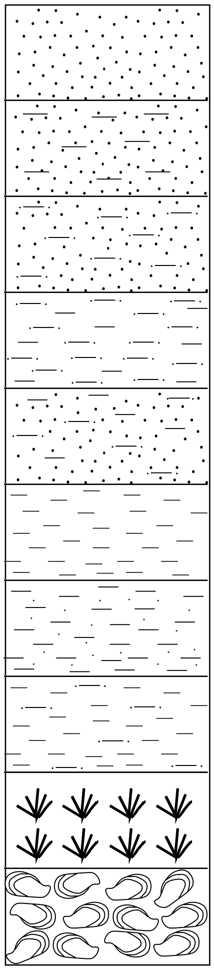
APPENDIX A

COLUMNAR SECTIONS OF
EEZ SAND RESOURCE
VIBRACORES AND FOUNDATION BORINGS

EXPLANATION OF PATTERNS AND SYMBOLS

SEDIMENT TYPES



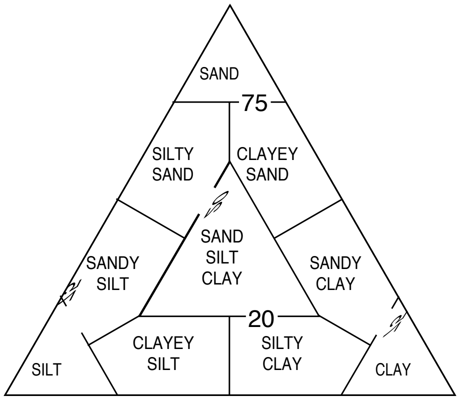
- SAND
- CLAYEY SAND
- SILTY SAND
- CLAYEY SILT
- SAND-SILT-CLAY
- CLAY
- SANDY CLAY
- SILTY CLAY
- PEAT
- OYSTER BIOSTROME

SAMPLE INDEX

310 - SEDIMENT SAMPLE

300 - C-14 SAMPLE

SEDIMENT TEXTURE NOMENCLATURE



ACCESSORIES

- OYSTER SHELL
- ARTICULATED PELCYPOD
- INARTICULATED PELCYPOD
- SHELL FRAGMENT
- PEBBLE
- GRANULE
- NODULE
- PEAT BALL
- ROOTS
- ORGANIC MATTER
- CRAB

SEDIMENTARY STRUCTURES

- SAND POCKET
- CLAY POCKET
- CLAYEY SAND POCKET
- SANDY CLAY POCKET
- MUD BURROW
- SAND BURROW
- CLAY DRAPE

BIOTURBATION INDEX*

(1) No bioturbation recorded; all original sedimentary structures preserved.
(2) Discrete, isolated trace fossils; up to 10% of original bedding disturbed.
(3) Approximately 10 to 40% of original bedding disturbed. Burrows are generally isolated, but locally overlap.
(4) Last vestiges of bedding discernable; approximately 40 to 60% disturbed. Burrows overlap and are not always well defined.
(5) Bedding is completely disturbed, but burrows are still discrete in places and the fabric is not mixed.
(6) Bedding is nearly or totally homogenized.

*(Droser and Bottjer, 1986)

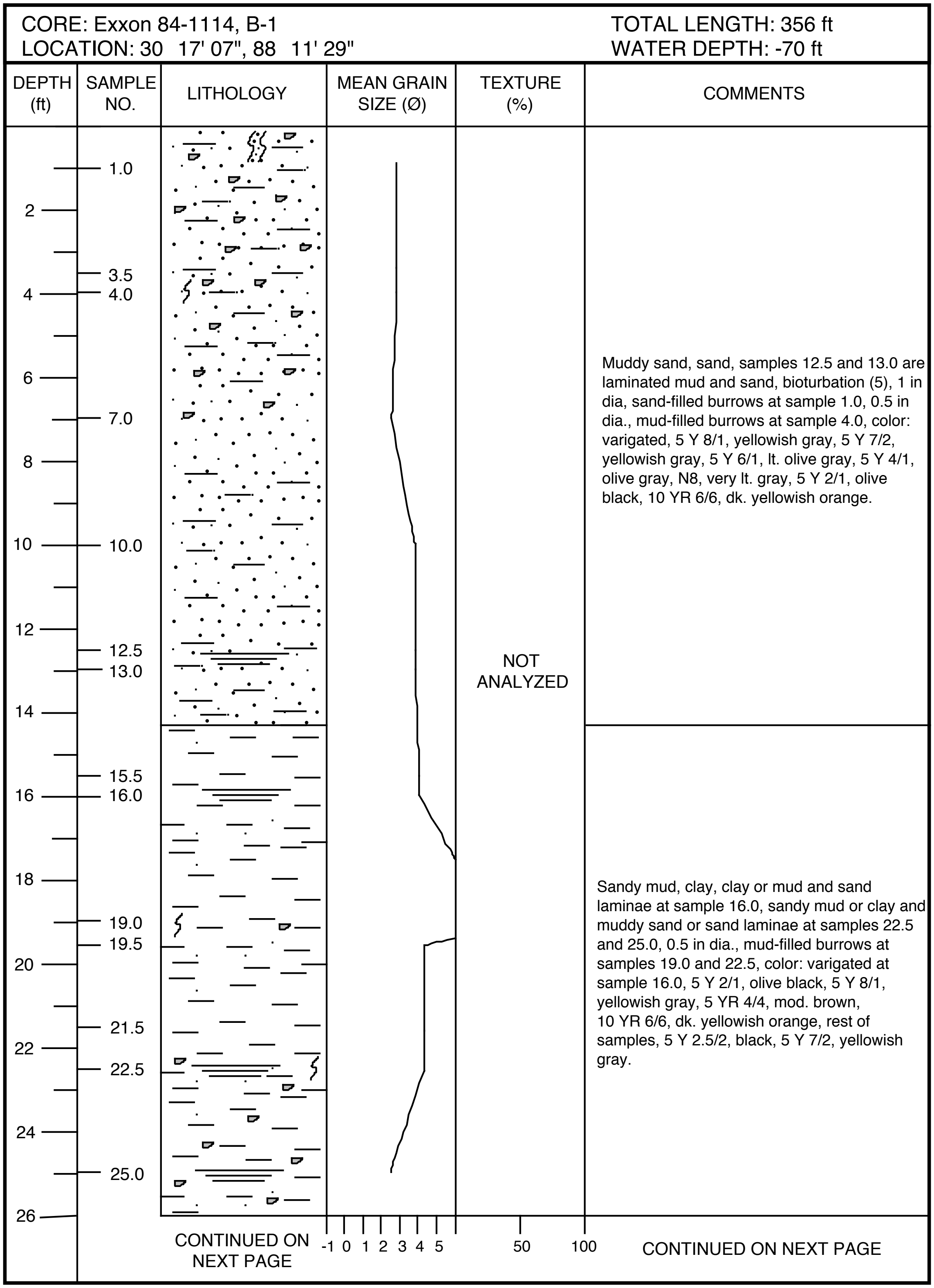


Figure A-1.--Columnar section of EEZ boring Exxon 84-1114, B-1.

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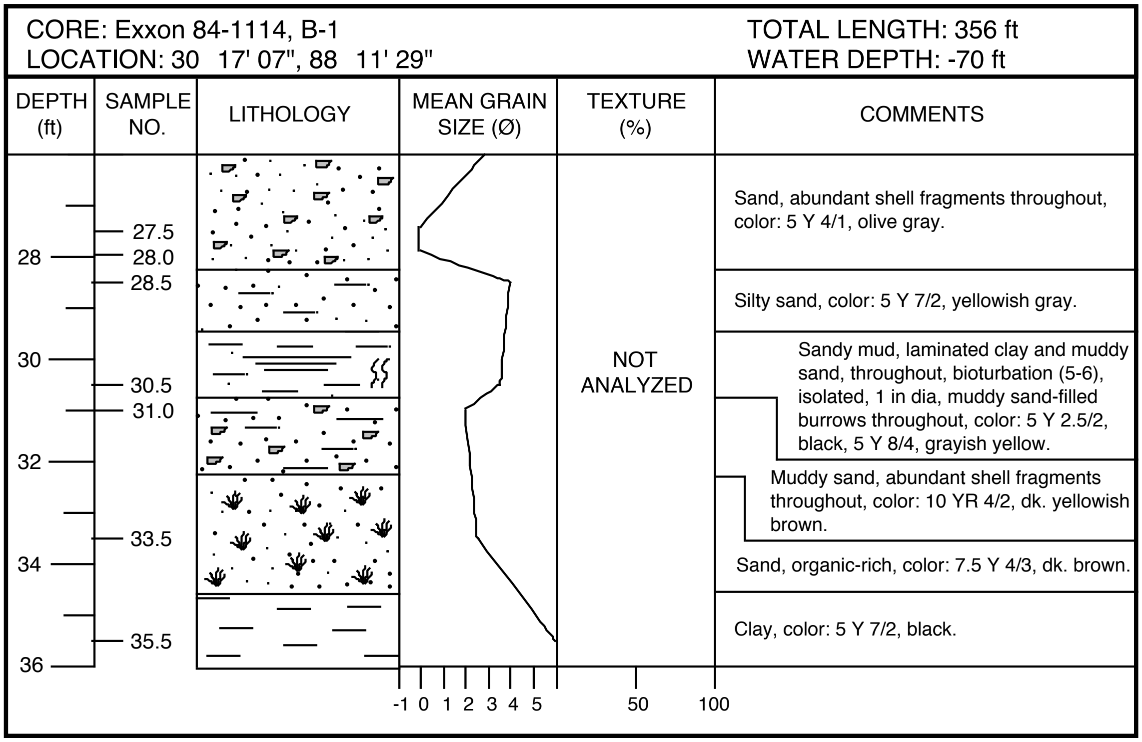

Figure A-1.--Columnar section of EEZ boring Exxon 84-1114, B-1.

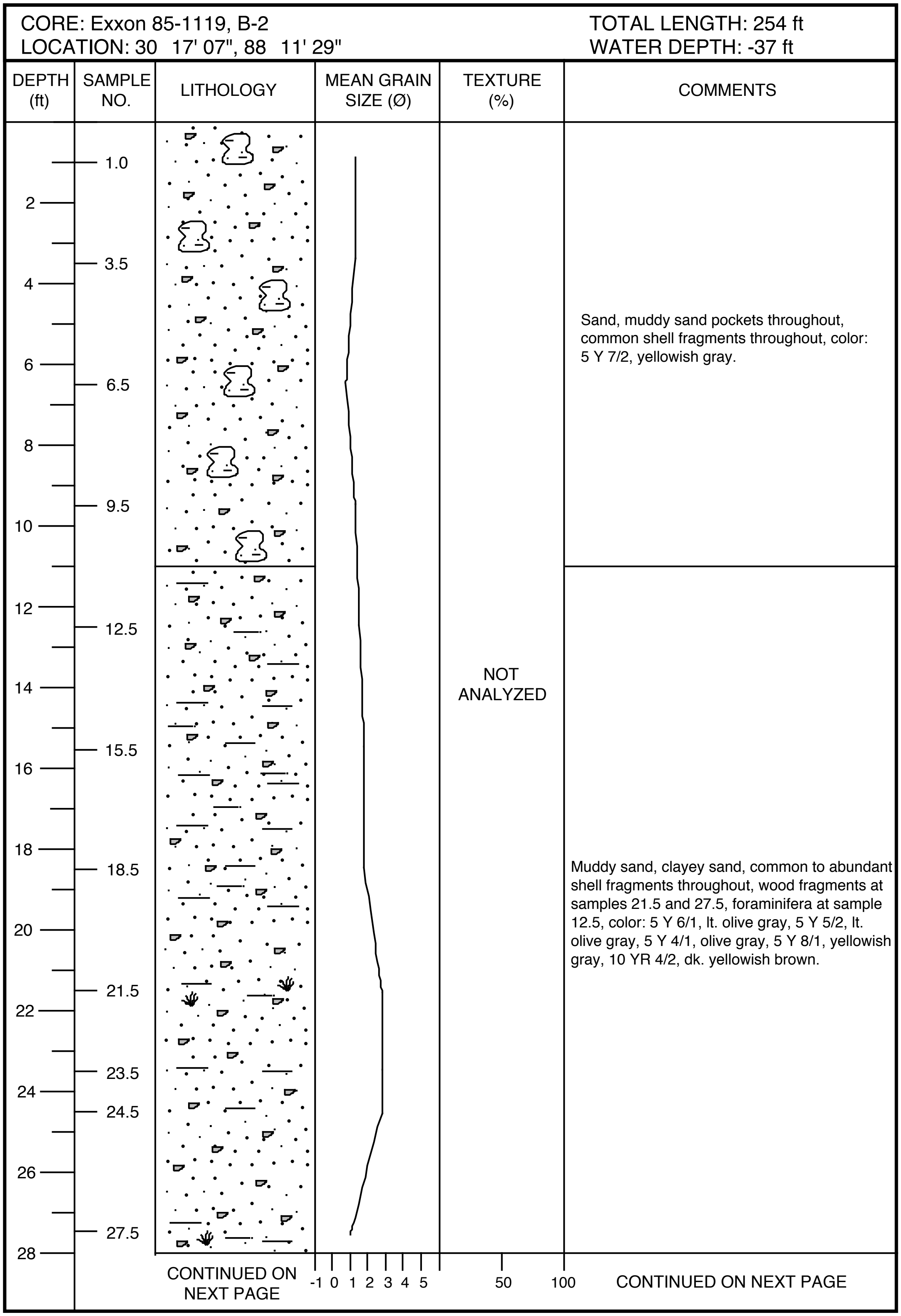

Figure A-2.--Columnar section of EEZ boring Exxon 85-1119, B-2.

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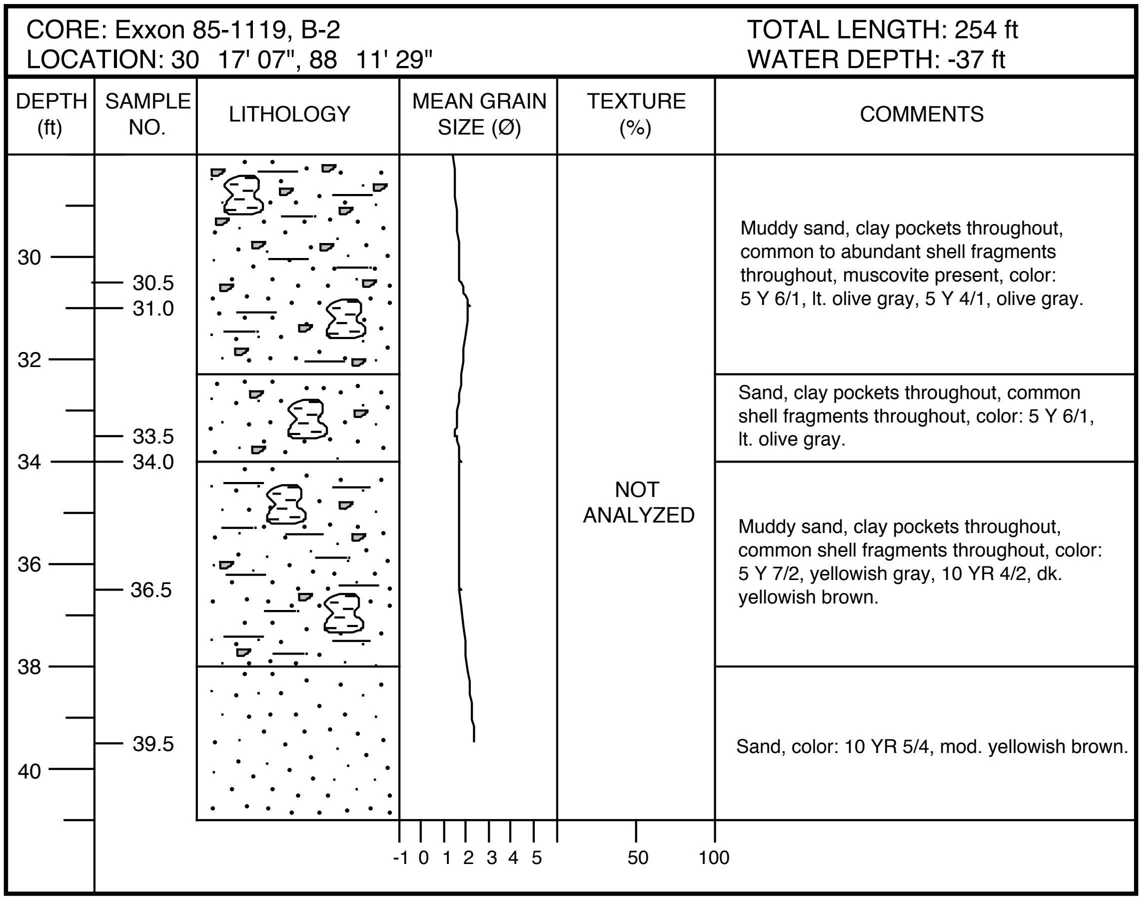


Figure A-2.--Columnar section of EEZ boring Exxon 85-1119, B-2.

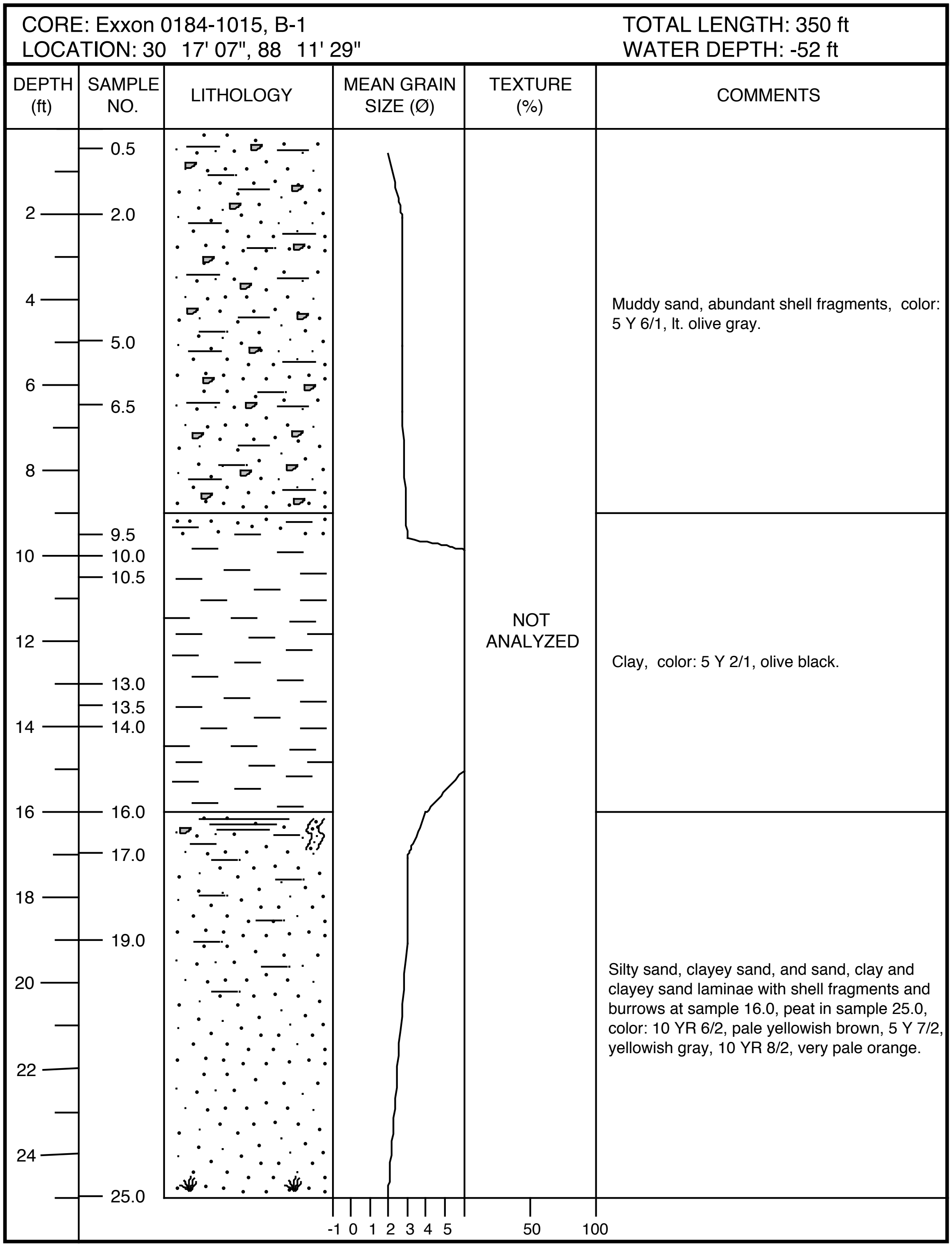


Figure A-3.--Columnar section of EEZ boring Exxon 0184-1015, B-1.

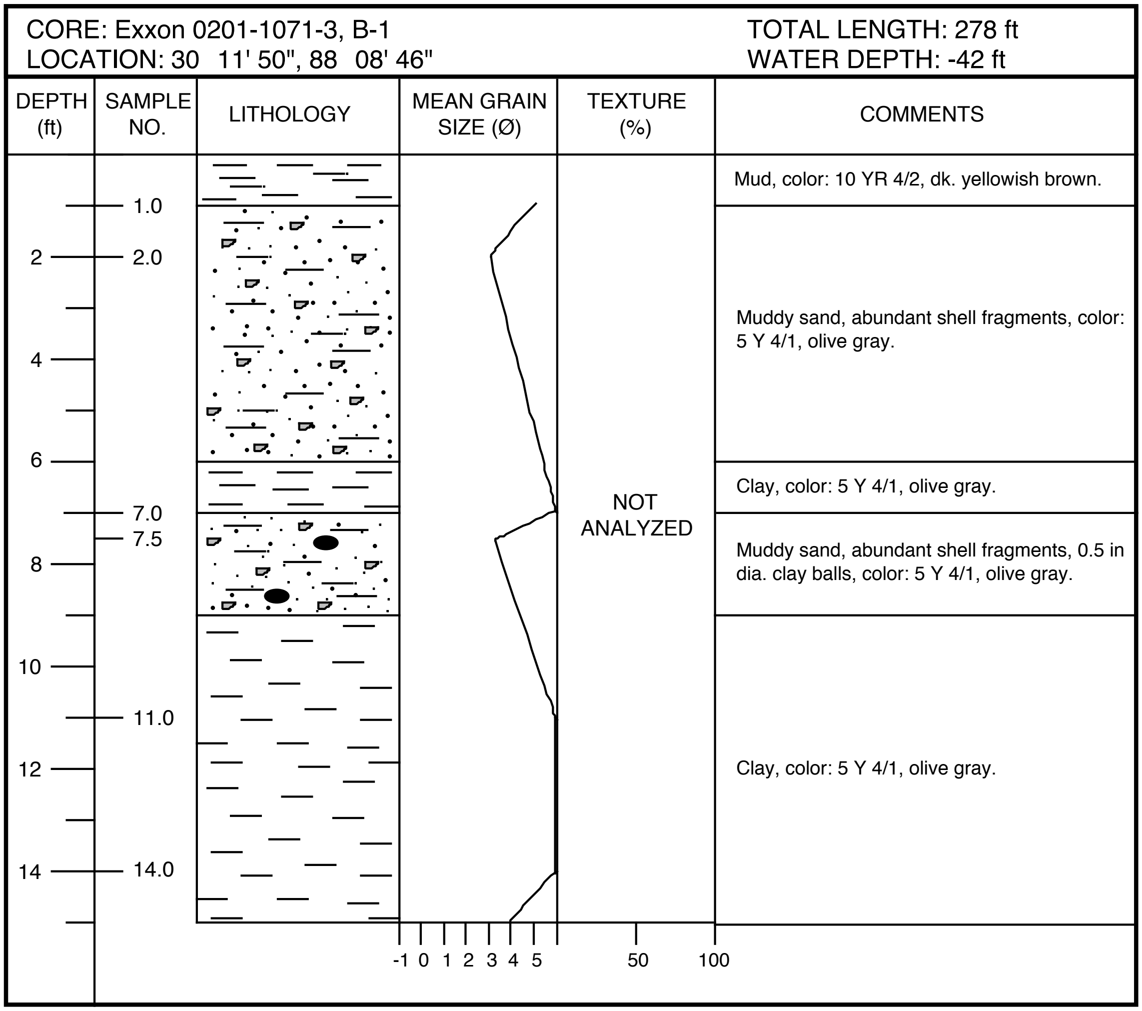


Figure A-4.--Columnar section of EEZ boring Exxon 0201-1071-3, B-1.

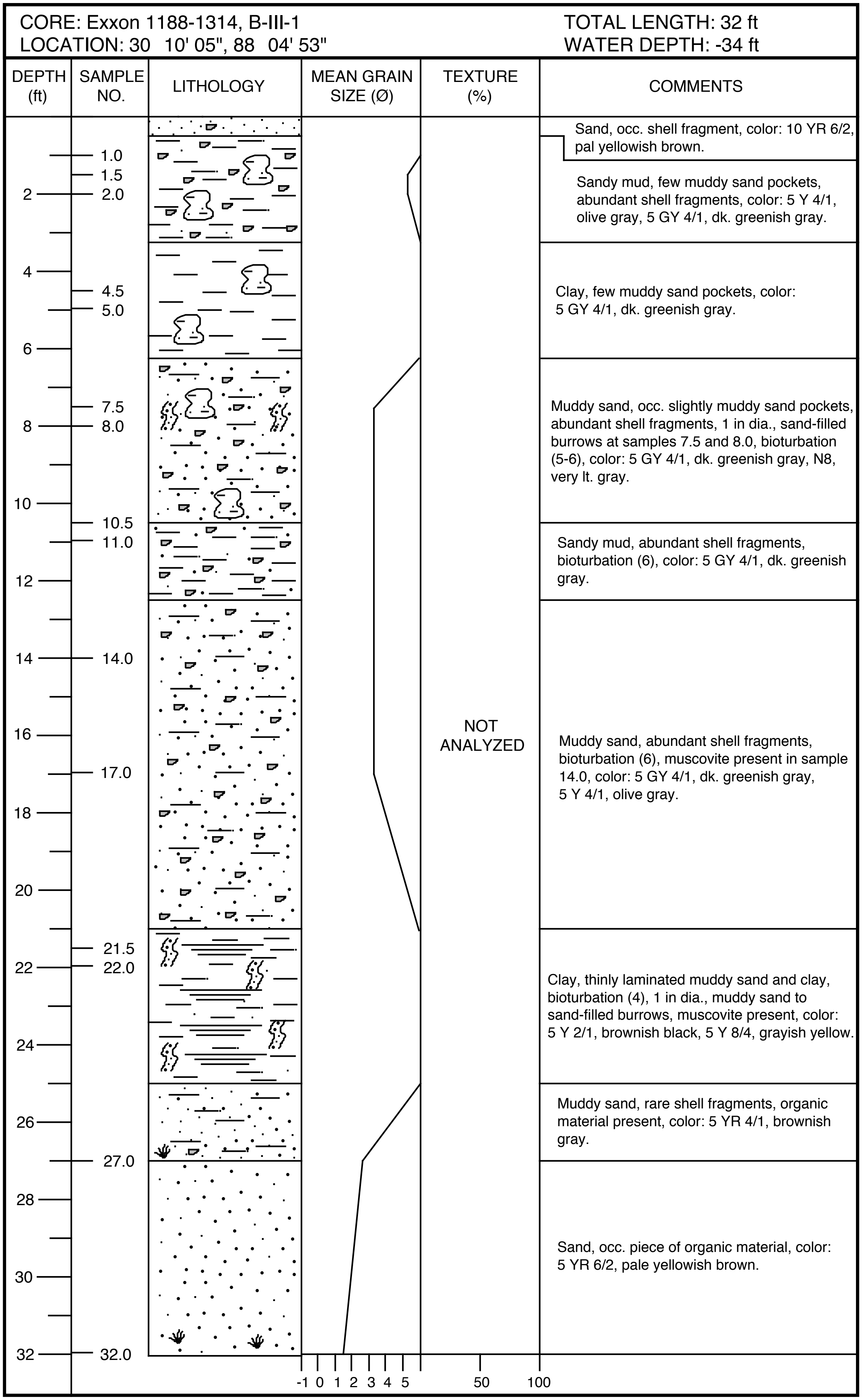


Figure A-5.--Columnar section of EEZ boring Exxon 1188-1314, B-III-1.

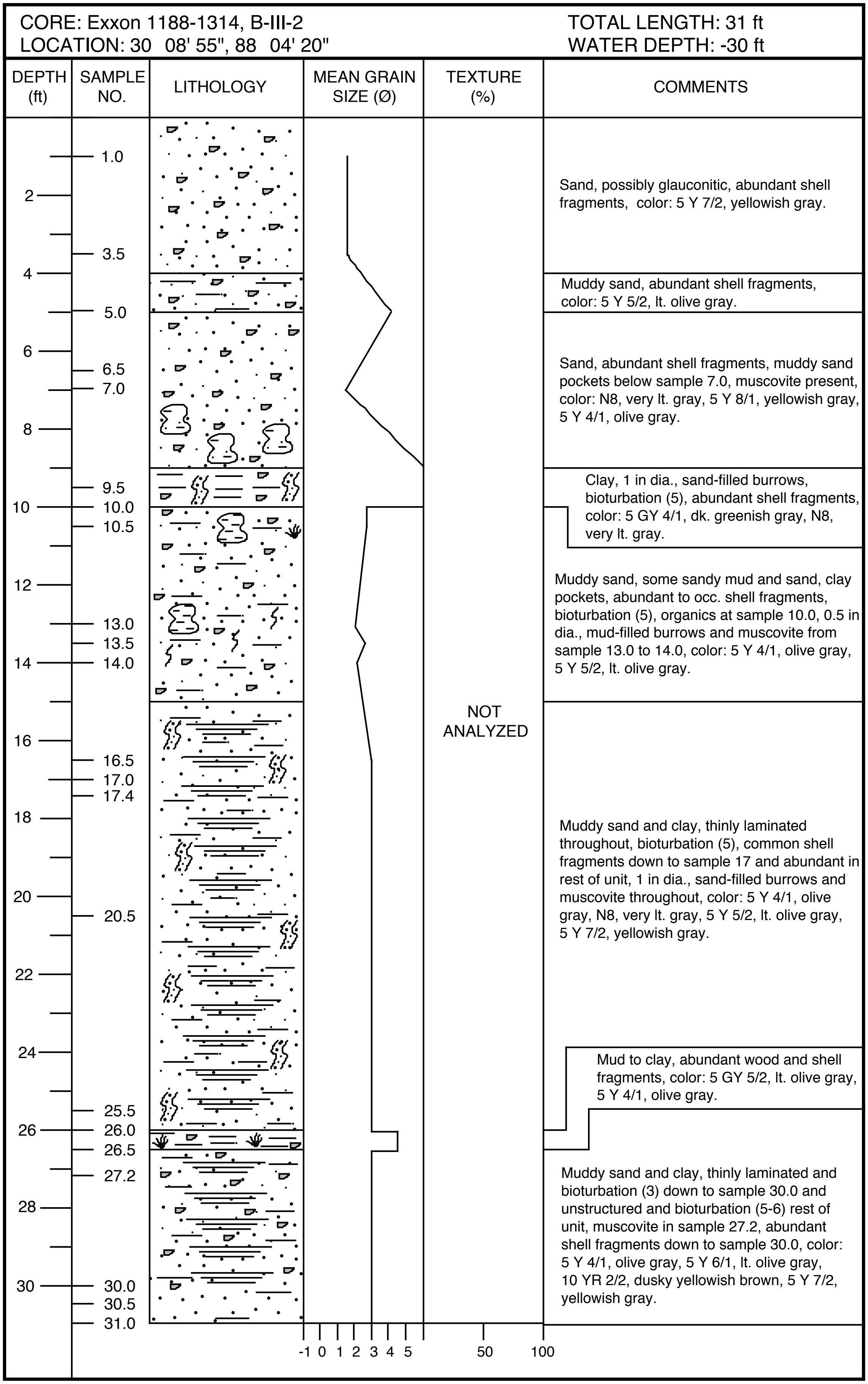


Figure A-6.--Columnar section of EEZ boring Exxon 1188-1314, B-III-2.

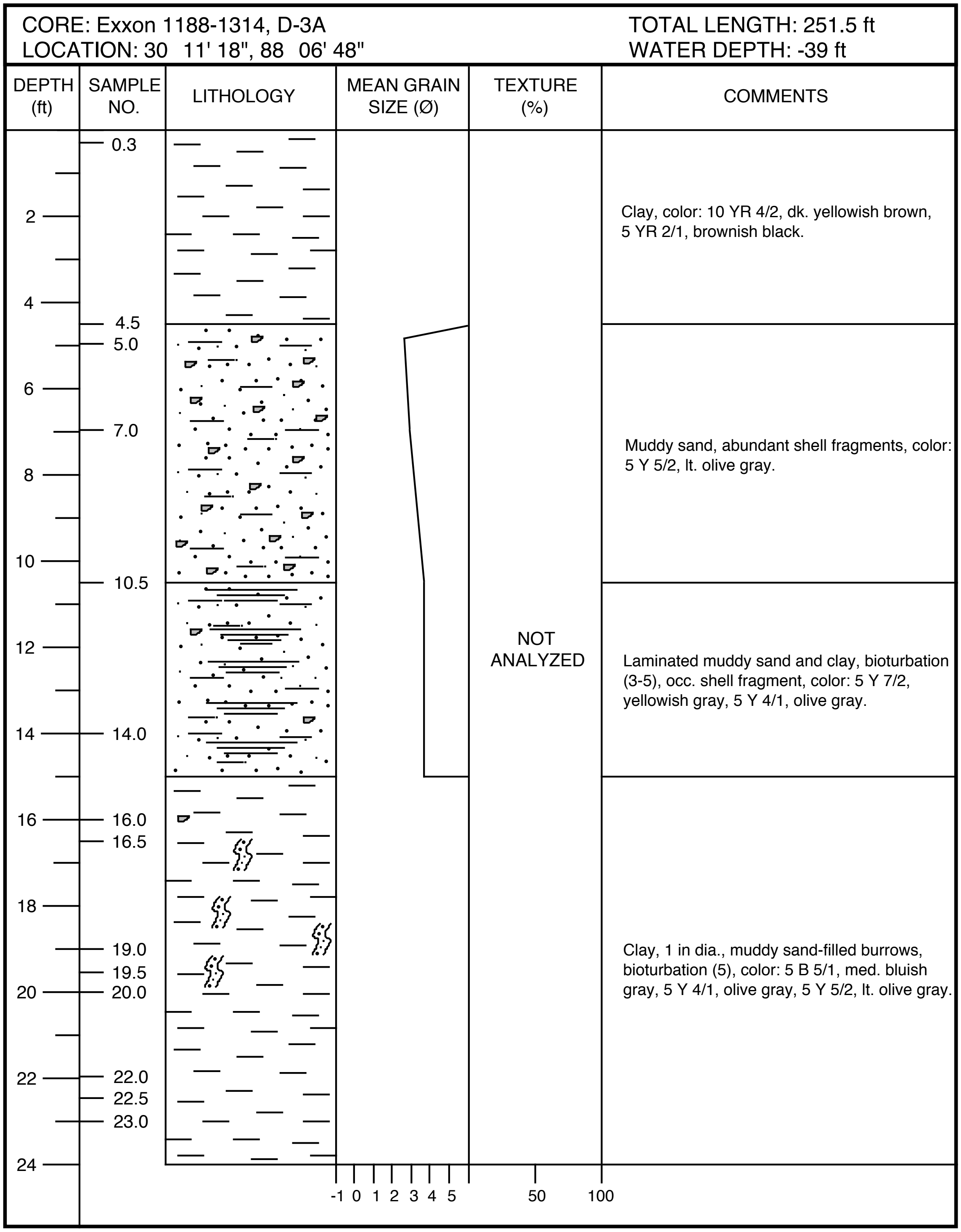


Figure A-7.--Columnar section of EEZ boring Exxon 1188-1314, D-3A.

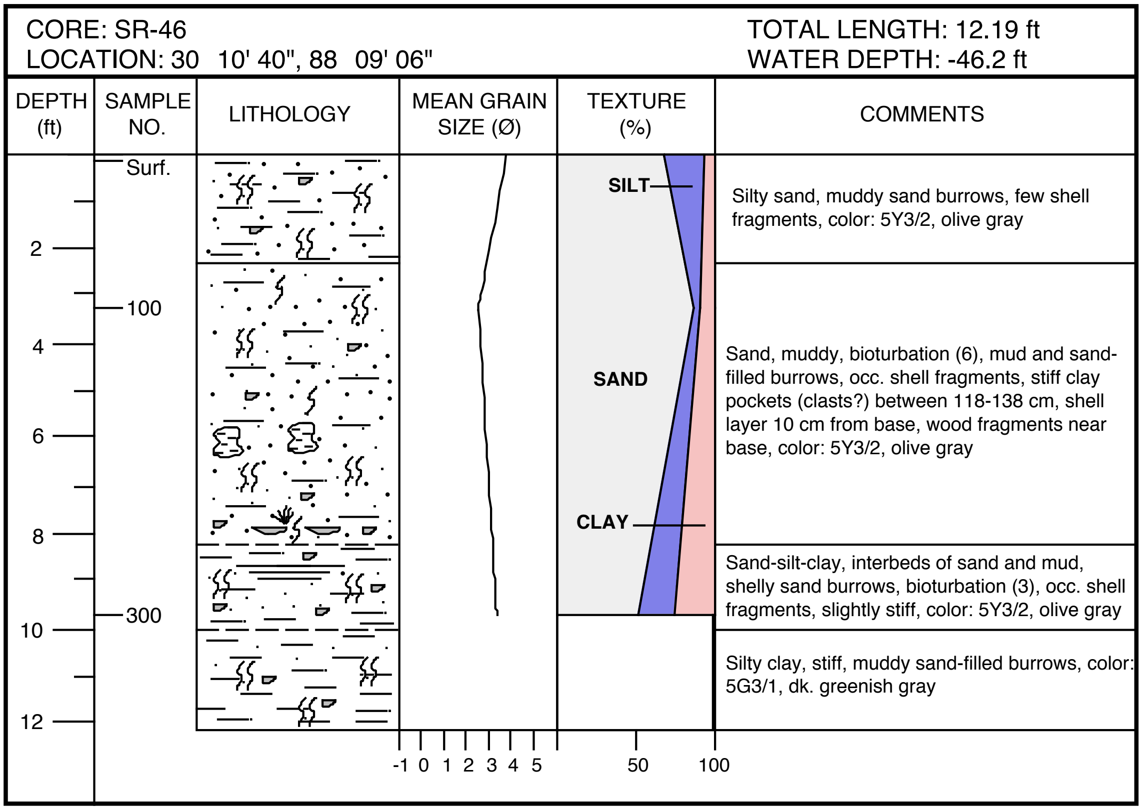


Figure A-8.--Columnar section of EEZ vibracore SR-46.

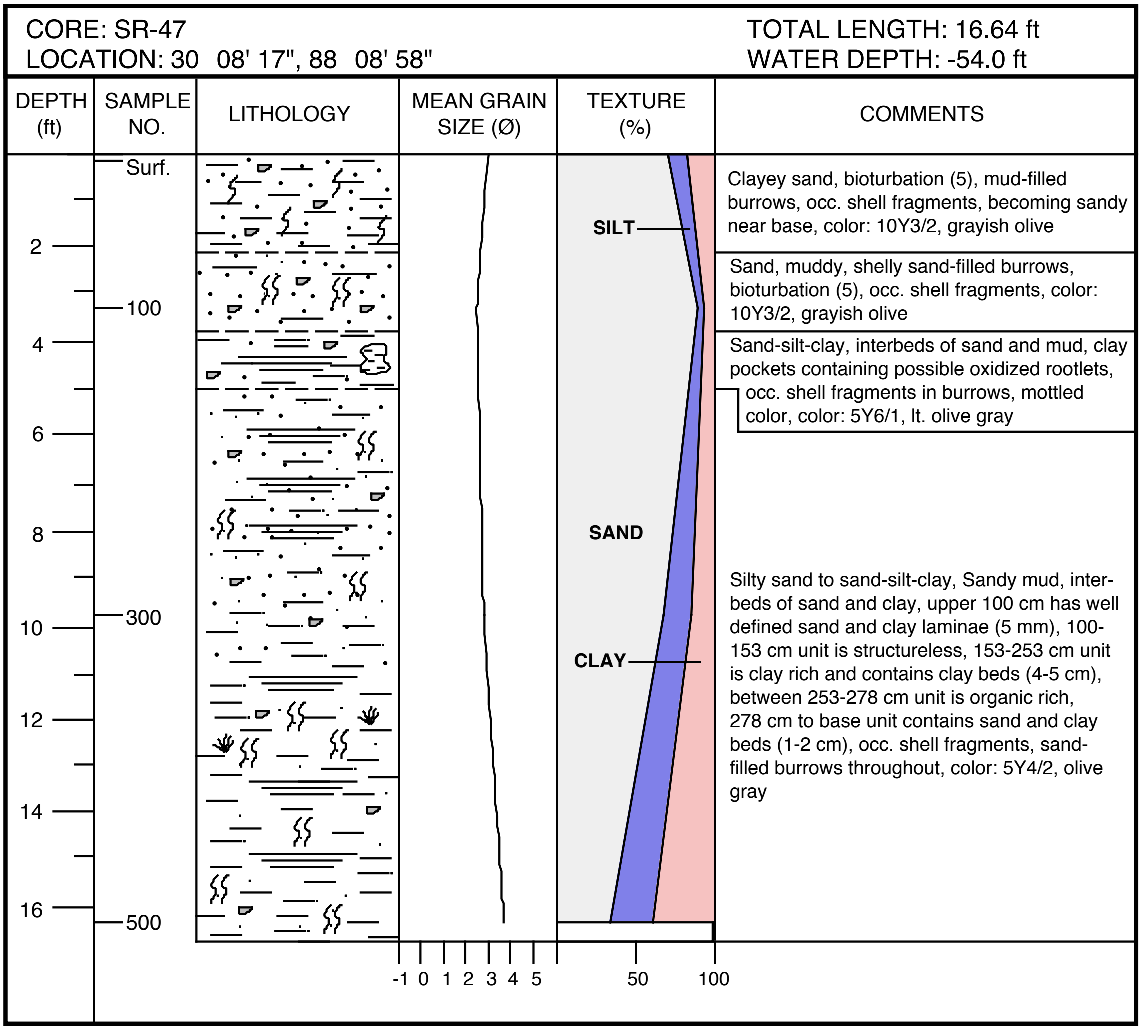
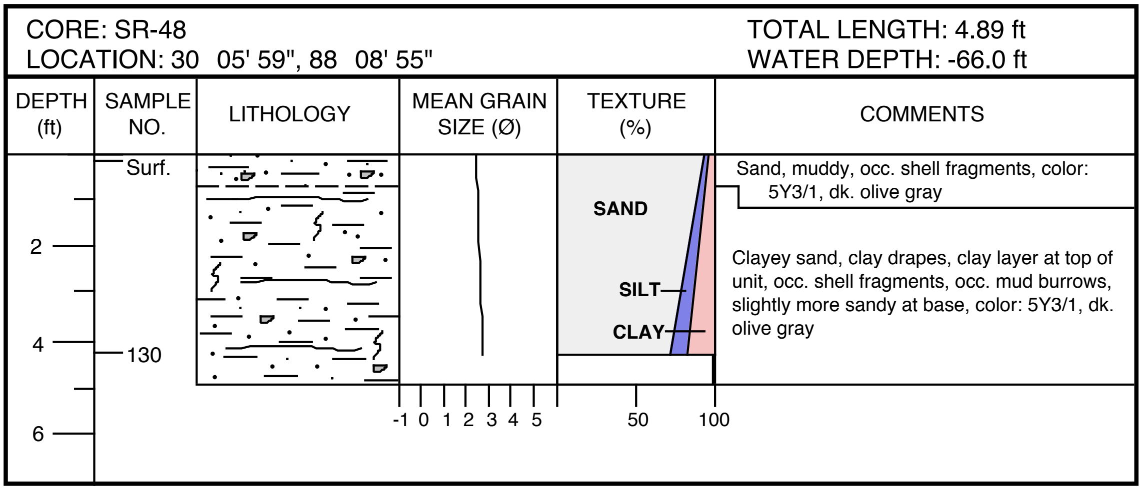


Figure A-9.--Columnar section of EEZ vibracore SR-47.



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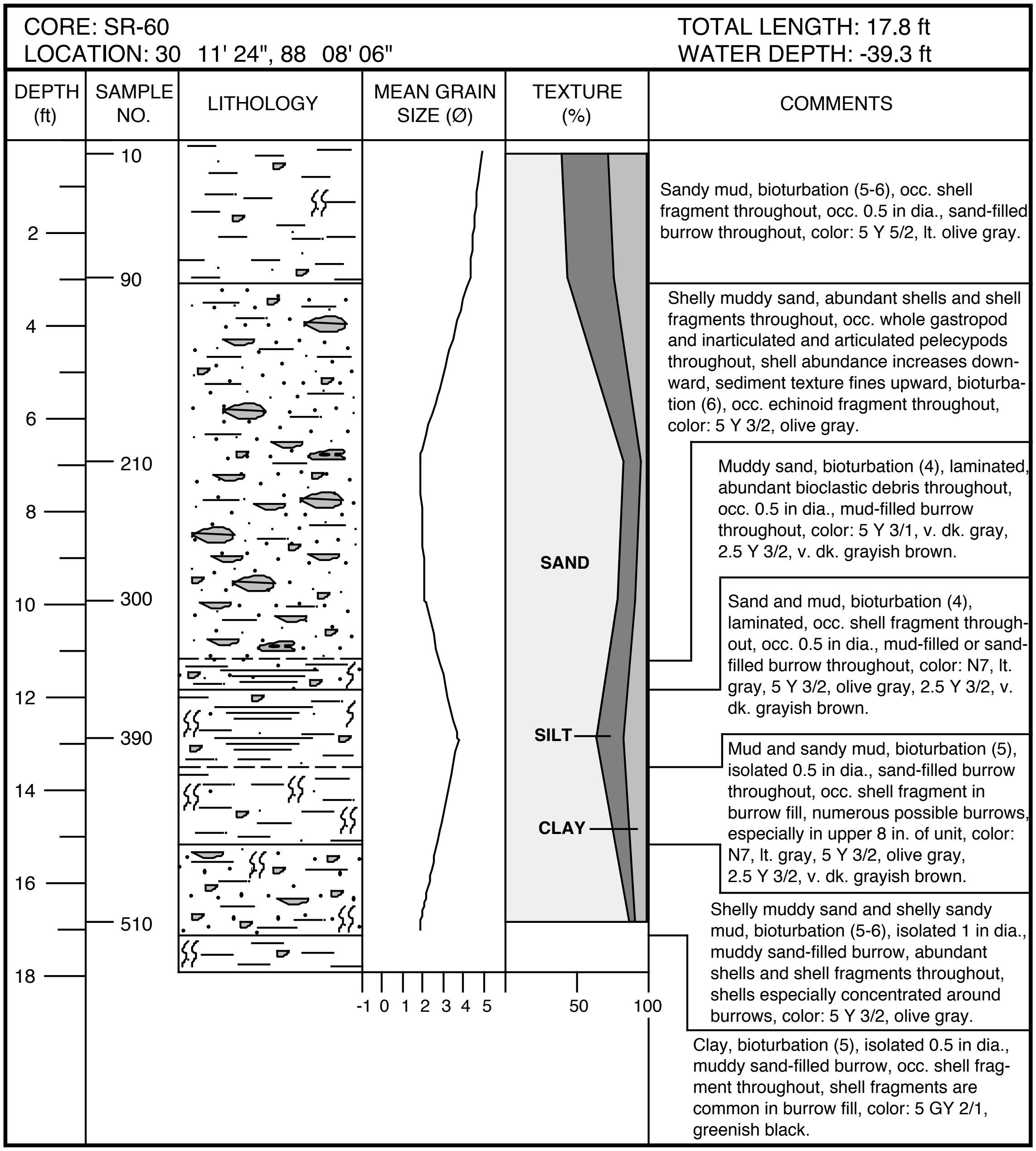


Figure A-11.--Columnar section of EEZ vibracore SR-60.

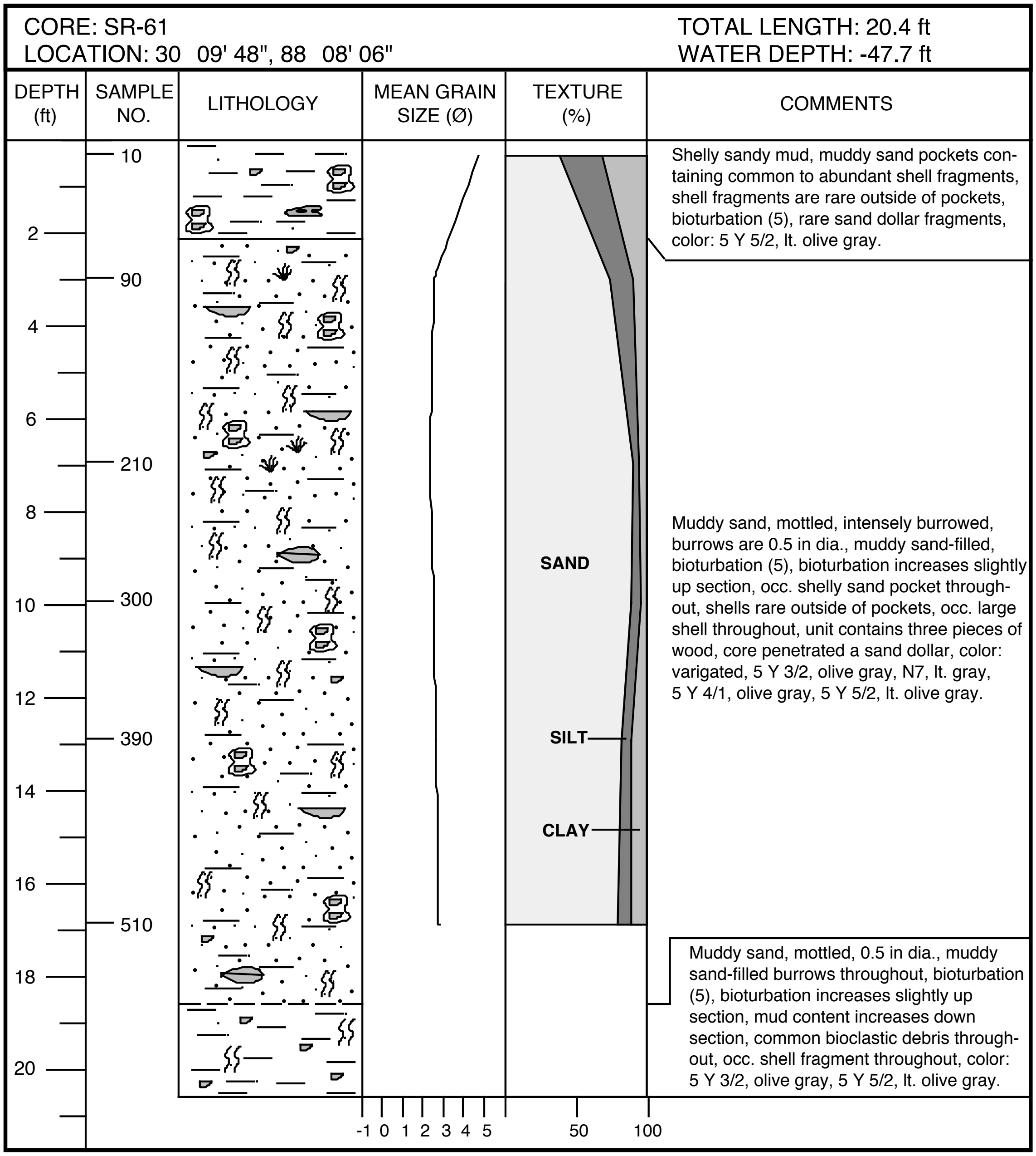


Figure A-12.--Columnar section of EEZ vibracore SR-61.

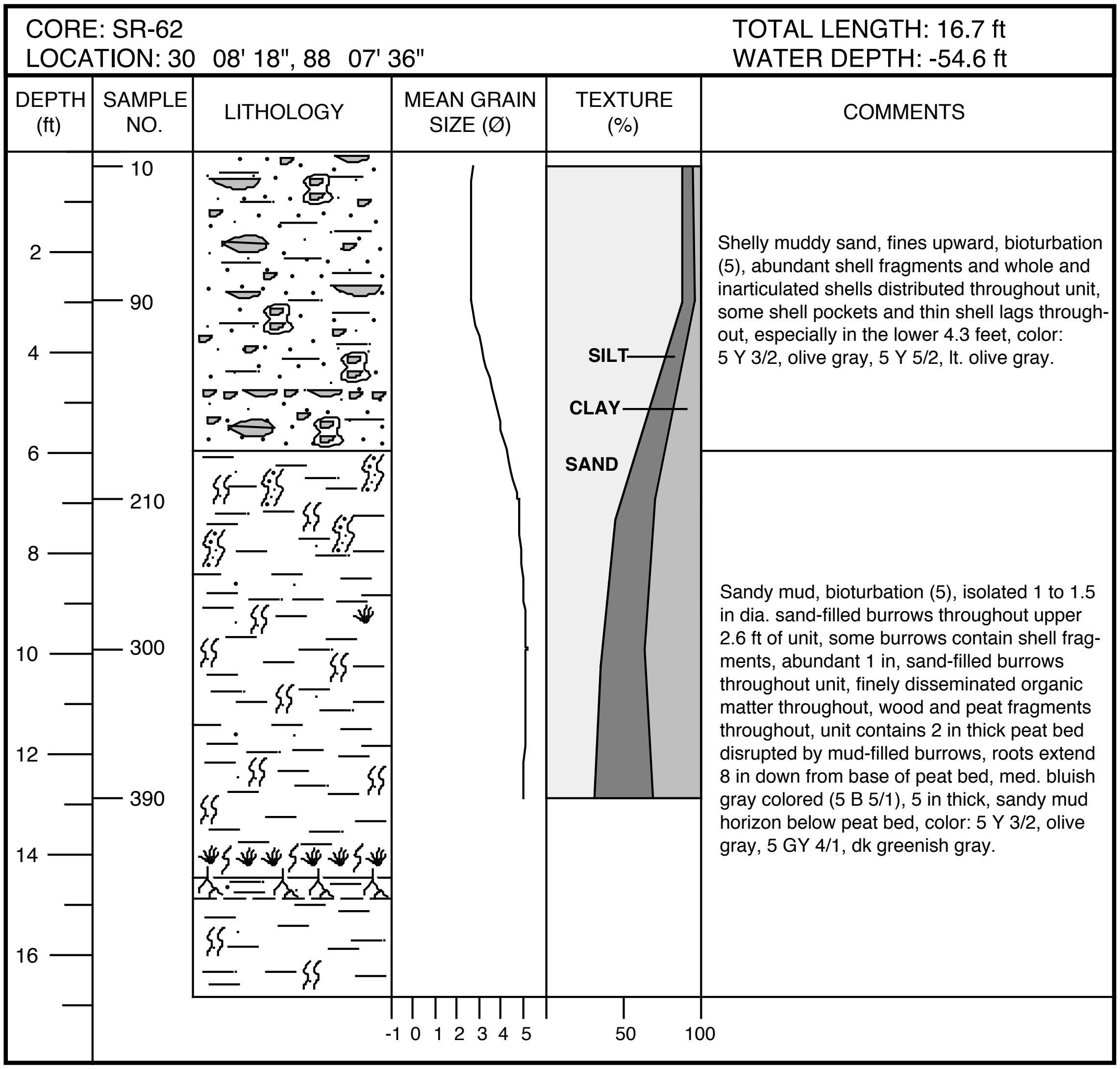
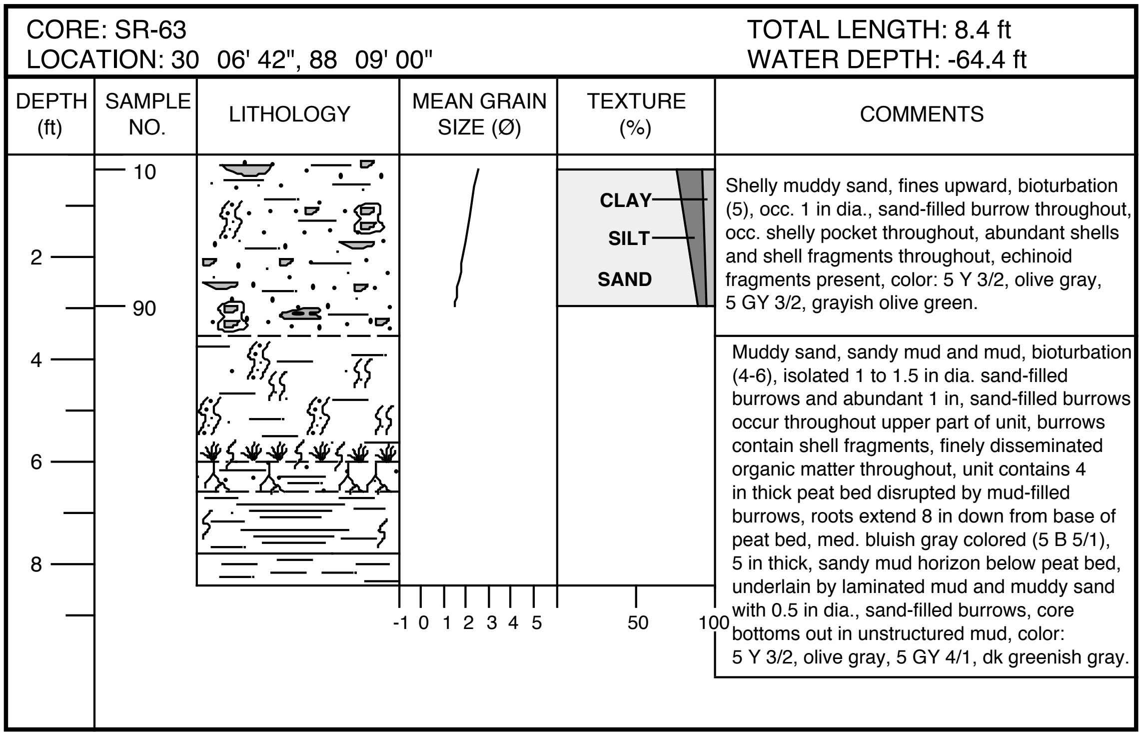


Figure A-13.--Columnar section of EEZ vibracore SR-62.



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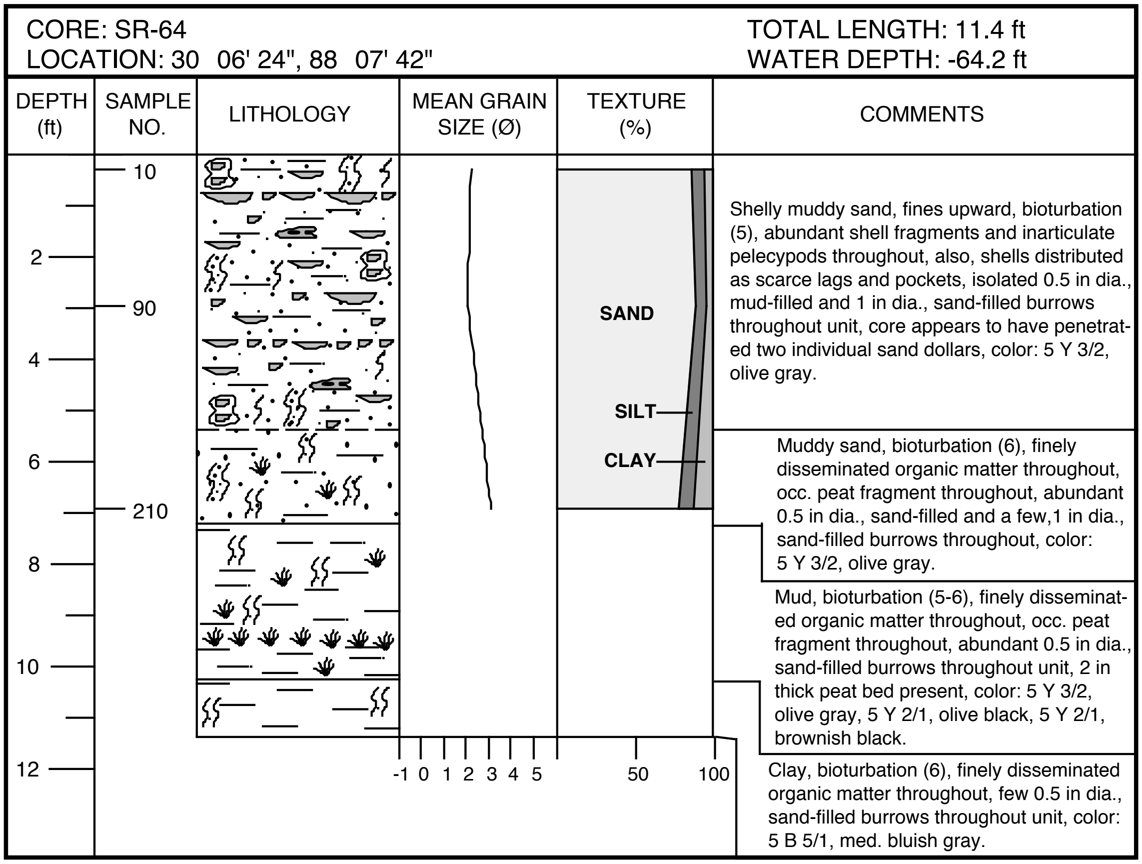

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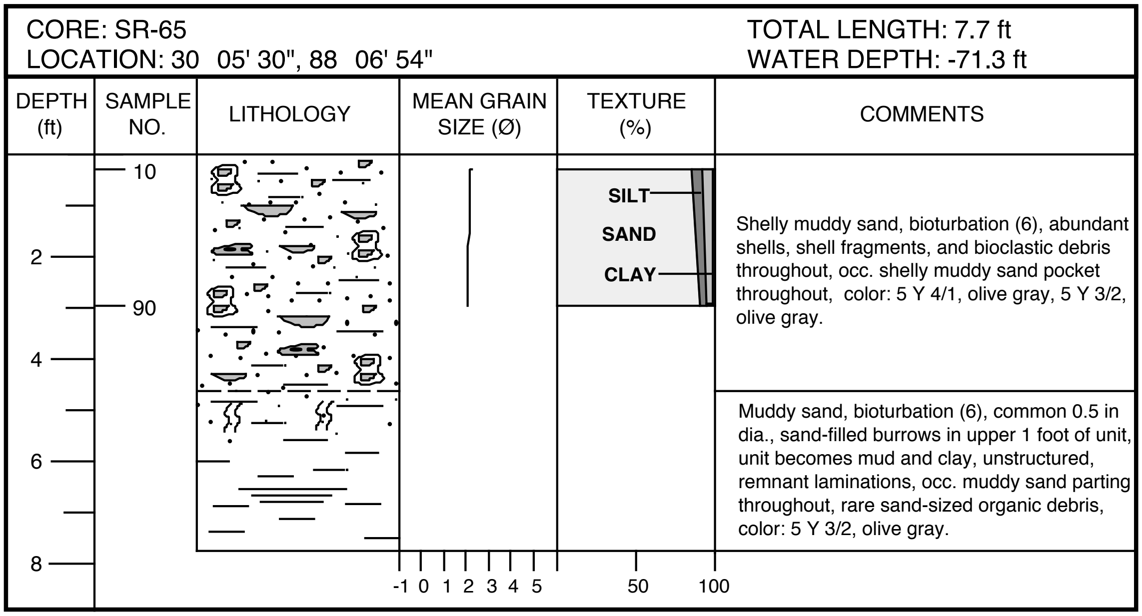

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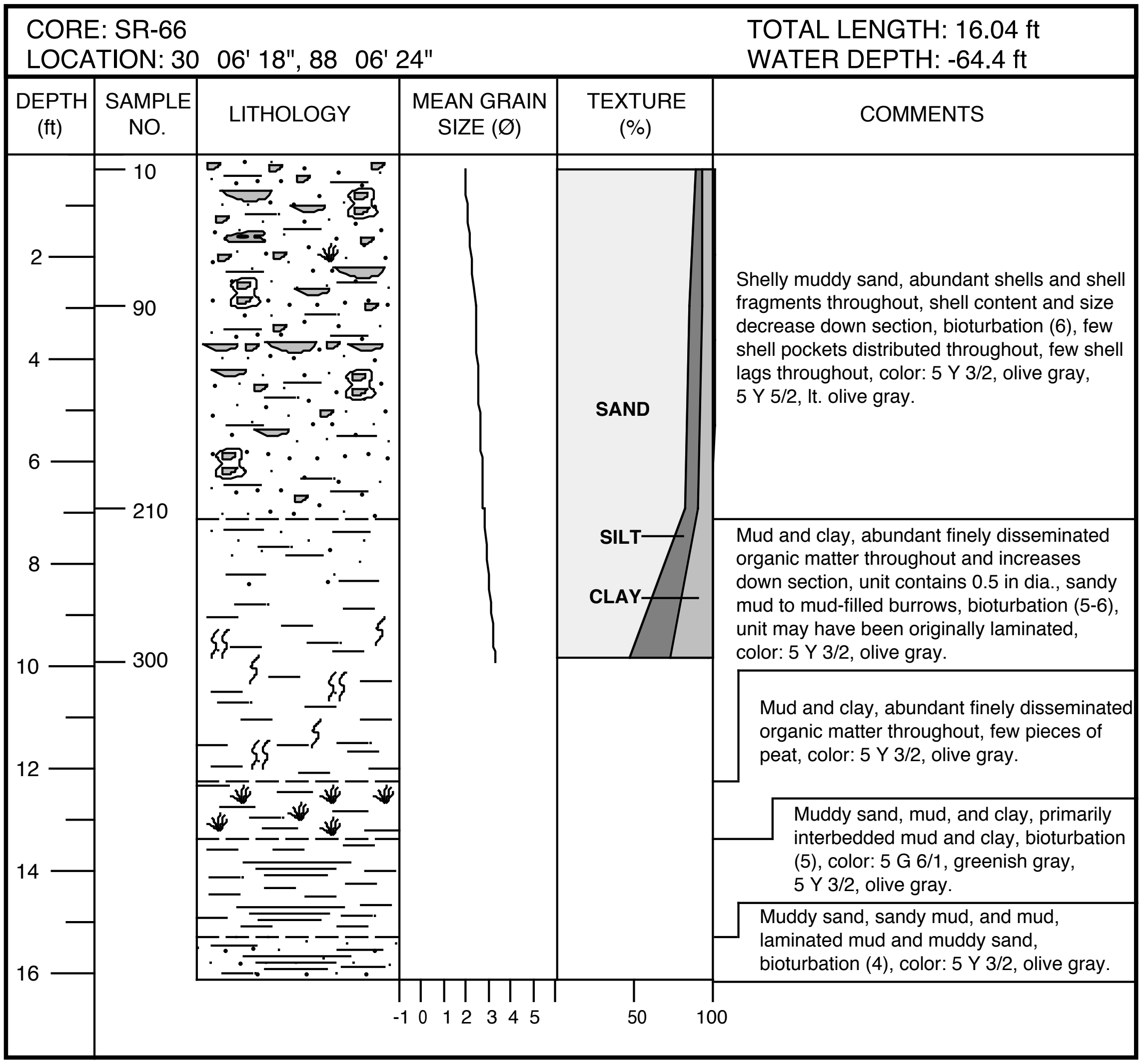

Figure A-17.--Columnar section of EEZ vibracore SR-66.

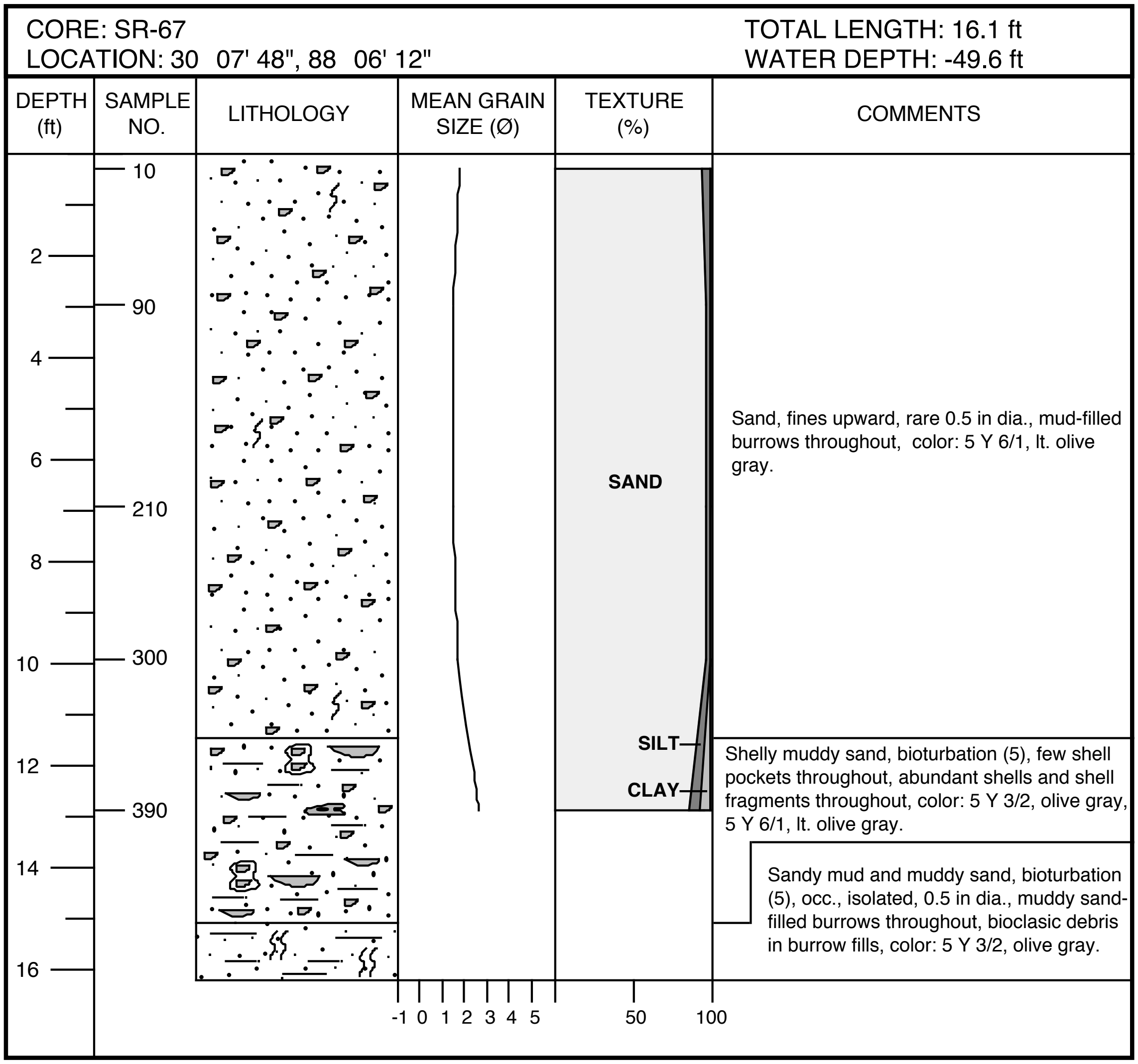

Figure A-18.--Columnar section of EEZ vibracore SR-67.

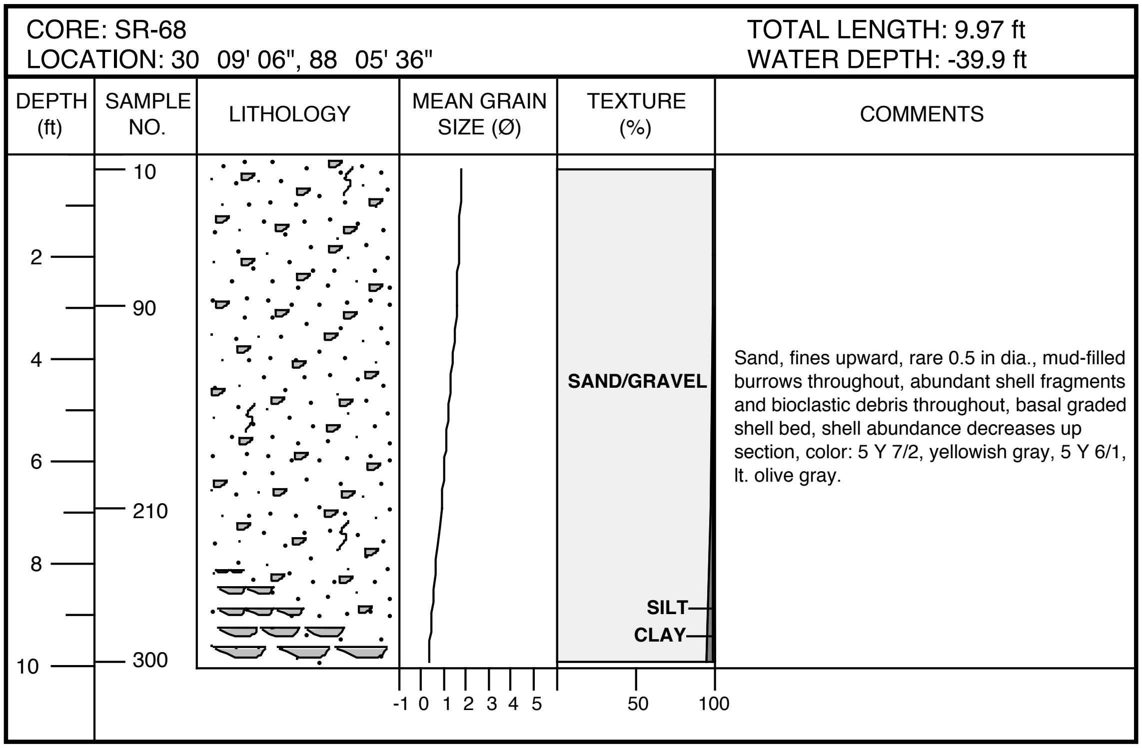

Figure A-19.--Columnar section of EEZ vibracore SR-68.

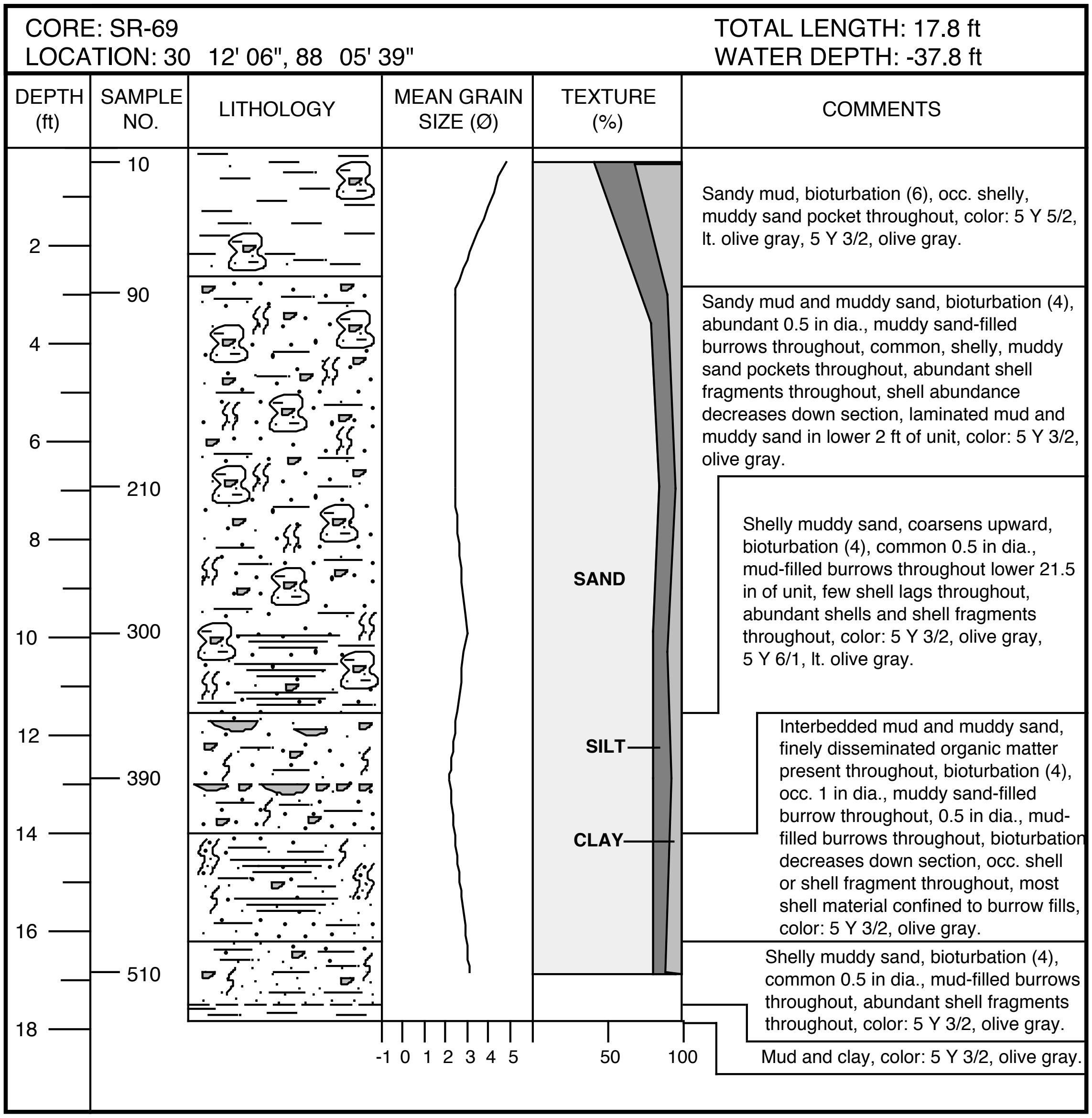

Figure A-20.--Columnar section of EEZ vibracore SR-69.

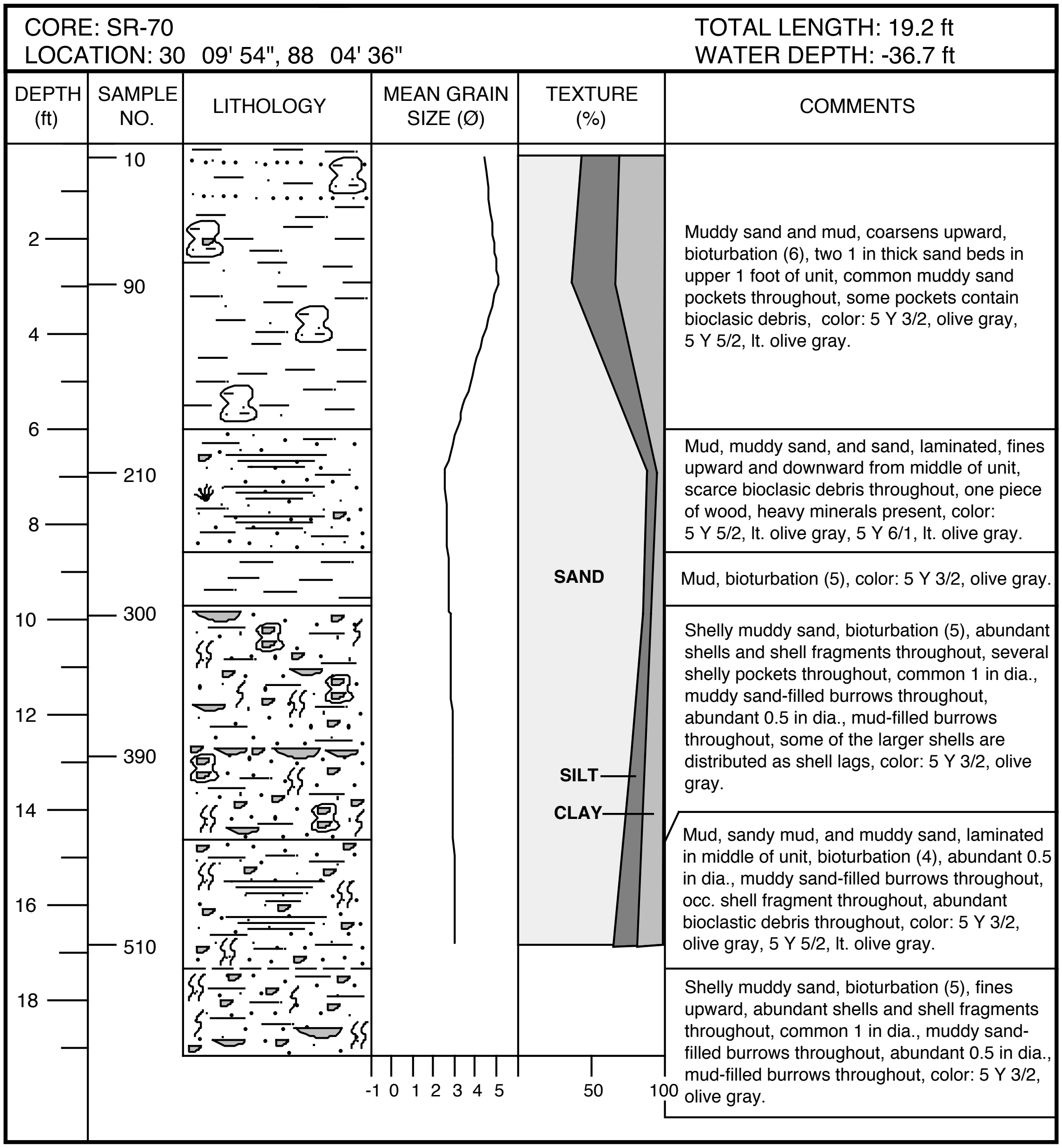

Figure A-21.--Columnar section of EEZ vibracore SR-70.

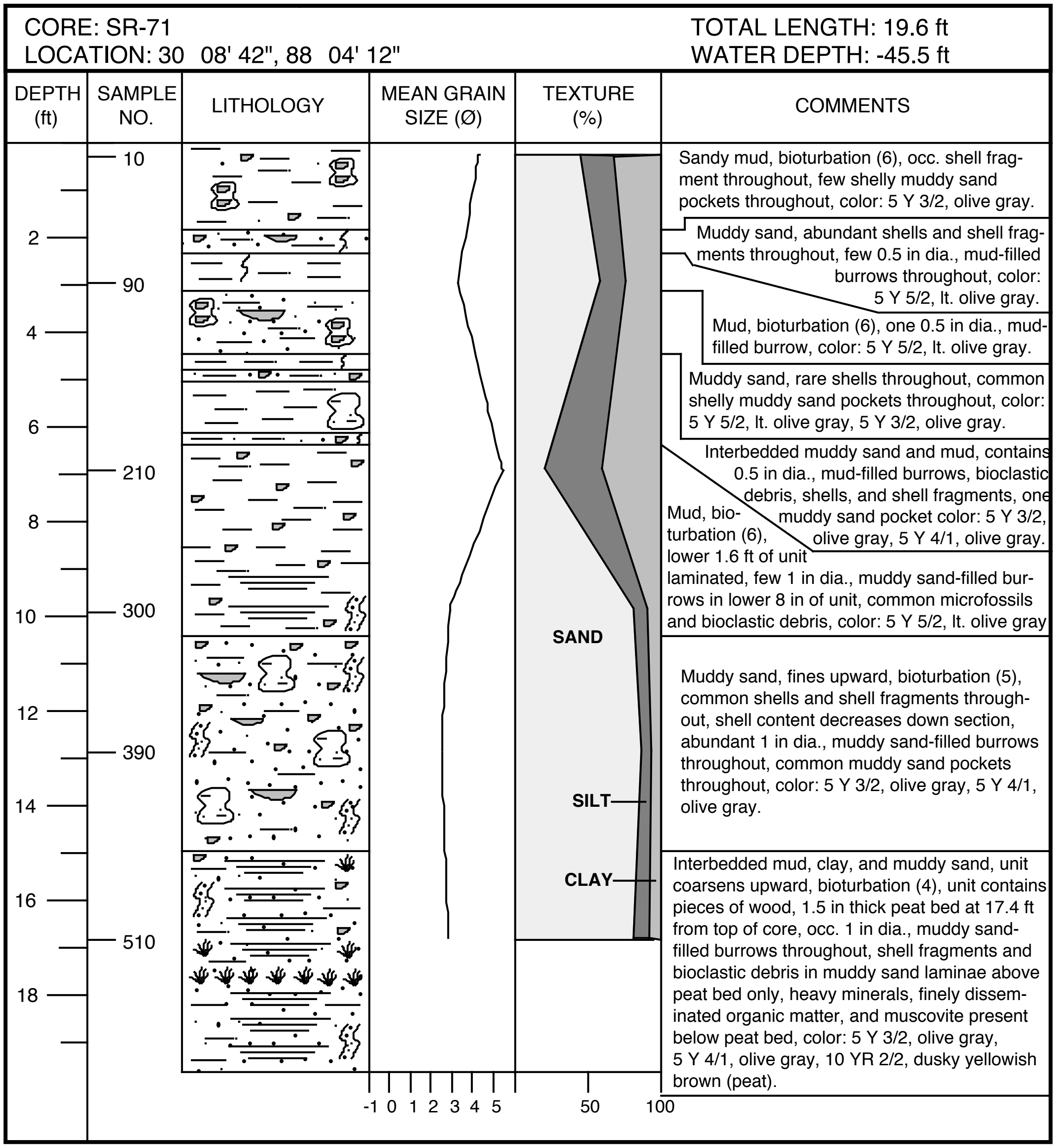

Figure A-22.--Columnar section of EEZ vibracore SR-71.

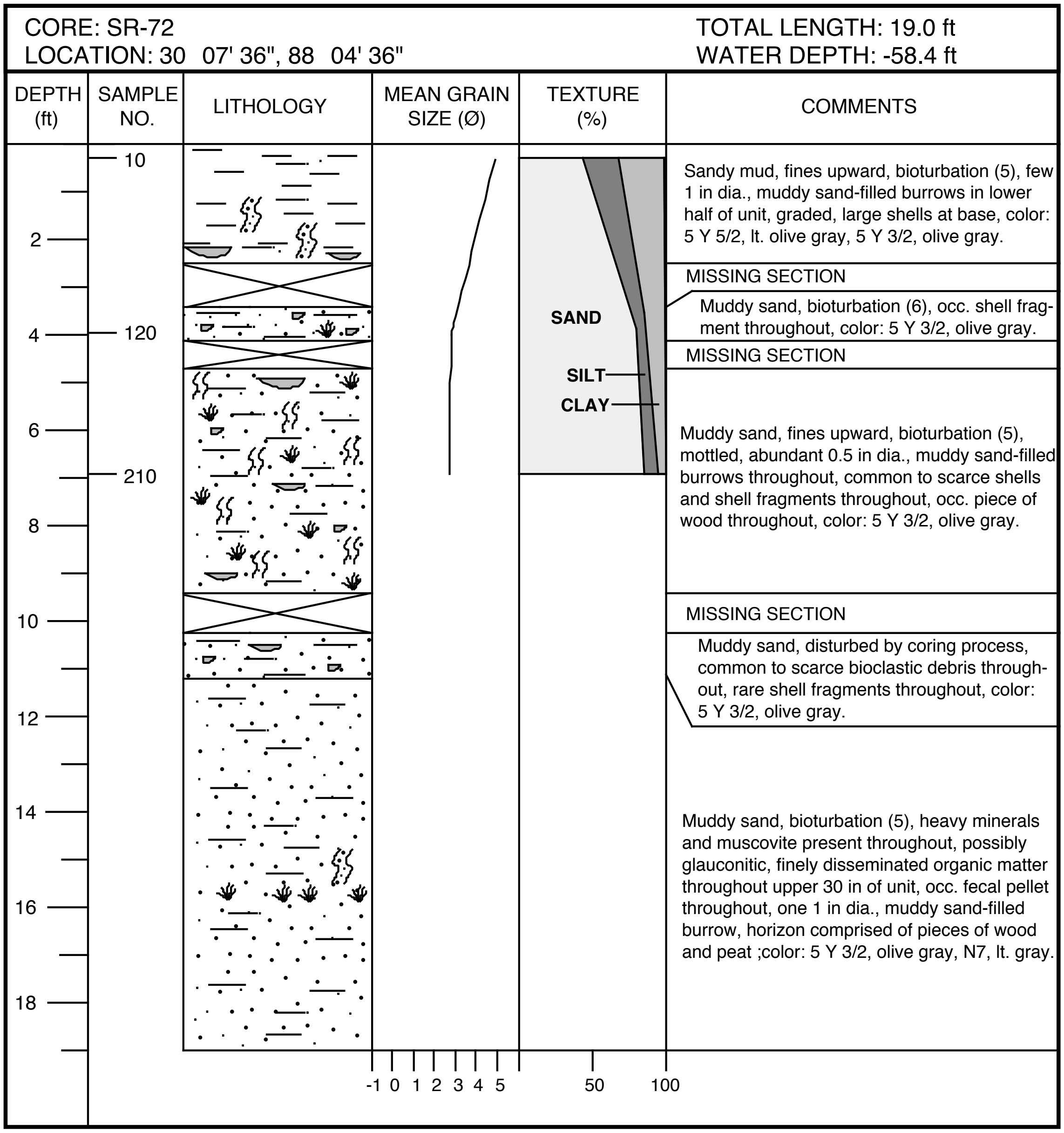

Figure A-23.--Columnar section of EEZ vibracore SR-72.

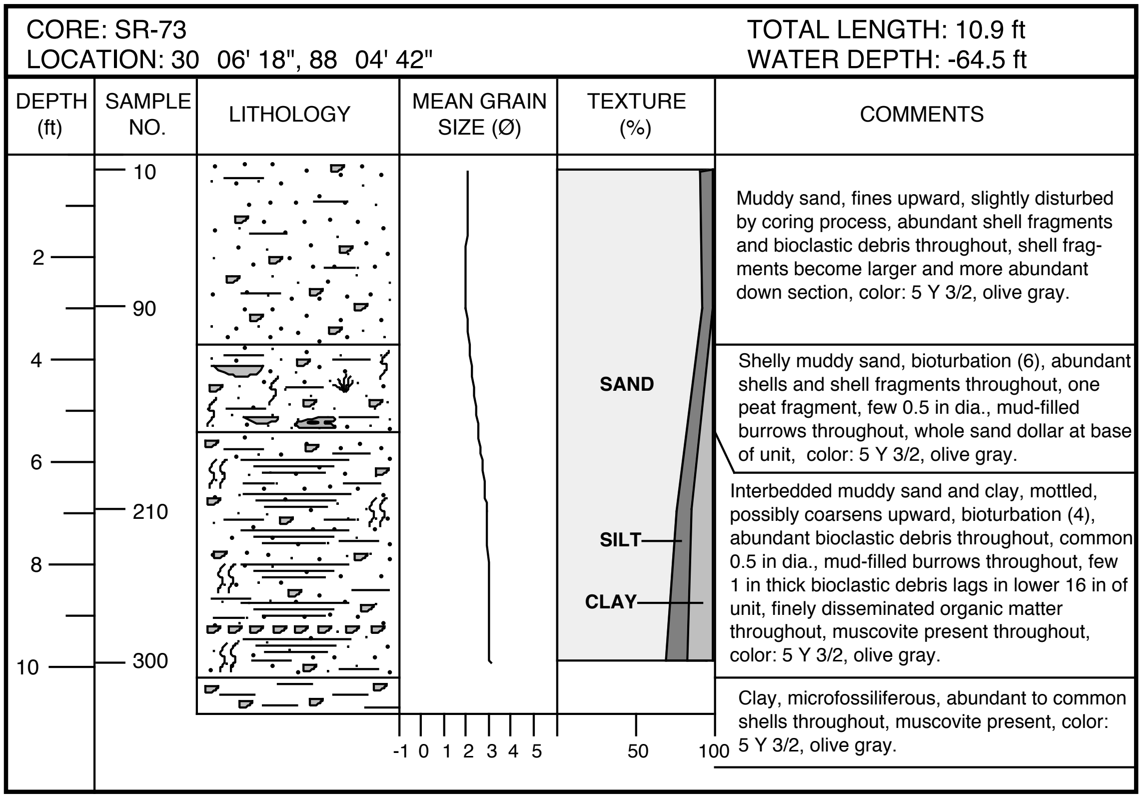

Figure A-24.--Columnar section of EEZ vibracore SR-73.

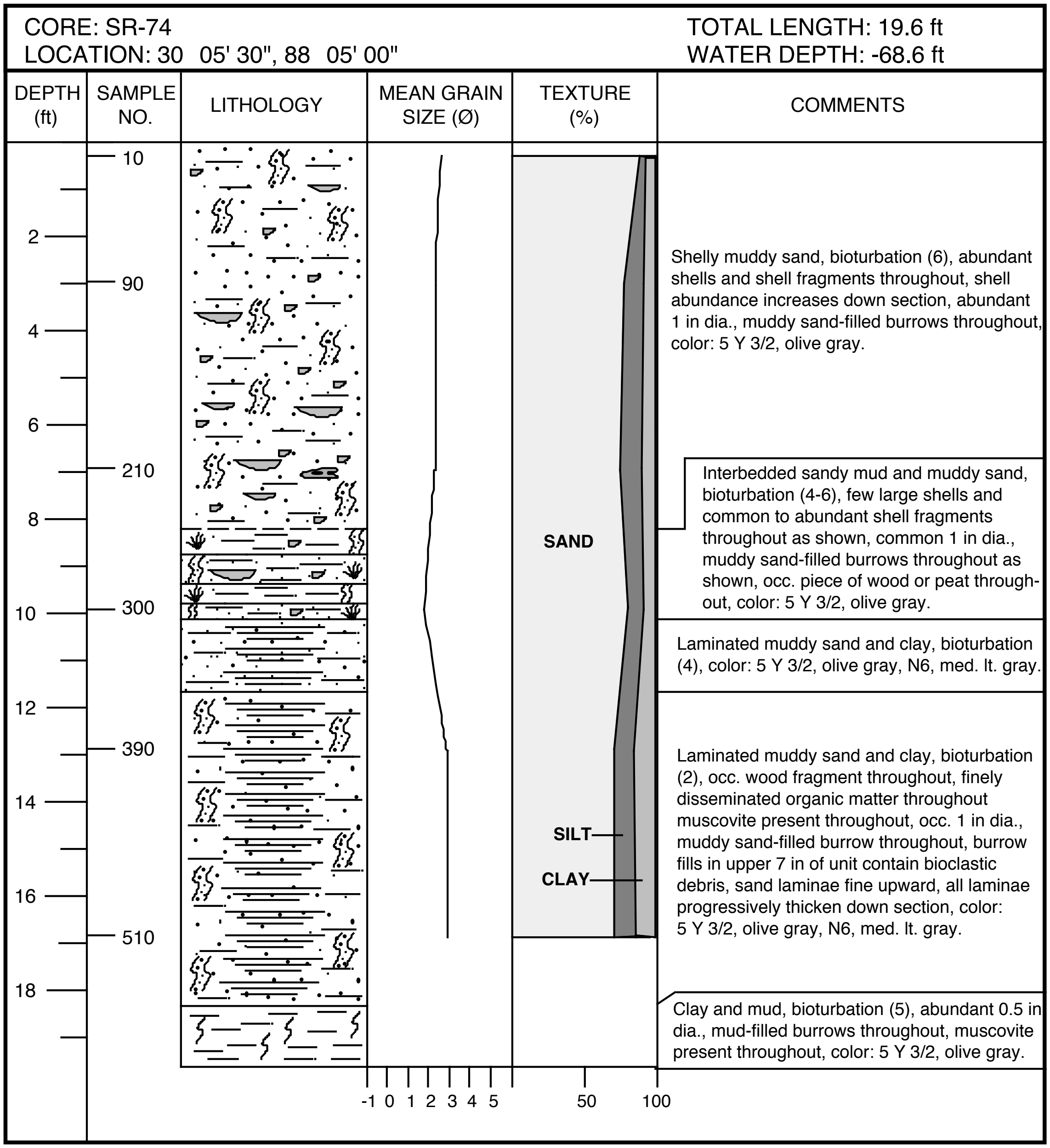

Figure A-25.--Columnar section of EEZ vibracore SR-74.

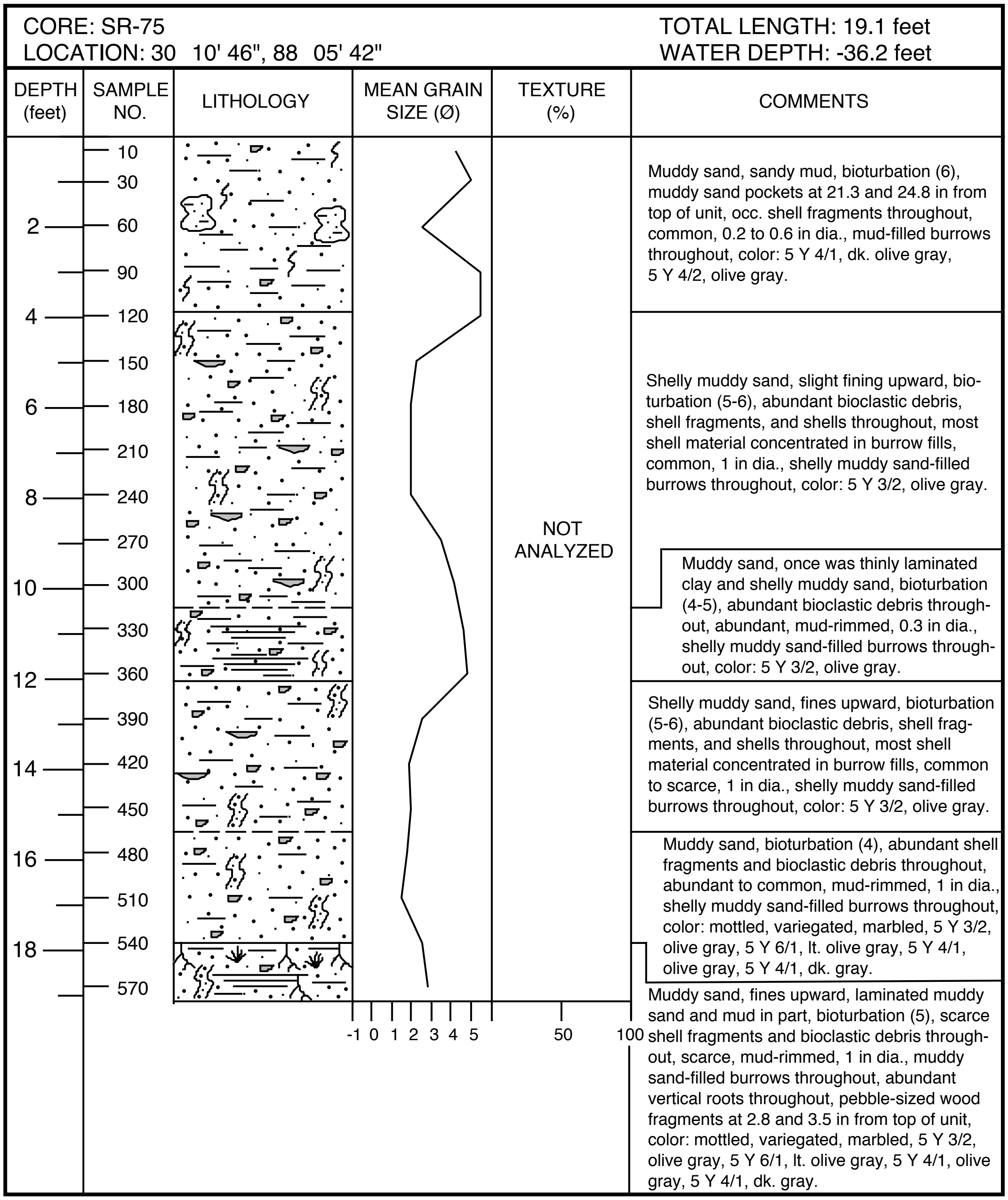

Figure A-26.--Columnar section of EEZ vibracore SR-75.

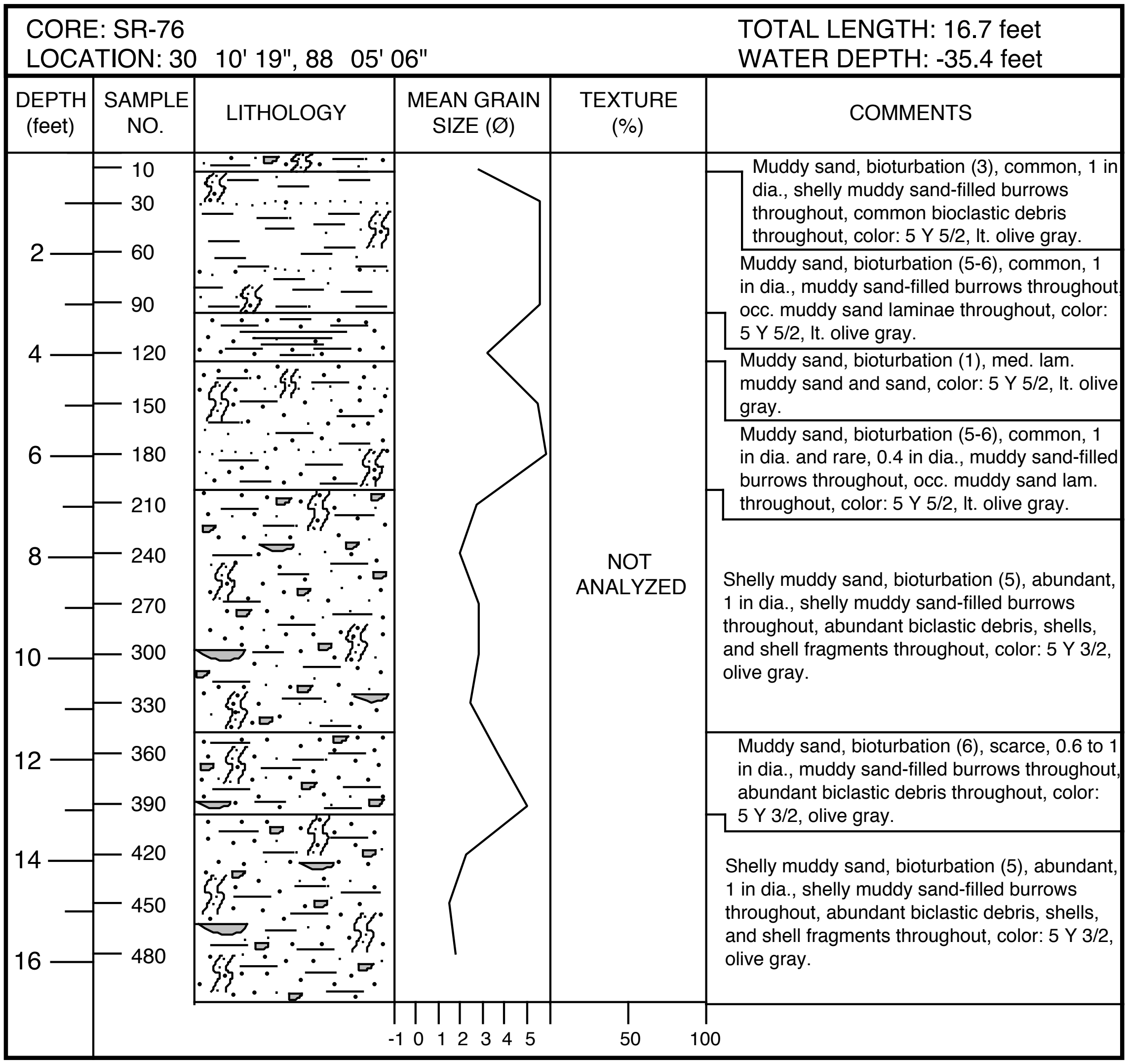

Figure A-27.--Columnar section of EEZ vibracore SR-76.

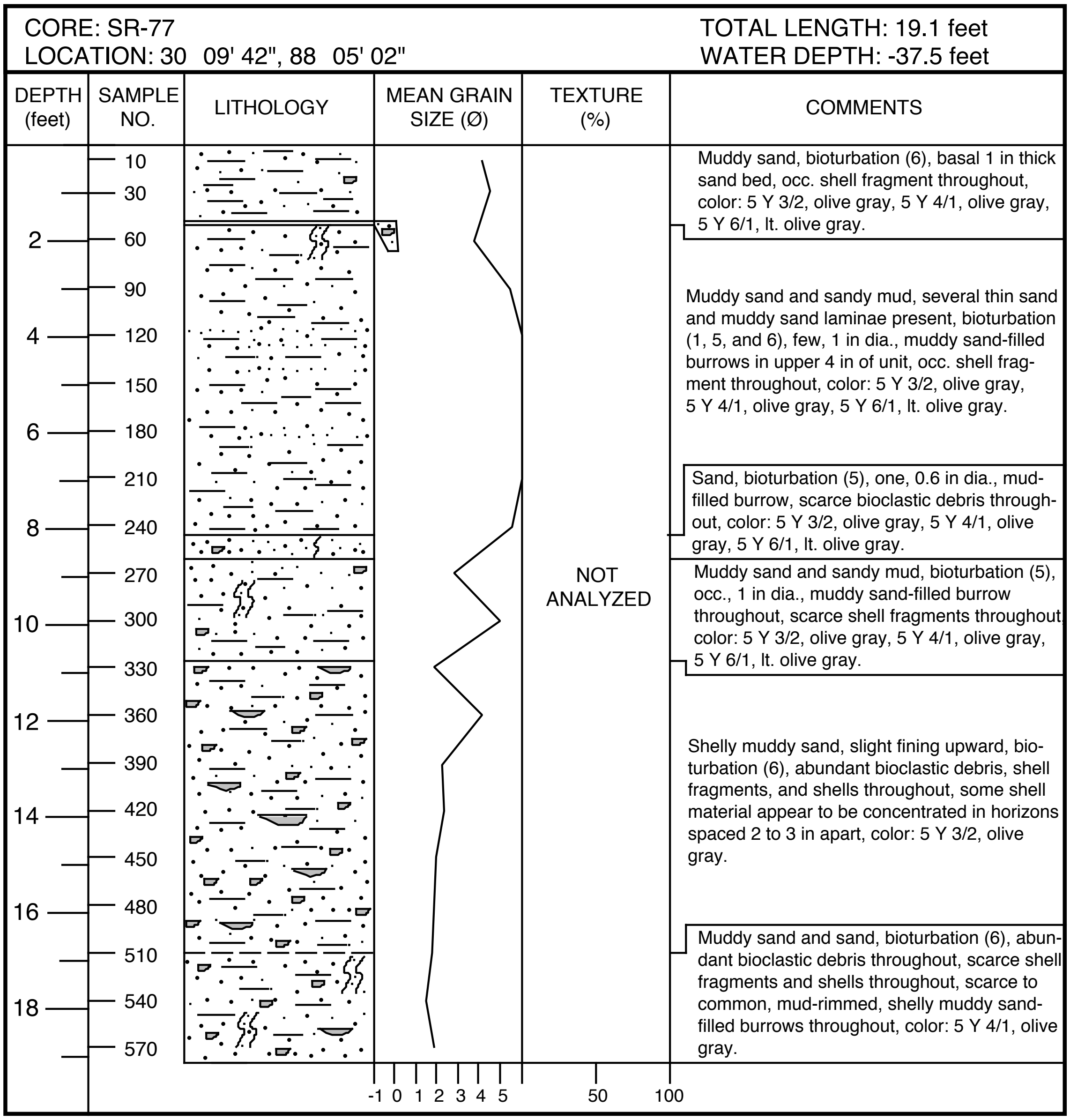

Figure A-28.--Columnar section of EEZ vibracore SR-77.

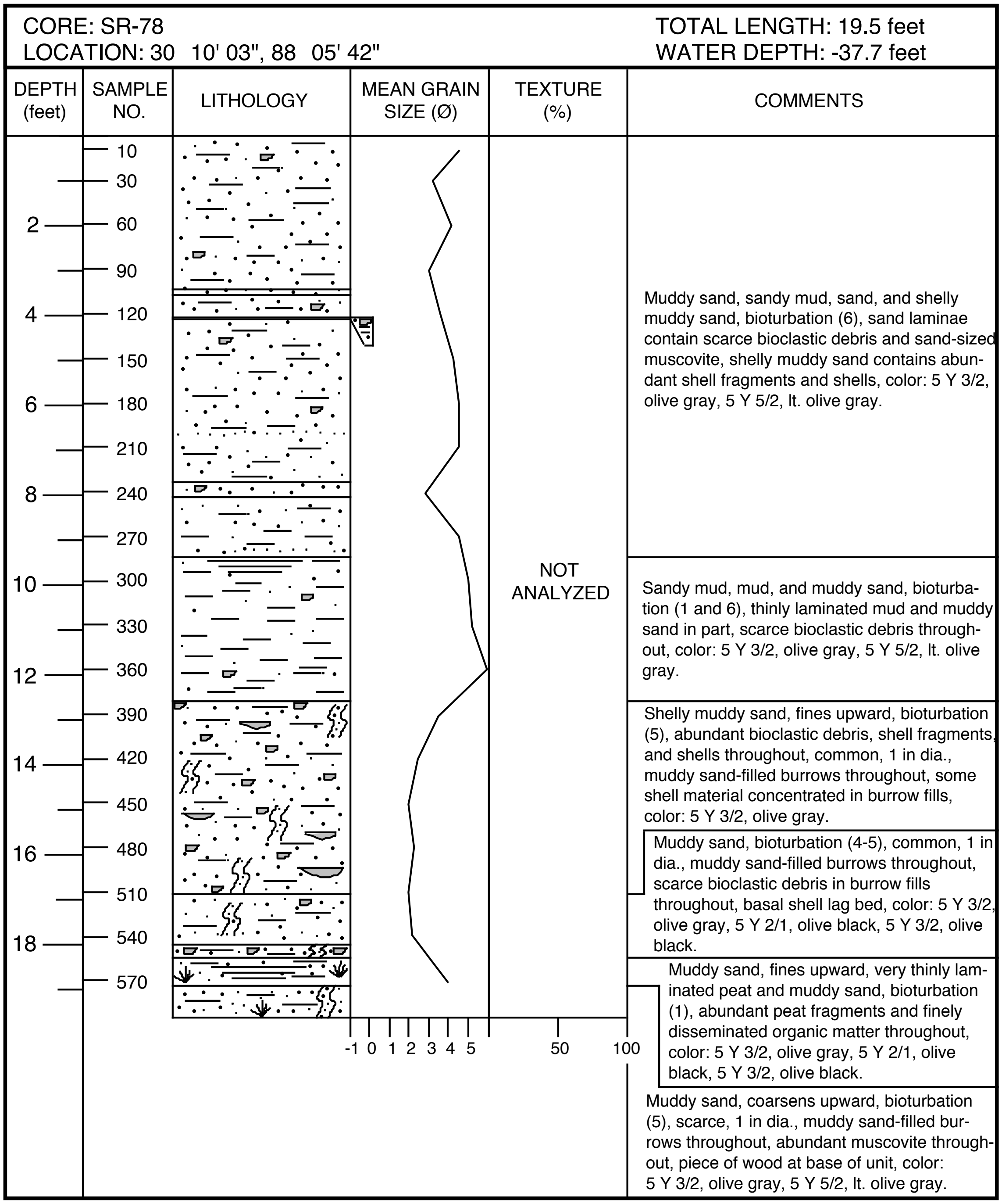

Figure A-29.--Columnar section of EEZ vibracore SR-78.

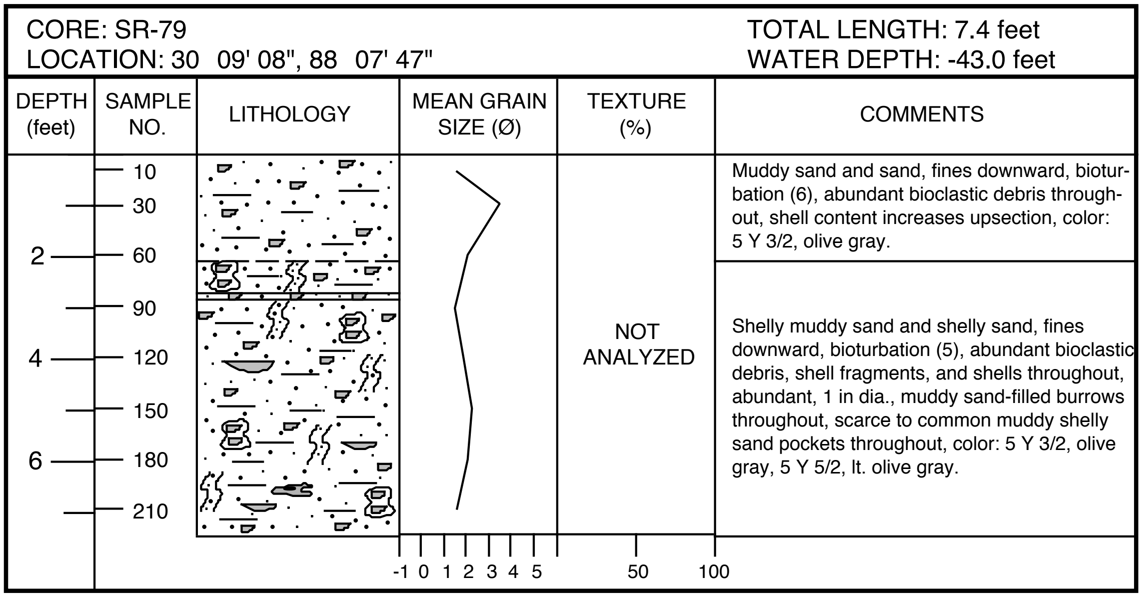

Figure A-30.--Columnar section of EEZ vibracore SR-79.

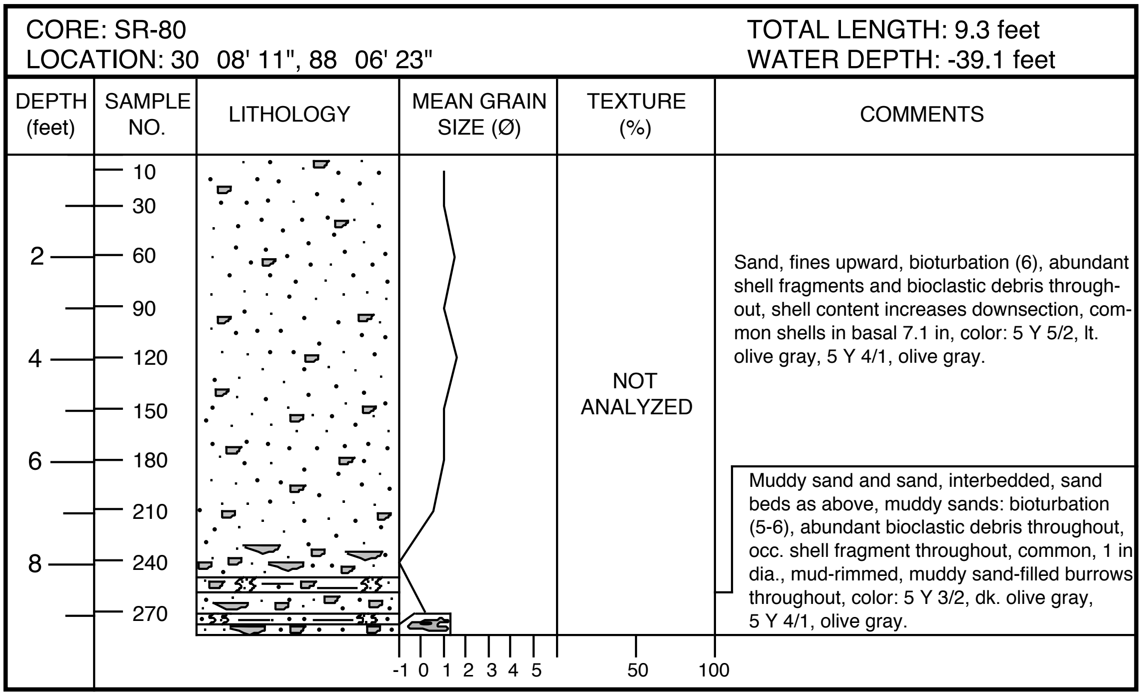

Figure A-31.--Columnar section of EEZ vibracore SR-80.

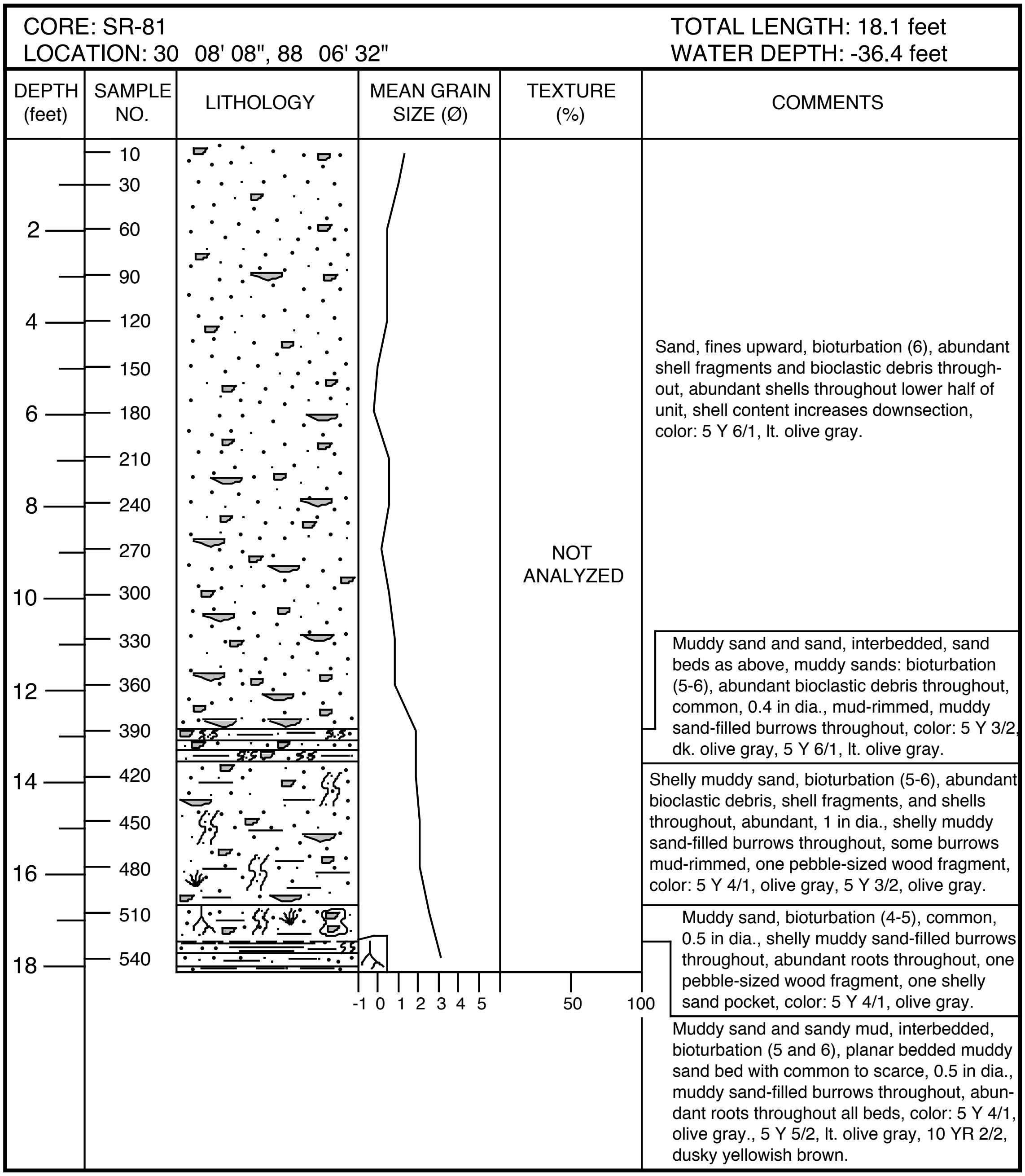

Figure A-32.--Columnar section of EEZ vibracore SR-81.

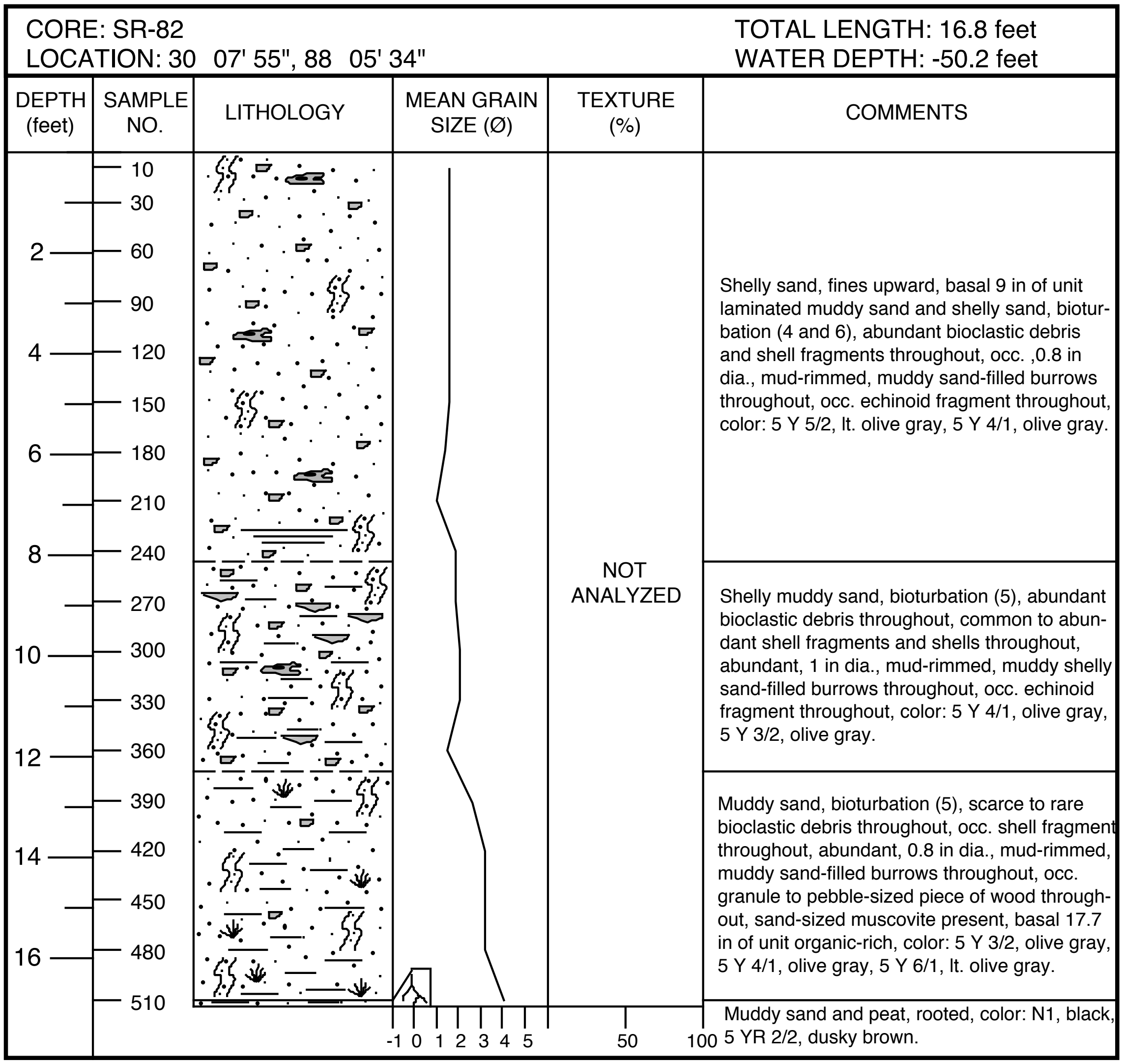

Figure A-33.--Columnar section of EEZ vibracore SR-82.

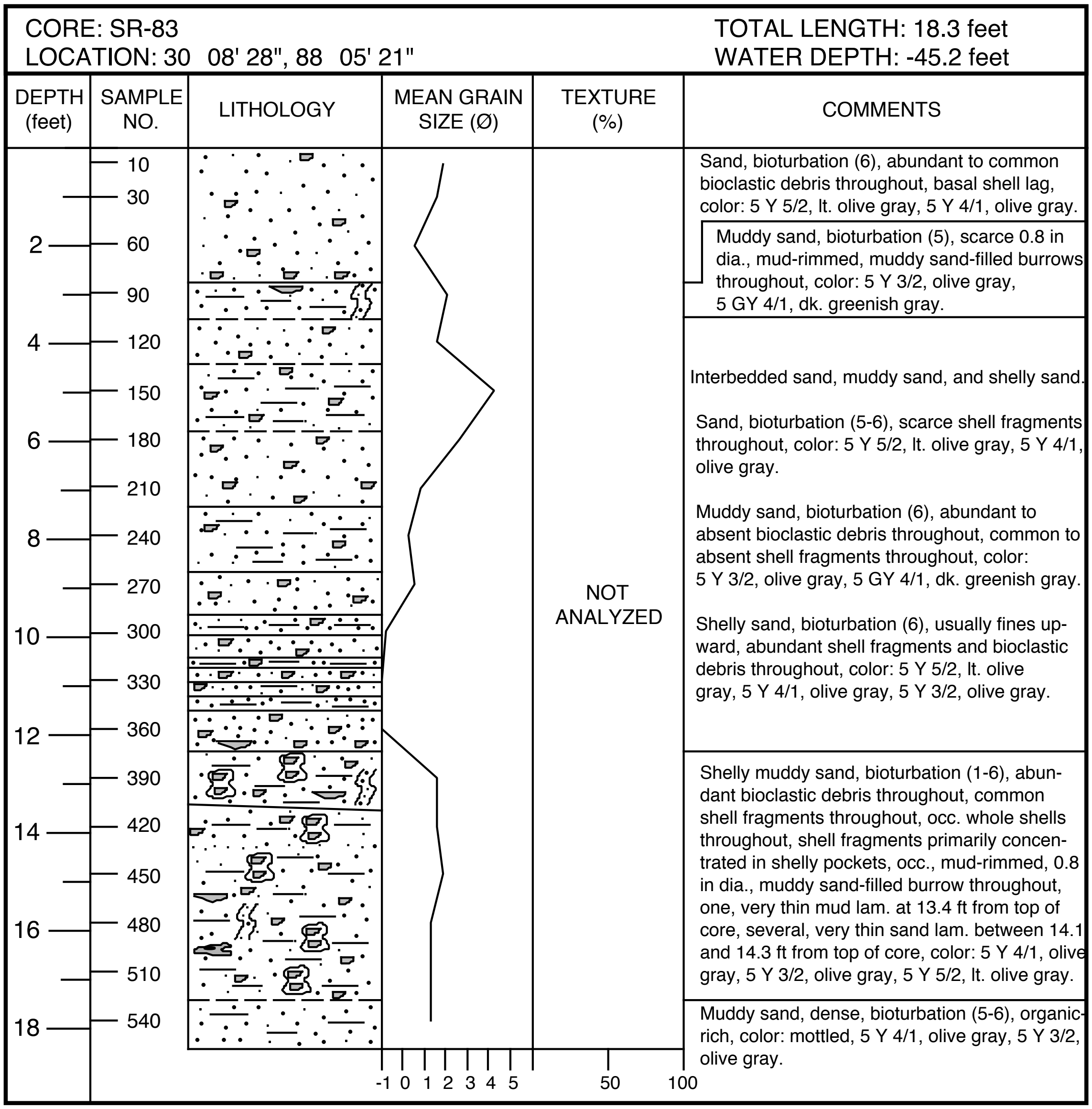

Figure A-34.--Columnar section of EEZ vibracore SR-83.

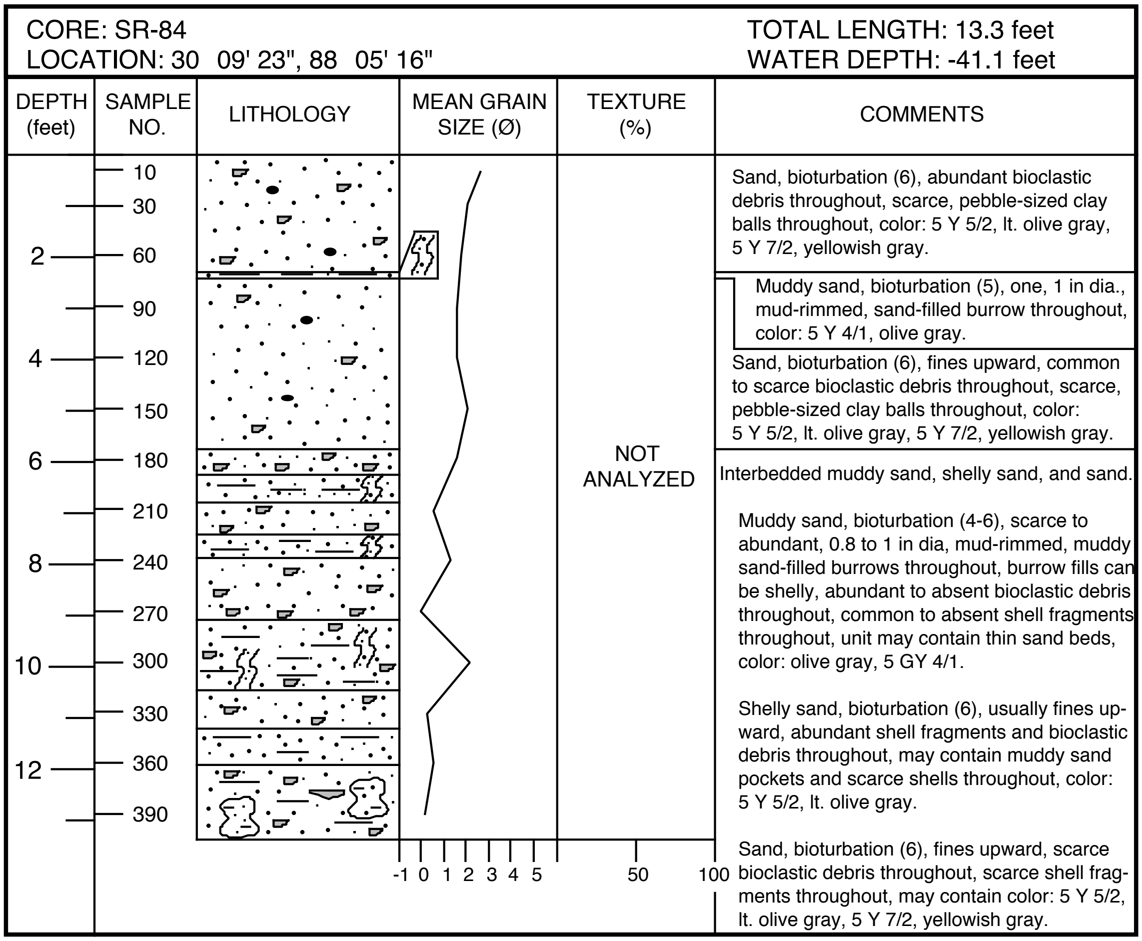

Figure A-35.--Columnar section of EEZ vibracore SR-84.