GEOLOGICAL SURVEY OF ALABAMA

Ernest A. Mancini
State Geologist

Environmental Geology Division
M. Scott Mettee, Director

GEOLOGIC AND ENVIRONMENTAL CHARACTERIZATION AND NEAR-TERM LEASE POTENTIAL 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 fulfillment of U.S. Department of the Interior, Minerals Management Service Cooperative Agreement No. 14-35-0001-30725

Note: this report was originally published in two volumes

Tuscaloosa, Alabama
1995

CONTENTS

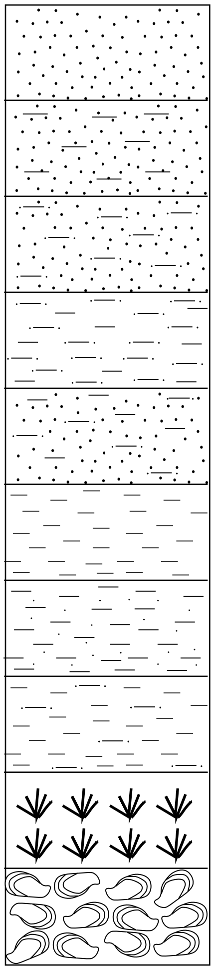
ILLUSTRATIONS

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

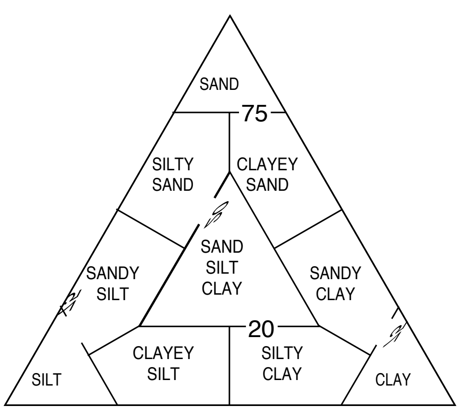
OYSTER BIOSTROME

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)

GEOLOGIC AND ENVIRONMENTAL CHARACTERIZATION AND NEAR TERM LEASE POTENTIAL OF AN OFFSHORE SAND RESOURCE SITE FOR USE IN BEACH NOURISHMENT PROJECTS ON DAUPHIN ISLAND, ALABAMA

by

Richard L. Hummell and W. Everett Smith

EXECUTIVE SUMMARY

Since 1986, the Minerals Management Service (MMS) 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 (non-fuel) 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 is to better characterize the sand resource potential of sand resource target area 4, which appears to have near term lease potential for use in beach nourishment projects on Dauphin Island. Characteristics of southeastern Dauphin Island shoreline sediments were compared with sand resource deposits in sand resource target area 4 to determine the compatibility of these deposits for use in beach nourishment projects. In addition, an evaluation of the physical and biological environmental impacts was completed.

Existing geological data was compiled to delineate the geologic framework of sand resource target area 4. Additionally, this study collected 15 vibracores and 15 bottom sediment samples which were analyzed and modeled with respect to grain size, sedimentary texture, lithofacies patterns, and three dimensional distribution of sediment type.

Evaluation of the geologic framework of sand resource target area 4 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 were analyzed in terms of areal extent and volume of sand, sediment size, and compatibility for beach nourishment. 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 comprised of an estimated 30 million cubic yards of Graded Shelly Sand Lithofacies was discovered in the east-central portion of the study area. The upper surface of this shelf sand ridge is exposed over about 8 square miles of seafloor in water depths ranging from 30 to 60 feet. The sand unit measures up to 11 feet thick at its center and has an average mean grain size, deduced from vibracore sediment samples, of 1.39 phi (medium sand) and average standard deviation of 0.89 phi (moderately sorted). The average major grain size classes for the sand unit are 3.5 percent shell gravel, 94.9 percent sand, 0.5 percent silt, and 1.1 percent clay. Vibracore sediment samples from the sand unit 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.

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 in sand resource target area 4 contains sufficient sand resources (30 million cubic yards) to nourish these shoreline segments and provide additional sand for future nourishment projects as the need arises.

New oceanographic data and 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.

Three types of preliminary environmental analyses were accomplished for this study, including the impacts of offshore sand dredging on shelf circulation; ongoing human marine activities; and local benthic biota. It was determined that dredging may not significantly alter background wave regimes; however, data are insufficient to model effects of major storms. Any dredging activities would need to avoid man made structures, shipping fairways, and archaeological sites. In general, this study has indicated that the biological impact of a dredge operation on the Graded Shelly Sand Lithofacies sand body would be reserved to sessile and slow moving benthic invertebrates living at the sand mining site and, possibly, those living at the point of sand discharge along the shoreline. Dredge produced turbidity is not considered to be a major environmental concern. All other species of invertebrates and vertebrates probably would not be impacted as they would avoid the dredge area. Sites of killed benthic invertebrates are expected to be recolonized in a series of successionary stages to their pre-disturbed levels of species diversity and abundance within an estimated two years. Additional work is required to confirm or refute these preliminary findings, however.

This study concludes that since much of the Alabama shoreline is undergoing significant, long-term erosion, critical threatened shorelines will need to have ongoing programs of replenishment if shoreline retreat is to be even temporarily halted. For the Alabama coastal zone, there are no local onshore volumes of appropriate sand available for any such large scale program. Sand resource target area 4 appears to hold sufficient reserves of appropriate sand resource material to nourish eroding southeastern Dauphin Island shoreline segments. A detailed geological, economic, and environmental evaluation of the Graded Shelly Sand Lithofacies sand unit is needed prior to initiation of dredging to ensure a cost-effective and environmentally sound mining program.

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 M. D. Fertitta, Mobil Exporation and Producing U.S. Inc. and the use of the Mobil dock on Dauphin Island for embarkation and disembarkation is appreciated.

Exxon Company, U.S.A. donated foundation boring logs and accompanying sediment samples in support of the geologic framework research.

We are indebted to Mark Vanhoose, Alabama Department of Conservation and Natural Resources, Marine Resources Division; and Kenneth J. Savastano and Rick Minkler, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Fisheries Service, Southeast Fisheries Science Center, Mississippi Laboratories, Stennis Space Center for providing the SEAMAP biological database for sand resource target area 4.

We wish to thank David J. Davies 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 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 (non-fuel) 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 and 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).

The present study, by the GSA, is aimed at continuing the goals of the Gulf Task Force. The primary objective for this study is to better characterize sand resource target area 4 (area 4), which appears to have near term lease potential for use in beach nourishment projects on Dauphin Island.

Research focused on the acquisition of additional data to determine shoreline loss for the period 1985-1993 along eroding Dauphin Island Gulf of Mexico shoreline segments. This data combined with shoreline loss determinations made by Parker and others (1993) for the period 1955-1985, will result 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. Prior research by the senior author on the ebb-tidal delta and nearshore Gulf of

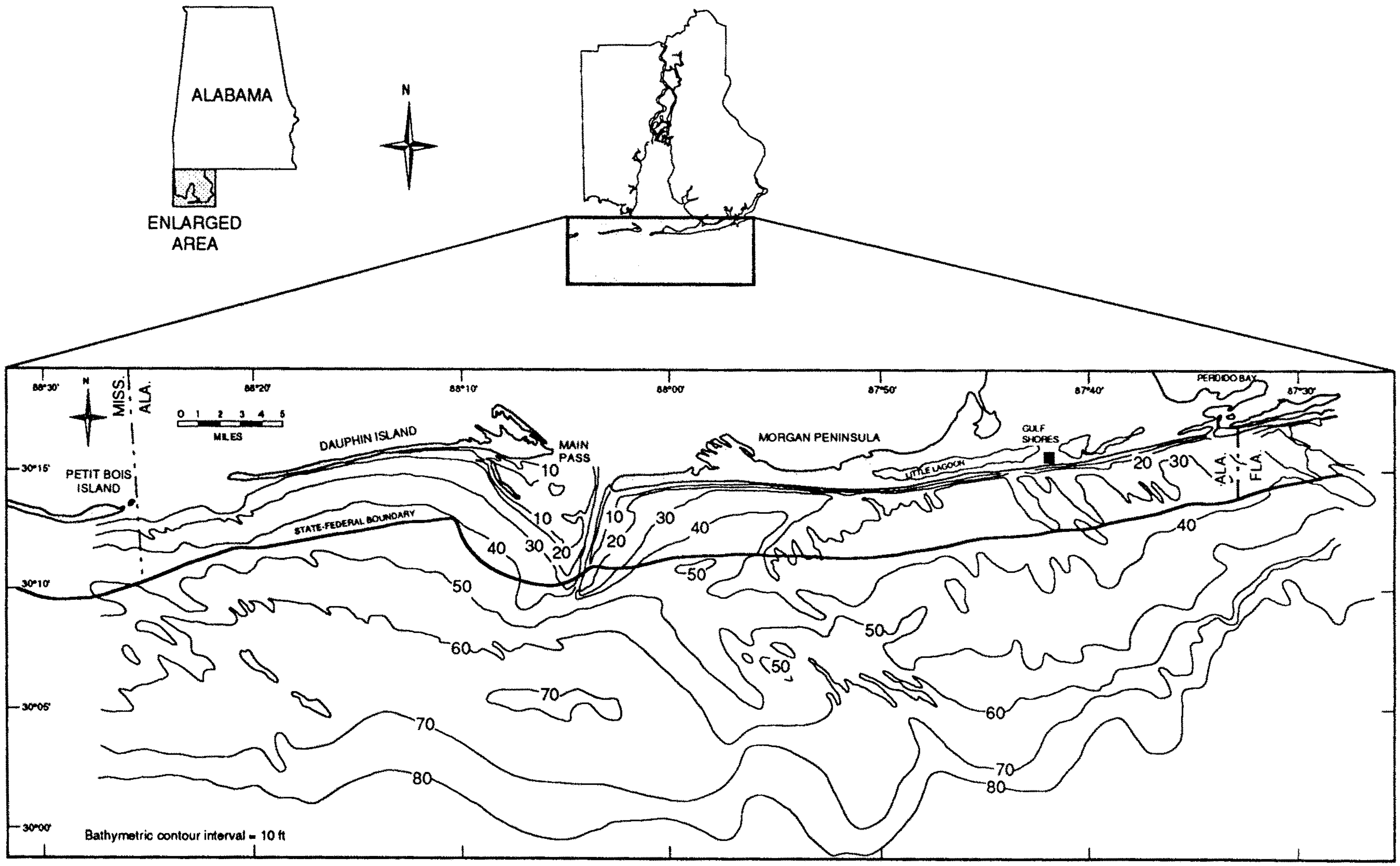


Figure 1.--Map of the Alabama EEZ (modified from Parker and others, 1993)

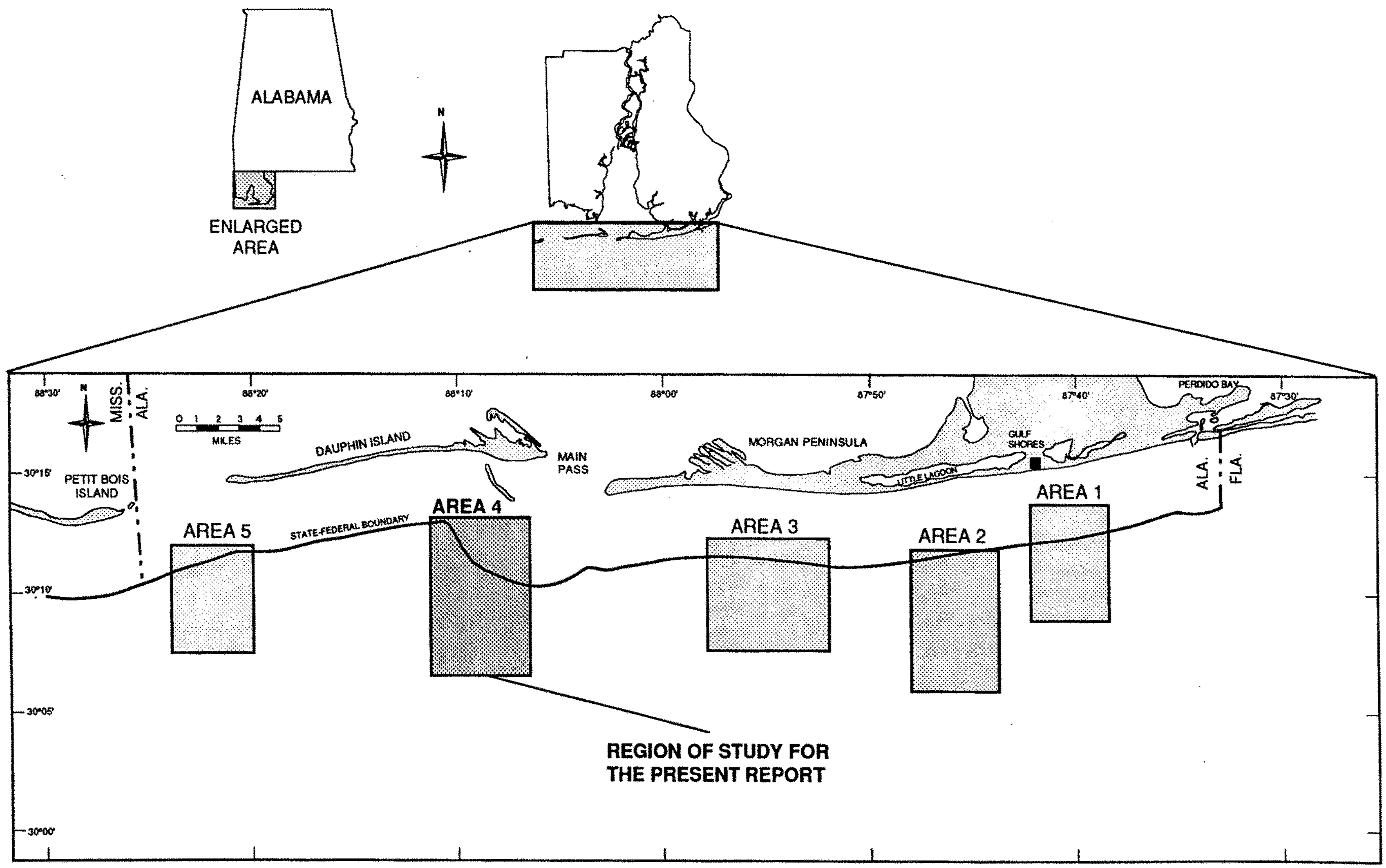


Figure 2.--Index map for EEZ sand resource target areas (modified from Parker and others, 1993).

Mexico (Hummell, 1990; Geological Survey of Alabama, 1993), 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 (Geological Survey of Alabama, 1993). 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) (Geological Survey of Alabama, 1993).

In light of these findings, it is 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. This study 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.

Similarly, there is a need to develop 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.

TASKS ACCOMPLISHED AND APPROACH FOLLOWED

The objectives of this study were to be accomplished through completion of six tasks designed to better characterize area 4, which appears to have near term lease potential for use in beach nourishment projects on Dauphin Island. The plan of study was designed to ensure that a coordinated effort was

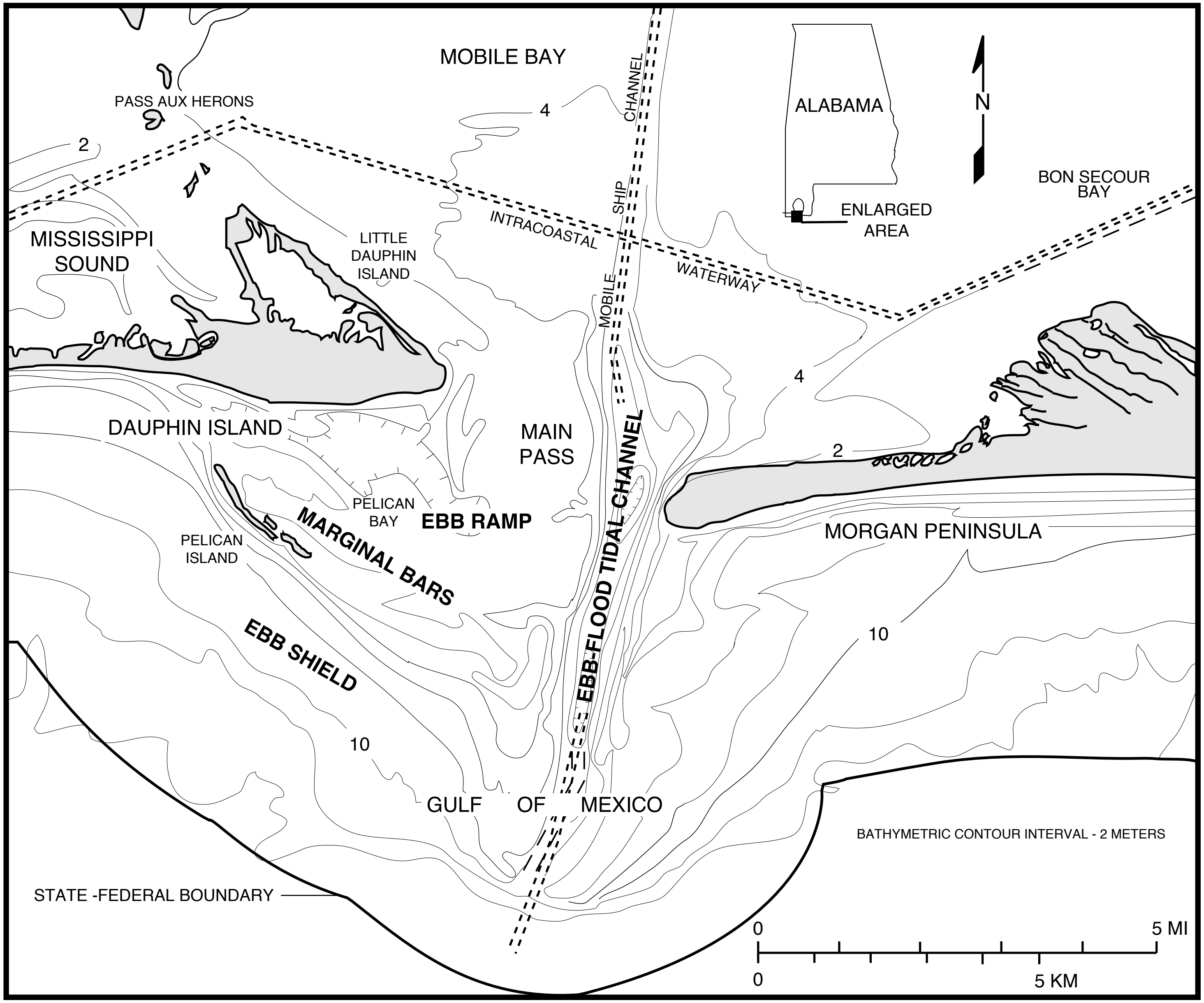


Figure 3.--Geomorphology of the ebb-tidal delta of Mobile Bay (modified from Hummell and others, 1993).

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. Prior knowledge of the geologic framework for area 4 was to be delineated. The approach utilized was to evaluate available published information and ongoing regional stratigraphic work of the GSA to determine onshore and offshore near surface stratigraphy and shelf morphology in area 4.

2. Assessment of shoreline loss for eroding Gulf of Mexico shoreline segments on eastern Dauphin Island for the period 1985-1993 and estimation of sand volume required to restore the most critically eroding segments of island shoreline to their 1955 positions was to be accomplished. The approach to accomplish this task was to obtain the needed data from ground surveys and photogrametric measurements of selected shoreline transects and bathymetric measurements adjacent to these transects. In addition, detailed analysis of beach sediment samples taken in conjunction with beach transects in the proposed restoration areas will be utilized to further delineate required grain size and aesthetic characteristics for replenishment materials. A determination was made of the fate of replenishment sand within specified time frames under present shoreline conditions.

3. Detailed geologic and resource characterization of sand deposits in area 4 was to be accomplished by the acquisition of additional geologic data and resource evaluation of identified target sand bodies. The approach followed was to utilize pre-existing vibracores, borings, seismic data, and prior research findings to collect a minimum of 10 additional vibracores to more accurately describe the sand deposits in area 4 and identify and characterize target sand bodies to ensure a cost-effective dredging operation. In addition, grain size, percent sand, sand thickness, and aesthetic quality was described to determine the resource potential of sand deposits in area 4. These data were compared to sediment characteristics of the eroding shoreline segments to estimate overfill factors and to determine if deposits in area 4 met volume requirements for replenishment and future maintenance of eroding southeastern Dauphin Island shoreline segments.

4. Benthic and nektonic faunal analysis of area 4 to identify the long-term community baseline and present benthic community structure as a prelude to a detailed faunal analysis of the target sand body and vicinity. The approach was to compile pre-existing biological data for area 4 and add the results of a preliminary benthic survey of sea bottom grab samples (bottom samples) collected at new vibracore locations. The data provided a means of tentatively identifying benthic communities and possible benthic community structure. To determine the composition of the area 4 fauna, reveal the existence of any endangered species, and identify benthic and nektonic organisms that might be impacted in a dredging operation, was necessary to compile biological data collected by more than one sampling methodology. Bottom samples provided a sample of sessile or slow moving fauna living on or within the upper several centimeters of the sea bottom, but did not provide information about larger, fast moving, or nektonic species which might be impacted by a dredging operation. The probability of capturing many of the species living in or on the sea bottom with a sea bottom grab sampler was small due to insufficient penetration of the seafloor by the sampling devise, small surface area sampled, or the ability of species to escape.

5. Additional geologic data to adequately describe sand resource sites in area 4 was to be acquired. The approach to accomplish this task required that sufficient bottom samples and vibracores be collected during the study to adequately determine the geologic framework of the study area and to characterize any target sand bodies.

6. Assessment of the physical processes in area 4 and eroding shoreline segments on southeastern Dauphin Island. Pre-existing wind wave, current, and tide data was collected and evaluated for area 4 and for the eroding shoreline segments on southeastern Dauphin Island. These data would aided in determining potential impacts of sand dredging and beach replenishment projects and estimating sand volume requirements for future maintenance after initiation of beach replenishment projects.

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

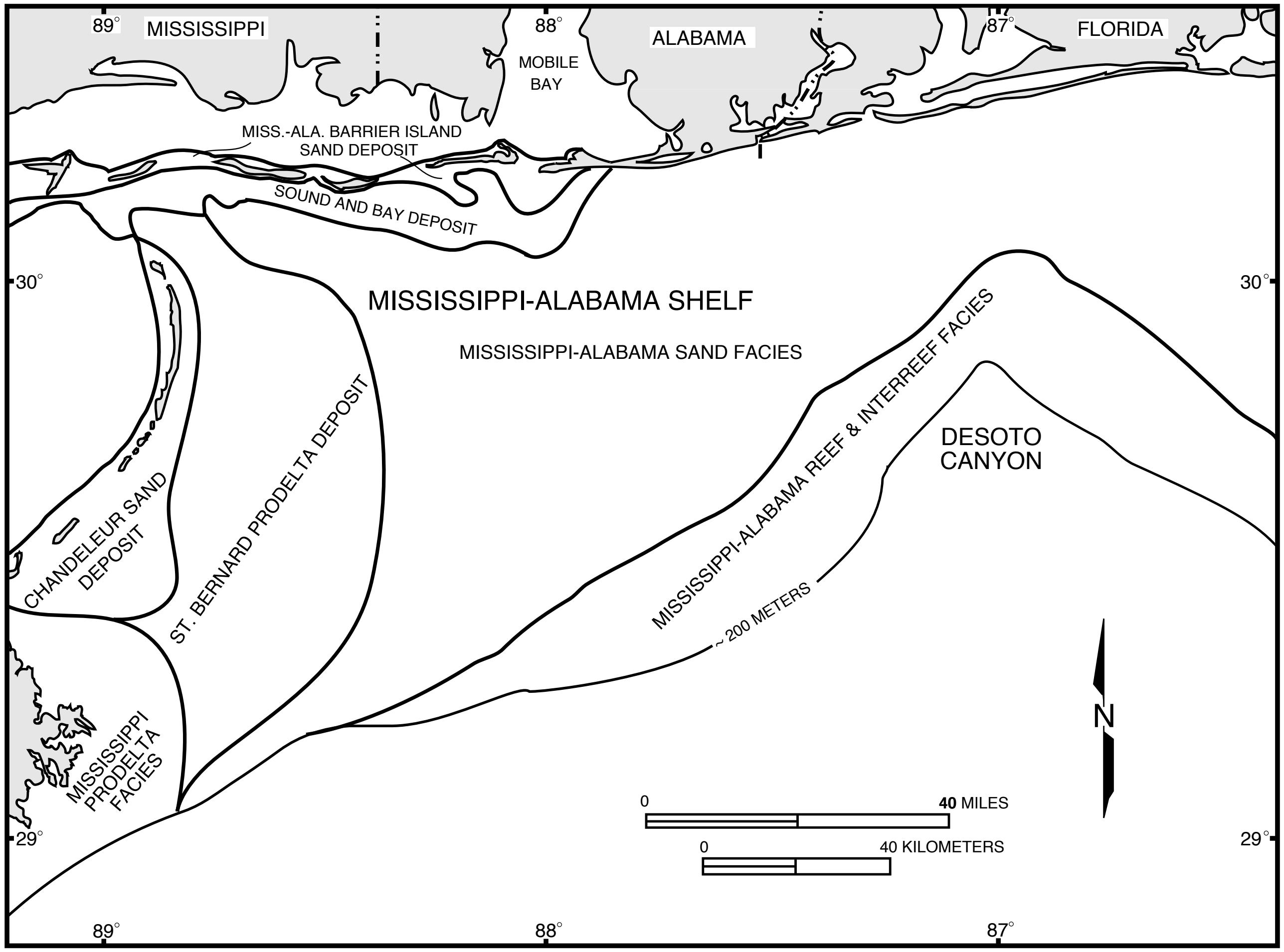


Figure 4.--Sedimentary facies on the Mississippi-Alabama shelf (modified from Ludwick, 1964; Boone, 1973).

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 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

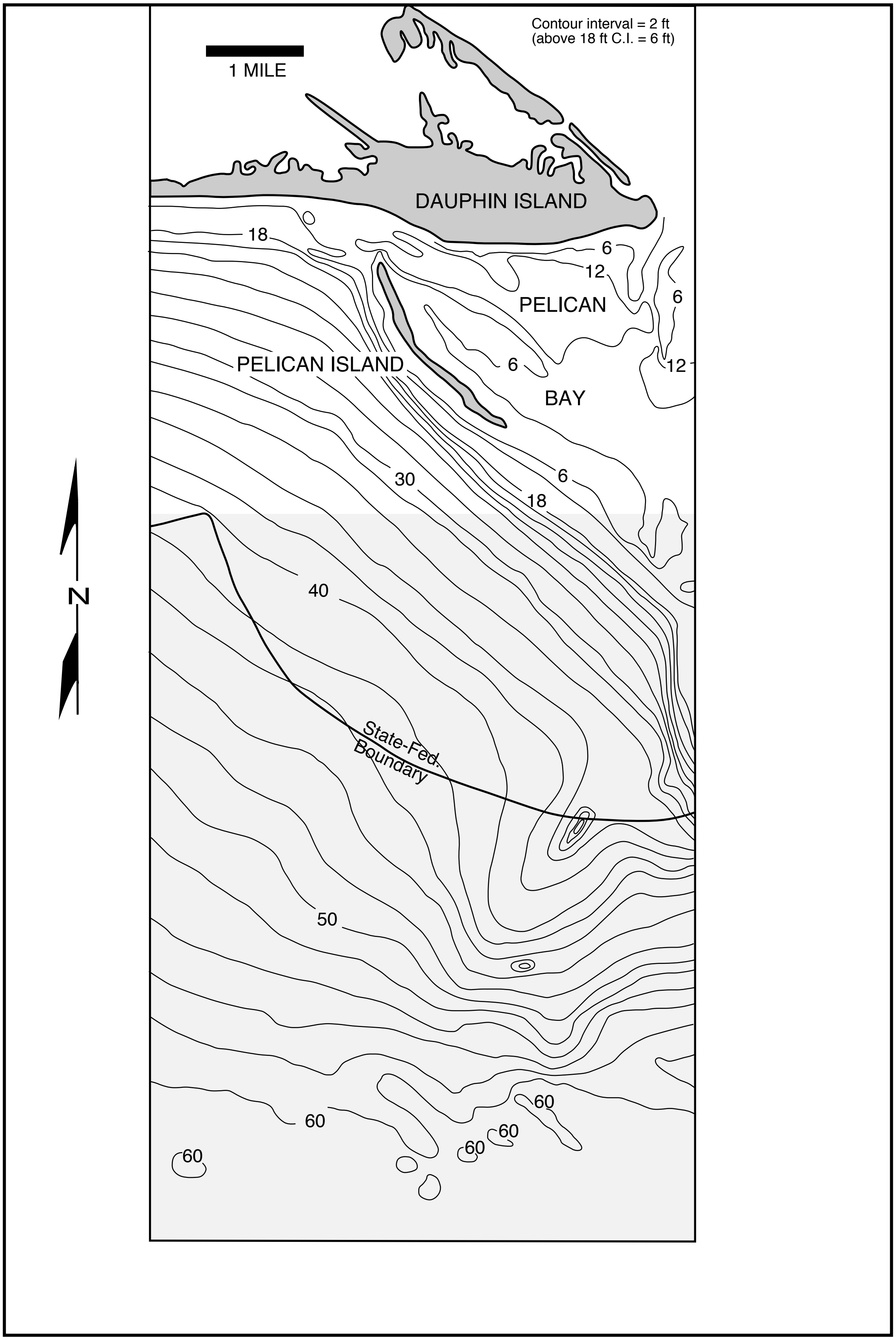


Figure 5.--Map of sand resource target area 4.

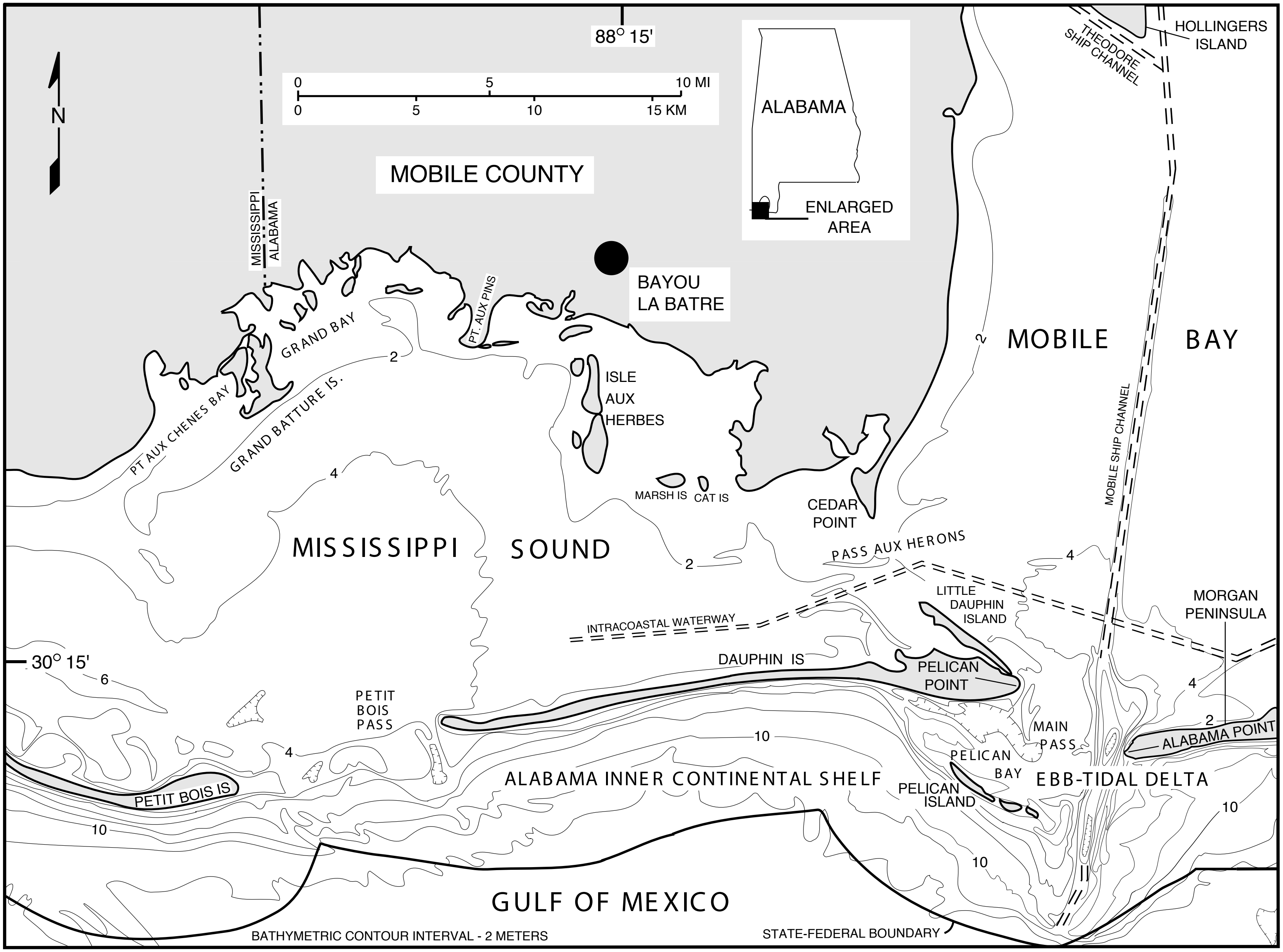


Figure 6.--Map of coastal Alabama showing the west Alabama inner continental shelf (modified from Hummell and others, 1993).

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 and 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, B. A., and Associates, Inc., 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, B. A., and Associates, Inc., 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 high rainfall over coastal Alabama. Rainfall 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.

CURRENTS AND CIRCULATION

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 both direct measurement and remote sensing techniques. These studies include Schroeder (1976, 1977a, 1977b, 1978a, 1978b, 1979), Schroeder and Lysinger (1979), Schroeder and Wiseman (1986), Wiseman and others (1988), Dinnel (1989), Stumpf and Pennock (1989), Stumpf and Gelfenbaum (1990), and Geological Survey of Alabama (1991, 1992, 1993). Several computer modeling studies of water circulation in Mobile Bay and Mississippi Sound have been carried out over the past two decades (see for example U.S. Army Corps of Engineers, 1984).

Circulation patterns in Mobile Bay and nearshore Alabama are controlled by the tides, river discharge into Mobile Bay, configuration of the coast and Mobile Bay, wave approach and wave energy, bathymetry and the Coriolis Force. The ebb- and flood-tides that flow into and out of Mobile Bay through Main Pass are of approximately equal duration, about 6 hours each (Chermock and others, 1974; Moser and Chermock, 1978). The change from flood to ebb to flood produces periods of slack water in Mobile Bay with zero current velocity (Chermock and others, 1974). When the rate of fresh water discharge into Mobile Bay from the Mobile-Tensaw River system is high, flood tide velocity slows and ebb tide velocity increases. The reverse is true when fresh water discharge is low. Fresh water has a lower specific gravity than salt water, so it tends to float on the surface. This can result in fresh water flowing southward over northward-moving saline water from the Gulf of Mexico.

The ebb and flood-tidal current patterns in the ebb-tidal delta region have not been studied. However, ebb/flood-tidal current data collected southwest of the study area (U.S. Army Corps of Engineers, 1985b), and south of the study area (Kjerfve and Sneed, 1984; Dinnel, 1989), plume studies (Abston and others, 1987), and the shape of the ebb-tidal delta itself, suggest that most flood waters flow into Mobile Bay through Main Pass from the south to east following the Mobile Ship Channel. Ebb-tidal waters appear to flow out of Mobile Bay, again following the ship channel, but southeasterly winds seem to force the surface water to flow down the west side of Main Pass and a significant portion empties into Pelican Bay and exits through Pelican Pass into the Gulf of Mexico (Abston and others, 1987). Longshore currents usually direct the exiting water masses toward the west unless offset by a strong westerly wind, in which case the water masses move southward or even eastward (Abston and others, 1987).

In the study area and vicinity, longshore currents generally flow from southeast to north-northwest at rates of 1 to 3 mph in response to prevailing wind and wave patterns out of the southeast (Chermock and others, 1974). These rates increase to 3 to 6 mph during incoming tides (Chermock and others, 1974). 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 (1955) 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.

NEARSHORE GULF OF MEXICO HYDROLOGY

Nearshore Gulf of Mexico waters can be periodically dominated by the Loop Current. However, sustained winds from the southeast provide the primary driving force that control water movements in the nearshore Gulf of Mexico (Vittor, B. A., and Associates, Inc., 1985). The prevailing wind and horizontal density gradients influence currents on the shelf. A southwesterly onshore wind results in a transient onshore-offshore two-layer flow system (onshore flow in the surface waters and offshore flow in the bottom waters) (Vittor, B. A., and Associates, Inc., 1985). Because the winds and waves are dominantly from the southeast (and therefore oblique to the approximately east-west orientation of the shoreline) water mass moves in a westerly directed spiral pattern down the coast (littoral drift). In addition to wind, waves, and the Loop Current, water circulation is strongly affected by the wind duration, water density stratification, and coastal geometry. Tidal forces and river flow influence Gulf of Mexico current movements to a lesser extent.

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, B. A., and Associates, Inc., 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, B. A., and Associates, Inc., 1985). In general, water temperature conforms less to air temperature with greater distance from shore and greater depth of the water column (Vittor, B. A., and Associates, Inc., 1985).

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, B. A., and Associates, Inc., 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, B. A., and Associates, Inc., 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, B. A., and Associates, Inc., 1985).

SURFACE SEDIMENTS OF AREA 4 AND VICINITY

The Mobile-Tensaw River system drains approximately 34,600 square miles in the states of Alabama, Georgia and Mississippi (Mettee, 1989). These areas include terrains of the Appalachian Valley and Ridge, Plateau, Piedmont, and Gulf Coastal Plain (fig. 7). 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. 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-

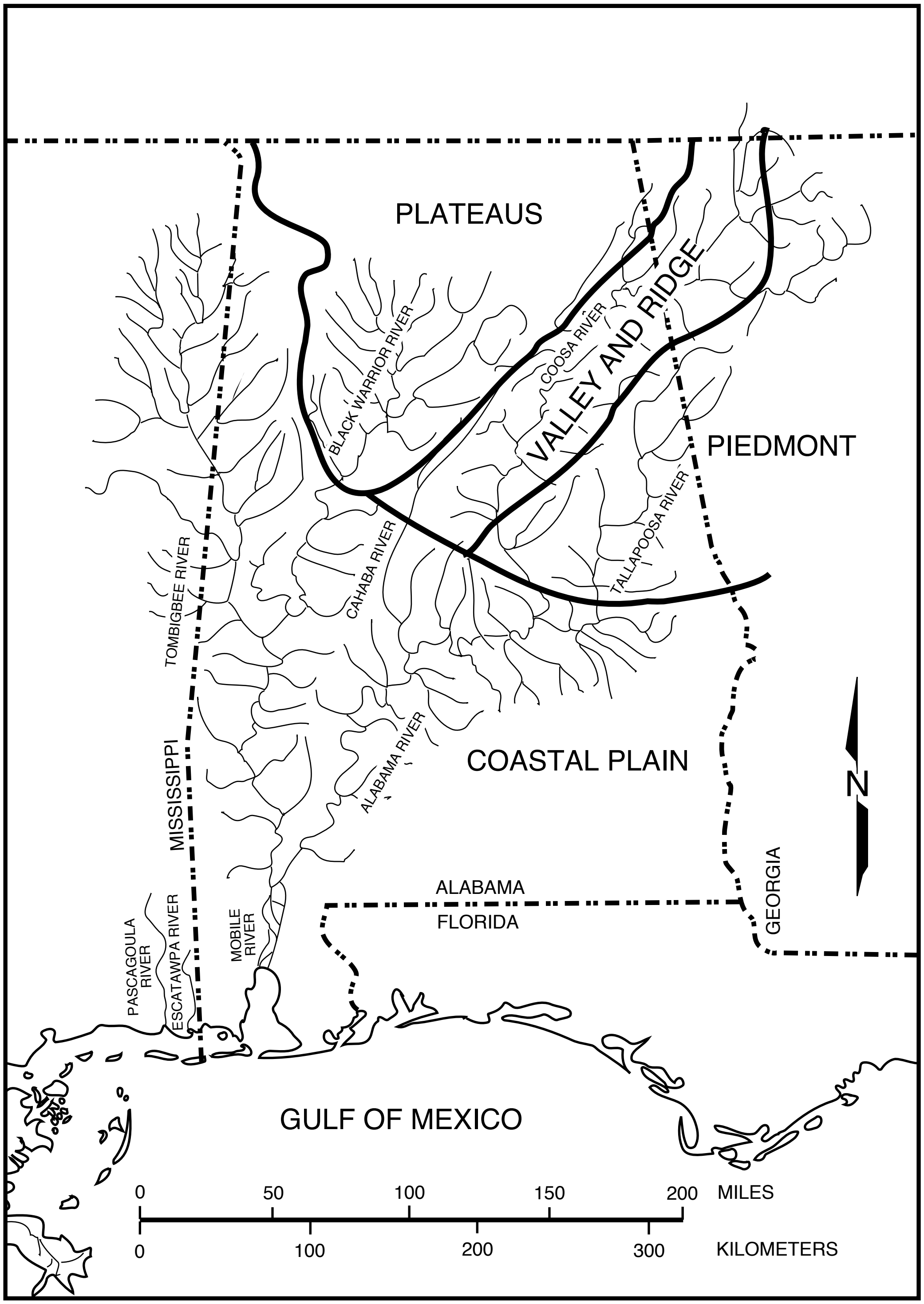


Figure 7.--Mobile River drainage basin (modified from Hardin and others, 1976).

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 this study 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. 8). 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 the present

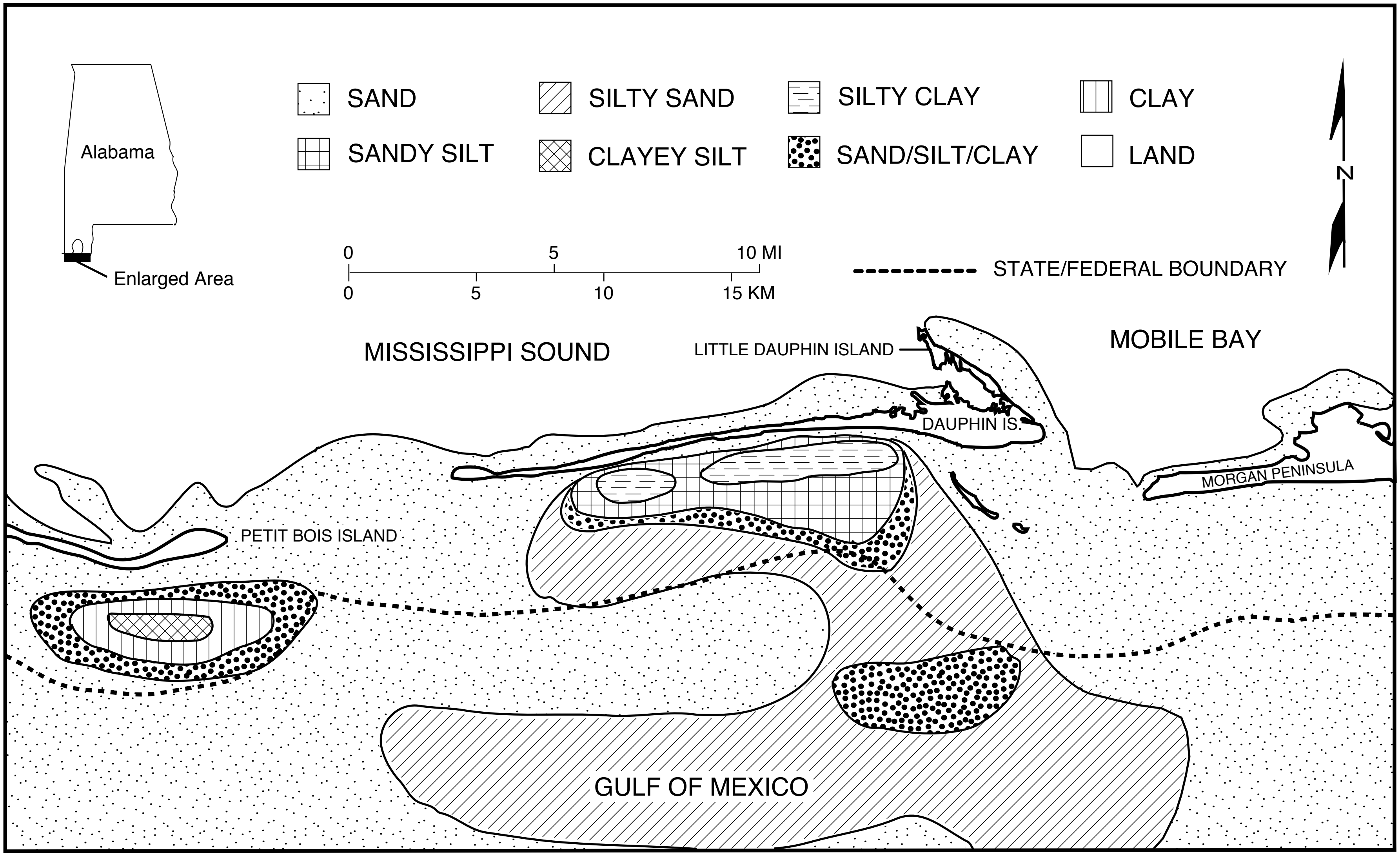


Figure 8.--Sediment distribution in the west Alabama inner continental shelf (modified from U.S. Army Corps of Engineers, 1984).

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. 8) 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. 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 8). 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 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, B. A., and Associates, Inc., 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 (1985a) 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.

The Geological Survey of Alabama (1993) 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 their 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.

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 (Geological Survey of Alabama, 1993). Information on the earlier Holocene transgressive history of coastal Alabama is derived from sediments on the continental shelf. Radiometric dates and sea level curves from Geological Survey of Alabama (1993) 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 Geological Survey of Alabama (1993), 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 was 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 (Geological Survey of Alabama, 1993). 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; Geological Survey of Alabama, 1993). 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). 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 (Geological Survey of Alabama, 1993). 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 (Geological Survey of Alabama, 1993).

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 (Geological Survey of Alabama, 1993). 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 (Geological Survey of Alabama, 1993). Ebb-tidal delta growth by vertical accretion and progradation continued throughout the late Holocene (Geological Survey of Alabama, 1993).

HOLOCENE GEOLOGIC HISTORY

Vibracores, borings, drill holes, and radiometric age dates of organic remains collected from the west Alabama inner continental shelf by Geological Survey of Alabama (1993) 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

(Geological Survey of Alabama, 1991, 1992) 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) (Geological Survey of Alabama, 1993).

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" (Geological Survey of Alabama, 1993). 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 (Geological Survey of Alabama, 1991, 1992, 1993). 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 (Geological Survey of Alabama, 1993). 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 (Geological Survey of Alabama, 1993).

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 (Geological Survey of Alabama, 1993). 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 mi 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 (Geological Survey of Alabama, 1991, 1992, 1993). 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 (Geological Survey of Alabama, 1993).

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).

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 Wisconsian sea level fall and reworking by coastal processes during Holocene sea level rise (Ludwick, 1964; Kindinger and others, 1982; Kindinger, 1988). During late Wisconsinian 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).

During regression associated with the late Wisconsian 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). 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). 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). Geological Survey of Alabama (1993) 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 Geological Survey of Alabama 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 during the present study for the 1985-95 period are based on erosion rates calculated from beach profile data for the period 1989-94.

Application of these 1989-94 erosion rates to the 1985-94 period involves the assumption that they have remained essentially constant over the 1985-95 period; however, information taken from imagery infer that some variability in shoreline erosion rates occurred during the 1985-95 period. Still, it is thought that 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.

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) for area 4 were reexamined and a determination was made concerning the need for additional subsurface information to prospect for sand bodies in area 4. Pre-existing seismic data for area 4 consists of unpublished seismic records collected by L. R. Bartek, Geology Department, University of Alabama, and his graduate students. 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.

Pre-existing sediment cores for area 4 consist of four borings from Geological Survey of Alabama (1993) and three vibracores from Parker and others (1993) (tables 1 and 2). Three borings were obtained from Exxon Company, U.S.A. for this study (table 2). The locations of these borings are shown on figure 9. 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 area 4 where they would be most useful for describing the framework geology and characterizing

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"

* from Parker and others (1993)

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.

sand resources. Fifteen vibracores were collected in the study area between May 16 and May 18, 1994. The vibracores were collected in water depths ranging from 37 to 71 ft and from 4 to 11 mi offshore. The vibracores ranged from 7.7 to 20.4 ft long and totaled 230.6 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-25).

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 LORAN-C.

The major steps involved in the laboratory analysis of the vibracores are presented in figure 10. The vibracore was first clamped into a wooden trough device and split longitudinally using a hand-held router equipped with a high

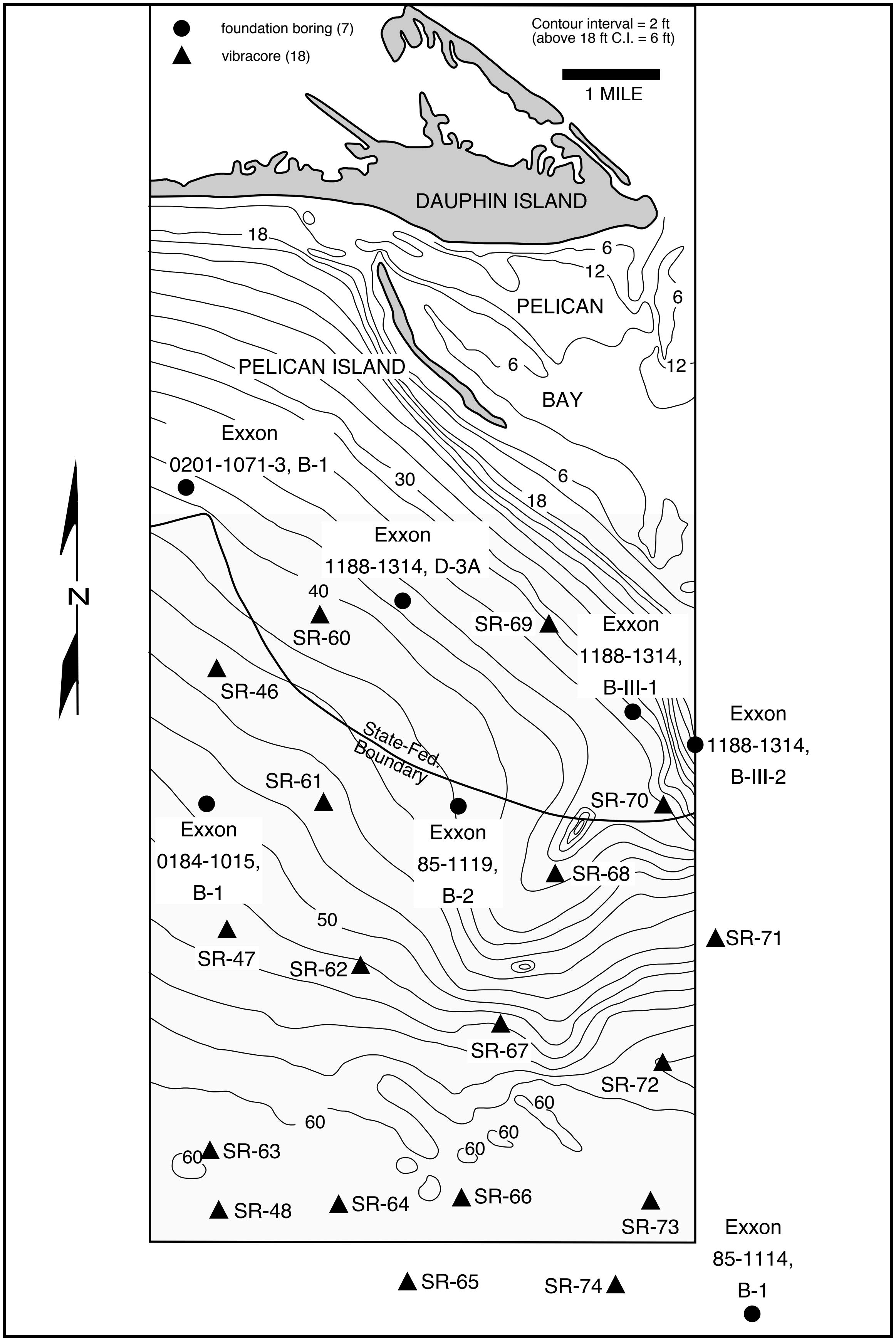


Figure 9.--Map of sand resource target area 4 showing location of vibracores and foundation borings.

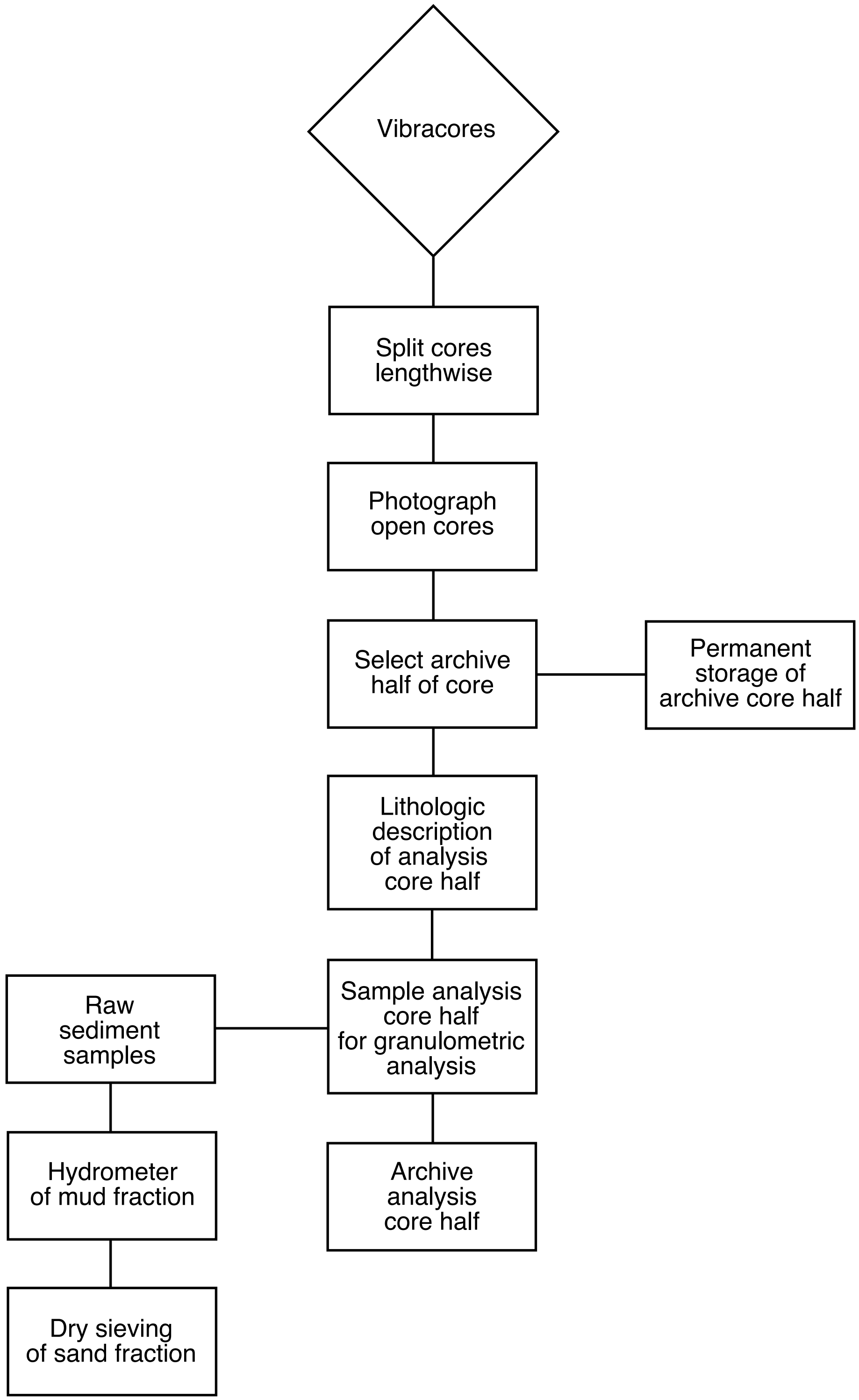


Figure 10.--Flow chart for the laboratory processing of vibracores.

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 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 and vibracore 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 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 gram, the units used by the balance.

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 grams. 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 grams. 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. Average and the range of parameters were determined by comparing all samples of a microfacies. The stratigraphic distribution of each microfacies was determined by construction of a series of cross sections, tables and sediment distribution maps.

AREA 4 SAND RESOURCES

Vibracores, borings, bottom samples, and biological samples were utilized to delineate and characterize sand deposits within area 4. Detailed laboratory analyses were performed on bottom, vibracore, and boring sediment samples to determine grain size characteristics and aesthetic quality. From this information, the potential of sand deposits to provide material for beach nourishment projects was evaluated based on the potential of nourishment material to meet specifications of beach sand quality and volume, and physical and biological environmental impacts of sand dredging.

Within area 4 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. Geologic cross sections, structure contour map of the top of the pre-Holocene, Holocene isopach map, and a surface sediment distribution map were prepared for area 4 to delineate and characterize the sand deposits.

RESOURCE POTENTIAL ANALYSIS

The sediment character of offshore deposits 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. Physical and environmental impacts of sand dredging were also considered for offshore deposits. The resource potential of the offshore deposits will be discussed for eroding shorelines of southeastern Dauphin Island.

BENTHIC FAUNAL ANALYSIS

Bottom samples were collected at each of the vibracore sites using a Ponar grab. This grab collects an approximately 200 square in sample of the upper few inches of the seabed. Bottom samples were split on board into sediment samples and biological samples. Sediment samples were placed in Zip-loc bags for storage. Each biological sample was washed with sea water through a 1 millimeter mesh sieve to remove fine-grained sediments. The coarse fraction remaining on the sieve was preserved in 10 percent formalin aqueous solution on board the research vessel and stored. All samples were stored at ambient temperature until transported to the laboratory.

Prior to laboratory examination of the coarse fractions, the formalin solution preservative was decanted off and the sample was washed in tap water. The formalin solution and tap water were neutralized using bleach and discarded. The coarse fractions were then permanently preserved in an 80 percent ethanol aqueous solution. Taxa were identified and abundance determined utilizing Abbott (1954), Abbott (1984), Barnes (1980), Barwis (1985), Hickman and others (1974), Morris (1973), Romashko (1974), and Warmke and Abbott (1961). Fragments were counted only if a unique part was present. Variability in sample size and sampling methodology between this study and prior biological studies in area 4, dictated the need to recast these data as strictly (presence/absence).

Pre-existing benthic and nektonic biological data for area 4 were obtained from Defenbaugh (1976), Dames and Moore (1979), U.S. Army Corps of Engineers (1982), and Parker and others (1993). In addition, the unpublished SEAMAP database (Southeast Area Monitoring and Assessment Program) for area 4 was obtained from the National Marine Fisheries Service and portions utilized for the present study. Since 1985, this biological initiative has utilized a stratified random seasonal sample design using trawls to amass a large, long-term database comprising species composition, abundance, and biomass of finfish and both decapod and stomatopod crustaceans collected from the Gulf of Mexico inner continental shelf including Alabama. Marine biologists of the Alabama Department of Conservation and Natural Resources, Marine Resources Division are responsible for collecting data in Alabama.

ASSESSMENT OF ERODING COASTAL SHORELINE

SEDIMENT 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.

Dauphin Island beaches are characteristically brilliant white to slightly buff in color, and consist primarily of fine to medium-grained quartz sand with minor amounts of shell fragments and accessory detrital minerals. At some localities along the eroding beaches, particularly in the vicinity of the Dauphin Island Park, various other sediment types are exposed in erosional scarps. These include sediments deposited within former environments associated with the island, including those of swamp, forest floor, estuary, sound, and other environments. Sediment samples taken on the beach in the eroding shoreline areas indicate a composite mean grain size of 1.89 Ø (medium sand) and sorting of 0.38 Ø (well sorted) (Parker and others, 1993). The native beach sediment averages 99.91 percent sand, 0.09 percent silt and clay, and is light gray in color (Parker and others, 1993).

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. Although, since 1955, erosion apparently has continued along the remainder of the island's Gulf of Mexico shoreline neither Parker and others (1993) nor the present investigation estimated volumes of sand for restoration of this shoreline, owing to imprecise data on erosional areas.

The present study included estimation of sand volumes necessary to restore southeastern Dauphin Island Gulf of Mexico beaches (fig. 11) eroded during the 10 year period 1985-95. These data are 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.

Table 3 summarizes estimates of sand volumes required to restore and stabilize southeastern Dauphin Island eroding shoreline segments delineated by Parker and others (1993). These data include a calculated overfill factor of 20 percent.

GEOLOGIC FRAMEWORK OF AREA 4

If we are to evaluate an area of the Alabama EEZ for its sand resource potential, it is essential that its geologic framework and lithofacies patterns be well documented. Such understanding for area 4 was not available prior to this study.

A database of available information pertaining to hard mineral occurrence in the EEZ, offshore Alabama, was compiled by Parker (1989). Evaluation of this database indicated a potential for significant deposits of sand, shell gravel, and heavy minerals to occur in this area; however, available data were not adequate to identify specific resource sites. The lack of vibracore and bottom sample data resulted in an effort by Parker and others (1993) to collect new vibracore and bottom sample data to adequately describe the framework geology and hard mineral resources in the Alabama EEZ. This study resulted in

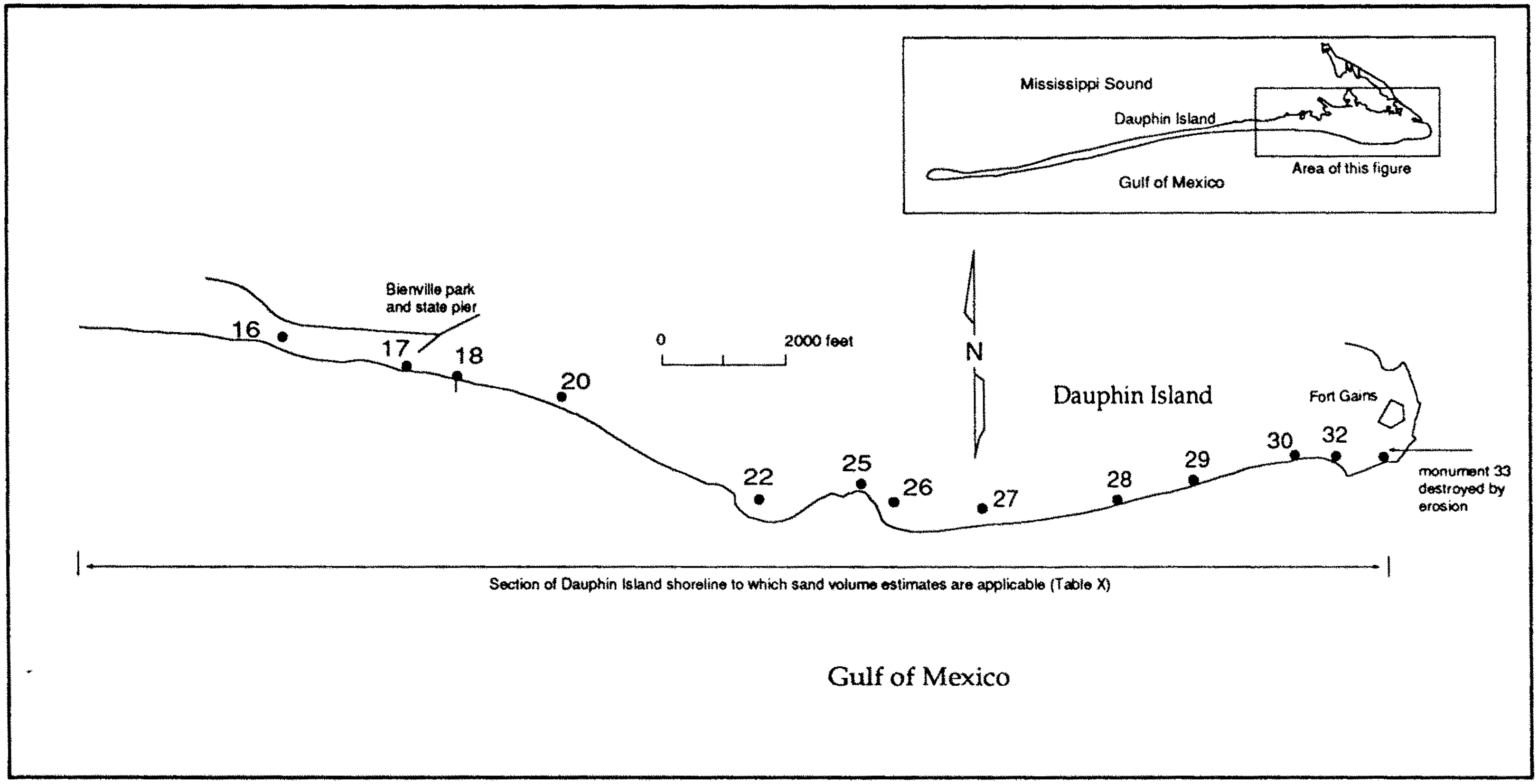


Figure 11.--Dauphin Island Gulf of Mexico shoreline to which sand volume estimates are applicable. Numbered black circles indicate locations of Geological Survey of Alabama beach profile stations used to estimate shoreline erosion rates.

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.

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 1985 positions	2,425,000

identification of five target areas that showed the potential for the presence of sand resources suitable for Alabama beach nourishment projects. The efforts of the current study are directed at describing in detail the framework geology of area 4 on the Alabama inner continental shelf with the intent of identifying and characterizing specific sand resources in this area. This portion of the study completed tasks 1, 3, and 5 of the project.

LITHOFACIES OF AREA 4

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 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 from the 18 vibracores, 7 borings, and 18 surface sediment samples collected for this study were also divided into a series of lithofacies following those defined by Parker and others (1993). It was found that the lithofacies classification scheme of Parker and others (1993) agreed well with those lithofacies defined by Geological Survey of Alabama (1993) in their study of the geologic framework of Alabama Gulf of Mexico waters and lithologic units described from area 4 in the present study.

The lithofacies defined for area 4 of the present study 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 Mud-Sand 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 utilized in the present study.

Grain size characteristics for each lithofacies are listed in table 4. Distribution of facies thickness by vibracore and boring is shown in table 5. Vibracore columnars showing a typical example of each facies are shown in figures 12 through 14.

GRADED SHELLY SAND LITHOFACIES

The Graded Shelly Sand Lithofacies is a commonly occurring facies, represented by 8 of a total of 68 samples evaluated for grain size (e.g., 12

Table 4.--Grain size characteristics of facies.

	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 thickness in feet
Facies	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum		
Sands	3.11	2.23	0.29	0.39	1.47	1.99	0	2	21.8	74.7	87.5	99.3	0.2	5.6	12.2	0.3	6.9	13.5	44	236.8
Clean sands																			0	0.6
Orthoquartzite																			0	0.6
Graded shelly sand	1.73	1.39	0.29	0.39	0.89	1.48	0.1	3.5	21.8	97.5	98.4	99.3	0.2	0.5	0.9	0.3	1.1	2.2	8	57.3
Dirty sands	3.11	2.41	1.65	1.11	1.58	1.99	0	1.6	8.5	74.7	85	94	2.3	6.7	12.2	2.3	8.2	13.5	36	178.9
Muddy sand	3.11	2.47	1.93	1.11	1.43	1.72	0	0.8	2.7	77.2	86.5	94	2.3	5.8	9.3	2.3	8	13.5	6	58.6
Muddy shelly sand	2.98	2.40	1.65	1.31	1.70	1.99	0.1	1.8	8.5	74.7	84.7	91.2	4	6.9	12.2	3.7	8.3	13.1	30	120.3
Biogenic sediments	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	0.8
Peat	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	0.8
Muddy sediments	5.40	3.86	1.72	1.13	1.49	2.01	0	0.6	5.3	21.6	54.6	87.7	5.5	21.5	38.8	6.8	23.9	33.4	24	162
Silty/clayey sands	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	5.6
Sand-silt-clay	5.40	4.61	3.23	1.35	1.46	1.74	0	0	0	21.6	40	55.7	19.5	29.4	38.8	24.8	30.6	33.4	14	87.1
Mud-sand interbeds	3.71	2.81	1.72	1.13	1.50	2.01	0	0.6	5.3	68.8	75.1	87.7	5.5	10.4	13.9	6.8	14.6	21.7	10	69.3
Pre-Holocene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	77.5

Table 5.--Facies distribution by foundation boring and vibracore.

Facies	Boring number						
	Exxon 0184-1015, B-1	Exxon 0201-1071-1, B-1	Exxon 84-1114, B-1	Exxon 85-1119, B-2	Exxon 1184-1314, B-III-1	Exxon 1184-1314, B-III-2	Exxon 1184-1314, D-3A
Sands							
Clean sands							
Orthoquartzite							
Graded shelly sand				11	0.5	8	
Dirty sands							
Muddy sand	9		12.9		2	5	
Muddy shelly sand		5	7	17	12.8		6
Biogenic sediments							
Peat							
Muddy sediments							
Silty/clayey sands		2					
Sand-silt-clay		2		10	15.8	2	4.5
Mud-sand interbeds			14.9			11	4.5
Pre-Holocene	16	6	1.5	3	11	5	9

Table 5.--Facies distribution by foundation boring and vibracore--Continued.

Facies	Vibracore number																		Total length in feet	Percent of total core length
	SR-46	SR-47	SR-48	SR-60	SR-61	SR-62	SR-63	SR-64	SR-65	SR-66	SR-67	SR-68	SR-69	SR-70	SR-71	SR-72	SR-73	SR-74		
Sands																			236.8	49.6
Clean sands																			0.6	0.1
Orthoquartzite			0.6																0.6	0.1
Graded shelly sand											11.4	10							57.3	12 12
Dirty sands																			178.9	37.5
Muddy sand	5.5	4.3		2			2.4	1.8	0.8	1.3	1.2		1.3			5.4	3.7		58.6	12.3
Muddy shelly sand				8.1	16.4	5.9	3.6	5.3	4.6	7.2	3.7		9.7	6.7	6.3	1.5	1.7	8.2	120.3	25.2
Biogenic sediments																			0.8	0.2
Peat						0.2	0.3	0.2							0.1				0.8	0.2
Muddy sediments																			162	34
Silty/clayey sands	1.7	1.9																	5.6	1.2
Sand-silt-clay	4		3.9	4.8	4.3	8.5		2.4		5			2.6	7.2	7.2	2.9			87.1	18.3
Mud-sand interbeds		8.3		2.3									3.8	5.3	4.2		4.8	10.2	69.3	14.5
Pre-Holocene				0.8		2.4	2.4	1.7	2.4	2.7			0.3		1.9	9.3	0.8	1.3	77.5	16.2 16.2

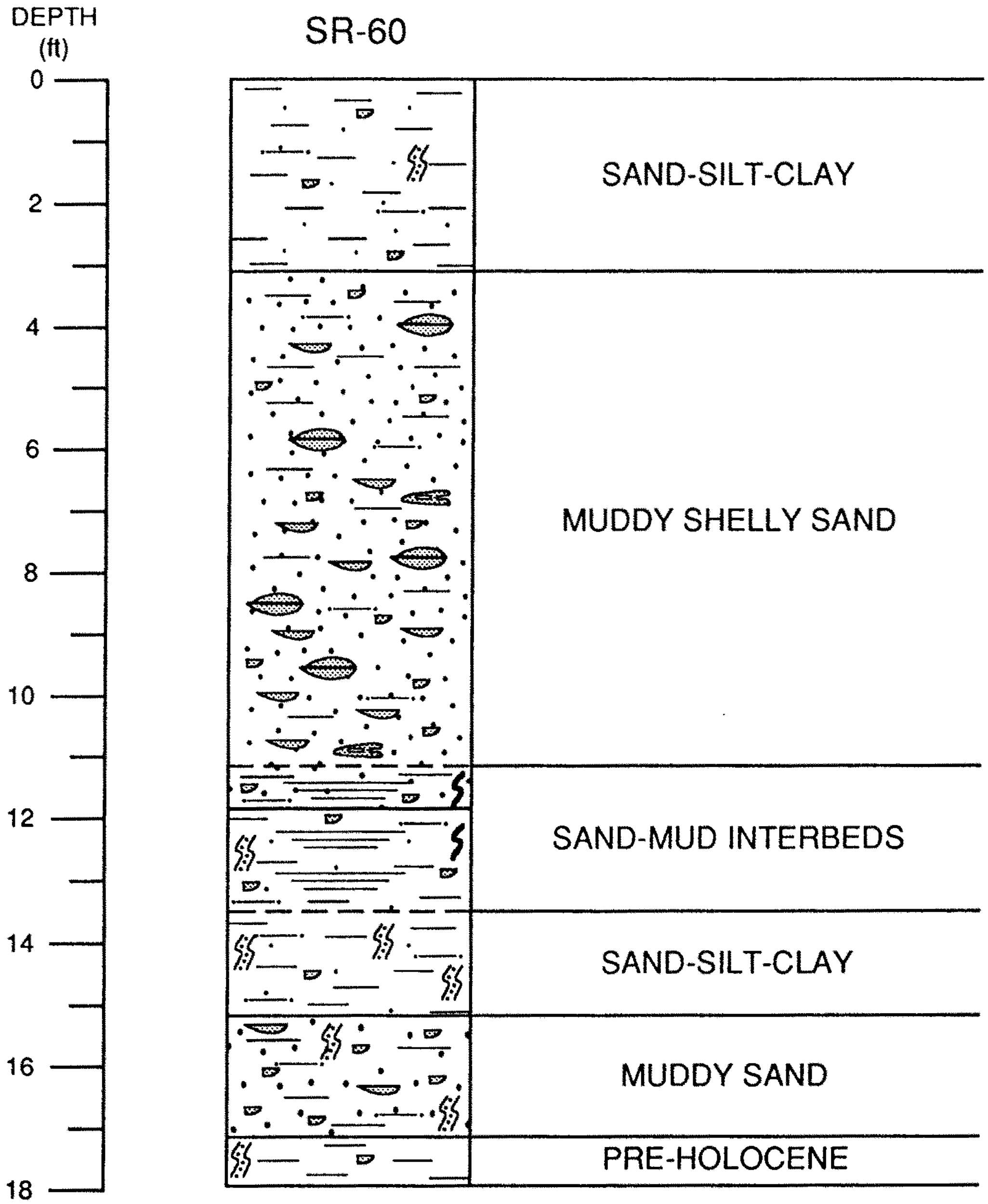


Figure 12.--Columnar section illustrating facies distribution in vibracore SR-60 (see figure 9 for vibracore location).

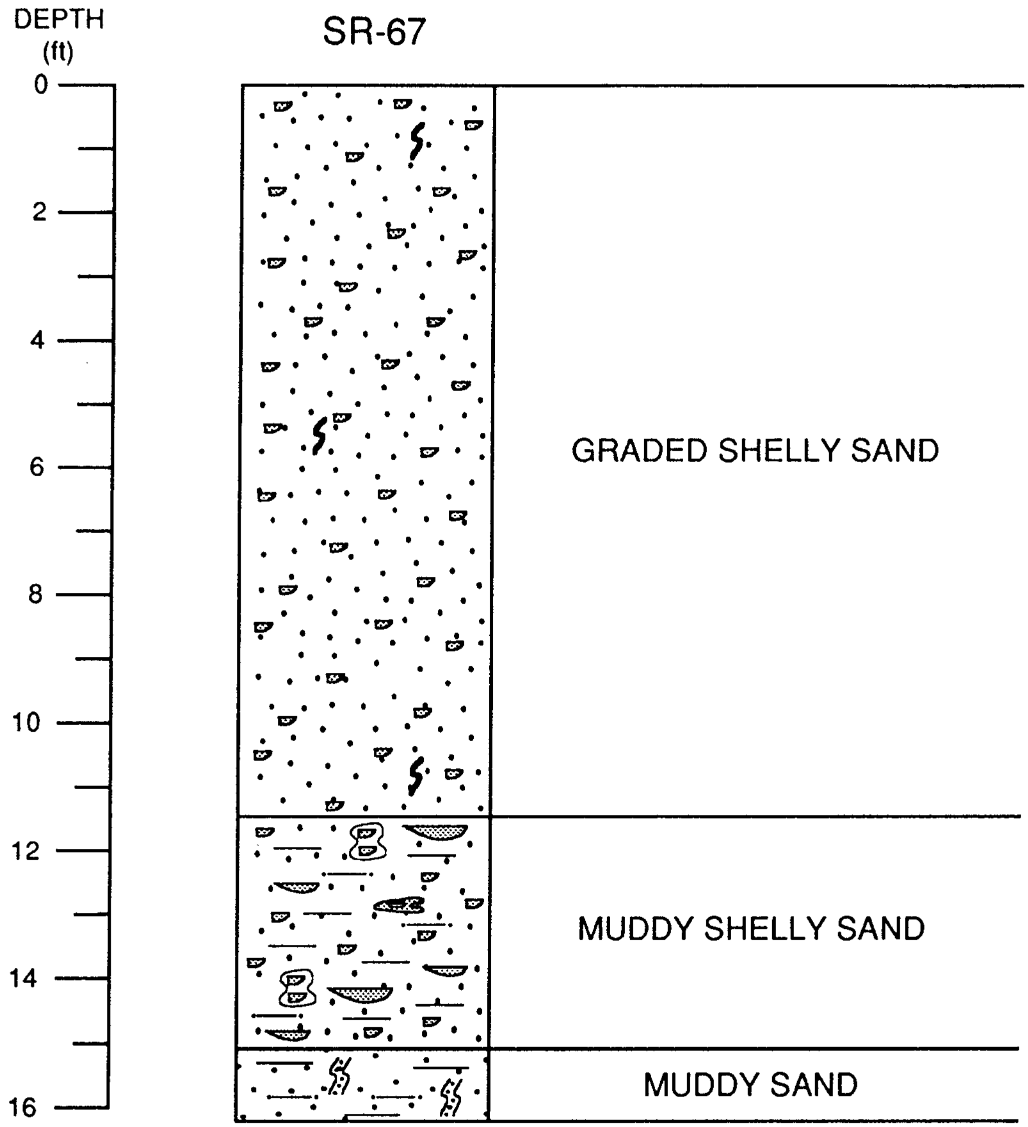


Figure 13.--Columnar section illustrating facies distribution in vibracore SR-67 (see figure 9 for vibracore location).

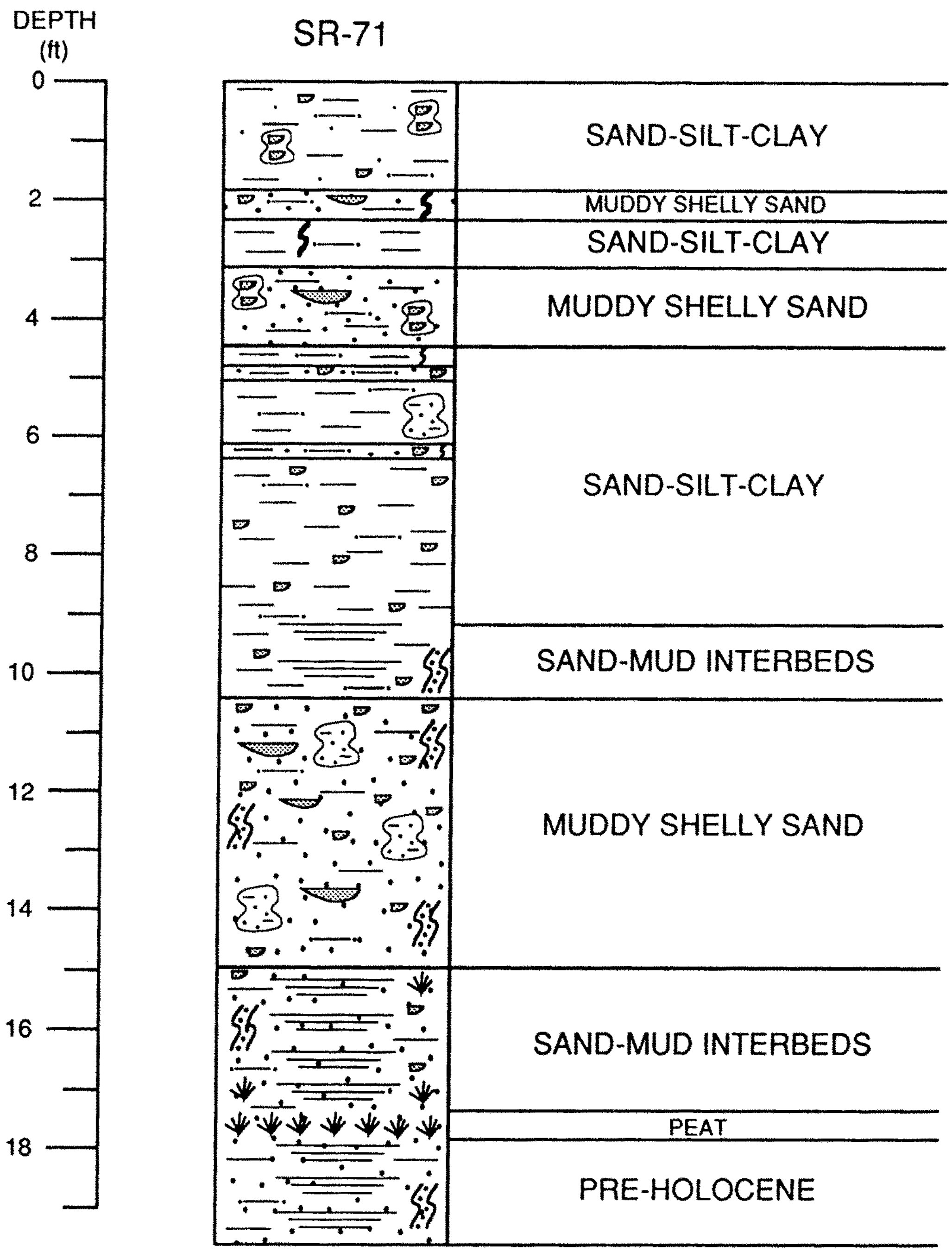


Figure 14.--Columnar section illustrating facies distribution in vibracore SR-71 (see figure 9 for vibracore location).

percent of all samples analyzed) (table 4). Total thickness sampled was 57.3 ft, or 12 percent of total core length (table 5).

This lithofacies is represented by a fining-upwards graded sequence of shell and clean sand in vibracores SR-67 and SR-68. Generally, the graded shelly sand lithofacies seen in vibracore SR-67 is typical of the facies appearance in area 4. All units 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 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 vibracore SR-68 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 appears to be massive (as shown in vibracores SR-67 and SR-68) seems to thin rapidly to a few ft thick at its margins (such as in boring Exxon 1188-1314, B-III-2).

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 1.39 Ø (medium sand, table 4); the range for mean grain size is from 0.29 Ø (coarse sand) to 1.73 Ø (medium sand). The average standard deviation for the graded shelly sand samples is 0.89 Ø (moderately sorted); values for standard deviation range from 0.39 Ø (well sorted) to 1.48 Ø (poorly sorted). Overall, the facies represents the coarsest average mean grain size, and the best sorting among all facies. 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 98.4 percent of the unit. The range of values for this material is quite low, 97.5 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 3.5 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 in) 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 94.9 percent for the lithofacies, the highest of any lithofacies.

Silt (4 to 8 Ø) is rare in all samples, with a mean of 0.5 percent and a range from 0.2 to 0.9 percent. Likewise, clay content (greater than 8 Ø) is extremely low, with a mean of 1.1 percent and a range of 0.3 to 2.2 percent. These are the lowest values for any facies. 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.

CLEAN SAND LITHOFACIES

ORTHOQUARTZITE MICROFACIES

The Clean Sand Lithofacies is the rarest lithofacies encountered in the vibracores and borings from area 4. This facies is represented by 0.6 ft of the Orthoquartize Microfacies in vibracore SR-48, representing 0.1 percent of total core length (table 5). This vibracore is from Parker and others (1993) and therefore, shows zero samples analyzed in table 4.

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 occational 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

The Dirty Sand Lithofacies is the most common lithofacies analyzed in this study (36 samples from 178.9 ft of core, or 37.5 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.

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) (table 4). 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). Again, these values are much higher than for the Graded Shelly Sand Lithofacies, indicating incorporation of much more fine-grained material in these sediments.

Sand/shell gravel content averages 85.0 percent, with a range from 74.7 to 94.0 percent. 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.

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. This average is an order of magnitude higher than for the Graded Shelly Sand Lithofacies. 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. Due to the much lower sand content, this lithofacies is not as viable a resource objective as are the Clean Sand and the Graded Shelly Sand Lithofacies.

MUDDY SAND MICROFACIES

In area 4 the Muddy Sand Microfacies is the less common of the Dirty Sand Lithofacies, representing 6 samples (table 4) from 58.6 ft of core (12.3 percent of total core length, table 5).

This microfacies is composed of a mud-rich sand that is rarely interbedded (vibracore SR-74), but often is highly mottled due to poorly preserved burrowing (vibracore SR-60), with a bioturbation index up to 5 (Droser and Bottjer, 1986). The burrows may be sand filled (vibracore SR-60) or mud filled (vibracore SR-46). The units generally contain scarce to abundant shells or shell fragments, but may have a few shells concentrated at the base (vibracore SR-46), or may contain occasional wood fragments (vibracore SR-72). Mud pockets rarely occur (vibracore SR-46). Bases of the units may be gradational (vibracore SR-46) or sharp (vibracore SR-64). Units are generally stratigraphically low, often close to or overlying the Pre-Holocene Lithofacies (vibracore SR-64 and boring Exxon 0184-1015, B-1). 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.

Average mean grain size is 2.47 Ø (fine sand). 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). Except for the Graded Shelly Sand Lithofacies, this sediment type has on average the best sorting of any other lithofacies or microfacies.

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. 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. This maximum value is lower than the maximum value for any other sand microfacies. The sand size fraction on average would represent 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. Clay content averages 8.0 percent, with a range from 2.3 to 13.5 percent. This is the highest clay content of any sand microfacies. This microfacies, while containing a reasonably high sand content, should not be the primary source of beach replenishment materials.

MUDDY SHELLY SAND MICROFACIES

The Muddy Shelly Sand Microfacies is common, consisting of 30 samples out of 68 samples processed (44.1 percent, table 4) representing 120.3 ft of core (25.2 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 (vibracore SR-60). Echinoid fragments are scarce (vibracore SR-60). The units can contain sand-filled burrows (vibracores SR-61 or SR-69) or raely, mud-filled burrows (vibracore SR-64). Shells are usually distributed in a chaotic to subhorizontal orientation, but can occur as shelly pockets (vibracores SR-65 or SR-69) or as shell lags (vibracores SR-62 or SR-64). Wood fragments rarely occur in this microfacies (vibracore SR-73).

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.

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. However, the Muddy Shelly Sand Microfacies would not be as good a sand resource due to its high silt and clay content. 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. This is the second lowest average among the sand microfacies. The range of values is from 74.7 to 91.2 percent; this wide range in values indicates relative diversity in sediment type due to differences in shell content. 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, 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. Thus, this is the most silt-rich of any sand microfacies. 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. This microfacies, while it contains a reasonably high sand content, would not be the primary target for exploitation of beach replenishment materials.

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. None of the peat samples were analyzed for grain size.

PEAT MICROFACIES

No grain size samples were taken in this microfacies (table 4), as it is composed of organic materials inappropriate for beach replenishment; it makes up a total of 0.8 ft of core length (0.2 percent of total core length, table 5).

This microfacies is composed of brown terrestrial plant debris in a muddy or sandy mud matrix (vibracores SR-62, SR-63, SR-64, and SR-71). These beds have been interpreted as marsh deposits (Kraft, 1971; Fletcher and others, 1990) and have been described throughout coastal Alabama (Geological Survey of Alabama 1991, 1992, 1993). 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 (Geological Survey of Alabama 1991, 1992, 1993). Rhizoliths (preserved root traces) may extend down into the underlying unit (vibracores SR-62 and SR-63). Peat beds may be disrupted by burrows (vibracores SR-62 and SR-63). This microfacies would make an inappropriate source for beach replenishment materials.

MUDDY SEDIMENT LITHOFACIES

The Muddy Sediment Lithofacies is a common lithofacies; it comprises 24 samples out of 68 (35.3 percent, table 4) representing 162.0 ft of core, or 34.0 percent of total recovered core (table 5). It 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.

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. 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).

This facies has, by far, the lowest sand/shell gravel component of any lithofacies analyzed, 54.6 percent. 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. Sand content, therefore, would be on average 54.0 percent, again the lowest of all the lithofacies.

Not surprisingly, fine-grained sediment was very abundant in the lithofacies. 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. Given the available sandy sediments, the Muddy Sediment Lithofacies is not a promising target for beach replenishment resources.

SILTY/CLAYEY SAND MICROFACIES

The Silty/Clayey Sand Microfacies is uncommon in the vibracores and borings from area 4 (table 5), being represented by no samples (table 4) and 5.6 ft of core (1.2 percent of total core length, table 5). It is present in vibracores SR-46 and SR-47 and boring Exxon 0201-1071-3, B-1 (table 5).

This microfacies occationally contains primary sedimentary structures, such as mud and sand laminae (vibracore SR-48). Mud drapes may be seen (vibracore SR-48) or clay balls (boring Exxon 0201-1071-3, B-1). Most units are structureless (vibracores SR-46 and SR-47). The lower contact may be sharp (vibracore SR-

46) or gradational (vibracore SR-47). Occasional shell fragments are seen (vibracores SR-47). Bioturbation is present, including sand-filled burrows (vibracore SR-46) and mud-filled burrows (vibracore SR-47).

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 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. Based on the findings of Parker and others (1993) and the results of the present study, the Silty/Clayey Sand Microfacies would not be a primary target for beach replenishment resources.

SAND-SILT-CLAY MICROFACIES

The Sand-Silt-Clay Microfacies is the most abundant microfacies in the Muddy Sediments Lithofacies, with 14 samples (20.6 percent) representing 87.1 ft of core (18.3 percent of total core) being analyzed for grain size (tables 4 and 5).

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 (vibracore SR-62). 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 (vibracores SR-62, SR-64, and SR-66). Bases may be gradational to fairly sharp.

This is by far the finest-grained microfacies analyzed, 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). 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). 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. No shell gravel was found in any sample in this microfacies. Therefore, sand content would average 40.0 percent and ranges from 21.6 to 55.7 percent.

Silt and clay are each as dominant in this facies as is sand/shell gravel. 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. This is also by far the most clay-rich microfacies. The Sand-Silt-Clay Microfacies would be a poor target for beach replenishment sands.

MUD-SAND INTERBEDS MICROFACIES

The Mud-Sand Interbeds Microfacies is common in area 4; it is represented by 10 samples (14.7 percent, table 4) taken from 69.3 ft of core (14.5 percent of total core length, table 5).

This microfacies contains interbedded very thin sand and mud laminae (vibracores SR-47, SR-73, and SR-74). 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 (vibracore SR-69). Sand-filled burrows are commonly seen (vibracore SR-47). 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 Geological Survey of Alabama (1993) as undifferentiated ebb-tidal delta lithofacies in their Holocene geologic framework investigations of Alabama Gulf of Mexico waters. As was found by the Geological Survey of Alabama (1993) 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.

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. Nonetheless, it is still 0.34 Ø smaller than the finest-grained microfacies from any of the other lithofacies. 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). 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. Only the Sand-Silt-Clay Microfacies contains a lower percentage. 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. Total sand content for the microfacies would therefore average 74.9 percent, the second lowest sand fraction after the Sand-Silt-Clay Microfacies.

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 this is the lowest average for any Muddy Sediment microfacies, it is still larger than any microfacies from another lithofacies. Clay content averages 14.6 percent, with a range from 6.8 to 21.7 percent. Only the Sand-Silt-Clay Microfacies has a higher average clay content. The Mud-Sand Interbeds Microfacies is a poor source for beach replenishment materials.

PRE-HOLOCENE LITHOFACIES

The Pre-Holocene Lithofacies was represented by 77.5 ft of core (16.2 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 studied most recently by Geological Survey of Alabama (1991, 1992, 1993), and Parker and others (1993). 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 (Geological Survey of Alabama, 1991, 1992, 1993).

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 (Geological Survey of Alabama, 1993). The unconformity is easily identifiable in vibracores and on 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 (Geological Survey of Alabama, 1993). This oxidized zone is absent in the pre-Holocene sediments sampled by borings and vibracores collected within the Mobile-Tensaw alluvial system (Geological

Survey of Alabama, 1991, 1992, 1993). 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 (Geological Survey of Alabama, 1993).

Estuarine units are comprised of a variety of sediment types including clay, clayey silt, silt, sandy mud, and sandy silt (boring Exxon 1188-1314, D-3A). 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 (boring Exxon 0184-1015, B-1) (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 (vibracore SR-71). Associated with fluvial sediments are semi-consolidated sandy clay and sandy muds that are frequently laminated (vibracore SR-71). 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.

Due to the variability in lithology, thickness of Holocene overburden, and consolidated nature of the Pre-Holocene Lithofacies, it is not an exploration target for beach replenishment materials.

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. The Clean Sand Lithofacies (Orthoquartzite Microfacies) would make an attractive choice for a sand resource target, except for the fact that the vibracores and borings indicate very little of this lithofacies is present in area 4. However, the Graded Shelly Sand Lithofacies is present in the study area as a massive, shelly sand deposit, most of the upper surface of which is exposed at seafloor. This lithofacies would make an excellent source of Dauphin Island shoreline nourishment sand. The Dirty Sands Lithofacies which is present in the study area as the Muddy Sand and Muddy Shelly Sand Microfacies, would be a less attractive resource target because of the mud content, overburden thickness, and close association with the mud-rich Muddy Sediments Lithofacies (separation of the two lithofacies may prove difficult in a mining operation). The three remaining lithofacies, the Biogenic Sediments Lithofacies (Peat Microfacies); the Muddy Sediments Lithofacies (Sand-Silt-Clay, Silty/Clayey Sand, and Sand-Mud Interbeds Microfacies), and the Pre-Holocene Lithofacies, are all inappropriate as beach nourishment sources due to improper aesthetics regarding their composition, grain size, or color.

SPATIAL DISTRIBUTION OF FACIES

In order to effectively estimate the volume of potential resources that may be available in each microfacies present in the study area and map microfacies geometry, important in any mining operation, it is essential to describe the spatial distribution of these facies. Figure 15 is a surface facies distribution map that shows the microfacies on the seafloor at each sample locality. Figure 16 is a map that shows the location of each of the nine cross sections through area 4. Figures 17 through 25 are geologic cross sections that show subsurface distribution of each facies. Table 5 shows the thickness of each microfacies at each vibracore and boring location.

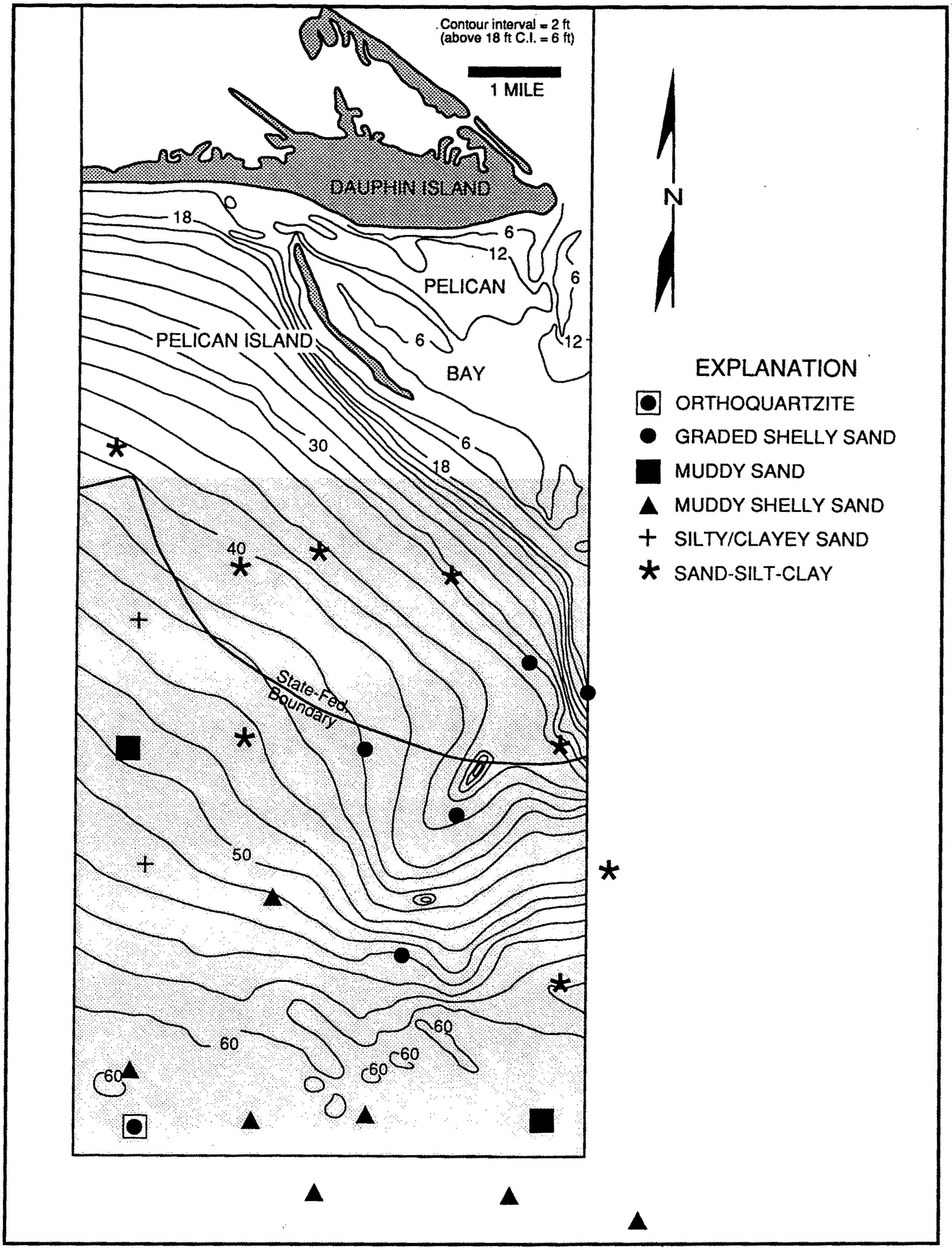


Figure 15.--Surface facies distribution in sand resource target area 4.

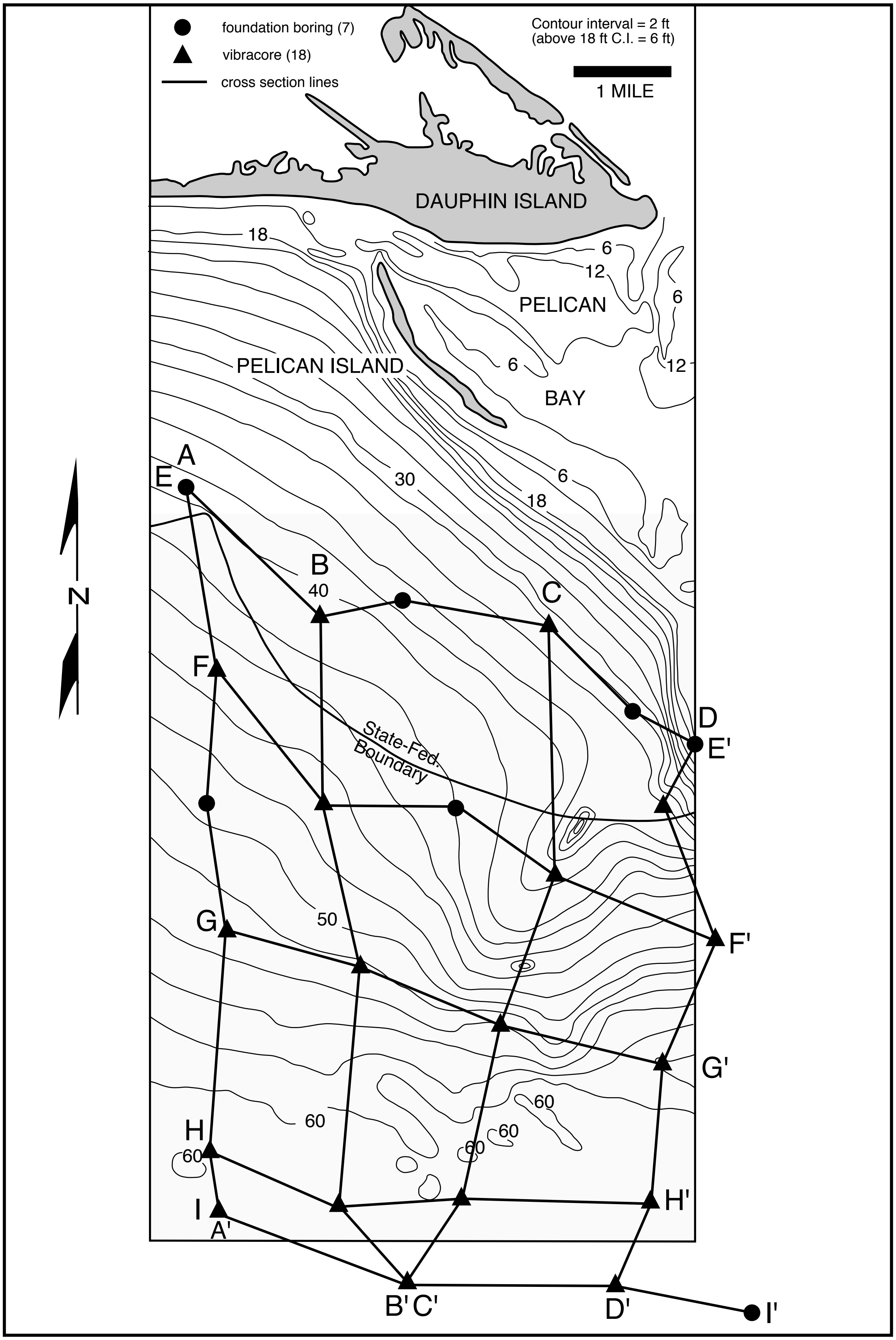


Figure 16.--Map of sand resource target area 4 showing location of vibracores, foundation borings, and cross sections.

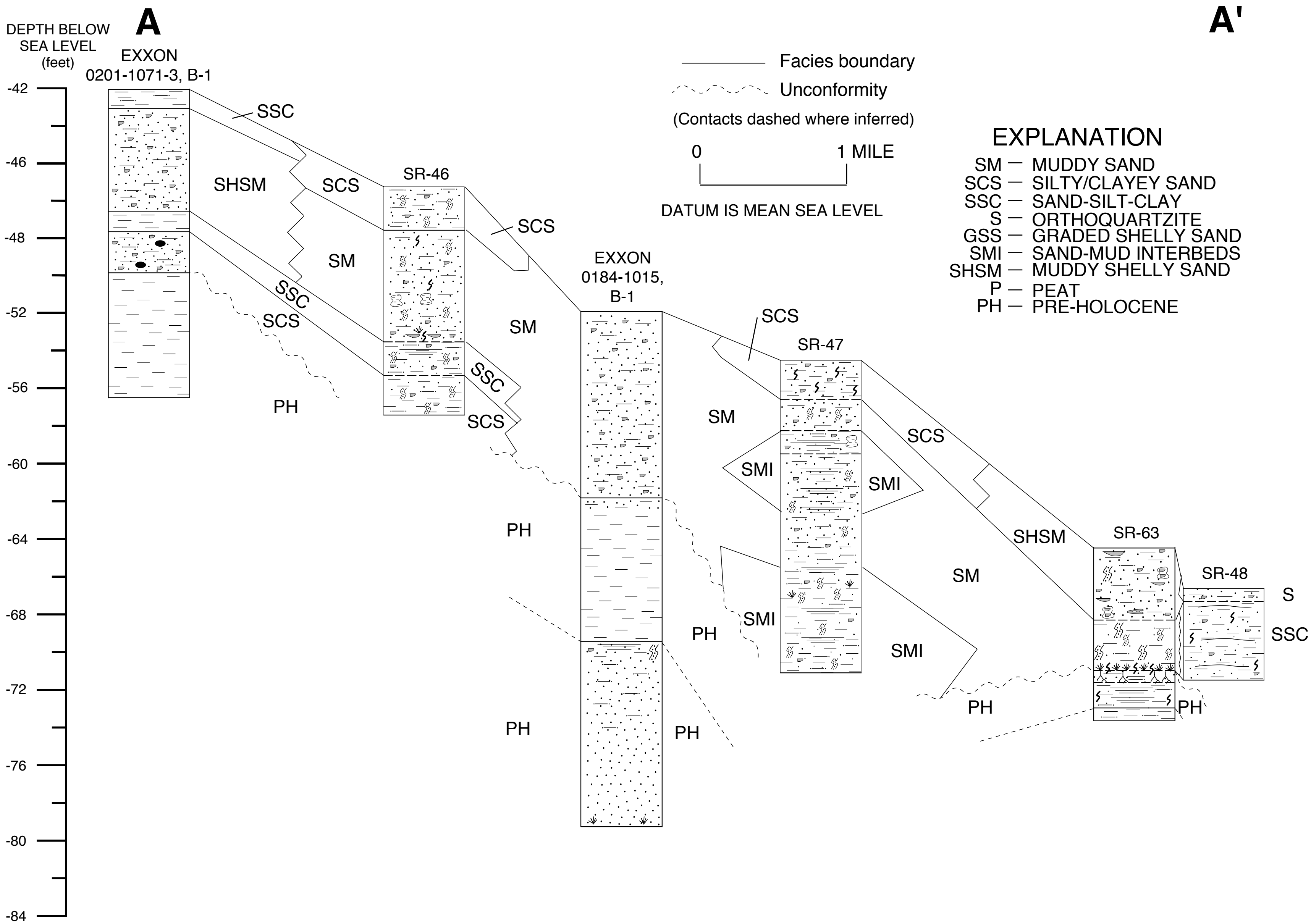


Figure 17.--Cross section A-A' (see figure 16 for cross section location).

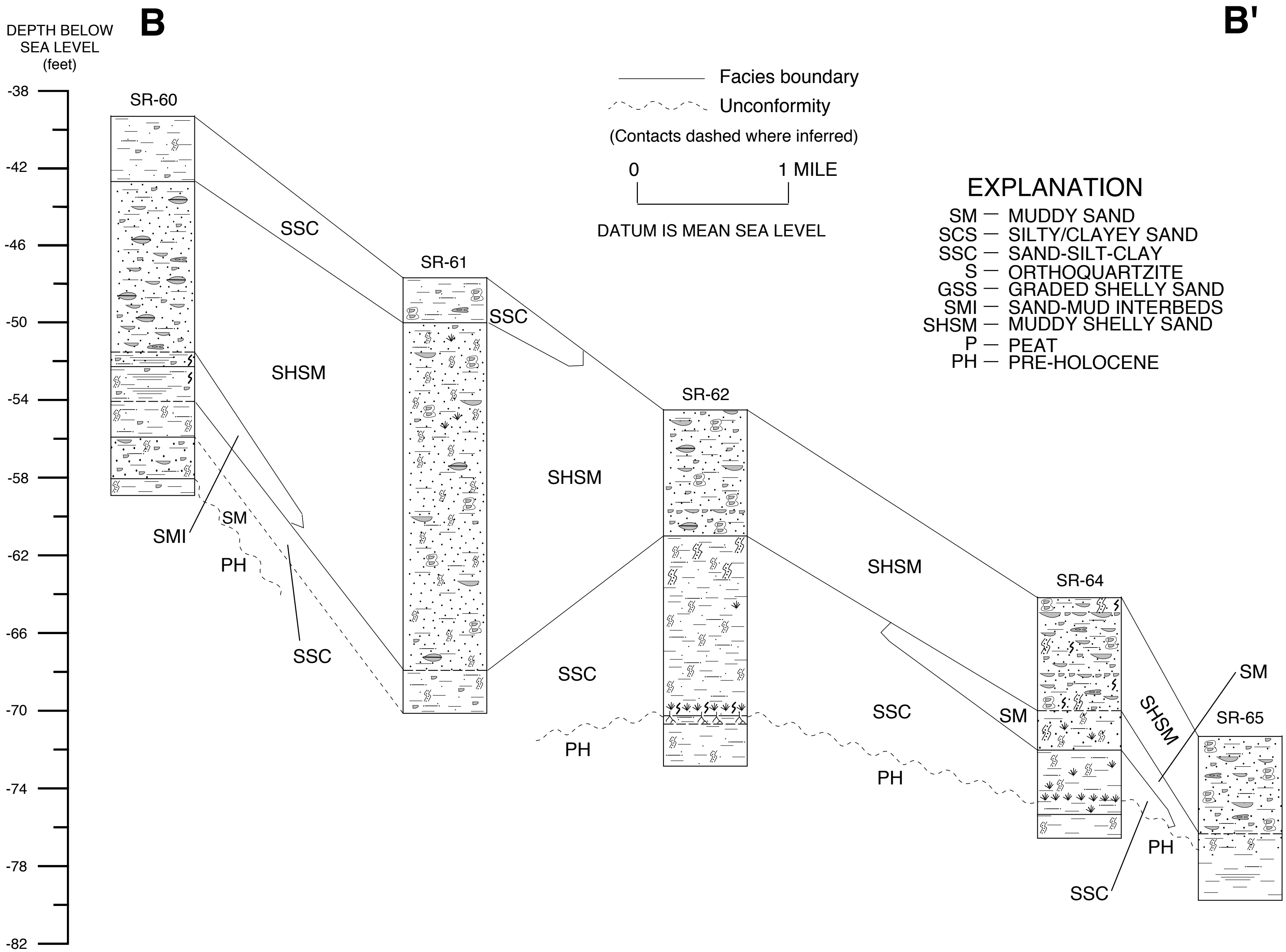


Figure 18.--Cross section B-B' (see figure 16 for cross section location).

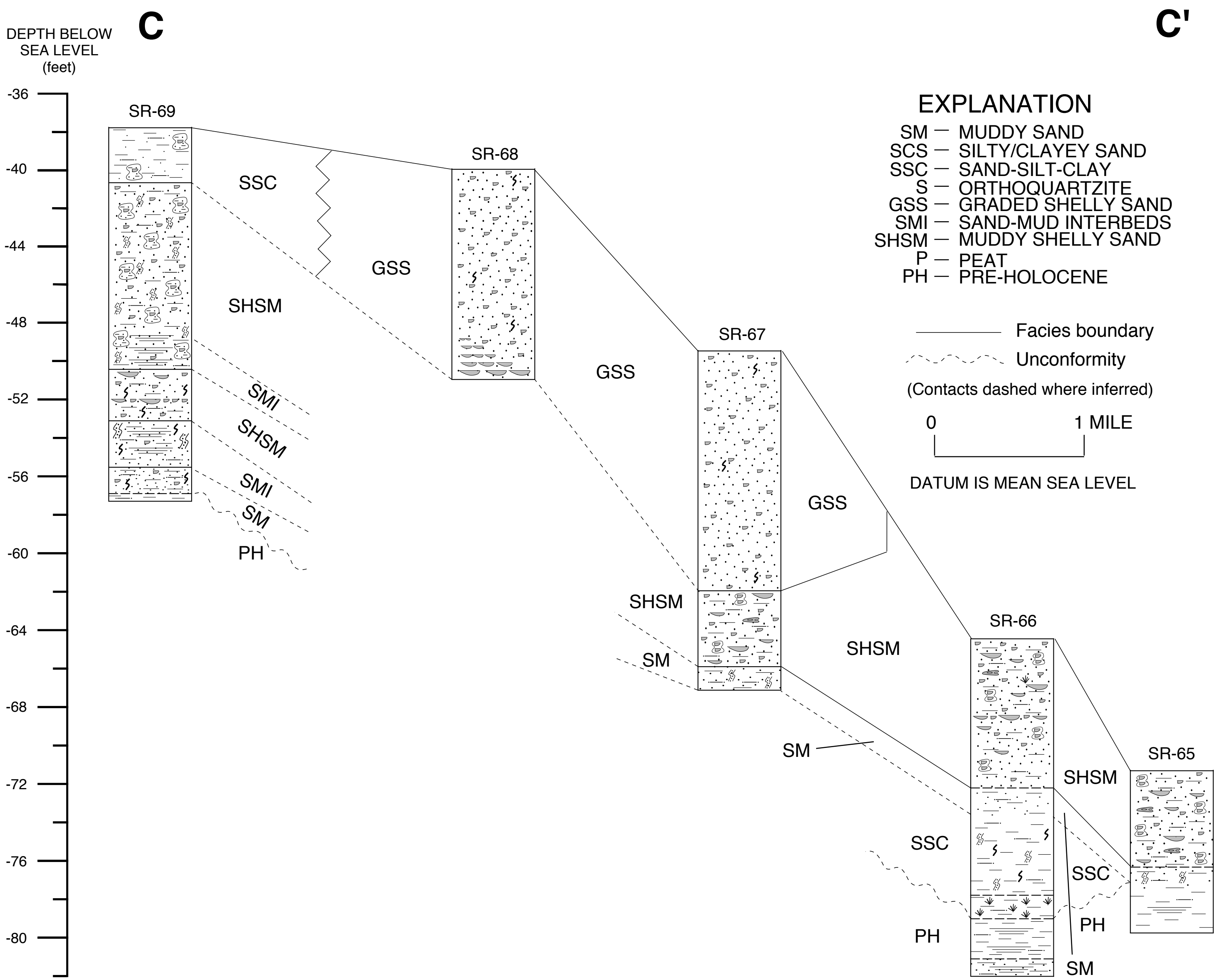


Figure 19.--Cross section C-C' (see figure 16 for cross section location).

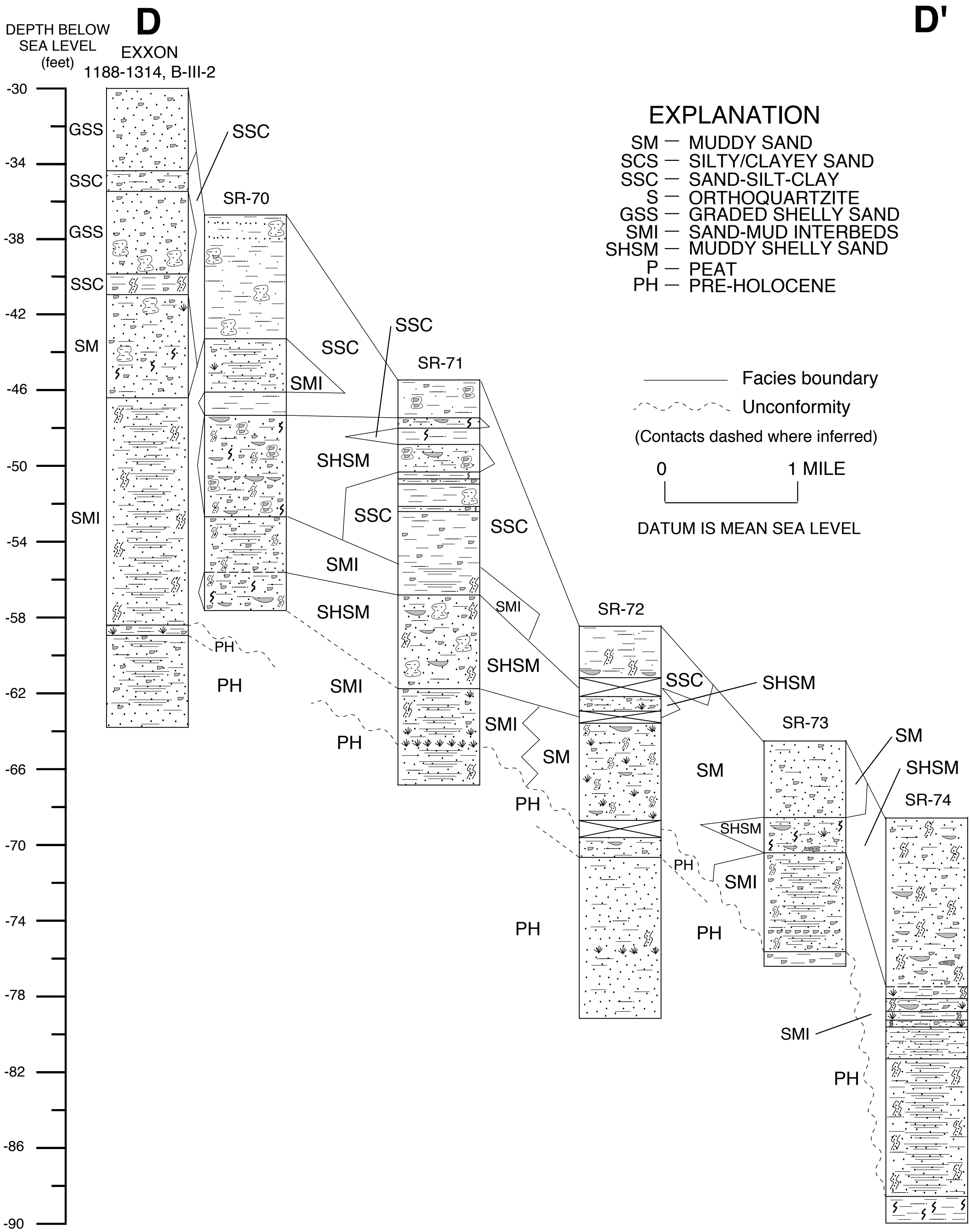


Figure 20.--Cross section D-D' (see figure 16 for cross section location).

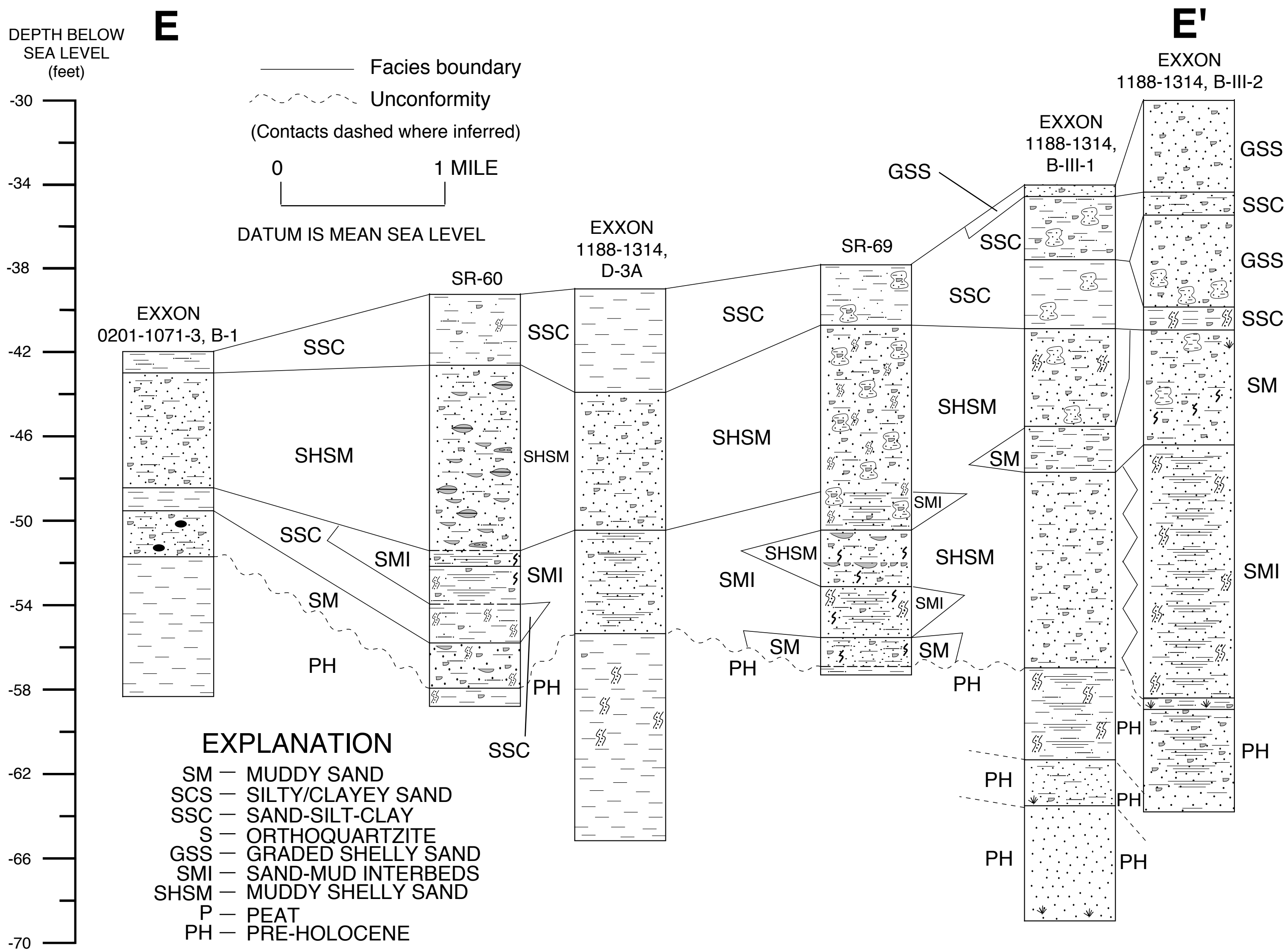


Figure 21.--Cross section E-E' (see figure 16 for cross section location).

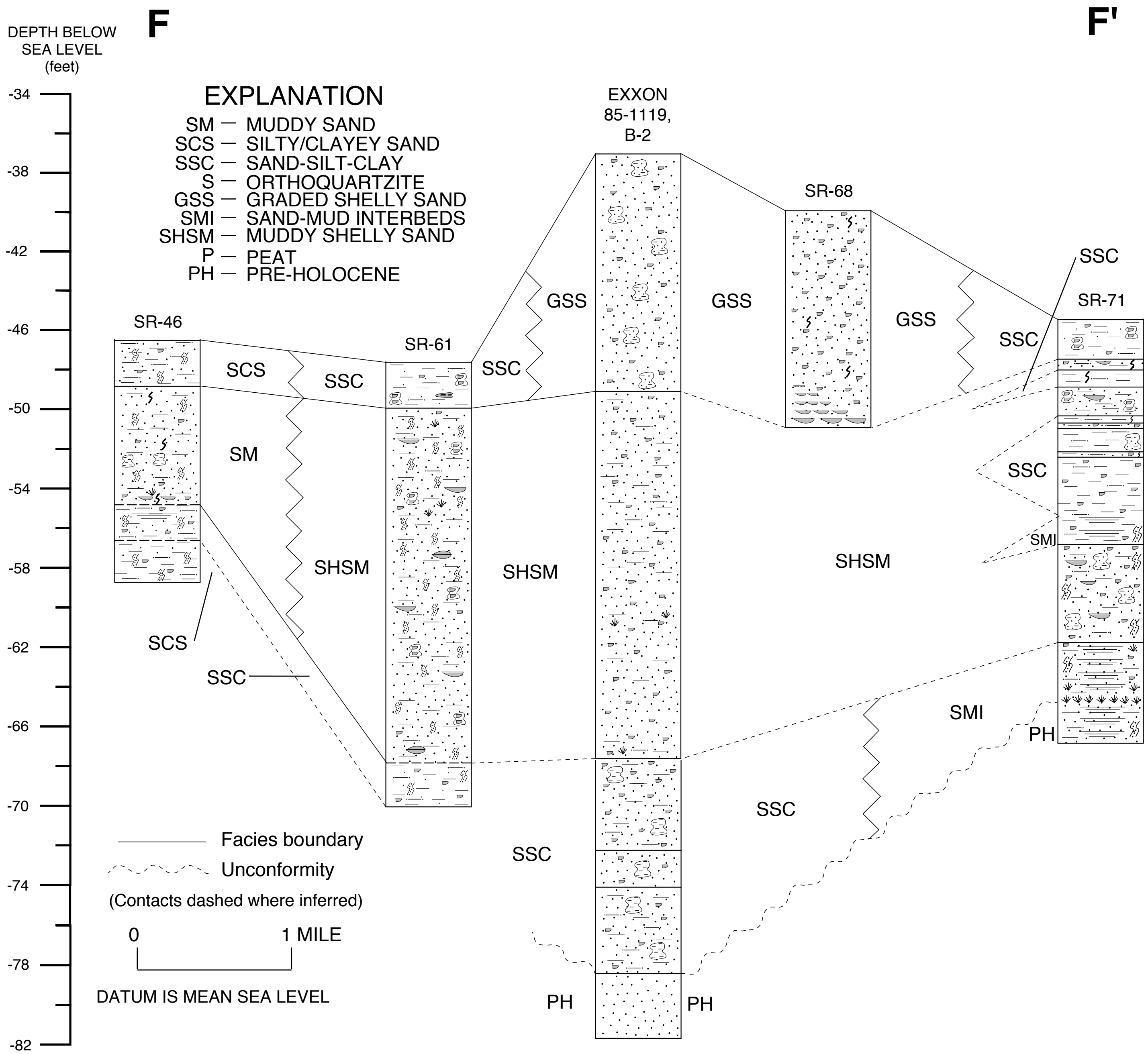


Figure 22.--Cross section F-F' (see figure 16 for cross section location).

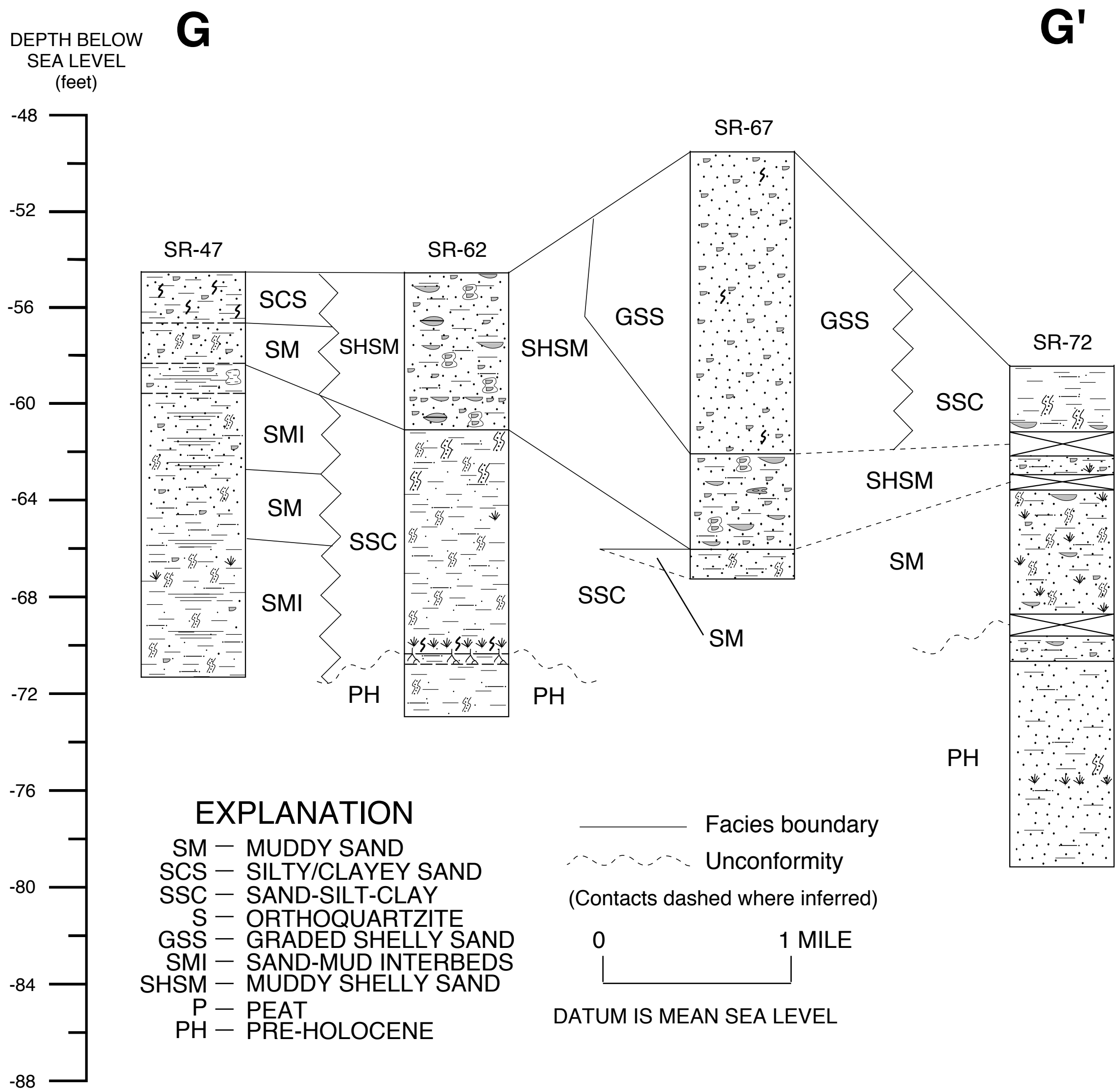


Figure 23.--Cross section G-G' (see figure 16 for cross section location).

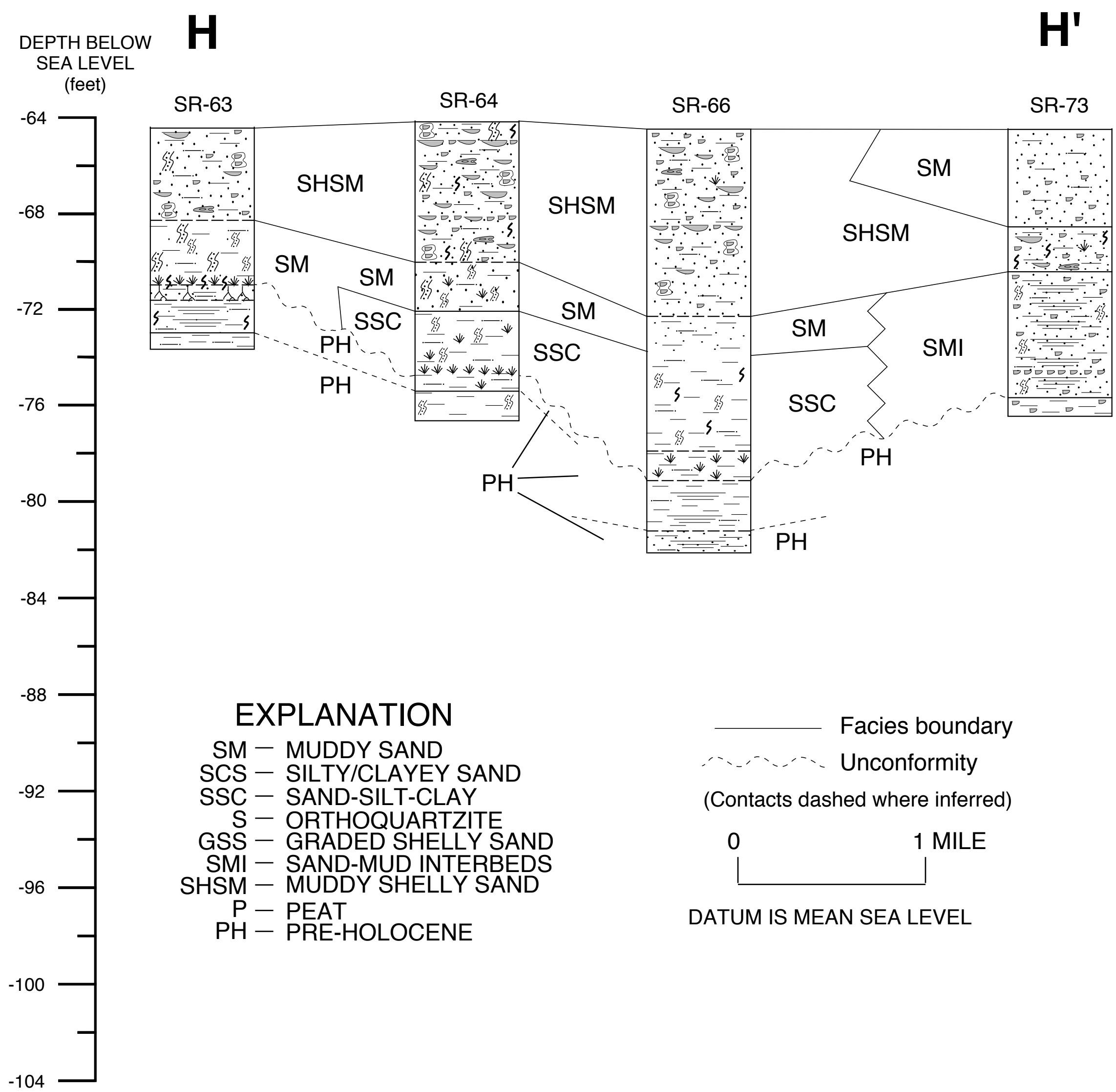


Figure 24.--Cross section H-H' (see figure 16 for cross section location).

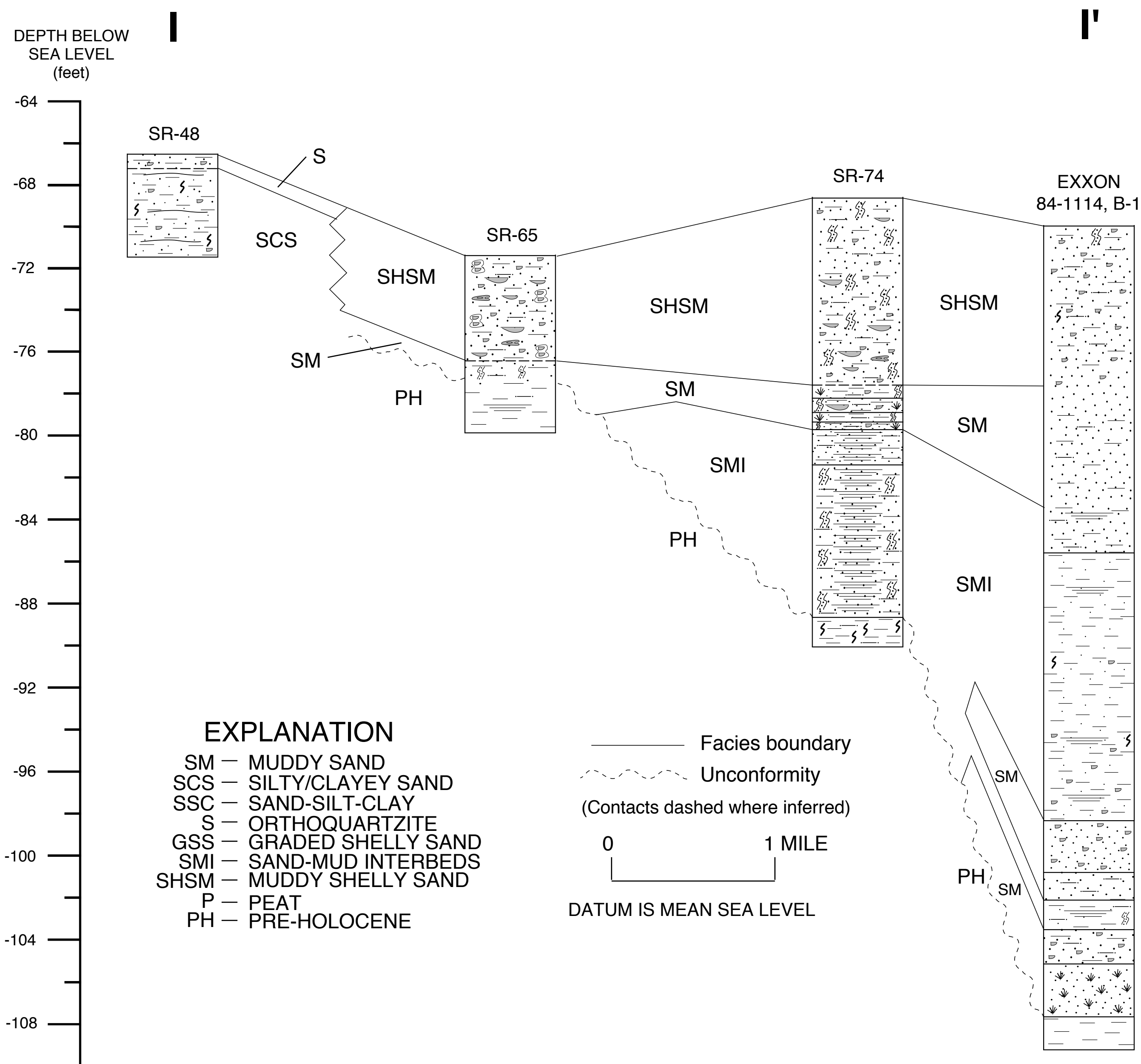


Figure 25.--Cross section I-I' (see figure 16 for cross section location).

SURFICIAL DISTRIBUTION OF MICROFACIES

Of the 9 microfacies evaluated for this study, only 6 can be found today at the sediment surface (fig. 15). Three microfacies that are not found at the sediment surface could not form there today: The Pre-Holocene Lithofacies (due to age considerations), the Peat Microfacies (due to environmental restrictions), and the Mud-Sand Interbeds (due to energy levels). The Sand-Silt-Clay Microfacies is the most common microfacies found at the sediment surface, accounts for 8 sample locations (32 percent), and is distributed in the northern half of the area 4 (fig. 15). The Muddy Shelly Sand Microfacies covers much of the southern half of area 4 and is second in frequency of occurrence at the sediment surface (7 samples or 28 percent). The third most abundant lithofacies or microfacies is also the most attractive facies in area 4 for sand resources, the Graded Shelly Sand Lithofacies. This lithofacies is confined to the east-central portion of area 4 and was encountered in 5 of the 25 bottom samples (20 percent) from area 4. This pattern can also be seen on figure 26, 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 clayey 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 and others, 1982). Tidal inflow and outflow through Main Pass redistributes estuarine sediments in the southern half of

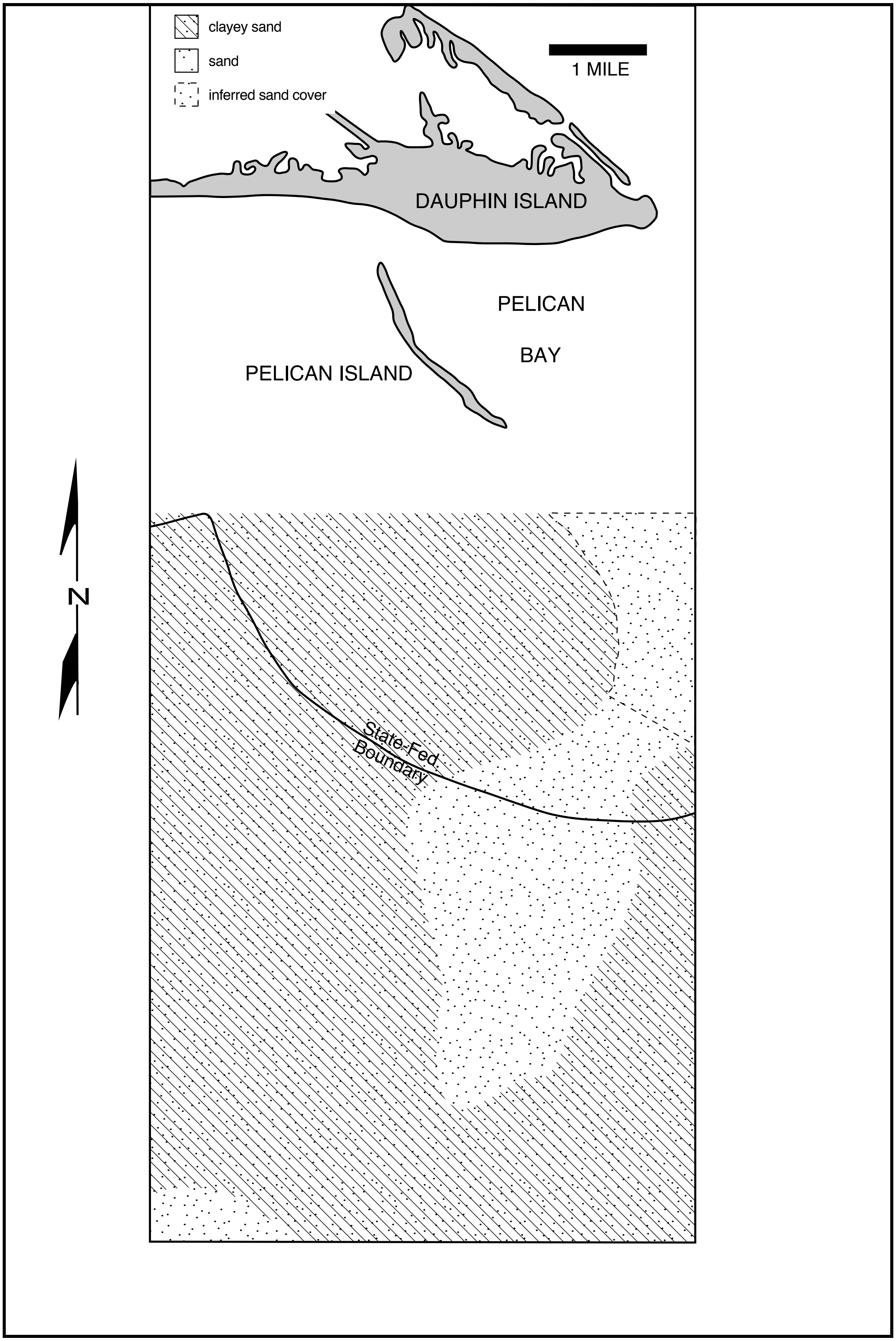


Figure 26.--Map of sand resource target area 4 showing surface sediment texture.

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. 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 26).

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, 1992). It is expected that in area 4, utilizing a sampling net finer than that used in the present study to prospect for sand bodies, 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 EEZ. Additionally, by delineating the facies that overlie a possible sand resource, depth of overburden can be determined; this enhances economic and environmental evaluations of proposed mining activities.

Utilizing the characteristics of the microfacies together with their vertical patterns, the conditions under which the sediments were deposited can be elucidated. By so doing, we can infer the depositional environment for the facies, e.g. the physical environment with its associated water depth, energy, etc., where the facies formed. Figure 27 shows a typical composite stratigraphic sequence of facies. It shows the general trend of the Ebb-Tidal Delta Depositional Environment overlying the pre-Holocene surface. These muddy delta sediments are overlain by the Muddy Shelly Sand Microfacies (Shelf Sand Sheet Depositional Environment). In east-central area 4, the Shelf Sand Ridge Depositional Environment stratigraphically overlies the Muddy Shelly Sand Microfacies. In the northern two-thirds of area 4, the Muddy Shelly Sand Microfacies is overlain by the Ebb-Tidal Delta Depositional Environment. In the southern one-third of area 4, both the upper Ebb-Tidal Delta and Shelf Sand Ridge Depositional Environments are absent, and the Muddy Shelly Sand Microfacies is exposed at the sea bottom. 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 (Geological Survey of Alabama, 1993).

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)

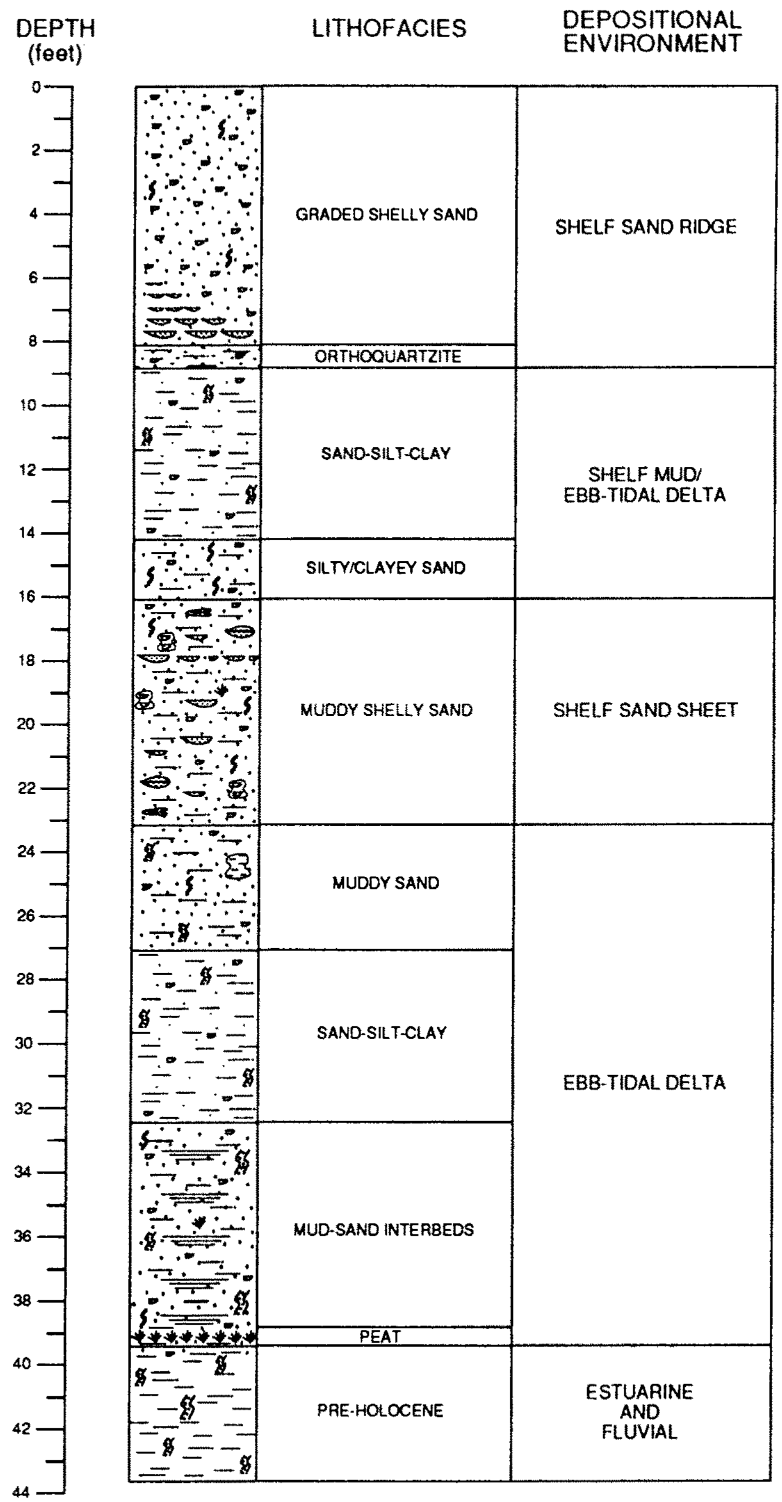


Figure 27.--Generalized stratigraphic sequence of sand resource target Area 4.

following transgression (review in Johnson, 1978; also see Ludwick, 1964, and Parker and others, 1992).

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 (non-storm) 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 (Stubblefield and Swift, 1976; Caston, 1972). 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; Geological Survey of Alabama, 1993) in Alabama Gulf of Mexico waters. Here deposits interpreted as this facies are widespread, massive, and take on a sheet-like geometry (Geological Survey of Alabama, 1993). 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, 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) and Geological Survey of Alabama (1993) 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 (Geological Survey of Alabama, 1993). 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 (Geological Survey of Alabama, 1993). 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). Geological Survey of Alabama (1993) 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 Geological Survey of Alabama (1993) 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 developed a depositional environmental classification that applied to a broad region of the Alabama EEZ, rather than, in the case of the present study, a scheme that applies locally. In addition, Parker and others (1993) could not benefit from the findings by Geological Survey of Alabama (1993) 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 Geological Survey of Alabama (1993) appear to be correlatable with area 4 subsurface lithologic units mapped 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 (Geological Survey of Alabama, 1993; Parker and others, 1993). 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 (Geological Survey of Alabama, 1993) which lithologically and genetically appears to be equivalent to open bay facies (Brande, 1983; Fletcher and others, 1990; Geological Survey of Alabama, 1991, 1992, 1993) 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 (Geological Survey of Alabama, 1993). 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 (Geological Survey of Alabama, 1993). 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 (Geological Survey of Alabama, 1993).

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 (Geological Survey of Alabama, 1993). 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 (Geological Survey of Alabama, 1993; Parker and others, 1993). 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 (Geological Survey of Alabama, 1993).

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 (Geological Survey of Alabama, 1993). At the surface and in the subsurface of Alabama State waters the lithologic units of both facies thin toward the southwest (Geological Survey of Alabama, 1993). 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 non-marine depositional environments (Geological Survey of

Alabama, 1993; Parker and others, 1993). In area 4, the pre-Holocene is interpreted as belonging estuarine and fluvial depositional environments.

In the sediment column of area 4 there is a rank order of lithofacies and microfacies in vertical sequence. Some facies are present throughout the study 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.

The Sand-Mud Interbeds Microfacies is most commonly seen near the bottom of vibracores and borings associated with other muddy units, especially the Sand-Silt-Clay Microfacies. It is not exposed at the sediment-water interface in area 4. 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 (Geological Survey of Alabama, 1993).

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) (Geological Survey of Alabama, 1993).

The Peat Microfacies formed in quiet marshy environments, either low salinity estuarine intertidal salt marshes or non-marine 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) (Geological Survey of Alabama

1991, 1992, 1993). Therefore, they are seen in area 4 associated with the Sand-Mud Interbed Microfacies, the Sand-Silt-Clay Microfacies, and the Pre-Holocene Lithofacies.

The Muddy Sand Microfacies formed in an ebb-tidal delta setting. Vibracores, borings, and bottom sediment samples collected by Geological Survey of Alabama (1993) 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. 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). It is present in the absence of the Graded Shelly Sand Lithofacies, Orthoquartzite Microfacies, or Sand-Silt-Clay Microfacies.

The Graded Shelly Sand Lithofacies, the most common 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 vibracore SR-48 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 series of geological cross sections (figs. 17 through 25) show trends in subsurface lithofacies and microfacies distributions in both dip-trending and strike-trending directions (fig. 16) to facilitate determination of lateral variability patterns for the facies. These facies are physically grouped in a Holocene age, 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; Geological Survey of Alabama, 1991, 1992, 1993). 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 (Geological Survey of Alabama, 1991, 1992, 1993). 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 non-marine 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), Geological Survey of Alabama (1991, 1992, 1993), and Parker and others (1993). 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 (Geological Survey of Alabama, 1991, 1992). Overlying these sediments are Holocene age transgressive deposits.

Area 4 seismic data consists of unpublished seismic records collected by L. R. Bartek, Geology Department, University of Alabama, and his graduate students. 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.

Eighteen of the 25 vibracores and borings used in the present study penetrated the late Pleistocene-early Holocene unconformable surface. Figure 28 is a map showing depths to this surface in ft below sea level. Geological Survey of Alabama (1993) produced a structure contour map of the surface in State waters of the west Alabama inner continental shelf. The boundaries of their database coincide with the boundaries of the area 4 database; thereby allowing their map to be extended to include area 4 (fig. 29). 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. 29). 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 of Dauphin Island (fig. 29) (Geological Survey of Alabama, 1993). The channel network does not appear to extend into area 4 and therefore probably lay to the northwest.

Figure 30 shows the total thickness of Holocene sediments measured in the vibracores and borings. These data was combined with the data base from

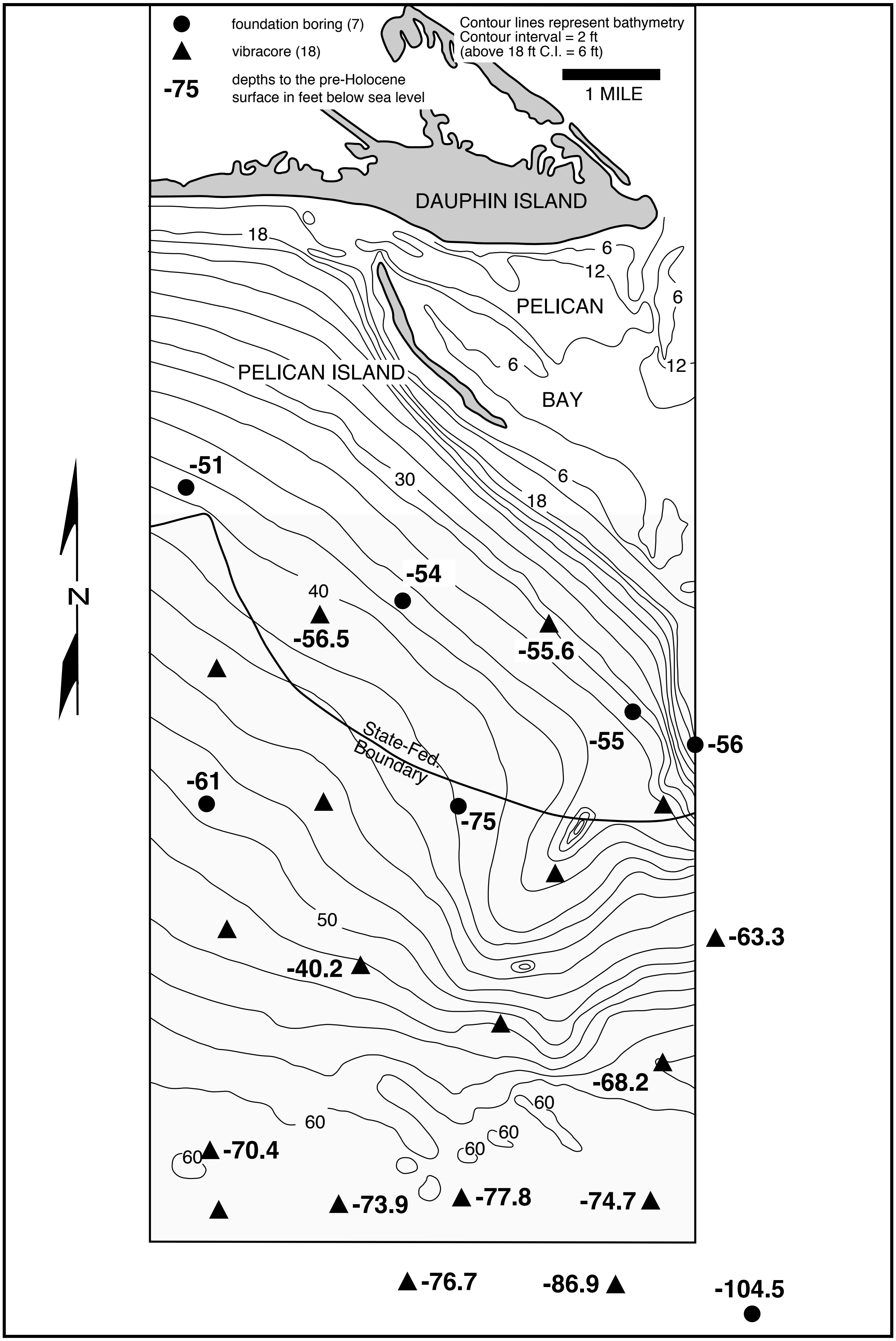


Figure 28.--Map of sand resource target area 4 showing depths to pre-Holocene surface.

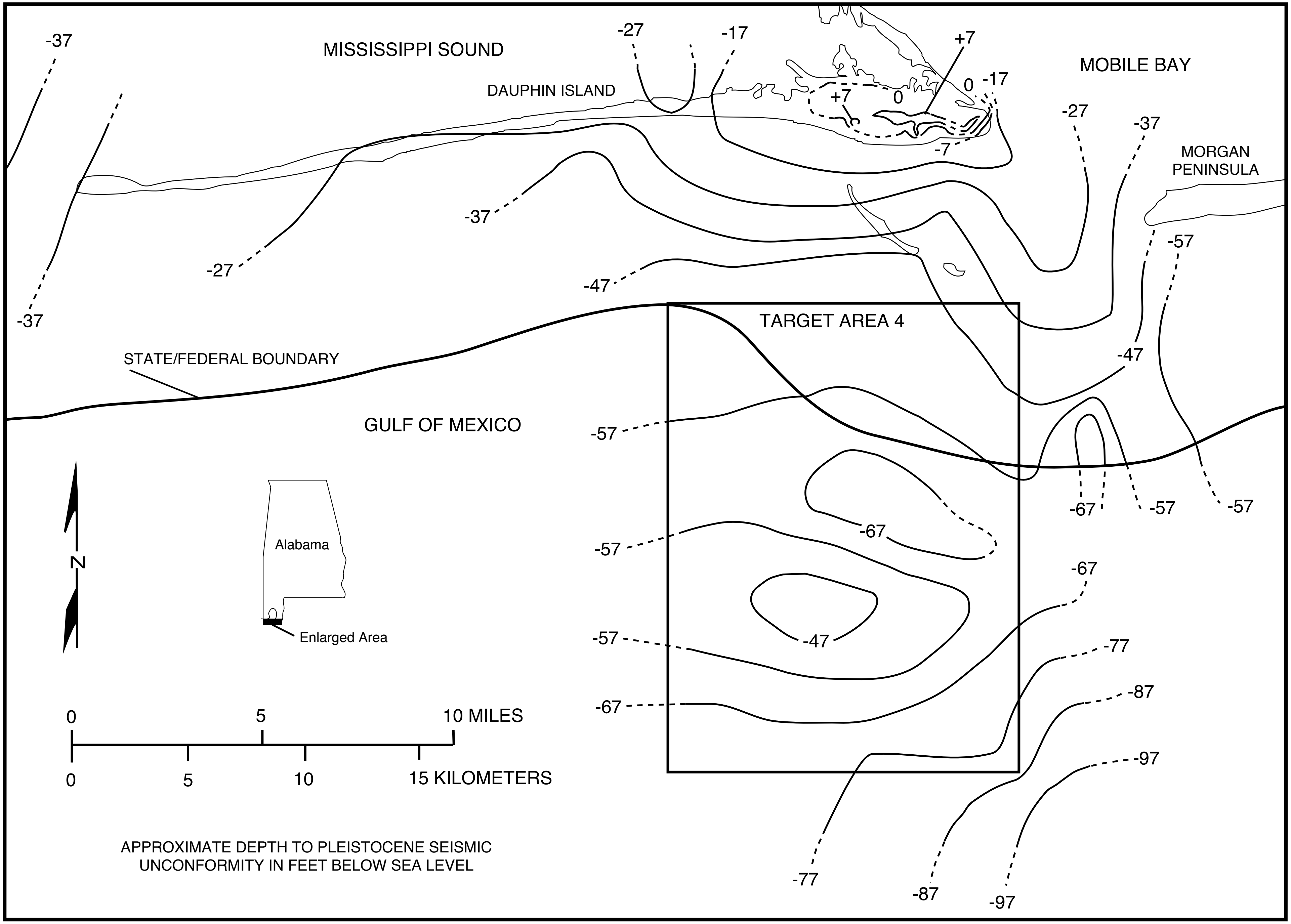


Figure 29.--Structure contour map of the Pleistocene-Holocene unconformity in the west Alabama inner continental shelf (modified from Hummell and others, 1993).

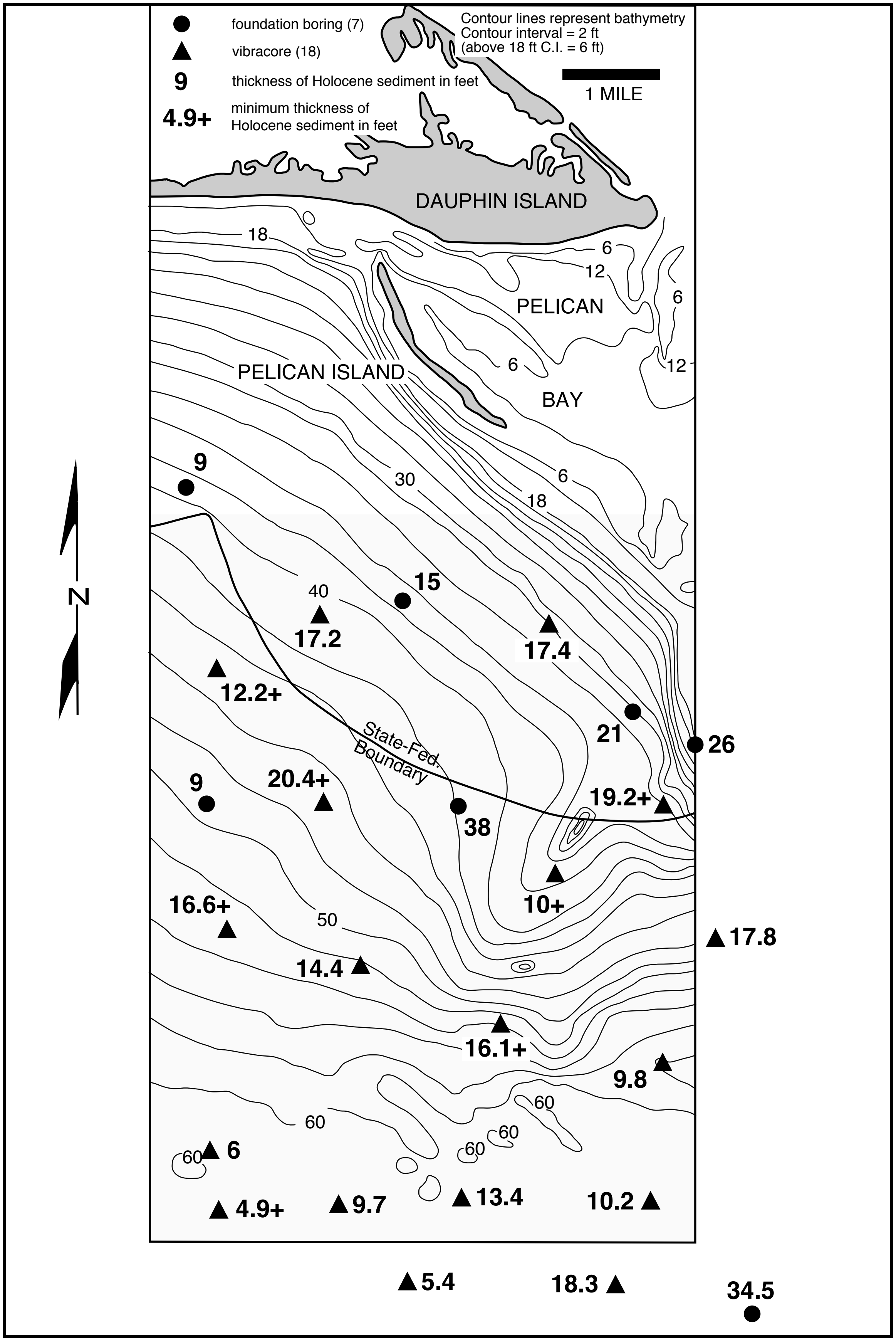


Figure 30.--Map of sand resource target area 4 showing thickness of Holocene sediments.

Geological Survey of Alabama (1993) to produce an isopach map of the Holocene sediments in area 4 (fig. 31). The Holocene depocenter lay in the central portion of the study area (fig. 31) and fills a paleotopographic low on the northeast side of a paleotopographic high (fig. 31). There appears to be another Holocene depocenter southeast of the study area (fig. 31).

DIP DIRECTION FACIES DISTRIBUTION

Holocene thickness and facies trends are portrayed in nine cross sections (four dip-trending and five strike-trending), taken together, form a grid with cells measuring between 1 and 2 mi on a side. The cross sections from the study area 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).

None of the vibracores or borings appear to have unquestionably encountered any fluvial-deltaic paleochannels. These channels have been mapped in Mobile Bay (Geological Survey of Alabama, 1991), Mississippi Sound (Geological Survey of Alabama, 1992), and on the Alabama continental shelf south and southwest of the study are (Vittor, B. A., and Associates, Inc., 1985; Kindinger, 1988; Parker, 1990). These channels no doubt exist within the study area, but without seismic data it is not feisible to describe subsurface

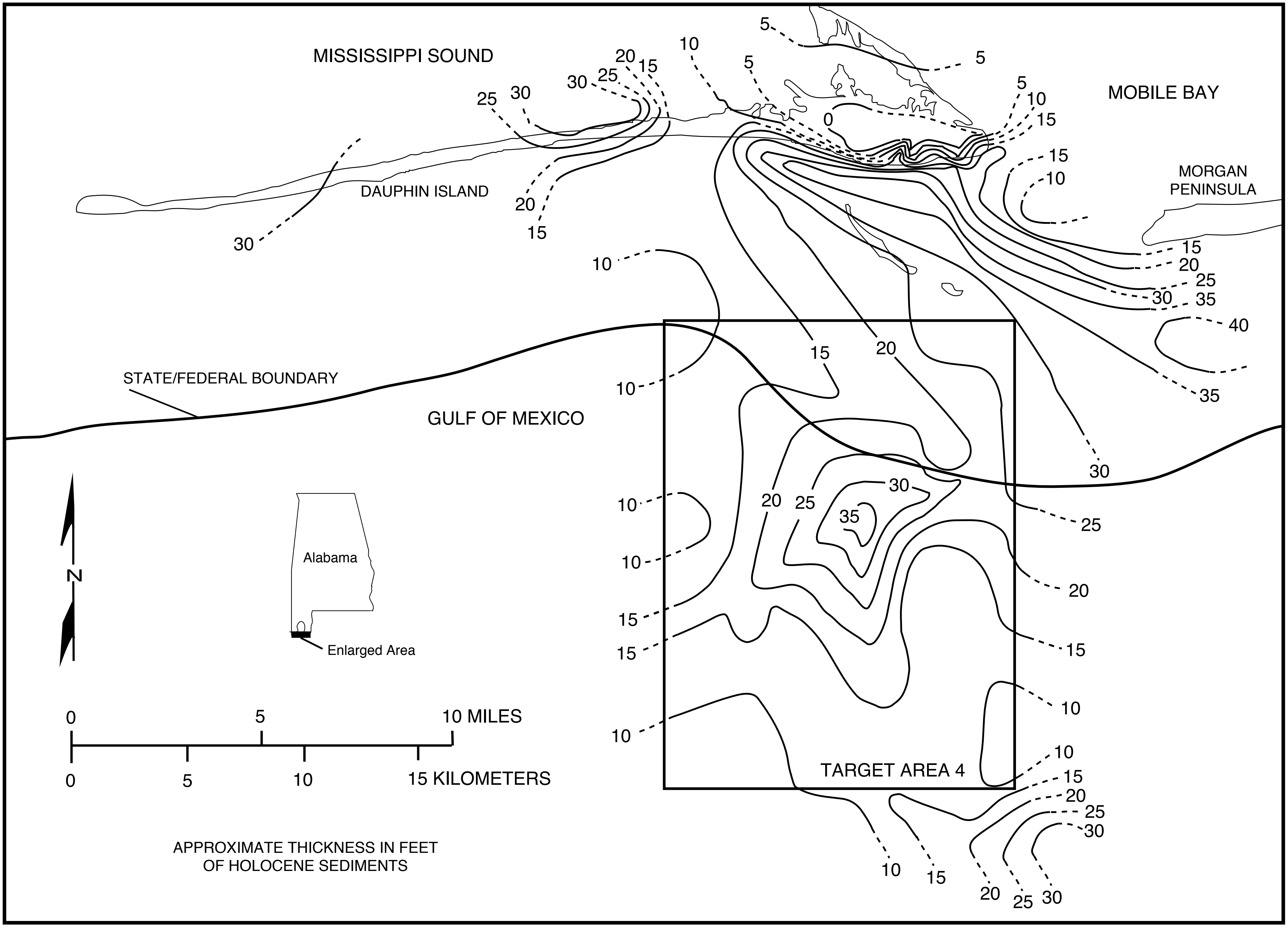


Figure 31.--Isopach map of Holocene sediments in the west Alabama inner continental shelf (modified from Hummell and others, 1993).

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 (Geological Survey of Alabama, 1991) and Mississippi Sound (Geological Survey of Alabama, 1992), there is a noticeable lack of paleosol development, rooted zones, marsh deposits, peat, and wood associated with the top of the pre-Holocene within the study area (where sampled by vibracores and borings). This was also noted by Geological Survey of Alabama (1993) in their 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' extends north-south along the western margin of area 4 (figs. 16 and 17). A stiff, clay or mud to sandy mud unit occurs at the top of the Pre-Holocene Lithofacies (fig. 17).

The basal Holocene section consists of lens shaped beds of the Sand-Mud Interbeds Microfacies, the Sand-Silt-Clay Microfacies, and the Silty/Clayey Sand Microfacies. A thin bed of the Peat Microfacies with roots preserved on top of an apparent paleotopographic high was sampled by vibracore SR-63. These facies are in turn overlain by a thick unit of the Muddy Sand Microfacies which extends almost the entire length of the cross section line. This microfacies is exposed at the sediment-water interface in the vicinity of boring Exxon 0184-1015, B-1 and interfingers with muddy microfacies at cross section end points. The sediment column along cross section A-A' is capped by thin units of the Silty/Clayey Sand, the Muddy Shelly Sand, the Sand-Silt-Clay, and the Orthoquartzite Microfacies.

Cross section B-B' (figs. 16 and 18) stretches approximately north-south through the west-central portion of the study area. 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. 18). 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. 29 and 18). The majority of the sediment column along cross section B-B' is comprised of the Muddy Shelly Sand Microfacies (fig. 18). A sheet of the Sand-Silt-Clay Microfacies caps the Muddy Shelly Sand Microfacies along the northern segment of the cross section.

Cross section C-C' (figs. 16 and 19) of the east-central portion of area 4, shows a relatively thick Holocene sedimentary deposit overlying pre-Holocene clays and muds. The basal Holocene in this north-south oriented cross section, is composed of thin beds of various muddy microfacies (fig. 19). As in cross section B-B' (fig. 18), much of the remainder of the preserved Holocene shown by cross section C-C' 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. 19). This lithofacies interfingers with a layer of the Sand-Silt-Clay Microfacies at the northern end of the cross section.

Cross section D-D' (figs. 16 and 20) is oriented north-south along the eastern margin of the study area. The Holocene section thickens where vibracores and borings encounter the proximal portion (ebb ramp) of the ebb-tidal delta of Mobile Bay and the western side of the Mobile-Tensaw alluvial channel (Geological Survey of Alabama, 1993) (fig. 20). In both cases, lithologic units become thinner, less laterally continuous, and the stratigraphic relationships between them become complex (fig. 20). In addition, the shallow stratigraphy along the Mobile-Tensaw alluvial valley would be disrupted by dredging activity associated with the Mobile Ship Channel. It is recommended that any sand mining project in area 4 avoid the eastern margin of the study area, as it would be difficult to follow a given clean sand body. In addition, a mining operation in this portion of the study area would be expected to encounter diminishing returns as the clean sand body being mined tended would tend to thin or pinch out.

The Pre-Holocene Lithofacies along cross section D-D' (fig. 20) 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. 20) 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 D-D'. It appears that the Graded Shelly Sand Lithofacies becomes laterally gradational with the shelf sand sheet facies of Geological Survey of Alabama (1993) toward the northeast, outside of area 4. In general, the Sand-Mud Interbeds Microfacies is found low in the sediment column along the cross section with the Muddy Sand and the Muddy Shelly Sand Microfacies toward the middle portion of the column (fig. 20). The Sand-Silt-Clay Microfacies comprises the top of the sediment column along the northern two-thirds of cross section D-D'.

STRIKE DIRECTION FACIES DISTRIBUTION

The remaining five cross sections are oriented either northwest-southeast (cross sections E-E', F-F' and G-G') or east-west (H-H' and I-I') across the study area (fig. 16). Cross section E-E' (figs. 16 and 21) lay along the northern margin of the study area. This cross section 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. 21). 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. 21). 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. 21).

Cross section F-F' (figs. 16 and 22) illustrates the shallow sediment column across the central portion of area 4. There are several noteworthy features shown by this cross section. Based on the vibracores and borings of this study, the Holocene sediment package 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 the study area (figs. 31 and 22). Based on the nine cross sections of area 4 developed in this study, the Graded Shelly Sand Lithofacies can be visualized as situated on top of a relatively massive unit of the

Muddy Shelly Sand Microfacies and laterally interfingering with mostly the Sand-silt-clay Microfacies. This concept is illustrated in cross section F-F' (fig. 22).

The late Pliestocene-early Holocene unconformable surface expresses the paleotopographic low noted on the structure contour map (fig. 29). The Pre-Holocene Lithofacies is represented by sand and muddy sand units (fig. 22). 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. 22). This deposit interfingers with other muddy microfacies at cross section endpoints (fig. 22). A bed of the Peat Microfacies occurs near the base of the Holocene section in vibracore SR-71 (fig. 22). 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. 22). The deposit of the Graded Shelly Sand Lithofaces forms a bathymetric high on the seafloor (fig. 5).

The shallow sediment column across the south-central portion of area 4 is shown in cross section G-G' (fig. 16 and 23). Here, the Holocene section begins to thin toward the southern flank of the Holocene depocenter (fig. 31). 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. 23). The basal Holocene is comprised of beds of the Sand-Silt-Clay, the Muddy Sand, and the Sand-Mud Interbeds Microfacies (fig. 23). As in cross sections E-E' and F-F', a conspicuous bed of the Muddy Shelly Sand Microfacies is present dominating the middle and upper portions of the Holocene sedimentary deposit (fig. 23). A surficial unit of the Graded Shelly Sand Lithofacies interfingers with beds of the Muddy Shelly Sand and the Sand-Silt-Clay Microfacies (fig. 23). The Graded Shelly Sand Lithofacies unit forms a positive relief feature on the seafloor.

Farther seaward of cross section G-G', along the southern margin of the study area, is cross section H-H' (figs. 16 and 24). 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. 24). 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. 24). 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. 24). 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. 24).

Cross section I-I' lay mostly outside of the southern boundary of area 4 as defined by Parker and others (1993) (figs. 16 and 25). None-the-less, a pre-existing vibracore and boring collected in close proximity to the study area permitted the construction of a cross section with the addition of just two new vibracores (fig. 16). The late Pleistocene-early Holocene unconformable surface dips steeply from west to east along the cross section line into the what may be the Mobile-Tensaw alluvial valley (fig. 25). The Pre-Holocene Lithofacies encountered here consist of clay and mud beds. The paleotopographic low is filled by what is interpreted as Holocene age ebb-tidal delta muddy sand, sandy mud, and sand of the Sand-Mud Interbeds and Muddy Sand Microfacies (fig. 25). The Holocene sediment fill is blanketed with a unit of the Muddy Shelly Sand Microfacies which interfingers with a thin bed of the Orthoquartzite Microfacies and a unit of the Silty/Clayey Sand Microfacies at the western end point of the cross section (fig. 25).

To summarize, the structure contour map (fig. 29) 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 (Geological Survey of Alabama, 1993) (fig. 31). It can be concluded from examination of the nine cross sections that microfacies of the Ebb-Tidal Delta Depositional Environment form the basal Holocene in the study area. 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 that formed in the Shelf Sand Ridge Depositional Environment is imbedded in the upper part of the Muddy Shelly Sand Microfacies. The unit of the Graded Shelly Sand Lithofacies laterally interfingers with ebb-tidal delta microfacies, the Muddy Shelly Sand Microfacies, and nearshore, shallow water facies (shelf mud, open bay, and surficial sand sheet) of Geological Survey of Alabama (1993).

SHELF SAND RIDGES

The Alabama EEZ contains an abundance of shelf sand ridges that generally are elongate in a NW-SE 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, 1992).

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

Three dimensional facies patterns are regionally predictable in the study area and have been summarized above. Sediments of possible use in beach nourishment are restricted to the clean shelly sands that comprise the Graded Shelly Sand Lithofacies unit in east-central area 4. The upper surface of this unit is exposed at the sediment-water interface, thereby eliminating the cost of overburden removal in any mining project. 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. The sand body is located 4.5 to 8.5 miles off the southeast coast of Dauphin Island, is exposed at the surface over an area of 8 square miles, and is located in water depths from approximately 30 to 60 ft below sea level.

Further work is needed to determine the details of sand body geometry. Additional surface and subsurface data are needed to determine the geographic limits of the sand body; the nature of its boundary with respect to surrounding lithologic units; whether the margins thin rapidly or gradually; and if the sand body is granulometrically (and facies) homogeneous or not.

RESOURCE POTENTIAL OF AREA 4

THE GRADED SHELLY SAND LITHOFACIES

The resource potential of the Graded Shelly Sand Lithofacies sand body in area 4 and onshore sand deposits was determined by comparing the sediment character of these deposits with the native sediment occurring on each of the eroding southeastern Dauphin Island shoreline segments. Since any new material added to the beach will be subjected to winnowing by coastal processes, it is important to determine the grain size characteristics of the native beach sediment and the sediment from the Graded Shelly Sand Lithofacies sand body in area 4. Sediment that is too fine will be removed and transported offshore by wave action and longshore currents, whereas coarser sediment may produce a steeper beach and will not be transported by wind to the backshore areas of the beach. Also important in considering beach replenishment of Dauphin Island is the aesthetic quality of the replenishment material. Most of the Alabama Gulf of Mexico shoreline is composed of clean white sand. Borrow material comprised of iron stained or dark colored sand would likely detract from the natural beauty of the beach and should not be considered suitable for beach nourishment.

There is insufficient subsurface data to accurately delineate the boundary of the Graded Shelly Sand Lithofacies sand body in the subsurface. Until future work provides additional subsurface information it is thought that since the sand body represents an active shelf sand ridge, the upper surface of which is exposed on the seafloor, it is likely that the outline of the microfacies on the seafloor represents a trace of the subsurface edge of the sand body. Based on the vibracores and borings from this study and idealized geometric shape of Gulf of Mexico shelf sand ridges it is estimated that the Graded Shelly Sand Lithofacies sand body in area 4 contains 30 million yd^3 of sediment.

As listed in tables 4 and 5, vibracore sediment samples of the Graded Shelly Sand Lithofacies had an average mean grain size of 1.39 Ø (medium sand) and average standard deviation (sorting) of 0.89 Ø (moderately sorted). The samples averaged 3.5 percent shell gravel, 94.9 percent sand, 0.5 percent silt, and 1.1 percent clay. Sediment color was mostly yellowish gray (5 Y 7/2), and light olive gray (5 Y 6/1).

Sand body sedimentary characteristics compare favorably with the characteristics of sediment samples collected from eroding southeastern Dauphin Island shoreline segments and analyzed by Parker and others (1993). These sediment samples have a composite mean grain size of 1.89 Ø (medium sand) and sorting of 0.38 Ø (well sorted). The native beach sediment averages 99.91 sand, 0.09 percent silt and clay, and is light gray in color (Parker and others, 1993). The present study has determined that an estimated 2.4 million yd^3 of sand would be required from area 4 for restoration of the southeastern Dauphin Island shoreline to its 1955 position. The Graded Shelly Sand Lithofacies sand body in area 4 can provide enough sand to restore Dauphin Island beach segments and permit future nourishment as the need arises.

POTENTIAL ONSHORE SAND RESOURCES

Parker and others (1993) evaluated potential alternative sources of beach replenishment sand for coastal Alabama. Their study evaluated the suitability of various sand units from Cenozoic age formations that crop out on land in Mobile and Baldwin Counties (fig. 32 and table 6). Most onshore sand production from coastal Alabama is from the Citronelle Formation (Dean, 1990). Parker and others (1993) concentrated their efforts on an evaluation of clean white sand samples collected from active and inactive sand pits from this formation. Their Citronelle samples have an average mean grain size of 1.69 Ø (medium sand) and average sorting of 0.82 Ø (moderately sorted). The samples averaged 98.3 percent sand and 1.7 percent silt and clay (Parker and others, 1993). This compares very well with the sedimentary characteristics of the Graded Shelly Sand Lithofacies sand body in area 4 and southeastern Dauphin Island shoreline samples.

Most Citronelle Formation samples analyzed by Parker and others (1993) were found to be aesthetically unsuitable for beach nourishment due to their pinkish color. Appropriate onshore sources of clean sand for beach replenishment were determined to be are very limited due to difficulties in

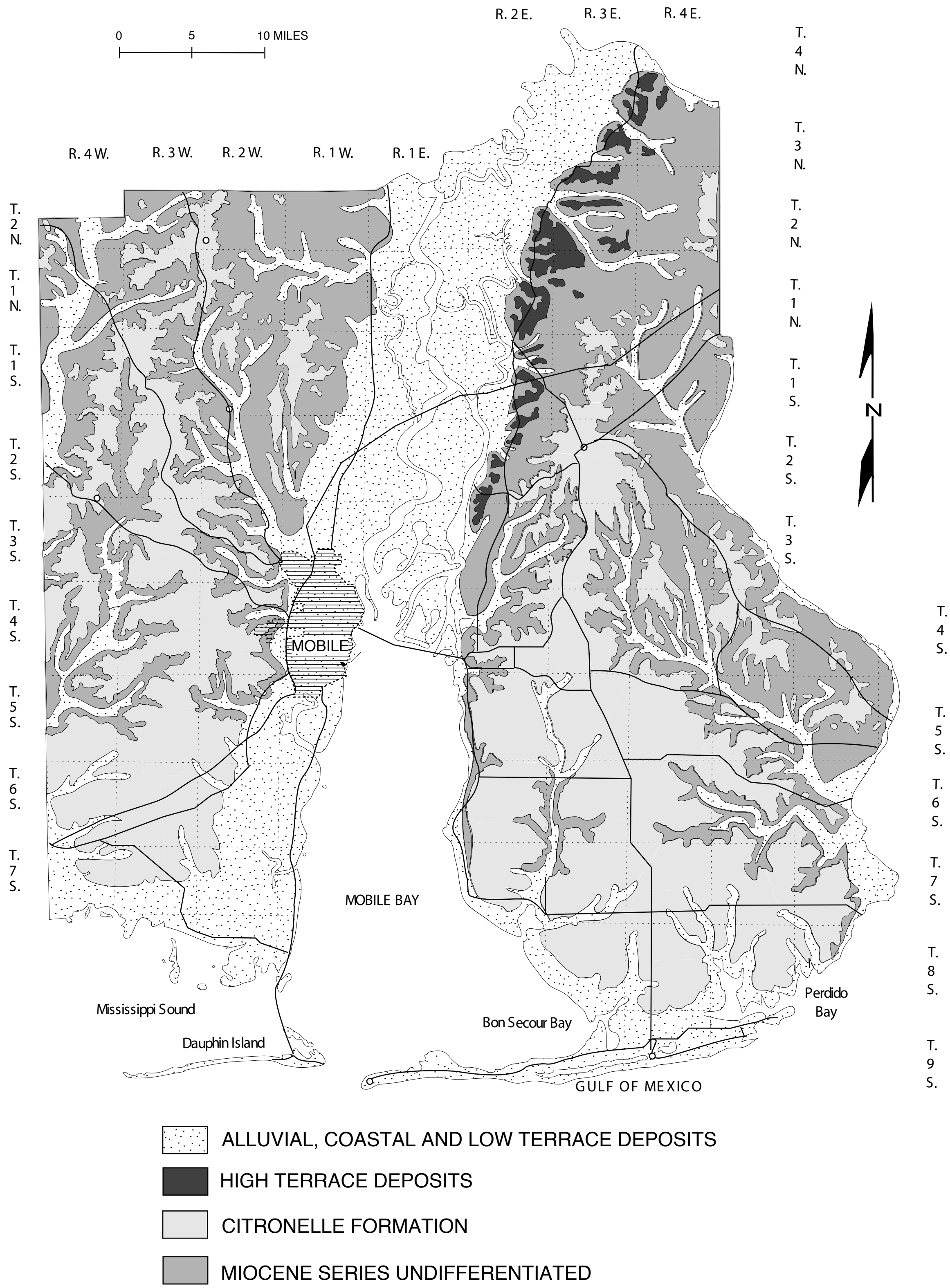


Figure 32.--Geologic map of Mobile and Baldwin counties (modified from Parker and others, 1993).

Table 6.--Chart of sedimentary formations that crop out or occur in the shallow subsurface in Baldwin County, Alabama (stratigraphically modified from Reed, 1971).

ERA	PERIOD	TIME SUB-DIVISION	EPOCH	AGE (THOUSANDS OF YEARS)	GEOLOGIC UNIT	LITHOLOGY
CENOZOIC	QUATERNARY		HOLOCENE	10	ALLUVIAL AND TERRACE DEPOSITS	Alluvial deposits consist of alluvium, beach, estuarine, swamp, stream, and deltaic deposits, including white, gray, black, orange, and brown, very fine- to coarse-grained sand, clayey sand, sandy clay, and peat. May include variable amounts of organic material with peat consisting primarily of organic material. Gravel may occur locally. High terrace deposits consist of white, gray, brownish-red, and orange, fine- to coarse-grained sand that is gravelly in many exposures. Lenticular beds of light-gray, orange, and yellow sandy clay occur locally.
			PLEISTOCENE	1,800		
	TERTIARY	NEOGENE	PLIOCENE	5,000	CITRONELLE FORMATION	Sand, dark-reddish-brown, gravelly, locally containing clay balls and clay partings; light-gray, orange, and brown sandy clay, and clayey sand; and quartz gravel. Yellowish-brown iron oxide-cemented sandstone at base of formation.
			MIOCENE	23,000	MIOCENE UNDIFFERENTIATED	Clay, sand, and sandy clay, light-gray, yellowish gray, yellow, and white, laminated to thin-bedded, and massive.

availability of appropriate sand volumes for beach replenishment (Parker and others, 1993). Overall, the Citronelle Formation deposits are not suitable for restoration of the Alabama Gulf of Mexico beach shorelines (Parker and others, 1993). Most offshore target area sands are aesthetically compatible with present coastal Alabama beach sands, with regard to color, since these deposits would likely turn into white sand after a short exposure on the beach (Parker and others, 1993). Therefore, the offshore sand bodies are a much more viable sand source than are the Cenozoic sand deposits of the onshore coastal zone (Parker and others, 1993).

ENVIRONMENTAL IMPACTS OF SAND MINING OF AREA 4

If sand resources were to be utilized from the Graded Shelly Sand Lithofacies sand body in area 4 for beach replenishment of eroding southeastern Dauphin Island shoreline segments, possible environmental impacts from the dredging operation must first be determined. Three types of preliminary environmental analyses were accomplished in this study: Impacts of offshore sand dredging on shelf circulation; on ongoing human marine activities; and on local biota. The first two will be evaluated in the section on "Physical Environmental Considerations"; results of a preliminary benthic survey are presented in the section "Benthic Biological Analysis".

PHYSICAL ENVIRONMENTAL CONSIDERATIONS

IMPACTS ON SHELF CIRCULATION AND SHORELINE EROSION

Parker and others (1993) considered the possible consequences of mining sand from offshore shelf sand ridges as it relates to changes in the prevailing regimes of inner continental shelf sediment transport and water circulation. Although they pointed out that long term oceanographic data and studies are needed for fair weather and storm inner continental shelf circulation before a determination can be made, it was concluded that under fair weather conditions, little shelf sediment is transported; high winds and waves are necessary to move sediment or to enhance offshore dredging impact on shorelines. They stressed the importance of modeling the hydrodynamic flow caused by modified Alabama shelf sand ridges under extratropical, pre-frontal wind and wave conditions, as well as during hurricanes, to identify any physical environmental impacts that mining activities may produce.

It is recommended in the present study that the prevailing erosion and sediment transport regimes along southeastern Dauphin Island shorelines be modeled prior to a demonstration project. This may provide the best estimate of the expected longevity of beach nourishing sediment and the fate of these sediments as the beach continues to erode.

The physical system of the Graded Shelly Sand Lithofacies unit in area 4 and vicinity should be modeled prior to any sand mining operation. In addition to evaluating the impact on the prevailing physical system by sand removal, these modeling efforts may indicate how to best mine the sand body to minimize any undesirable outcomes.

IMPACTS ON ECONOMIC ACTIVITIES

The Alabama EEZ is utilized very heavily by several industries; thus impacts on marine economic activities must be carefully evaluated. Figure 33 is a map showing the locations of major hazards in area 4 and vicinity. This map does not contain all hazards that might be impacted by any sand dredging operation (such as, archaeological sites). Such a detailed assessment would be part of an EIS relating to the specific portion of the Graded Shelly Sand Lithofacies body that is to be dredged.

Mobile, at the head of Mobile Bay, is a major port for seagoing and inland water transport. It is the primary port linking the inland Tenn-Tom Waterway and the Mobile-Tensaw River system with overseas ports. The artificially maintained Mobile Ship Channel runs from the Port of Mobile through Mobile Bay and Main Pass (fig. 33). Navigation fairways extend offshore from the Pass in several directions. Any dredging or alteration of water depths must avoid all such navigational waterways.

Both State and Federal waters in the EEZ have high potential for hydrocarbon reserves. Most of area 4 has been leased for hydrocarbon exploration. Drilling and production activities entail placement on the seafloor of various facilities, including drilling platforms, production platforms, wellheads, pipelines, etc (fig. 33). Obviously, any sand resource dredging must avoid all such present facilities; identification of all such locations in a proposed mining area would be essential.

Since 1987, the U.S. Army Corps of Engineers, Mobile District, has been conducting an experiment to determine the fate of dredge spoil material placed in disposal sites on the Alabama inner continental shelf and whether an artificial bathymetric high (berm) consisting of dredge material would enhance local

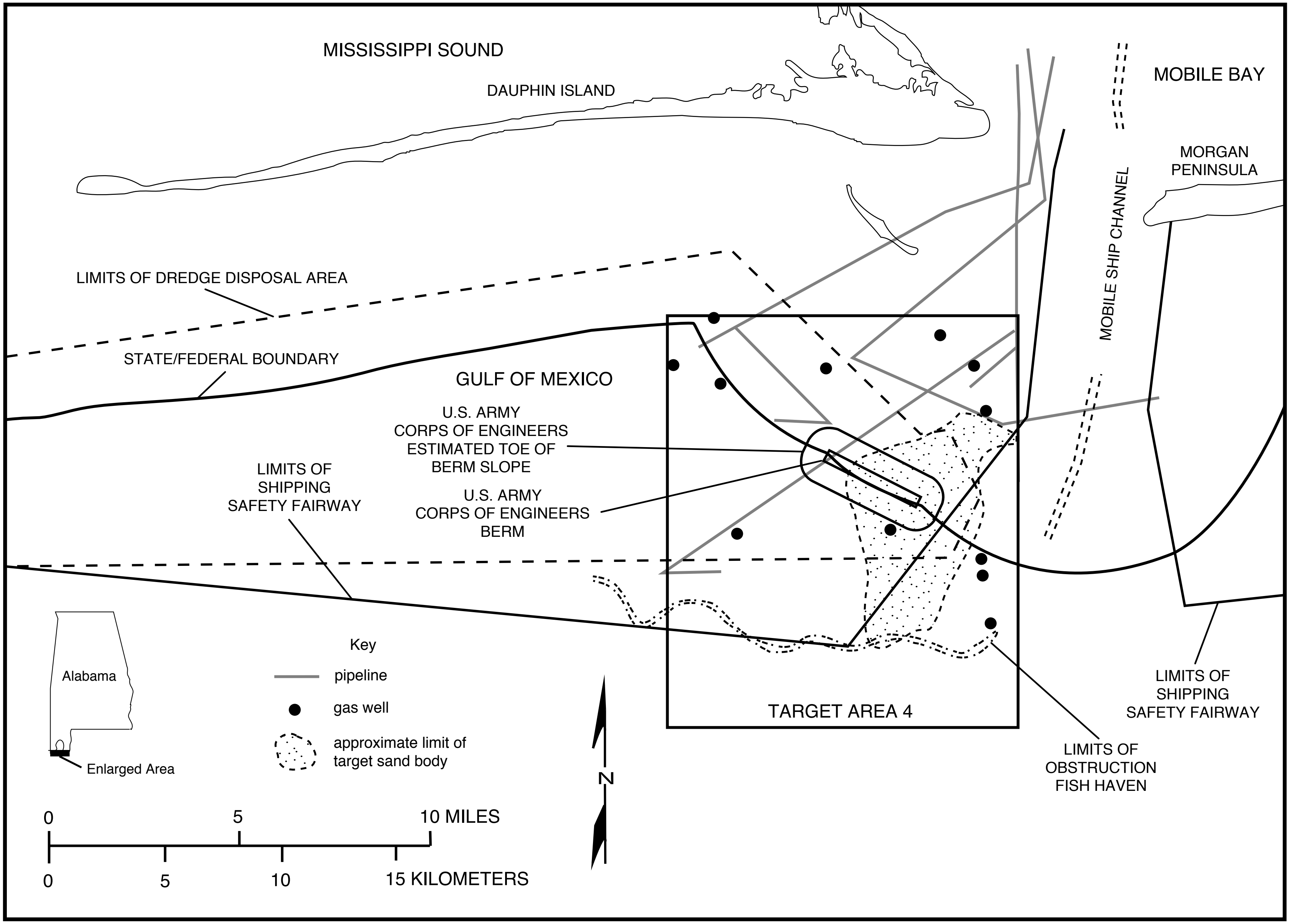


Figure 33.--Hazards map of sand resource target Area 4.

biological productivity (Browning, Inc., 1987; John E. Chance and Associates, Inc., 1993). The most nearshore berm is located in area 4 (fig. 33). The study includes a monitoring program that periodically conducts a hydrographic survey of the berm. In addition, researchers routinely granulometrically analyze bottom sediment samples from the surface of the berm and continental shelf between the berm and Pelican Island.

The berm experiment should not be impacted by mining the eastern portion of the Graded Shelly Sand Lithofacies. Sediment transport in area 4 appears to be toward the southwest; away from the berm and sea bottom sampling area. In addition, the Graded Shelly Sand Lithofacies sand body is estimated to contain over an order of magnitude more sand than is needed to nourish eroding southeastern Dauphin Island shoreline segments. Even if a mining operation is confined to the eastern side of the sand body, there should be adequate sand resources for beach nourishment.

Fishing, both commercial and sport, is a major industry in the Alabama EEZ. Any impact to this industry would need to be carefully delineated. Preliminary studies indicate the likelihood of only minimal impact on the industry from sand resource mining. No live bottom/hardbottom sites or reefs, often sites of concentrations of fishes, are known to exist in area 4. An obstruction fish haven lies along the 60 ft isobath in the southern portion of the study area (fig. 33). If the southern margin of the Graded Shelly Sand Lithofacies is avoided, it is unlikely that the obstruction fish haven would be impacted by a mining operation. Man-made structures associated with hydrocarbon drilling and production in the study area are attractive sites for recreational fishing. In addition, no nurseries for juveniles of economically significant finfish or shellfish are thought to exist in area 4. Nonetheless, additional study to evaluate these preliminary findings would be required before mining could begin.

BENTHIC BIOLOGICAL ANALYSIS

If offshore sand resources were recovered for transport to beach replenishment sites, local biota would be impacted. This is especially true of specifically the benthic biota, those organisms that live on or in the seafloor, would be physically displaced or killed by dredging activities. Therefore, a preliminary survey of the benthic and nektonic fauna was conducted in area 4 as a prelude to a detailed faunal analysis of the sand body and vicinity. The approach was to compile pre-existing biological data for area 4 and add the results of a preliminary benthic survey of bottom samples collected at new vibracore locations. The purpose was to determine what species were found to be living in the study area and reveal the presence of endangered or economically valuable species.

RESULTS AND INTERPRETATIONS

TAXONOMIC COMPOSITION

Table 7 is a list of those living benthic and nektonic species reported to be present in area 4. As mentioned previously, in order to obtain an accurate census of those species that occur in the study area, more than one sampling technique must be employed, because organisms occupy different parts of the water and sediment columns. In addition, organisms vary in their abilities to avoid or escape from various biological sampling devises. A more quantitative approach is beyond the scope of this study as it would require extensive sampling of the study area. This detailed sampling should be reserved for an Environmental Impact Statement (EIS) of the actual mine site. An attempt was

Table 7.-- Taxa reported to occur in sand resource target area 4. A=Defenbaugh (1976). B= Dames and Moore (1979). C= U.S. Army Corps of Engineers (1982). D, E, F, and G=SEAMAP (unpub. data, June 1985, October 1988, June1991, and October 1993, repestively). H= Parker and others (1993). I= this stuudy (may 1994). 1= trawl sample. 2= box core sample. 3= Elkman grab sample. 4= Ponar grab sample.

taxa	study								
	A	B	C	D	E	F	G	H	I
	1	2	2	1	1	1	1	3	4
Phylum Porifera									
Halichondria sp. A	P								
Phylum Cnidaria									
Renilla muelleri	P								
Phylum Rhynchocoela									
Cerebratulus lacteus (?)			P				P		
Phylum Sipunculida									
Phascolion strombi	P								
Phylum Annelida									
Aglaophamus verrilli			P						
Arcidea wassi			P						
Arcidea sp. H			P						
Asychis elongata			P						
Aurelia sp.			P						
Brania wellfleetensis			P						
Ceratocephale oculata			P						
Clymenella torquata			P						
Cossura soyeri			P						
Diopatra cuprea			P						
Diopatra sp.								P	P
Goniada littorea			P						
Lumbrineris sp.			P						
Magelona sp. F			P						
Mediomastus sp.			P						
Melinna maculata			P						
Myriochele oculata			P						
Nodomastus lobatus			P						
Owenia fusiformis			P						
Paleanotus heteroseta			P						
Paraprionospio pinnata			P						
Poecilochaetus johnsoni			P						
Prionospio cirrifera			P						
Prionospio cristata			P						
Protula tubularia	P								
Sigambra tentaculata			P						
Spiophanes bombyx			P						
Tauberia gracilis			P						
Tharyx annulosus			P						
Misc. annelids								P	P
Phylum Brachiopoda									
Glottidia pyramidata			P						
Phylum Mollusca									
Aequipecten muscosus		P							
Aequipecten sp.								P	
Anadara transversa								P	
Anomia simplex								P	
Argopecten gibbus		P							
Cadulus sp.								P	
Cantharus cancellaria									P
Cerithium eburneum									P
Chione cancellata								P	
Chione latilirata								P	
Chione paphia									P
Corbula sp.								P	
Dentalium texasianum								P	
Dentalium eboreum								P	P
Diplodonta nucleiformis								P	
Epitonium albidum									P
Laevicardium pictum		P							
Loligo pealei	P			P					
Lolliguncula brevis				P	P	P			
Lucina amiantus								P	
Mulina lateralis								P	
Murex fulvescens	P								
Mysella planulata								P	
Noetia ponderosa									P
Nuculana acuta								P	
Nuculana cf. proxima			P						
Nuculana concentrica			P				P		P
Oliva sayana								P	
Olivella sp.								P	
Pandora trilineata								P	
Polinices duplicatus								P	
Solen viridis									P
Strigilla carnaria								P	
Tellina agilis									P
Tellina alternata								P	
Tellina sayi									P
Tellina versicolor			P				P		
Terebra protexta								P	
Turris sp.								P	
Varicorbula sp.								P	
Vermicularia spirata		P							
Venericardia tridentata									P
Phylum Arthropoda									
Acanthohaustorius sp. A			P						
Ampelisca agassizi			P						
Ampelisca sp. B			P						

taxa	study								
	A	B	C	D	E	F	G	H	I
	1	2	2	1	1	1	1	3	4
Ampelisca sp. C			P						
Anoplodactylus lentus		P							
Aspidosiphone gosnoldi			P						
Automate evermanni			P						
Calappa sulcata	P								
Callanassa acanthochirus			P						
Callinectes similis	P			P	P	P	P		
Dodochela sidneyi	P								
Hepatus epheliticus				P					
Leucon sp. A			P						
Ovalipes stephensoni				P					
Oxyurostylis smithi			P						
Palicus alternatus		P							
Parthenope fraterculus		P							
Penaeus aztecus	P			P	P	P			
Penaeus duorarum				P		P			
Penaeus setiferus					P	P	P		
Persephona aquilonaris	P								
Petrochirus diogenes				P					
Portunus gibbesii	P			P			P		
Portunus spinicarpus		P							
Portunus spinimanus		P							
Protohaustorius sp. A			P						
Pylopagurus coralinus		P							
Scyllarus chacei		P							
Sicyonia brevirostris	P	P		P					
Sicyonia dorsalis	P				P				
Solenocera atlantidus	P	P							
Squilla empusa	P			P		P	P		P
Squilla neglecta	P								
Synalpheus townsendi		P							
Trachypenaeus constrictus	P								
Trachypenaeus eneus				P		P			
Trachypenaeus similis	P								
Xenanthura brevitelson			P						
crab claw								P	
Phylum Echinodermata									
Arbacia punctulata		P							
Astropecten duplicatus		P							
Encope michelini			P						
Eucidaris tribuloides		P							
Goniaster tessellatus		P							
Hemipholis elongata			P						
Luidia alternata		P							
Luidia clathrata	P	P							
Lytechinus variegatus		P							
Micropholis atria			P						
Ophiolepis elegans		P							
brittle star									P
sea cucumber									P
Phylum Hemichordata									
sea squirt									P
Phylum Chordata (fishes)									
Anchoa hepsetus					P		P		
Anchoa mitchilli					P	P	P		
Bairdiella chrysura						P			
Brachiostoma caribaeum			P						
Centropristis philadelphicus				P	P				
Chloroscombrus chrysurus					P		P		
Cynoscion arenarius					P	P	P		
Diplectrum bivittatum				P					
Etropus crossotus				P	P	P			
Harengula jaguana					P	P	P		
Lagodon rhomboides					P	P	P		
Leistomus xanthurus					P		P		
Larimus fasciatus							P		
Menticirrhus americanus						P	P		
Micropogonias undulatus					P	P	P		
Ophidion welshi				P		P			
Peprilus alepidotus					P				
Peprilus burti					P		P		
Prionotus longispinous				P		P	P		
Prionotus rubio					P				
Prionotus tribulus				P		P			
Polydactylus octonemus					P				
Saurida brasiliensis				P					
Scomberomorus maculatus							P		
Selene setapinnis				P			P		
Sphoeroides parvus				P					
Sphyraena guachancho					P				
Stenotomus caprinus				P	P				
Syacium papillosum				P					
Symphurus plagiusa				P					
Syngnathus louisianae				P					
Synodus foetens				P	P		P		
Trichiurus lepturus					P		P		
Trinectes maculatus							P		

made in this study to utilize pre-existing quantitative data to generate a quantitative species list. This approach was not feasible, because of difficulties in rectifying species counts, due chiefly to differences between sampling methodologies and level of taxonomic classification for counted taxa.

Table 7 shows how biological sampling devises can selectively trap certain species and miss other species. In general, studies employing a trawl (table 7, studies A, D, E, F, and G) tend to sample fish and nektonic species of arthropods; whereas studies utilizing a box corer (table 7, studies B and C), Ekman grab (table 7, study H), or Ponar grab (table 7, study I) generally sample benthic species (Phyla Annelida, Brachiopoda, Mollusca, Echinodermata, and bottom dwelling members of Phylum Arthropoda).

None of the taxa found in area 4 are listed as endangered or threatened species by the U.S. Fish and Wildlife Service (1992). In Alabama, commercially important taxa include various species of arthropod and fish (O'Neil and Mettee, 1982; Vittor, B. A., and Associates, Inc., 1985). The commercially valuable brown shrimp (*Penaeus aztecus*), white shrimp (*Penaeus setiferus*), and pink shrimp (*Penaeus duorarum*) occur in area 4 (table 7, Phylum Arthropoda). Their free-swimming lifestyle accounts for their capture only in trawls (table 7). The shrimp would probably not be impacted by a dredging operation on the Graded Shelly Sand Lithofacies sand body, as their swimming and migratory nature (O'Neil and Mettee, 1982) would enable them to avoid the mining site. However, increased suspended solids from shell dredging in Mobile Bay was observed to attract shrimp (U.S. Army Corps of Engineers, 1973). The turbid waters may provide particulate food or habitat for the shrimp (U.S. Army Corps of Engineers, 1973). The blue crab (*Callinectes sapidus*) and other commercially important crabs (O'Neil and Mettee, 1982; Vittor, B. A., and Associates, Inc., 1985) were not collected in area 4. No commercially important molluscs (O'Neil and Mettee, 1982) were collected in the study area. No commercially important fishes (table 7, Phylum Chordata) (O'Neil and Mettee, 1982) were caught in area 4. However, three species of sport fish (O'Neil and Mettee, 1982) appear in the list of taxa present in the study area. These include the spotted seatrout (*Cynoscion nebulosus*), Atlantic croaker (*Micropogonias undulatus*), and the Spanish mackerel (*Scomberomorus maculatus*) (table 7, Phylum Chordata). These fish would not likely be impacted by a dredging project as they would tend to avoid the area (U.S. Army Corps of Engineers, 1977).

Approximately six endangered species of cetaceans occur in the Gulf of Mexico (Schmidly, 1981; Jefferson and others, 1992; U.S. Fish and Wildlife Service, 1992). They are the blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*), right whale (*Eubalaena glacialis*), sei whale (*Balaenoptera borealis*), and sperm whale (*Physeter catodon*). Generally, the great whales inhabit the continental slope and deep oceanic waters and have not been sighted in area 4 (Schmidly, 1981; Jefferson and others, 1992). It is concluded that these cetaceans would not be impacted by a dredging operation in area 4 as they probably do not occur there or they would avoid the area (U.S. Army Corps of Engineers, 1977).

Five species of sea turtle, all endangered or threatened species, are known to occur in Alabama waters (O'Neil and Mettee, 1982). These are the Atlantic green turtle (*Chelonia m. mydas*), Atlantic hawksbill turtle (*Eretmochelys i. imbricata*), Atlantic loggerhead turtle (*Caretta c. caretta*), Atlantic ridley (*Lepidochelys kempi*), and Atlantic leatherback turtle (*Dermochelys c. coriacea*). It is possible that these sea turtles would be impacted by a sand dredging project in area 4, but their swimming abilities would allow them to easily avoid the area.

The bottlenose dolphin (*Tursiops truncatus*) and spotted dolphin (*Stenella plagiodon*) are the only species of marine mammal commonly found in area 4

(Schmidly, 1981; O'Neil and Mettee, 1982; Jefferson and others, 1992). Neither of these species are classified as endangered or threatened. It is reasonable to expect that these species of dolphin would avoid a dredge operation in area 4.

TAXONOMIC DISTRIBUTION

Table 8 lists the frequency of living taxa contained in bottom samples collected at each new vibracore location. The raw counts have been adjusted to reflect the differences in sample size between vibracore locations and table 8 lists the adjusted numbers. As the table shows, 82.4 percent of the total living fauna collected is comprised of annelids (mostly oligocheates and polycheates). A solitary species of the Phylum Rhynchocoela (species of flattened worms similar in appearance to flatworms) is the next most abundant organism at a frequency of 6.2 percent of the living fauna collected from area 4. The remaining living species collected are comprised mostly of molluscs, with one species of arthropod, two echinoderms, and one hemichordate all representing less that 2 percent each of the total fauna. It is not known why no living invertebrate species were collected at vibracore SR-74.

Annelids other than *Diopatra sp.* were collected at all vibracore locations except for SR-67 and SR-68 where the Graded Shelly Sand Lithofacies occurs at the sediment-water interface (table 8). Marine oligocheates and polycheates generally prefer a muddy sand environment with rocks and shells (Barnes, 1980) which may account for their apparent absence from vibracore locations SR-67 and SR-68.

Table 8.--Frequency distribution of living taxa in sea bottom sediment samples from vibracore locations in sand resource Area 4.

Taxa	Sea bottom living species frequency at target Area 4 vibracore stations*															Total Frequency
	SR-60	SR-61	SR-62	SR-63	SR-64	SR-65	SR-66	SR-67	SR-68	SR-69	SR-70	SR-71	SR-72	SR-73	SR-74	
Facies†	ssc	ssc	shsm	shsm	shsm	shsm	shsm	gss	gss	ssc	ssc	ssc	ssc	sm	shsm	
Phylum Rhynchocoela																
Cerebratulus lacteus (?)						1	2	8	2							13
Phylum Annelida																
Miscellaneous annelids	17	9	4	9	14	8	8			2	19	17	8	7		122
Diopatra sp.				8	13	4	10	13		1				3		52
Phylum Mollusca																
Cantharus cancellaria						1				1						
Cerithium eburneum									2		1					3
Chione paphia						1				1						
Dentalium eboreum				1												1
Epitonium albidum					1				1							
Noetia ponderosa				1												1
Nuculana concentrica	1	1														2
Solen viridis				1				2								3
Tellina agilis				1												1
Tellina sayi				1												1
Venericardia tridentata			1													1
Phylum Arthropoda																
Squilla empusa	1				2											3
Phylum Echinodermata																
Ophiolepis elegans		1														1
sea cucumber								2				2				
Phylum Hemichordata																
sea squirt			2													2
Total frequency and percent	19	11	7	22	28	15	20	23	4	3	20	17	10	12	0	211

*Counts have been adjusted to account for differences in sediment sample size.

†Graded Shelly Sand Lithofacies (gss), Muddy Sand Microfacies (sm), Muddy Shelly Sand Microfacies (shsm), and Sand-Silt-Clay Microfacies (ssc).

The Genus *Diopatra* is comprised of species that live in vertically oriented tubes constructed of mucus and armored with debris (primarily shell fragments) (Barnes, 1980). The tube is almost completely buried in the sea bottom. The feeding habits of this group of marine oligocheates require good water circulation (Barnes, 1980), so they are found in abundance on nearshore, sandy substrates with wave or current action. As can be seen in table 8, living individuals of *Diopatra sp.* were collected at vibracore locations SR-63 thru SR-67, SR-69, and SR-73. *Diopatra sp.* is most abundant at vibracores along the southern margin of the study area (vibracores SR-63, SR-64, SR-66, and SR-67) in primarily open shelf Muddy Shelly Sand Microfacies (table 8 and fig. 9).

Living individuals of species of the Phylums Mollusca, Arthropoda, Echinodermata, and Hemichordata are too few numerically to conclude much about their distribution in area 4 (table 8). The data suggests that these species are least common in the east-central portion of the study area (table 8 and fig. 9).

BENTHIC COMMUNITIES

Major benthic communities studies (see for example, Dames and Moore, 1979 and Brooks and Giammona, 1989) in the Alabama Gulf of Mexico have concentrated on the outer continental shelf in water depths greater than 60 ft. Defenbaugh (1976) and U.S. Army Corps of Engineers (1982) have studied the macroinvertebrates of the nearshore Gulf of Mexico.

Defenbaugh (1976) studied the benthic macroinvertebrates collected in trawls taken from throughout the northern margin of the Gulf of Mexico. He defined the occurrence and distribution of these invertebrates in waters ranging from about 60 to 600 ft. However, some of his samples were collected in shallower water, with a few in close proximity to area 4.

Defenbaugh (1976) defined twelve faunal assemblages for the northern Gulf of Mexico from water depths of 13 to 656 ft. Area 4 falls within the Pro-delta Sound Assemblage which is characterized as occurring in relatively shallow water from about 13 to 60 ft (Defenbaugh, 1976). Defenbaugh (1976) found that where this assemblage occurs the sea bottom is generally a silty mud, occasionally mixed with sand or shell. This assemblage lives in waters with salinities in the range of 24 to 36 ppt (Defenbaugh, 1976). Table 9 lists the invertebrate species that define this faunal assemblage.

Differences between the species lists by Defenbaugh (1976) and the present study relate to the use of different sampling devises (trawl versus Ponar grab, respectively) and size of the study area. The range of the Pro-delta Sound Assemblage stretches from Pensacola, Florida to the eastern side of the Mississippi Delta and from Mississippi Sound seaward to the Chandeleur Islands (Defenbaugh, 1976). Since this assemblage is generalized for this entire region, it is not realistic to expect the assemblage to apply equally well everywhere, including area 4.

Nonetheless, certain species of benthic invertebrates were found in common with both Defenbaugh (1976) and the present study (tables 8 and 9). Two molluscs, *Cantharus cancellaria* and *Noetia ponderosa*, were collected in both studies, along with the arthropod *Squilla empusa*, and the echinoderm *Ophiolepis elegans*.

U.S. Army Corps of Engineers (1982) characterized the benthic communities in Mississippi Sound, southern Mobile Bay, and nearshore Gulf of Mexico south of Mississippi Sound and Mobile Bay. They collected box core sediment samples during the fall at 96 stations ranging in water depth from 4 to

Table 9.--Invertebrate faunal assemblages applicable to sand resource target Area 4.

Defenbaugh (1976) Pro-delta Sound Assemblage (trawl sampler)	U.S. Army Corps of Engineers (1982) Offshore Mud Bottom (box core sampler)	U.S. Army Corps of Enginners (1982) Offshore Mixed Sediment (Muddy Sand) (box core sampler)
Phylum Cnidaria	Phylum Rhynchocoela	Phylum Annelida
Leptogorgia virgulata	*Cerebratulus cf. lacteus* •	*Aglaophamus verrilli* †
Renilla mulleri	Phylum Annelida	*Aricidea sp. C* • †
Phylum Mollusca	*Diopatra cuprea* • †	*Lumbrineris spp.* •
Cantharus cancellaria	*Magelona cf. phyllisae* • †	*Magelona cf. phyllisae* •
Chione clenchi	*Mediomastus spp.* •	*Mediomastus spp.*•
Noetia ponderosa	*Myriochele oculata* • †	*Melinna maculata* †
Sinum perspectivum	*Paraprionospio pinnata* •	*Nereis micromma* †
Phylum Arthropoda	Phylum Mollusca	*Paraprionospio pinnata* •
Calappa sulcata	*Nuculana concentrica* †	*Prionospio cristata* •
Callinectes similis	Phylum Arthropoda	*Tauberia gracilis* †
Hepatus epheliticus	*Goldfingia trichocephala* •	Phylum Arthropoda
Pagurus pollicaris	*Oxyurostylis smithi* †	*Goldfingia trichocephala* •
Penaeus aztecus	Phylum Echinodermata	*Photis macromanus* †
Persephona aquilonaris	*Hemipholis elongata* †	
Persephona crinata	*Micropholis atra* †	
Portunus gibbesii		
Sicyonia dorsalis		
Squilla empusa		
Trachypenaeus similis		
Phylum Echinodermata		
Hemipholis elongata		
Luidia clathrata		
Mellita quinquiesperforatas		
Ophiolepis elegans		

•Numerically dominant taxa.
†Characteristic taxa.

94 ft (U.S. Army Corps of Engineers, 1982). These same stations were resampled during the following spring. Five of their stations fall within area 4.

Utilizing various statistical techniques, the U.S. Army Corps of Engineers (1982) delineated three major and two minor inshore habitats, and three offshore habitats. Two offshore habitats, Mud Bottom and Mixed Sediment (Muddy Sand), best described the invertebrates collected at the stations that fall within area 4. These habitats are listed in table 9. The U.S. Army Corps of Engineers (1982) distinguished those species that are diagnostic for a given habitat from those that are numerically dominant for the habitat (table 9).

The Offshore Mud Bottom Habitat is found in shallow water mud and organic-rich sediments (U.S. Army Corps of Engineers, 1982). The Offshore Mixed Sediment (Muddy Sand) Habitat is located in somewhat deeper waters than the Offshore Mud Bottom Habitat and exhibits higher and more stable salinities (U.S. Army Corps of Engineers, 1982). Sediments in the Offshore Mixed Sediment (Muddy Sand) Habitat are very fine sands (U.S. Army Corps of Engineers, 1982).

The U.S. Army Corps of Engineers (1982) habitat species lists in table 9 and the area 4 species list in table 8 reflect the similarities in nature of the samples that were collected in both studies. The U.S. Army Corps of Engineers (1976) study utilized a box corer and the present study employed a Ponar grab sampler, both obtaining a bottom sample that collects benthic epifaunal and infaunal invertebrates. In the present study, annelids dominated the the fauna numerically as in the Offshore Mud Bottom and Offshore Mixed Sediment (Muddy Sand) Habitats (tables 8 and 9). The rhynchocoelid, *Cerebratulus lacteus*, is common to both the present study and the Offshore Mud Bottom Habitat of the U.S. Army Corps of Engineers (1982).

Even though the present study is preliminary in nature, there are enough similarities to suggest that the living benthic invertebrate fauna sampled in area 4 probably belongs to the Offshore Mud Bottom Habitat of the U.S. Army Corps of Engineers (1982). A more detailed biological study (as part of an EIS) would be required to verify this designation. It is recommended that more than one sampling devise be used (for example, a trawl and box corer) to achieve a more complete sampling of the fauna in area 4. Because annelids dominant numerically and taxonomically the living benthic invertebrate fauna of the study area, it is recommended that this segment of the population be examined in much greater detail. It is likely that such an EIS based study would show that the benthic invertebrate fauna encompasses both the Pro-delta Sound Assemblage of Defenbaugh (1976) and the Offshore Mud Bottom Habitat of U.S. Army Corps of Engineers (1982).

SEDIMENT DREDGING IMPACT ON BENTHIC ORGANISMS

None of the living bentic species collected in area 4 are considered to be endangered or even rare species. Most are common constituents of inner shelf to nearshore benthic assemblages in the Gulf of Mexico. Therefore, even if local populations were impacted by sediment removal activities, recruitment from nearby populations would likely lead to a return to background population levels within a short period of time (Taylor, 1978).

There have been several studies where benthic communities in Mississippi Sound and Mobile Bay were evaluated before and after dredge and disposal operations with regard to species composition, diversity, and species abundance. These studies include May (1973), U.S. Army Corps of Engineers (1973, 1977, 1982), and Taylor (1978)

One of the effects of a dredging operation is to increase the level of turbidity in the water column (U.S. Army Corps of Engineers, 1973, 1977). Turbidity of water is attributable to suspended and colloidal matter distributed throughout the water column (U.S. Army Corps of Engineers, 1973). Turbidity is a measure of the extent to which the intensity of light passing through a liquid is reduced by the suspended matter (U.S. Army Corps of Engineers, 1973). The immediate consequence of turbidity is to reduce photosynthesis in the euphotic zone, which disrupts the balance between productivity and respiration in the water column (U.S. Army Corps of Engineers, 1973, 1977). The net increase in respiration leads to a decrease in oxygen levels in the water column, which can be detrimental, especially to benthic communities (U.S. Army Corps of Engineers, 1977).

Whether turbidity will effect organisms depends on the concentration of suspended particulates; duration organisms are exposed to turbid waters; prevailing current, wave, and wind activity; tidal cycle; and the type of benthic community exposed to turbid waters (U.S. Army Corps of Engineers, 1973, 1977, 1982). In Mobile Bay (muddy sediments) surface turbidities from dredging operations approach normal levels within 1,200 to 1,500 ft from the point of disturbance (U.S. Army Corps of Engineers, 1973).

It is predicted that turbidity generated from a dredge operation in area 4 will not greatly impact organisms living in that region. The Graded Shelly Sand Lithofacies sand body contains very little mud and silt to become suspended in the water column. The sand body is mostly exposed at the sediment-water interface, thereby greatly reducing the suspension of fine-grained particles during removal of overburden deposits. In general, fish, mobile invertebrates, and marine mammals are not largely effected by dredging operations because they either leave or avoid areas having excessive turbidity (U.S. Army Corps of Engineers, 1977).

The actual sand mining and discharge of the mined sand on the shoreline has the greatest impact on benthic communities. Unless organisms can swim or crawl away they are likely to be killed by the dredge machinery, or buried by sediments at the mine site or shoreline sand discharge site (U.S. Army Corps of Engineers, 1973, 1977). Molluscs and annelids would be the hardest hit invertebrate groups (U.S. Army Corps of Engineers, 1973). The majority of the studies relating to the post-dredge recovery of benthic invertebrate communities have shown that populations were reestablished within six weeks to two years, following perturbation (U.S. Army Corps of Engineers, 1982). Benthic invertebrate recolonization of shallow water marine sediments proceeds through a series of faunal successions (U.S. Army Corps of Engineers, 1982). Early stage succession begins within a few days with the arrival of swimming crustaceans; mobile annelids and echinoderms; and the settling of larval forms of opportunistic species of annelids and bivalves on to the substratum from the overlying water column (U.S. Army Corps of Engineers, 1982). Later phases of succession involve the gradual reestablishment of less opportunistic, longer lived, and less mobile species (U.S. Army Corps of Engineers, 1982). U.S. Army Corps of Engineers (1982) divided the benthic species that characterize the Offshore Mud Bottom and Offshore Mixed Sediment (Muddy Sand) Habitats delineated for nearshore Gulf of Mexico waters into three groups of successionary colonizers. Their listings are shown in table 10. The faunal list assembled for the present study (table 8) is too incomplete to attempt a faunal successionary breakdown.

In summary, biological impact of a dredge operation in the Graded Shelly Sand Lithofacies sand body would be reserved to sessile and slow moving

Table 10.--Candidate species for Group I, II, and III colonizers of offshore mud bottom and mixed sediment faunal assemblages (modified from U.S. Army Corps of Engineers, 1982).

Faunal Assemblage	Group I	Group II	Group III
Offshore Mud Bottom	Phylum Annelida *Magelona cf. phyllisae* *Mediomastus spp.* *Myriochele oculata* *Paraprionospio pinnata* Phylum Mollusca *Mulinia lateralis* Phylum Arthropoda *Oxyurostylis smithi*	Phylum Rhynchocoela *Cerebratulus cf. lacteus* Phylum Mollusca *Nuculana concentrica* Phylum Arthropoda *Goldfingia trichocephala* Phylum Echinodermata *Hemipholis elongata* *Micropholis atraa*	Phylum Annelida *Diopatra cuprea* *Notomastus lobatus* Phylum Mollusca *Nassarius acutus* Phylum Arthropoda *Pinnixa pearsei*
Offshore Mixed Sediment	Phylum Annelida *Aglaophamus verrilli* *Magelona cf. phyllisae* *Mediomastus spp.* *Paraprionospio pinnata* Phylum Arthropoda *Photis macromanus*	Phylum Annelida *Aricidea sp. C* *Lumbrineris spp.* *Melinna maculata* *Nereis micromma* *Prionospio cristata* Phylum Arthropoda *Goldfingia trichocephala*	Phylum Annelida *Clymeneila torquata* *Notomastus sp. C* *Tauberia gratilis* Phylum Mollusca *Tellina versicolor* Phylum Arthropoda *Callianassa acanthochirus*

benthic invertebrates living at the sand mining site, and possibly, those living at the point of sand discharge along the shoreline. It is estimated that sites of killed benthic invertebrates are expected to be recolonized to their pre-disturbed levels of species diversity and abundance within two years.

SUMMARY AND CONCLUSIONS

The objectives of this study were accomplished through the completion of the six tasks outlined in the "Introduction". These 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. The geologic framework of area 4 was delineated utilizing the available literature and expertise of GSA personnel. 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.

2. 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 (30 million yd^3) to nourish these shoreline segments and provide additional sand for future nourishment projects as the need arises.

3. Pre-existing vibracores, borings, seismic data, and prior research findings guided the collection of 15 vibracores that were utilized to more accurately describe the sand

deposits in area 4, and identify and characterize target sand bodies to ensure a cost-effective dredging operation. In addition, grain size, percent sand, sand thickness, and aesthetic quality was described to determine the resource potential of sand deposits in area 4.

This work led to the discovery of a unit comprised of the Graded Shelly Sand Lithofacies located in the east-central portion of area 4 that contains an estimated 30 million yd^3 of sediment. The upper surface of this shelf sand ridge is exposed over about 8 square miles of seafloor and measures up to 11 ft thick at its center. The sand unit lay in water depths ranging from 30 to 60 ft. The average mean grain size of vibracore sediment samples taken from the sand unit is 1.39 Ø (medium sand) and average standard deviation is 0.89 Ø (moderately sorted). The average major grain size classes for the sand unit are 3.5 percent shell gravel, 94.9 percent sand, 0.5 percent silt, and 1.1 percent clay.

4. Benthic and nektonic faunal analysis of pre-existing data and new data acquired from 15 bottom samples collected in area 4 enabled identification of the long-term community baseline and present benthic community structure as a prelude to a detailed faunal analysis of the Graded Shelly Sand Lithofacies sand body and vicinity. None of the invertebrate taxa collected in area 4 are endangered or threatened species. The benthic invertebrate fauna in area 4 is numerically dominated by annelids with minor representation by rhynchocoelids, molluscs, arthropods, echinoderms and hemichordates. Nektonic species collected in area 4 are comprised mostly of arthropods and chordates (fishes). Vertebrate species are rare in the study area except for the common occurrence of two species of dauphin. The benthic invertebrate fauna in the study area can be classified as a probable hybrid of the Pro-delta Sound Assemblage of Defenbaugh (1976) and the Offshore Mud Bottom Habitat of U.S. Army Corps of Engineers (1982).

In general, this study has indicated that biological impact of a dredge operation in the Graded Shelly Sand Lithofacies sand body would be reserved to sessile and slow moving benthic invertebrates living at the sand mining site, and possibly, those living at the point of sand discharge along the shoreline. Turbidity is not considered to be a major environmental concern. All other species of invertebrates and vertebrates would likely not be impacted as they would escape from or avoid the dredge area. Sites of killed benthic invertebrates are expected to be recolonized in a series of successionary stages to their pre-disturbed levels of species diversity and abundance within an estimated two years.

5. This study acquired additional geologic data to adequately describe offshore sand resource sites in area 4. The database used for describing the geologic framework and sand resources in the study area included 18 vibracores, 15 bottom samples, and 7 borings. These samples were analyzed and modeled with respect to grain size, sedimentary texture, lithofacies patterns, spatial distribution of sediment type, and benthic ecology.

6. Assessment of the physical processes in area 4 and eroding shoreline segments on southeastern Dauphin Island indicate that new oceanographic and sediment transport data should be collected and modeling studies should be carried out before a definitive determination can be made about the potential impacts of sand dredging and beach replenishment projects. Such 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.

Several important general conclusions may therefore be drawn from this study. Much of the Dauphin Island shoreline in the Mobile Bay-Mississippi Sound system, is undergoing significant, long-term erosion. If the political and regulatory decisions are made to alleviate this, critical threatened shorelines will need to have ongoing programs of replenishment. Sources of appropriate sand must be identified, and economic and environmental evaluations completed to determine the cost effectiveness and environmental impacts of such a program. For the Alabama coastal zone, there are no local onshore volumes of appropriate sand available for any large scale replenishment program.

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: 1) a determination should be made concerning the presence of any archaeological sites; 2) a more detailed assessment of man-made structures in the sand body location is required; 3) a detailed biological study should be conducted on the sea bottom overlying the sand body; 4) additional vibracores are required to delineate the sand body geometry and granulometric homogeneity to ensure a cost-effective program of sand resource recovery; 5) 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; 6) a demonstration project needs to be conducted to test the findings of this study; and 7) networking with agencies must occur to develop recommendations pertinent to a demonstration project, EIS, and a full scale shoreline nourishment project. It is strongly recommended that these additional studies be accomplished prior to initiation of any serious discussion on utilization of sand resources from area 4.

REFERENCES CITED

Abbott, R.T., 1954, American seashells: New York, Van Nostrand, 541 p.

__1984, Florida shells: Melbourne, Florida, American Malacologists, 64 p.

Abston, J.R., Dinnel, S.P., Schroeder, W.W., Schultz, A.W., and Wiseman, W.J., Jr., 1987, Coastal sediment plume morphology and its relationship to environmental forcing: Main Pass, Mobile Bay, Alabama, Coastal Sediments '87:, New Orleans, American Society of Civil Engineers.

Aigner, Thomas, 1985, Storm depositional systems: Berlin, Springer-Verlag, Lecture Notes in Earth Sciences, v. 3, 174 p.

Barnes, R.D., 1980, Invertebrate zoology (4th ed.): Philadelphia, W.B. Saunders Co., 870 p.

Barwis, J.H., 1985, Tubes of the modern polychaete *Diopatra cuprea* as current velocity indicators and as analogs for Skolithos-Monocraterion, *in* Curran, H.A., ed., Biogenic structures: Their use in interpreting depositional environments: Society of Economic Paleontologists and Mineralogists Special Publication no. 35, p. 225-236.

Boone, P.A., 1973, Depositional systems of the Alabama, Mississippi, and western Florida coastal zone: Gulf Coast Association of Geological Societies Transactions, v. 23, p. 266-277.

Brande, Scott, 1983, Seismic survey, geological stratigraphy, and dredge spoil studies of Mobile Bay region, Alabama: Mississippi-Alabama Sea Grant Consortium, Final report 1980-1983, Project no. R/ER- 6, 71 p.

Bridges, P.H., 1975, The transgression of a hard substrate shelf: the Llandovery (Lower Silurian) of the Welsh Borderland, Journal of Sedimentary Petrology, v. 45, p. 74-94.

Brooks, J.M., and Giammona, C.P., eds., 1989, Mississippi-Alabama marine ecosystem study annual report year 1: Minerals Management Service report MMS 88-0071, 230 p. + 345 p. appendix.

Browning, Inc., 1987, Report of survey of Gulf of Mexico south of Dauphin Island, Alabama: Mobile District, U.S. Army Corps of Engineers, project no. C-87-196, 256 p..

Carlston, C.W., 1950, Pleistocene history of Coastal Alabama: Geological Society of America Bulletin, v. 61, p. 1119-1130.

Caston, V.N.D., 1972, Linear sand banks in the southern North Sea: Sedimentology, v. 18, p. 63-78.

Chermock, R.L., Boone, P.A., and Lipp, R.L., 1974, The environment of offshore and estuarine Alabama: Alabama Geological Survey Information Series 51, 135 p.

Chuang, W-S., Schreoeder, W.W., and Wiseman, W.J., Jr., 1982, Summer current observations off the Alabama coast: Contributions in Marine Science, v. 25, p. 121-131.

Coleman, J.M. and Wright, L.D., 1975, Modern river deltas: variability of processes and sand bodies, *in* Broussard, M.L., ed., Deltas, Models for Exploration: Houston, Texas, Houston Geological Society, p. 99-149.

Coleman, S.M., Halka, J.P., Hobbs, C.H., III, Mixon, R.B., and Foster, D.S., 1990, Ancient channels of the Susquehanna River beneath Chesapeake Bay and the Delmarva Peninsula: Geological Society of America Bulletin, v. 102, no. 9, p. 1268-1279.

Cowardin, L.M., Carter, Virginia, Golet, F.C., and Laroe, E.T., 1979, Classification of wetlands and deepwater habitats of the United States: Washington, D.C., U.S. Government Printing Office, Publication FWS/OBSS-79-31, 103 p.

Crance, J.H., 1971, Description of Alabama estuarine areas: Alabama Marine Resources Bulletin 6, 85 p.

Dames and Moore, 1979, MAFLA final report on the Mississippi, Alabama, Florida, outer continental shelf baseline environmental survey 1977/1978: U.S. Bureau of Land Management, contract no. AA550-CT7-34, 1379 p.

Davis, R.A., and Klay, J.M., 1989, Origin and development of Quarternary terrigenous inner shelf sequences, southwest Florida: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 341-347.

Dean, Lewis, ed., 1990, Minerals in Alabama: Geological Survey of Alabama Information Series 641, 49 p.

Defenbaugh, R.E., 1976, A study of the benthic macroinvertebrates of the continental shelf of the northern Gulf of Mexico: College Station, Texas, Texas A&M University Ph.D. dissertation, 410 p.

Dinnel, S.P., 1989, Circulation and sediment dispersal on the Louisiana-Mississippi-Alabama continental shelf: Louisiana State University, unpublished Ph.D. dissertation, 173 p.

Donoghue, J.F., 1989, Sedimentary environments of the inner continental shelf, northeastern Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 355-363.

Doyle, L.J., and Sparks, T.N., 1980, Sediments of the Mississippi, Alabama and Florida (MAFLA) continental shelf: Journal of Sedimentary Petrology, v. 50, p. 905-916.

Droser, M.L., and Bottjer, D.J., 1986, A semiquantitative field classification of ichnofabric: Journal of Sedimentary Petrology, v. 56, p. 558-559.

Drummond, S.E., Jr., and Stow, S.H., 1979, Hydraulic differentiation of heavy minerals, offshore Alabama and Mississippi: Geological Society of America Bulletin, v. 90, no. 9, p. 1429-1457.

Exxon Company, U.S.A., 1986, Production of hydrocarbon resources from offshore state leases in Mobile and Baldwin Counties, Alabama: Environmental information document submitted in support of applications for permits from the Mobile District, U.S. Army Corps of Engineers, 460 p.

Fairbank, N.G., 1962, Minerals from the Eastern Gulf of Mexico: Deep-Sea Research, v. 9, p. 307-338.

Fletcher, C.H., Knebel, H.J., and Kraft, J.C., 1990, Holocene evolution of an estuarine coast and tidal wetlands: Geological Society of America Bulletin, v. 102, p. 283-297.

Foxworth, R.D., Priddy, R.R., Johnson, W.B., and Moore, W.S., 1962, Heavy minerals from recent beaches of the Gulf coast of Mississippi and associated islands: Mississippi Geological Survey Bulletin 93, 92 p.

Friedman, G.M., and Sanders, J.E., 1978, Principles of sedimentology: New York, John Wiley and Sons, p. 792.

Garcia, A.W., 1977, Dauphin Island littoral transport calculations: U.S., Army Engineer Waterways Experiment Station Miscellaneous Paper H-77-11, 12 p.

Geological Survey of Alabama, 1991, Draft final annual report on sediment distribution and geological framework of Mobile Bay, Alabama, U.S. Geological Survey cooperative agreement no. 14-08-0001-A0775, 207 p.

__1992, Draft final annual report on sediment distribution and geological framework of the Alabama portion of Mississippi Sound, Alabama, U.S. Geological Survey cooperative agreement no. 14-08-0001-A0775, 175 p. + 36 p. appendix.

__1993, Draft final annual report on sediment distribution and geological framework of the west Alabama inner continental shelf, Alabama, U.S. Geological

Survey cooperative agreement no. 14-08-0001-A0775, 175 p. + 66 p. appendix.

Goldstein, August, Jr., 1942, Sedimentary petrologic provinces of the northern Gulf of Mexico: Journal of Sedimentary Petrology, v. 12, p. 77-84.

Grabau, A.W., 1924, Principles of stratigraphy (2nd ed.): New York, A.G. Seiler, 1185 p.

Griffin, G.M., 1962, Regional clay-mineral facies, products of weathering intensity and current distribution in the northeastern Gulf of Mexico: Geological Society of America Bulletin, v. 73, p. 737-768.

Hardin, J.D., Sapp, C.D., Emplaincourt, J.L, and Richter, K.E., 1976, Shoreline and bathymetric changes in the coastal areas of Alabama, A remote sensing approach: Alabama Geological Survey Information Series 50, 125 p.

Hayes, M.O., 1967, Hurricanes as geological agents: Case studies of Hurricane Carla, 1961, and Cindy, 1963: Texas Bureau of Economic Geology Report of Investigations No. 61, 54 p.

Hennessy, J.T., and Zarillo, G.A., 1987, The interrelation and distinction between flood-tidal delta and washover deposits in a transgressive barrier island: Marine Geology, v. 78, p. 35-56.

Hickman, C.P., Sr., Hickman, C.P., Jr., and Hickman, F.M., 1974, Integrated principles of zoology (5th ed.): St. Louis, C.V. Mosby Company, 1025 p.

Hobson, R.D., 1977, Review of design elements for beach-fill evaluation: U.S. Army Corps of Engineers Coastal Engineering Research Center, Technical Paper no. 77-6, 51 p.

Hubbard, D.K., Oertel, George, and Nummedal, Dag, 1979, The role of waves and tidal currents in the development of tidal-inlet sedimentary structures and sand body geometry examples from North Carolina, South Carolina and Georgia: Journal of Sedimentary Petrology, v. 49, no. 4, p. 1073-1092.

Hummell, R.L., 1990, Main Pass and the ebb-tidal delta of Mobile Bay, Alabama: Alabama Geological Survey Circular 146, 45 p.

Hsu, K.J., 1960, Texture and mineralogy of recent sands of the Gulf Coast: Journal of Sedimentary Petrology, v. 30, no. 3, p. 380-403.

Imperato, D.P., Sexton, W.J., and Hayes, M.O., 1988, Stratigraphy and sediment characteristics of a mesotidal ebb-tidal delta, North Edisto Inlet, South Carolina: Journal of Sedimentary Petrology, v. 58, no. 6, p. 950-958.

Israel, A.M., Ethridge, F.G., and Estes, E.L., 1987, A sedimentologic description of a microtidal, flood-tidal delta, San Luis Pass, Texas: Journal of Sedimentary Petrology, v. 57, no. 2, p. 288-300.

James, W.R., 1975, Techniques in evaluating suitability of borrow material for beach nourishment: U.S. Army Corps of Engineers Coastal Engineering Research Center, Technical Manual no. 60, 73 p.

Jefferson, T.A., Leatherwood, Stephen, Shoda, L.K.M., and Pitman, R.L., 1992, Marine mammals of the Gulf of Mexico: a field guide for aerial and shipboard observers, Texas A&M University Printing Center, College Station, 92 p.

John E. Chance and Associates, Inc., 1993, Report of survey of hydrographic surveys, Mobile harbor stable berm, survey number 9: Mobile District, U.S. Army Corps of Engineers, contract no. DACW-01-93-D-0009, 55 p. + 27 p. appendix + 4 enclosures.

Johnson, H.D., 1978, Shallow siliciclastic seas, *in* Reading, H.G., ed., Sedimentary environments and facies: New York, Elsevier, p. 207- 258.

Kidwell, S.M., and Holland, S.M., 1991, Field description of coarse bioclastic fabrics: Palaios, v. 6, p. 426-434.

Kindinger, J.L., 1988, Seismic stratigraphy of the Mississippi-Alabama shelf and upper continental slope: Marine Geology, v. 83, p. 79-94.

Kindinger, J.L., Miller, R.J., Stelting, C.E., and Bouma, A.H., 1982, Depositional history of Louisiana-Mississippi outer continental shelf: U.S. Geological Survey Open-File Report 82-1077, 48 p.

Kindinger, J.L., Penland, Shea, Williams, S.J., and Suter, J.R., 1989, Inner shelf deposits of the Louisiana-Mississippi-Alabama region, Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 413-420.

Kjerfve, B., and Sneed, J.E., 1984, Analysis and synthesis of oceanographic conditions in the Mississippi Sound offshore region: Final Report, v. 1 and II, Contract DACW 01-83-R-0014, Mobile District, U.S. Corps of Engineers, 253 p.

Kraft, J.C., 1971, Sedimentary facies patterns and geologic history of a Holocene marine transgression: Geological Society of America Bulletin, v. 82, p. 2131-2158.

Lewis, D.W., 1984, Practical sedimentology: New York, Van Nostrand Reinhold Co. Inc., 229 p.

Lockwood, Millington, and McGregor, B.A., 1988, Proceedings of the 1987 exclusive economic zone symposium on mapping and research: Planning for the next 10 years: U.S. Geological Survey Circular 1018, 175 p.

Louisiana Geological Survey, 1991, Characterization of the development potential of Ship Shoal sand for beach replenishment of Isles Dernieres: Louisiana Geological Survey, U.S. Minerals Management Service, Cooperative Agreement #14-12-0001-30404, 164 p.

Ludwick, J.C., 1964, Sediments in the northeastern Gulf of Mexico, *in* Miller, R.L., ed., Papers in marine geology: New York, MacMillan Co., p. 208-238.

Mancini, E.A., and Payton, J.W., 1981, Petroleum geology of South Carlton field, lower Tuscaloosa "Pilot sand," Clarke and Baldwin Counties, Alabama: Gulf Coast Association of Geological Societies Transactions, v. 31, p. 139-147.

Mancini, E.A., and Tew, B.H., 1988, Paleogene stratigraphy and biostratigraphy of southern Alabama: Gulf Coast Association of Geological Societies-Gulf Coast Section/Society of Economic Paleontologists and Mineralogists 38th Annual Convention, New Orleans, Louisiana, Field Trip Guidebook, 63 p.

May, E.B., 1973, Environmental effects of hydraulic dredging in estuaries: Alabama Marine Resources Bulletin 9, 85 p.

McBride, R.A., Byrnes, M.R., Penland, Shea, Pope, D.L., and Kindinger, J.L., 1991, Geomorphic history, geologic framework, and hard mineral resources of the Petit Bois Pass Area, Mississippi-Alabama, *in* Coastal depositional systems in the Gulf of Mexico, Quaternary framework and environmental issues: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists Foundation, Twelth Annual Research Conference, Program with Abstracts, p. 116-127.

McFarlan, Edward, Jr., and LeRoy, D.O., 1988, Subsurface geology of the Late Tertiary and Quaternary deposits, coastal Louisiana and the adjacent continental shelf: Gulf Coast Association of Geological Societies Transactions, v. 38, p. 421-433.

Mettee, M.F., O'Neil, P.E., Pierson, J.M., and Suttkus, R.D., 1989, Fishes of the western Mobile River basin in Alabama and Mississippi: Geological Survey of Alabama Atlas 24, 170 p.

Milliman, J.D., and Emery, K.O., 1968, Sea-levels during the past 35,000 years: Science, v. 162, p. 1121-1123.

Moore, R.C., 1949, Meaning of facies: Geological Society of America Memoir 39, 34 p.

Morris, P.A., 1973, A field guide to shells of the Atlantic and Gulf Coasts and the West Indies: Boston, Houghton Mifflin Co., 330 p.

Morton, R.A., 1981, Formation of storm deposits by wind-forced currents in the Gulf of Mexico and the North Sea: International Association of Sedimentologists Special Publication no. 5, p. 385-396.

Moser, P.H., and Chermock, R.L., eds., 1978, Geologic and hydrologic environmental atlas of Mobile and Baldwin Counties, Alabama: Alabama Geological Survey open file report, 210 p.

Murray, G.E., 1961, Geology of the Atlantic and Gulf Coastal Province of North America: New York, Harper and Brothers, 692 p.

National Oceanic and Atmospheric Administration, 1991a, Nautical chart, Mississippi Sound and approaches, Dauphin Island to Cat Island, No. 11373, 1:80,000: Washington, D.C., NOAA, National Ocean Survey, 1 sheet.

__1991b, Nautical chart, Mobile Bay, No. 11376, 1:80,000: Washington, D.C., NOAA, National Ocean Survey, 1 sheet.

__1991c, Nautical chart, Pensacola Bay and approaches, No. 11382, 1:80,000: Washington, D.C., NOAA, National Ocean Survey, 1 sheet.

Neumann, C.C., Cry, E.C., and Jarvinen, B.J., 1981, Tropical Cyclones of the North Atlantic Ocean, 1871-1980. National Climate Center, 23 p.

Nummedal, Dag, Penland, Shea, Gerdes, Robert, Schramm, William, Kahn, Jacob, and Roberts, Harry, 1980, Geologic response to hurricane impact on low-profile Gulf coast barriers: Gulf Coast Association of Geological Societies Transactions, v. 30, p. 183-195.

O'Neil, P.E., and Mettee, M.F., eds., 1982, Alabama coastal region ecological characterization: 2. a synthesis of environmental data, Alabama Geological Survey Information Series 61, 346 p.

Otvos, E.G., 1975, Late Pleistocene transgressive unit (Biloxi Formation), northern Gulf coast: American Association of Petroleum Geologists Bulletin, v. 59, p. 148-154.

__1976, Mississippi offshore inventory and geological mapping project: Mississippi Marine Research Council, Long Beach, Mississippi, 27 p.

__1979, Barrier island evolution and history of migration, north-central Gulf coast: *in* Leatherman, S. P., ed., Barrier islands: New York, Academic Press, p. 291-319.

__1982, Coastal geology of Mississippi, Alabama and adjacent Louisiana areas: The New Orleans Geological Society Guidebook, 66 p.

__1985, A new stratigraphic system, geologic evolution, and potential sand resources in the Mississippi Sound area, Mississippi-Alabama: Mississippi Mineral Resources Institute Open File Report 85-6F, 71 p.

__1986, Stratigraphy and potential economic sand resources of the Mississippi-Alabama barrier island system and adjacent offshore areas: Mississippi Mineral Resources Institute Open File Report 86-1F, 67 p.

Parker, S.J., 1989, Occurrence, economic potential and mining feasibility of sand, gravel, heavy mineral, and carbonate rock rubble resources in the exclusive economic zone in offshore Alabama, *in* John, C.J., project coordinator, Preliminary assessment of non- fuel mineral resources in the outer continental shelf exclusive economic zone of the Gulf of Mexico: Louisiana Geological Survey, U.S. Minerals Management Service Cooperative Agreement #14-12-0001-30404, Report, p. A1-A52.

__1990, Assessment of nonhydrocarbon mineral resources in the exclusive economic zone in offshore Alabama: Alabama Geological Survey Circular 147, 73 p.

Parker, S.J., and Hummell, R.L., 1992, Holocene stratigraphy of Mobile Bay, Alabama: *in* Coastal depositional systems in the Gulf of Mexico: Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists Twelfth Annual Research Conference Program and Abstracts, p. 177-181.

Parker, S.J., Davies, D.J., and Smith, W.E., 1993, Draft final annual report on geological, economic, and environmental characterization of selected near-term leasable offshore sand deposits and competing onshore sources for beach nourishment, Minerals Management Service cooperative agreement no. 14-35-0001-30630, 223 p. + 60 p. appendix.

Parker, S.J., Shultz, A.W., and Schroeder, W.W., 1992, Sediment characteristics and seafloor topography of a palimpsest shelf, Mississippi-Alabama continental shelf, *in* Quaternary coasts of the United States: Lacustrine and marine systems: Society of Economic Paleontologists and Mineralogists Special Publication no. 48, p. 243-251.

Pyle, T.E., Henry, V.J., McCarthy, J.C., Giles, R.T., and Neurauter, T.W., 1975, Baseline monitoring studies, Mississippi, Alabama, Florida outer continental shelf, 1975-1976: Volume 5, Geophysical investigations for biolithologic mapping of the MAFLA-OCS lease area, Bureau of Land Management, Washington, D.C., BLM/ST-78/34, 267 p.

Raymond, D.E., 1985, Depositional sequences in the Pensacola Clay (Miocene) of southwest Alabama: Alabama Geological Survey Bulletin 114, 87 p.

Raymond, D.E., Osborne, W.E., Copeland, C.W., and Neathery, T.L., 1988, Alabama stratigraphy: Alabama Geological Survey Circular 140, 97 p.

Reed, J.C., 1988, Correlation of Cenozoic sediments on the Gulf of Mexico OCS: Oil and Gas Journal, v. 86, no. 1, p. 54-59.

Reineck, H.-E., and Singh, I.B., 1986, Depositional sedimentary environments: New York, Springer-Verlag, 551 p.

Romashko, Sandra, 1974, The shell book: Miami, Windward Publishing, 64 p.

Rucker, J.B., and Snowden, J.O., 1989, Relict progradational beach ridge complex on Cat Island in Mississippi Sound: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 531-539.

Ryan, J.J., and Goodell, H.G., 1972, Contemporary sediments, Part 1 of Marine geology and estuarine history of Mobile Bay, Alabama, *in* Nelson, B.W., ed., Environmental framework of coastal plain estuaries: Geological Society of America Memoir 133, p. 517-554.

Schmidly, D.J., 1981, Marine mammals of the southeastern United States coast and the Gulf of Mexico, U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C., FWS/OBS-80/41, 163 p.

Schroeder, W.W., 1976, Physical environmental atlas of coastal Alabama: Mississippi-Alabama Sea Grant Consortium MASGP-76-034, 275 p.

__1977a, Sea truth and environmental characterization studies of Mobile Bay, Alabama, utilizing ERTS-1 data collection platforms: Remote Sensing of Environment, v. 6, p. 27-43.

__1977b, The impact of the 1973 flooding of the Mobile River system on the hydrography of Mobile Bay and east Mississippi Sound: Northeast Gulf Science, v. 1, p. 68-76.

__1978a, 1977 Physical environmental atlas of coastal Alabama (1977 Supplement): Mississippi-Alabama Sea Grant Consortium MASGP-76-034-(1977s), 62 p.

__1978b, Riverine influence on estuaries: A case study: *in* Wiley, M.L., ed., Estuarine Interactions: New York, Academic Press, Inc., p. 347-364.

__1979, The dispersion and impact of Mobile River system waters in Mobile Bay, Alabama: Water Resources Research Institute Bulletin 37, 48 p.

Schroeder, W.W., and Lysinger, W.R., 1979, Hydrography and circulation of Mobile Bay, *in* Loyacano, H.A., and Smith, J.P., eds., Symposium on the Natural Resources of the Mobile Bay estuary, Alabama: Alabama Coastal Area Board, Mississippi-Alabama Sea Grant Consortium, U.S. Fish and Wildlife Service, p. 75-94.

Schroeder, W.W., and Wiseman, W.J., Jr., 1986, Low-frequency shelf estuarine exchange processes in Mobile Bay and estuarine systems on the northern Gulf of Mexico: *in* Wolfe, D.A., ed., Estuarine Variability: New York, Academic Press, Inc., p. 355-367.

Sha, L.P., 1989, Holocene-Pleistocene interface and three-dimensional geometry of the ebb-delta complex, Texel Inlet, The Netherlands: Marine Geology, v. 89, p. 207-228.

Smith, W.E., 1986, Geomorphology of Coastal Baldwin County, Alabama: Alabama Geological Survey Bulletin 124, 86 p.

__1988, Geomorphology of the Mobile delta: Alabama Geological Survey Bulletin 132, 133 p.

Stapor, F.W., Jr., Mathews, T.D., and Lindfors-Kearns, F.E., 1991, Barrier-island progradation and Holocene Sea Level History in southwest Florida: Journal of Coastal Research, v. 7, no. 3, p. 815-838.

Stow, S.H., Drummond, S.E., and Haynes, C.D., 1975, Occurrence and distribution of heavy minerals, offshore Alabama and Mississippi: Society of Mining Engineers-AIME Transactions, v. 260, p. 75-77.

Stubblefield, W.L. and Swift, D.J.P., 1976, Ridge development as revealed by sub-bottom profiles on the central New Jersey shelf: Marine Geology, v. 20, p. 315-334.

Stumpf, R.P., and Gelfenbaum, Guy, 1990, Effects of high river discharge on suspended sediments in Mobile Bay, Alabama: EOS, v. 71, p. 1406-1407.

Stumpf, R.P., and Pennock, J.R., 1989, Calibration of a general optical equation for remote sensing of suspended sediments in a moderately turbid estuary: Journal of Geophysical Research, v. 94, p. 14363-14371.

Suter, J.R., Berryhill, H.L., Jr., and Penland, Shea, 1985, Environments of sand deposition, southwest Louisiana continental shelf: Gulf Coast Association of Geological Societies Transactions, v. 35, p. 495-503.

Swift, D.J.P., 1976, Continental sedimentation, *in* Stanley, D.J., and Swift, D.J.P., Jr., eds., Marine sediment transport and environmental management: New York, John Wiley and Sons, p. 225-310.

Swift, D.J.P., Duane, D.B., and McKinney, T.F., 1973, Ridge and swale topography of the Middle Atlantic Bight, North America: Secular response to the Holocene hydraulic regime: Marine Geology, v. 15, p. 227-247.

Swift, D.J.P., Stanley, D.J., and Curray, J.R., 1971, Relict sediments on continental shelves: A reconsideration: Journal of Geology, v. 79, p. 322-346.

Taylor, J.L., 1978, Evaluation of dredging and open water disposal on benthic environments: Gulf Intracoastal Waterway - Apalachicola Bay, Florida, to Lake Borgne, Louisiana, Mobile District, U.S. Army Corps of Engineers, 51 p.

Trewartha, G.T., and Horn, L.H., 1980, An Introduction to Climate: New York, McGraw-Hill, p. 273-283.

Tolson, J.S., Copeland, C.W., and Bearden, B.L., 1983, Stratigraphic profiles of Jurassic Strata in the western part of the Alabama Coastal Plain: Alabama Geological Survey Bulletin 122, 425 p.

U. S. Army Corps of Engineers, 1955, Perdido Pass (Alabama Point) Alabama, beach erosion control study: Washington, D.C., U.S. Government Printing Office.

__1973, Environmental investigations of dredging activities in Mobile Bay, Alabama: Mobile District, U.S. Army Corps of Engineers, 53 p.

__1977, Final environmental statement of Theodore Ship Channel and Barge Channel extension Mobile Bay, Alabama: Mobile District, U.S. Army Corps of Engineers, 351 p.

__1979, Draft Technical report on Mobile Harbor, Alabama: Mobile District, U. S. Army Corps of Engineers, 757 p.

__1984, Exploration and production of hydrocarbon resources in coastal Alabama and Mississippi: Mobile District, U.S. Army Corps of Engineers, 615 p.

__1985a, General design memorandum, Mobile Harbor deepening: Design Memorandum no. 1, Appendix A, Geology and Soils: Mobile District, U.S. Army Corps of Engineers, 384 p.

__1985b, Supplemental environmental impact statement, Mobile Harbor, Alabama: Channel improvements, offshore dredged material disposal: Mobile District, U. S. Army Corps of Engineers, 498 p.

U.S. Department of the Navy, 1986, Draft environmental impact statement United States Navy: Gulf Coast Strategic Homeporting: Mobile, Alabama, Appendix V.

U.S. Fish and Wildlife Service, 1992, Endangered and threatened wildlife and plants; 50 Code of Federal Regulations (CFR) 17.11 & 17.12, p. 1-38.

Upshaw, C.F., Creath, W.B., and Brooks, F.L., 1966, Sediments and microfauna off the coast of Mississippi and adjacent states: Mississippi Geological Survey Bulletin 106, 127 p.

Van Andel, T.H., and Poole, D.M., 1960, Sources of recent sediments in the northern Gulf of Mexico: Journal of Sedimentary Petrology, v. 30, p. 91-122.

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S., and Hardenbol, Jan, 1988, An overview of the fundamentals of sequence stratigraphy and key definitions, *in* Wilgus, C.K., Posamentier, H.W., Ross, C.A., and Kendall, C.G.St.C., eds., Sea-level changes: An integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication no. 42, p. 39-45.

Vittor, B.A., and Associates, Inc., 1985, Tuscaloosa trend regional data search and synthesis (volume 1-synthesis report): Final report submitted to Minerals Management Service, New Orleans, Louisiana, contract no. 14-12-001-30048, 477 p.

Warmke, G.L., and Abbott, R.T., 1961, Caribbean seashells: New York, Dover, 348 p.

Wilson, J.L., 1975, Carbonate facies in geologic history: New York, Springer Verlag, 471 p.

Wiseman, W.J., Jr., Schroeder, W.W., and Dinnel, S.P., 1988, Shelf-estuarine water exchanges between the Gulf of Mexico and Mobile Bay, Alabama: American Fisheries Society Symposium, v. 3, p. 1-8.

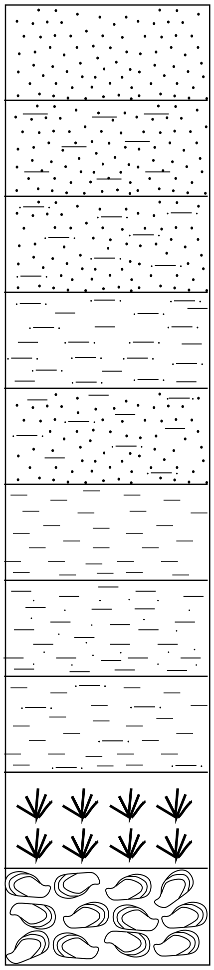
Woolsey, J.R., 1984, Exploration for industrial minerals in Mississippi Sound and adjacent offshore territories of Mississippi and Alabama: Mississippi-Alabama Sea Grant Consortium, MASGP-83-019, 21 p.

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

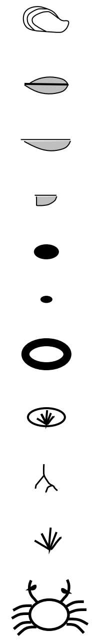
SANDY CLAY

SILTY CLAY

PEAT

OYSTER BIOSTROME

ACCESSORIES



OYSTER SHELL

ARTICULATED PELCYPOD

INARTICULATED PELCYPOD

SHELL FRAGMENT

PEBBLE

GRANULE

NODULE

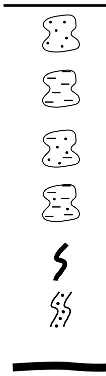
PEAT BALL

ROOTS

ORGANIC MATTER

CRAB

SEDIMENTARY STRUCTURES



SAND POCKET

CLAY POCKET

CLAYEY SAND POCKET

SANDY CLAY POCKET

MUD BURROW

SAND BURROW

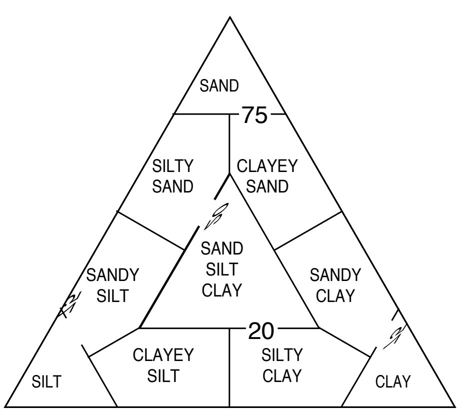
CLAY DRAPE

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)

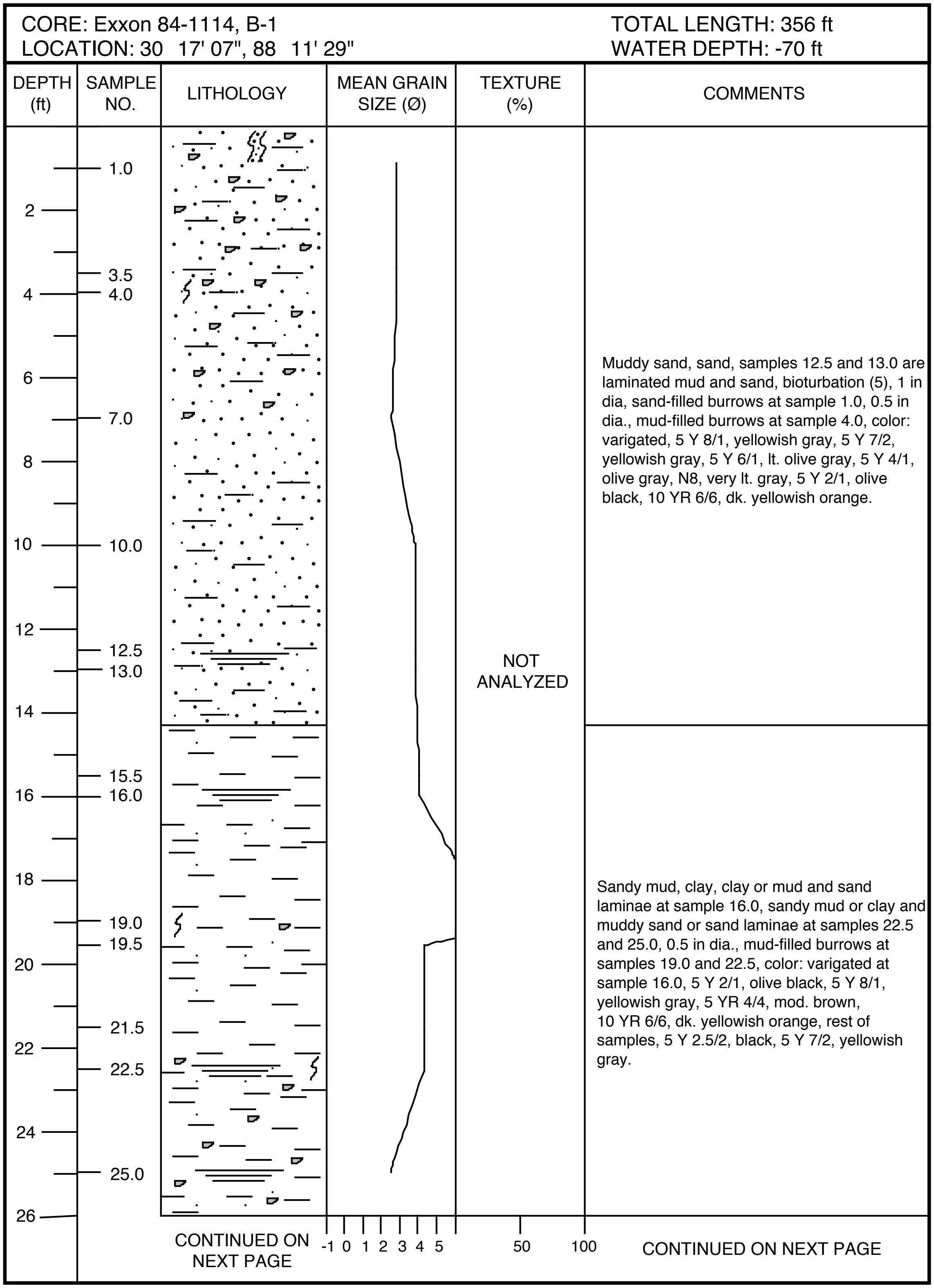


Figure A-1.--Columnar section of EEZ boring Exxon 84-1114, B-1.

CONTINUED FROM PREVIOUS PAGE

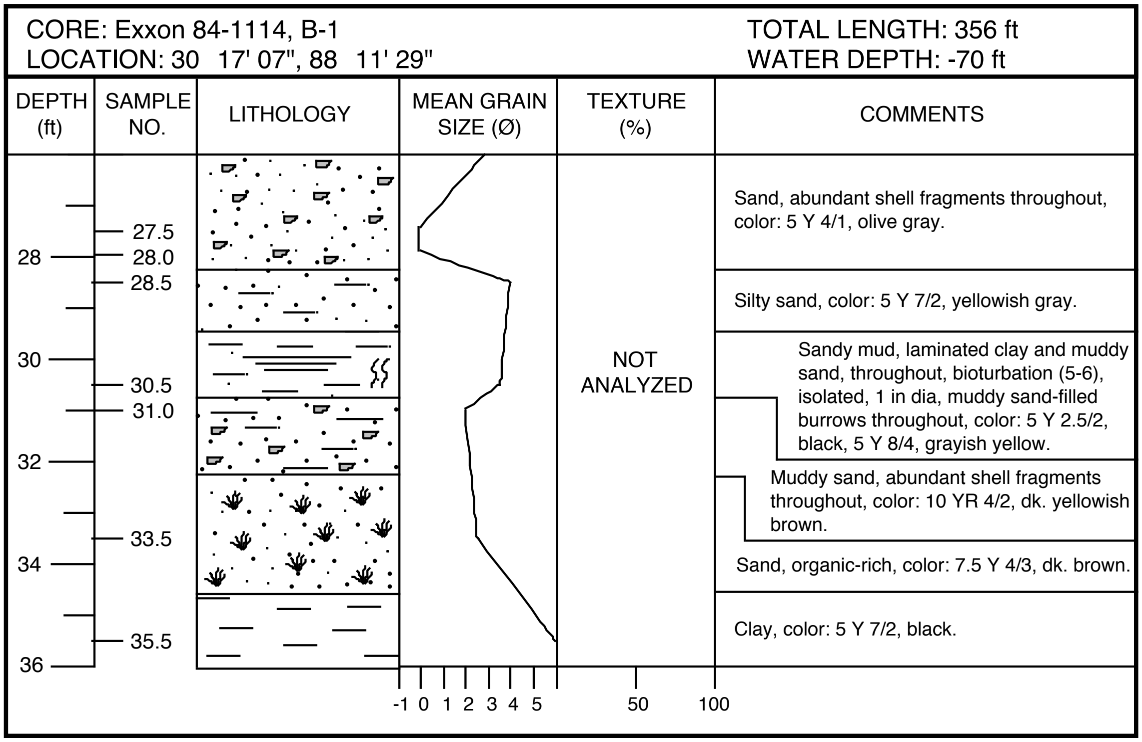


Figure A-1.--Columnar section of EEZ boring Exxon 84-1114, B-1.

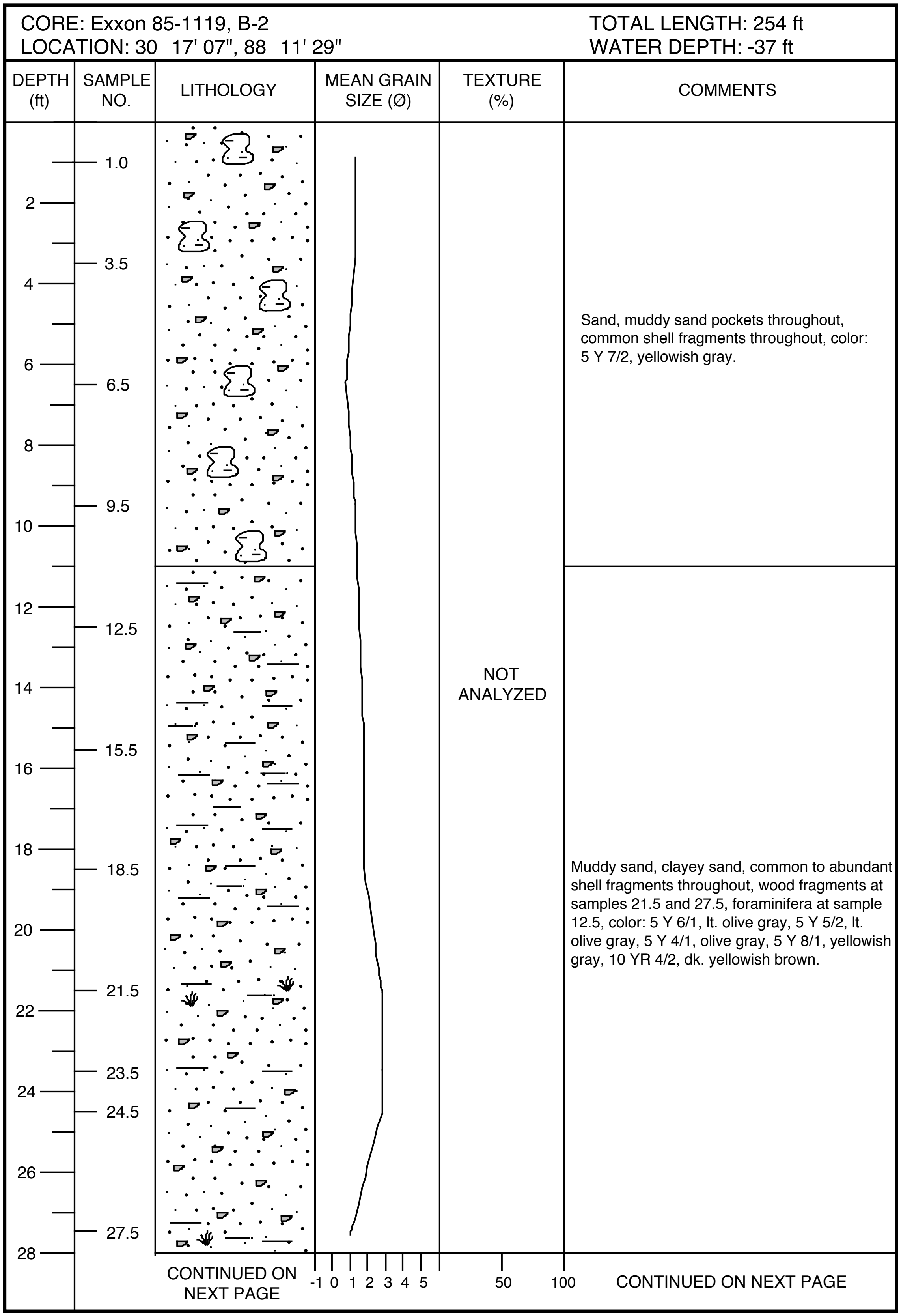


Figure A-2.--Columnar section of EEZ boring Exxon 85-1119, B-2.

CONTINUED FROM PREVIOUS PAGE

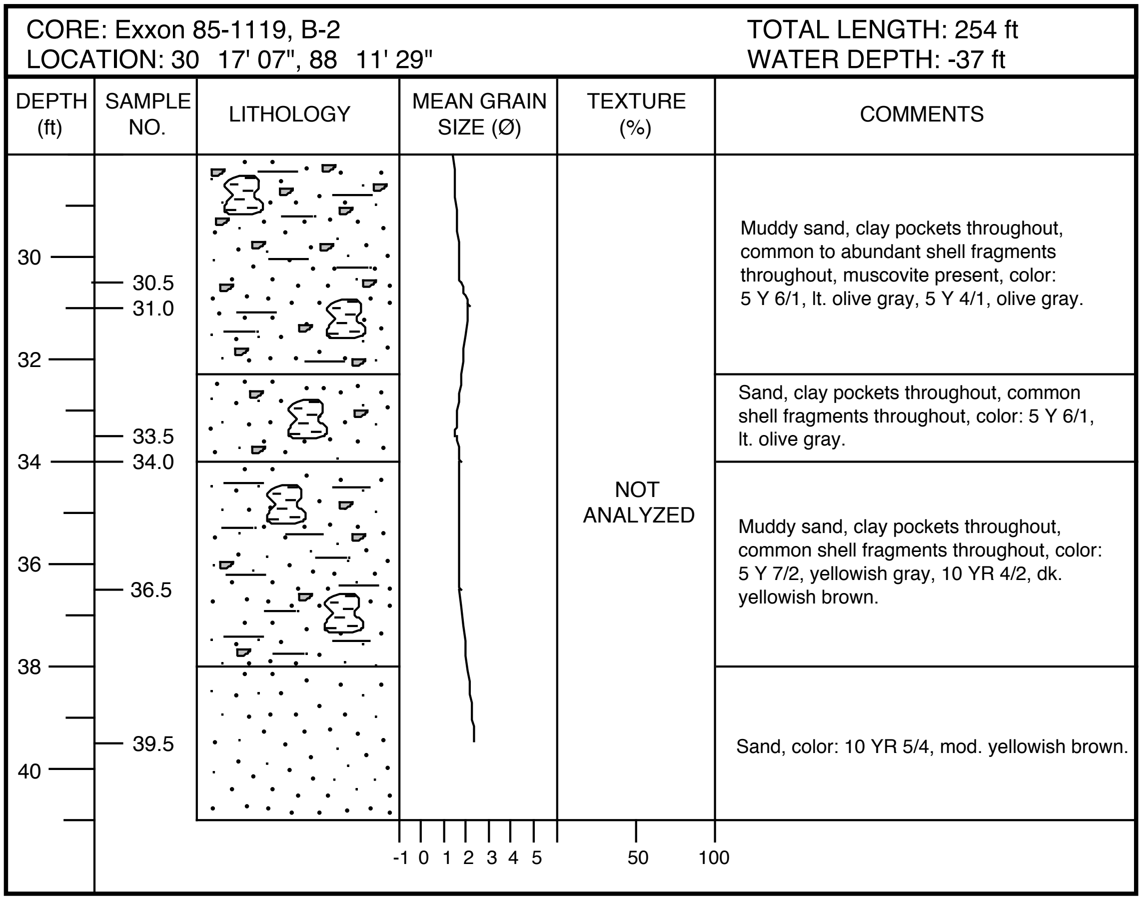


Figure A-2.--Columnar section of EEZ boring Exxon 85-1119, B-2.

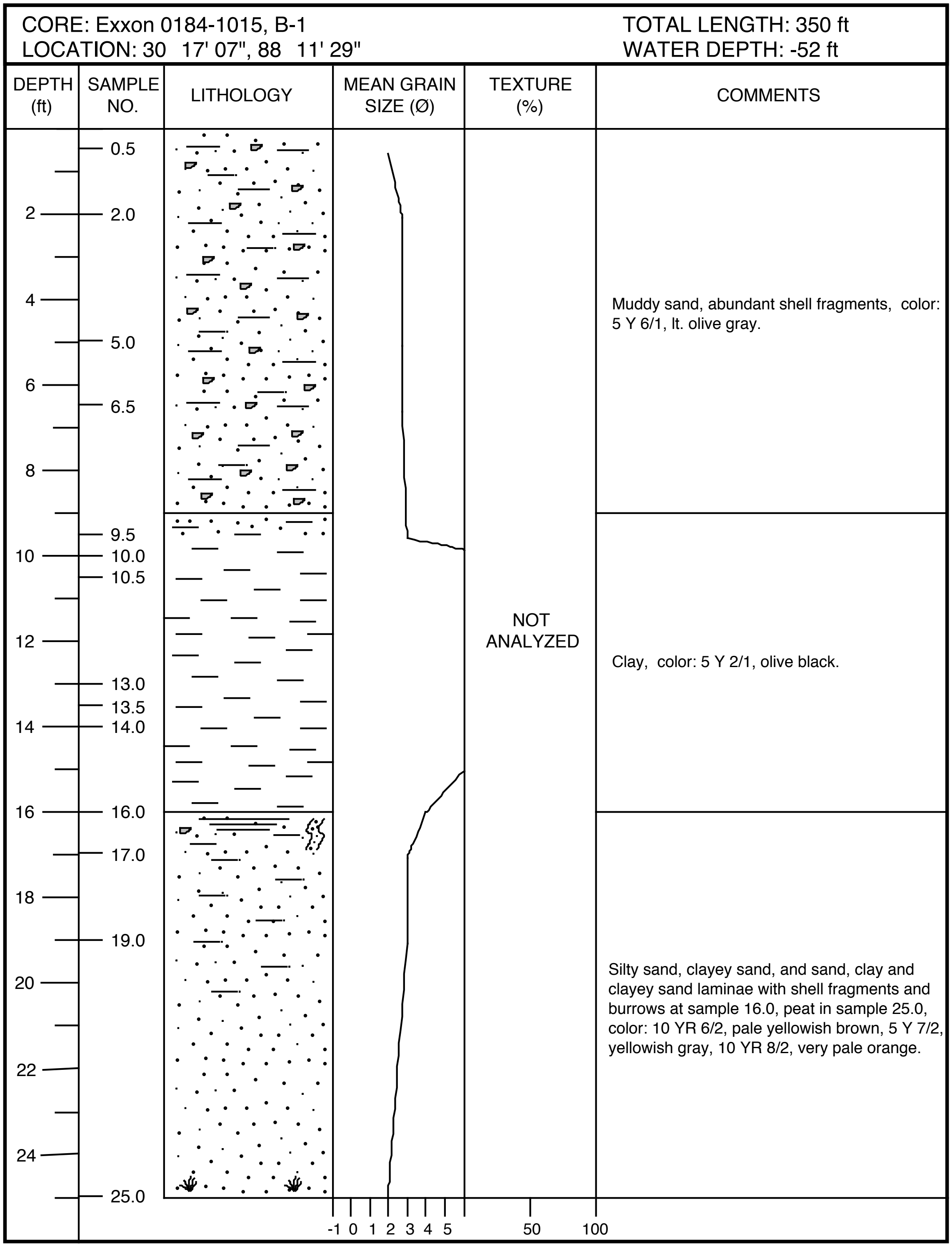


Figure A-3.--Columnar section of EEZ boring Exxon 0184-1015, B-1.

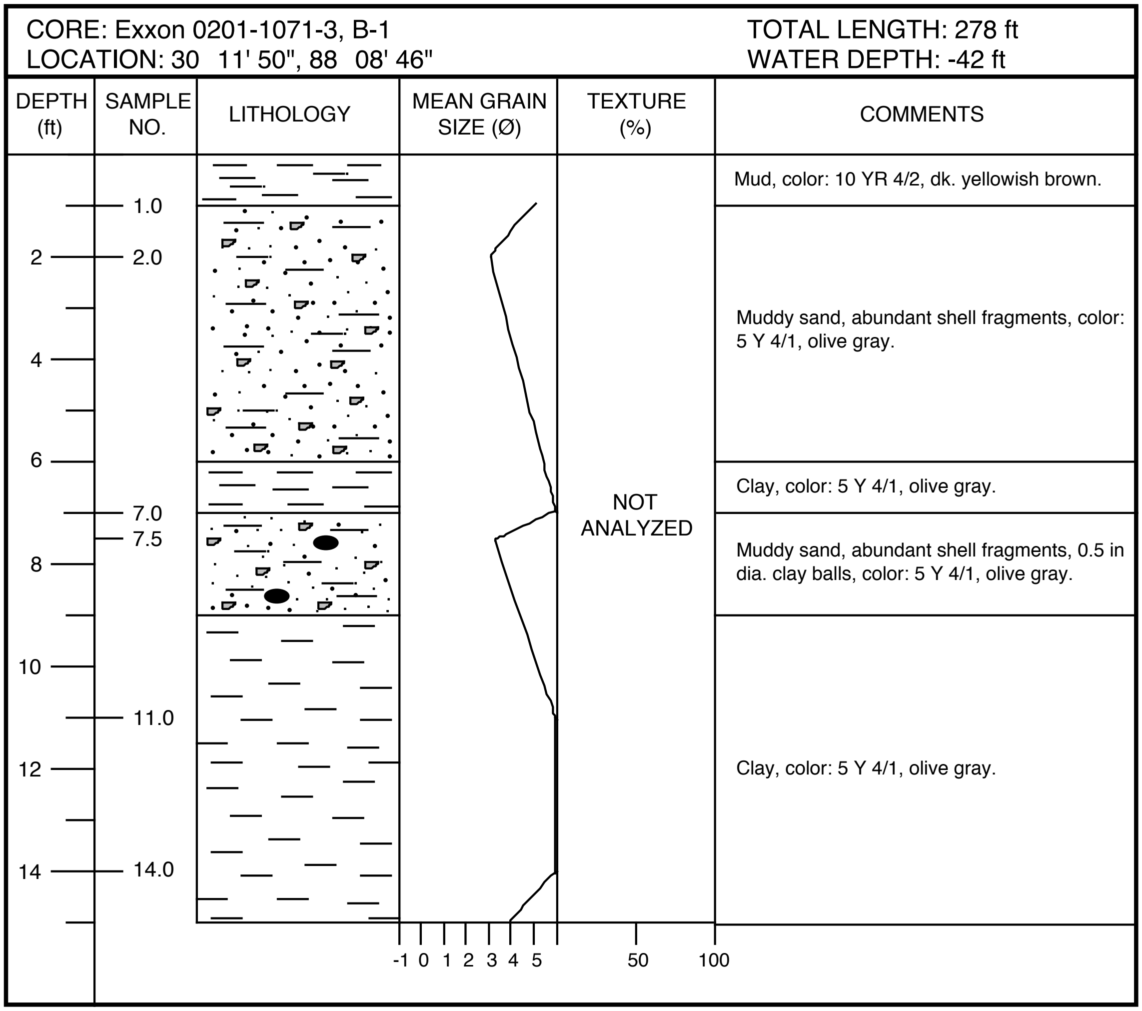


Figure A-4.--Columnar section of EEZ boring Exxon 0201-1071-3, B-1.

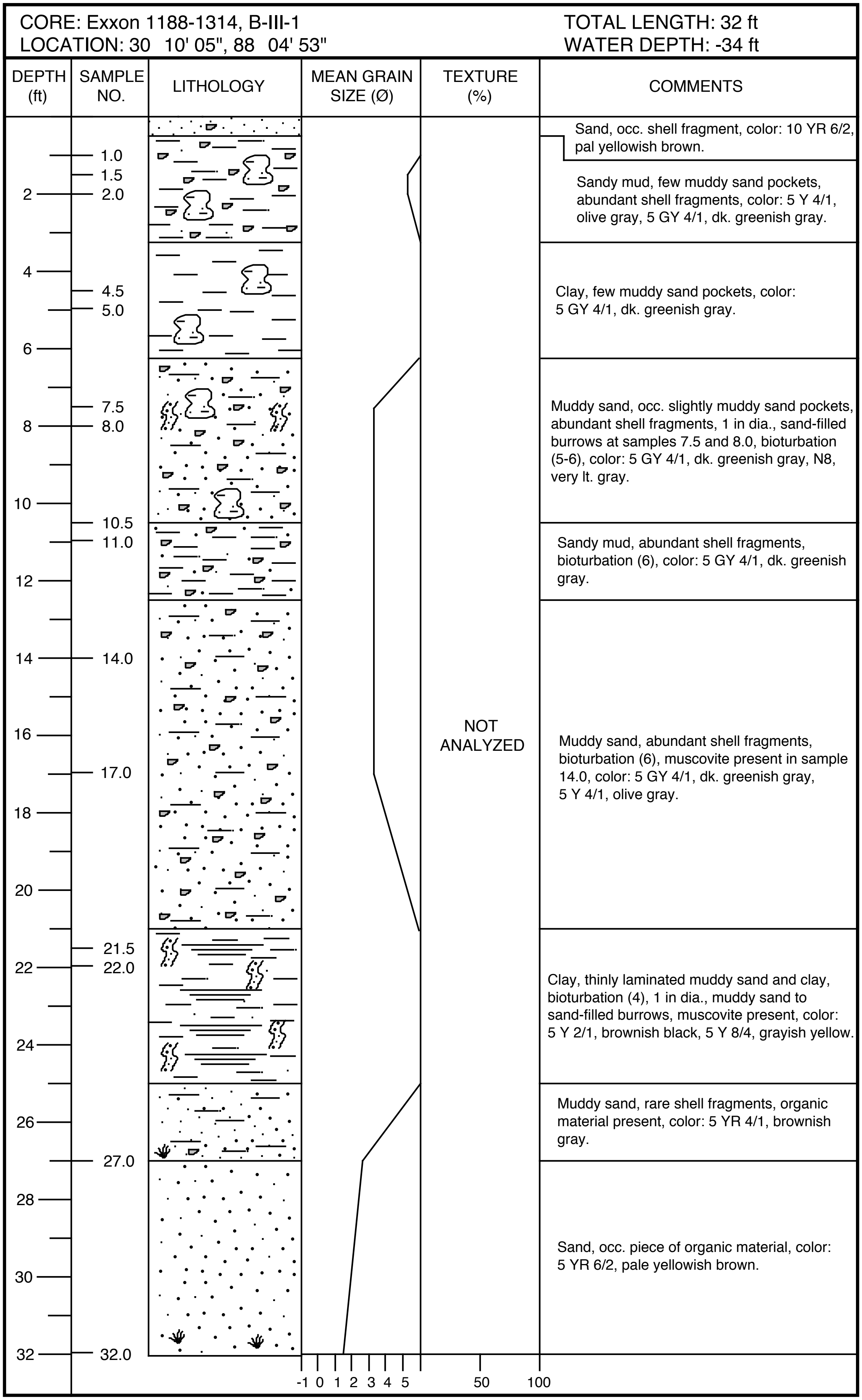


Figure A-5.--Columnar section of EEZ boring Exxon 1188-1314, B-III-1.

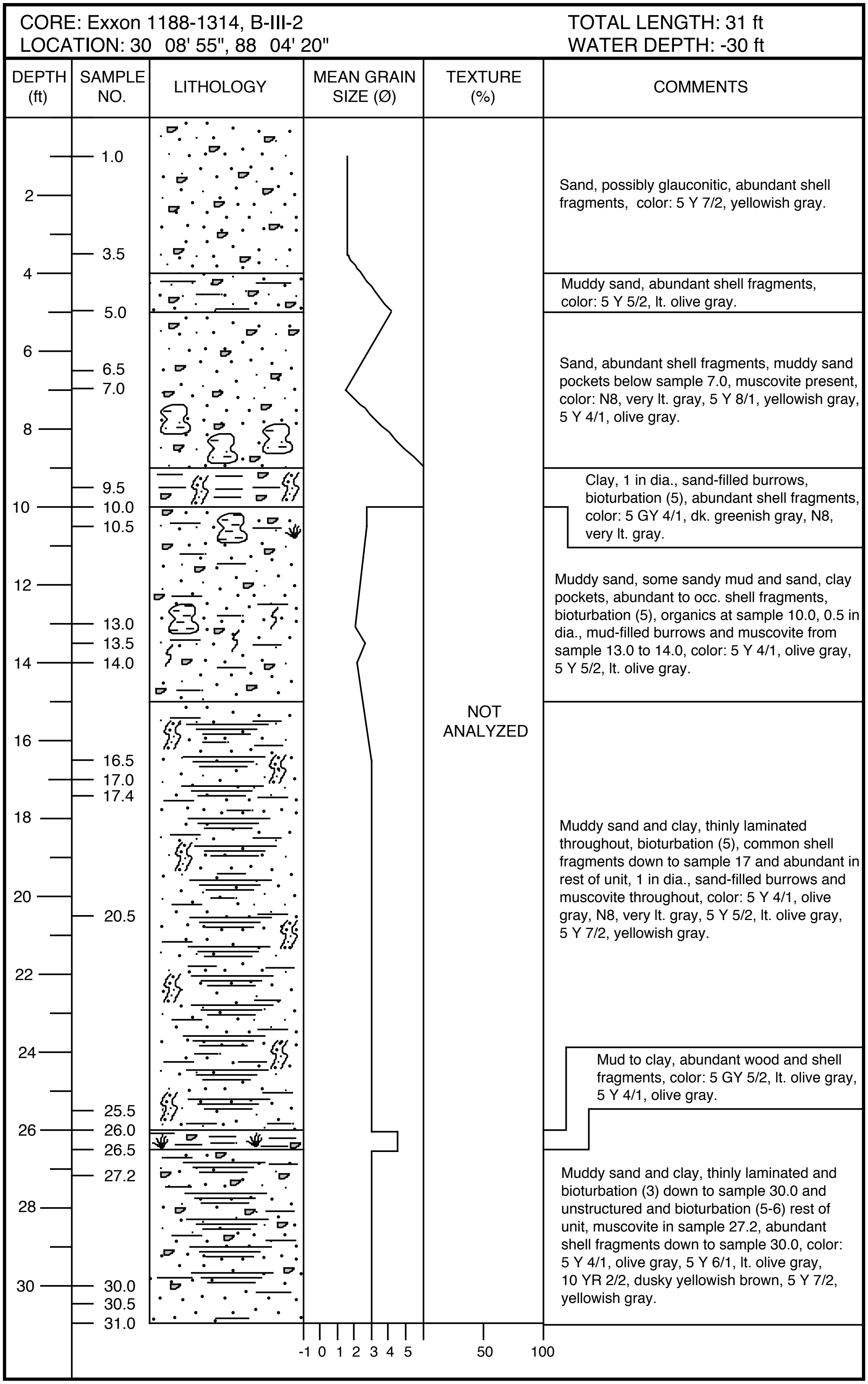


Figure A-6.--Columnar section of EEZ boring Exxon 1188-1314, B-III-2.

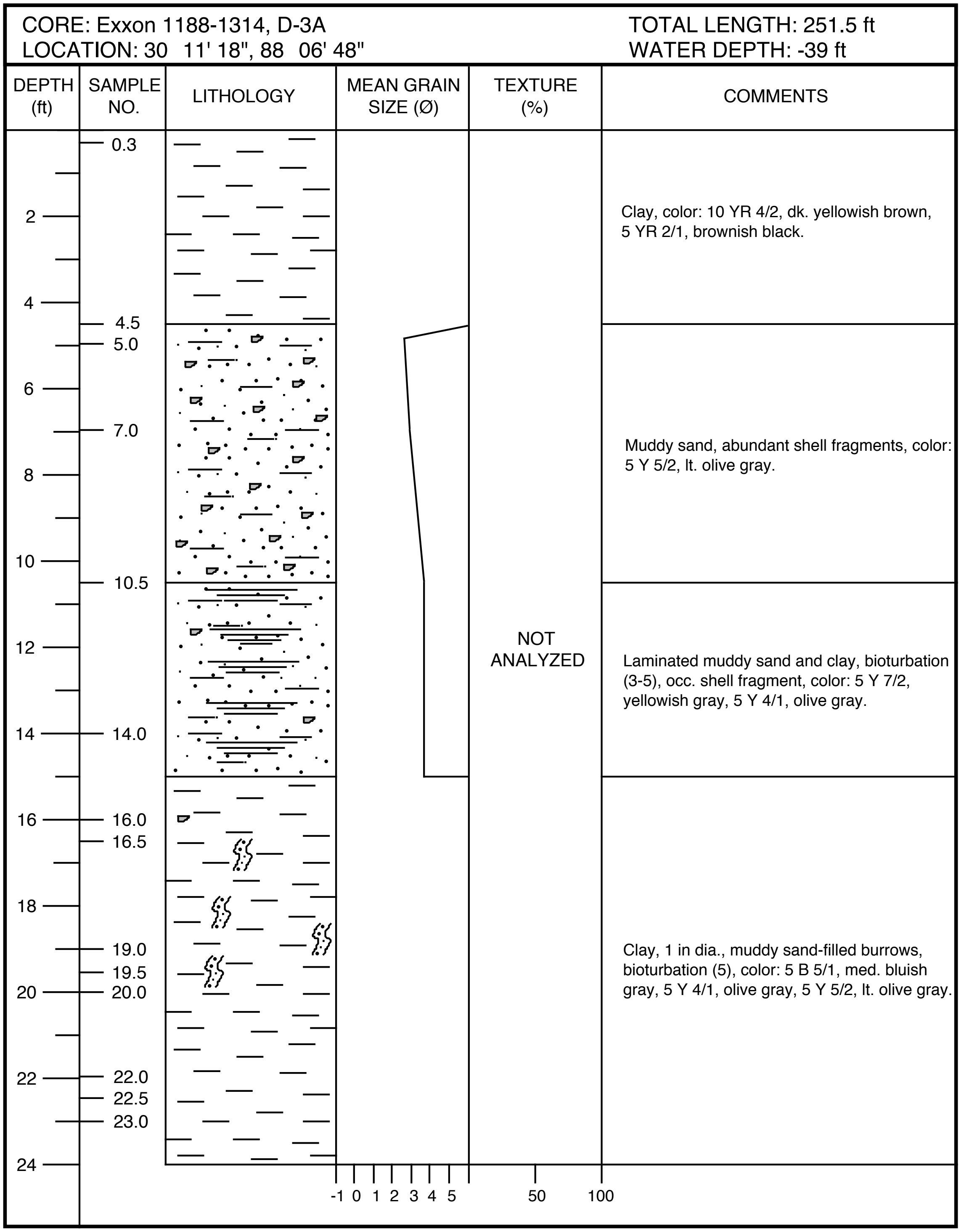


Figure A-7.--Columnar section of EEZ boring Exxon 1188-1314, D-3A.

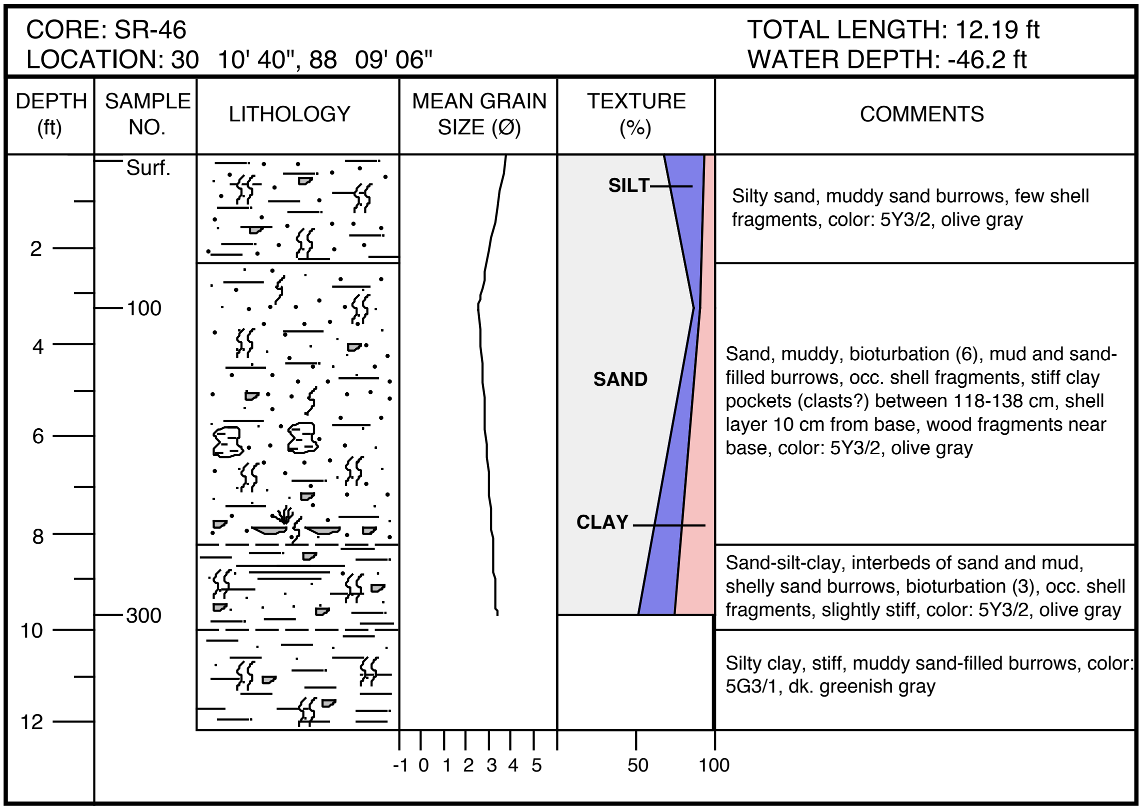


Figure A-8.--Columnar section of EEZ vibracore SR-46.

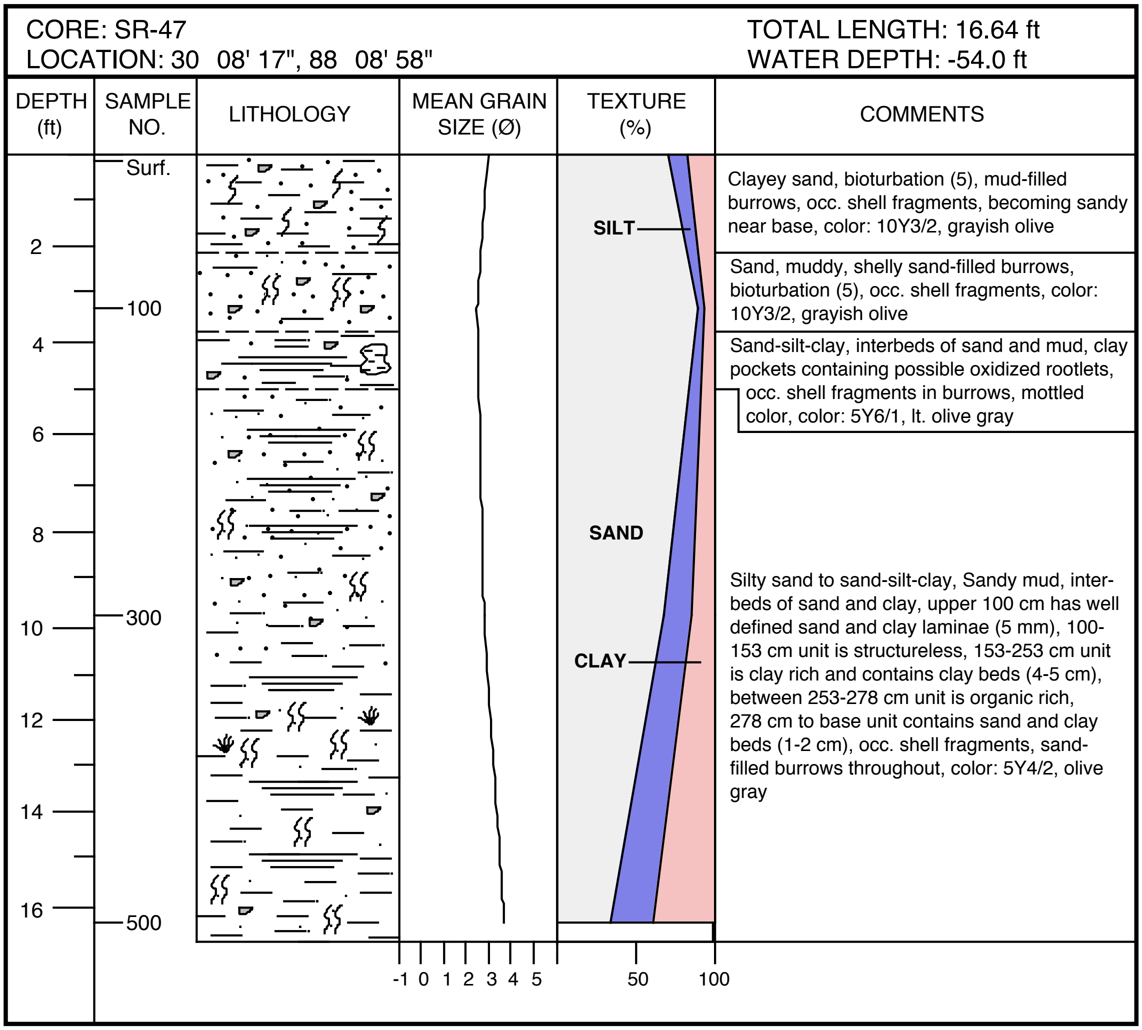


Figure A-9.--Columnar section of EEZ vibracore SR-47.

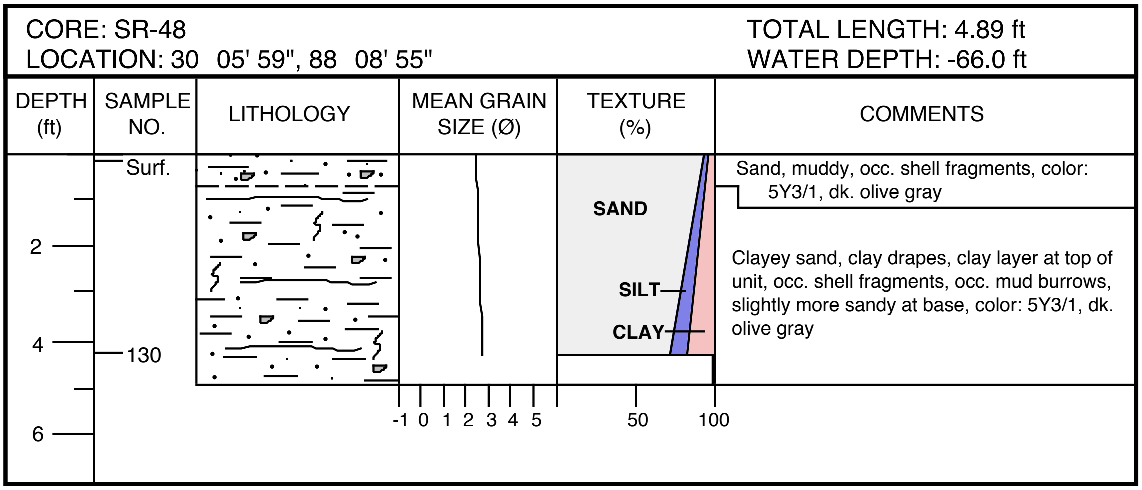


Figure A-10.--Columnar section of EEZ vibracore SR-48.

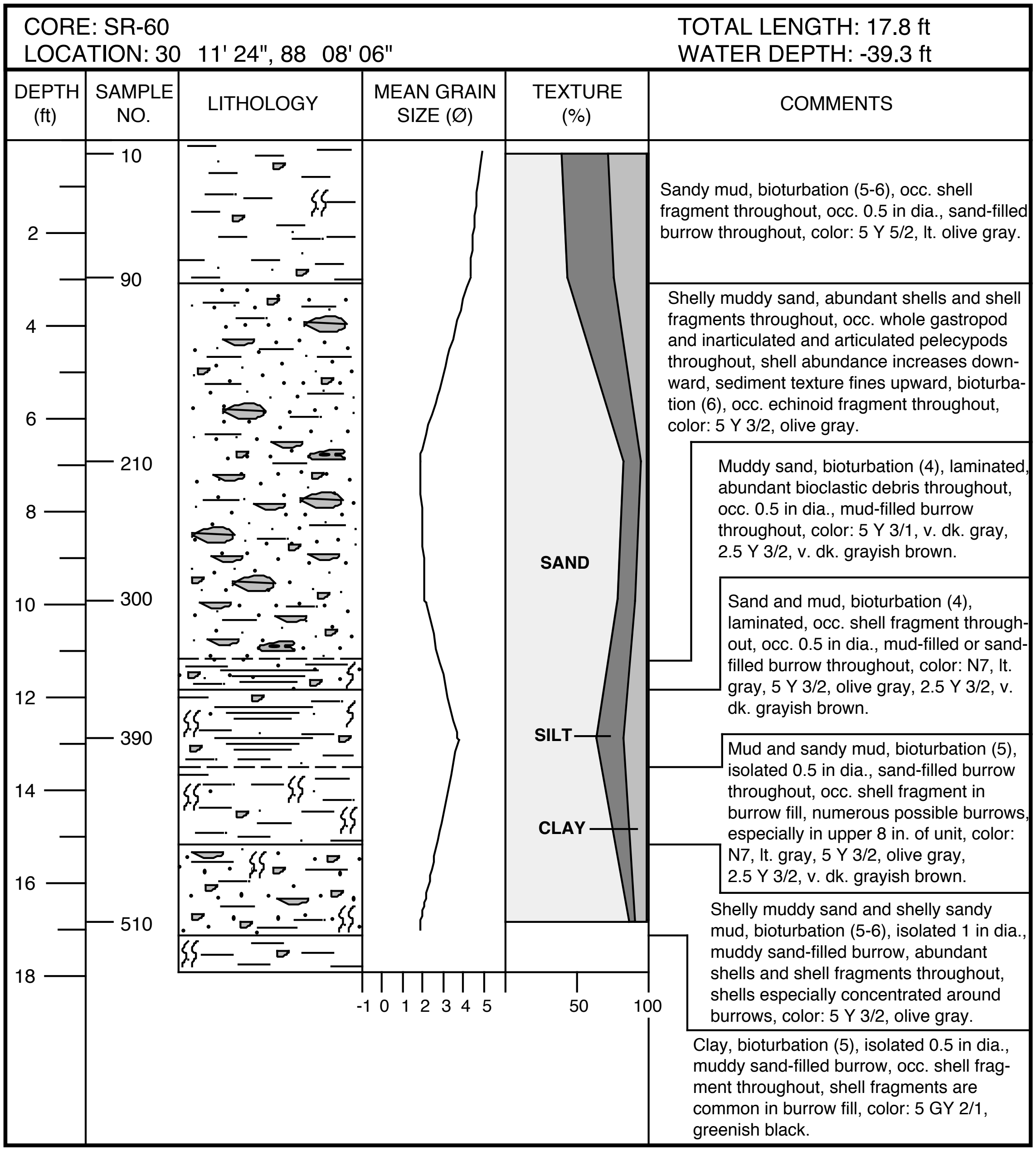


Figure A-11.--Columnar section of EEZ vibracore SR-60.

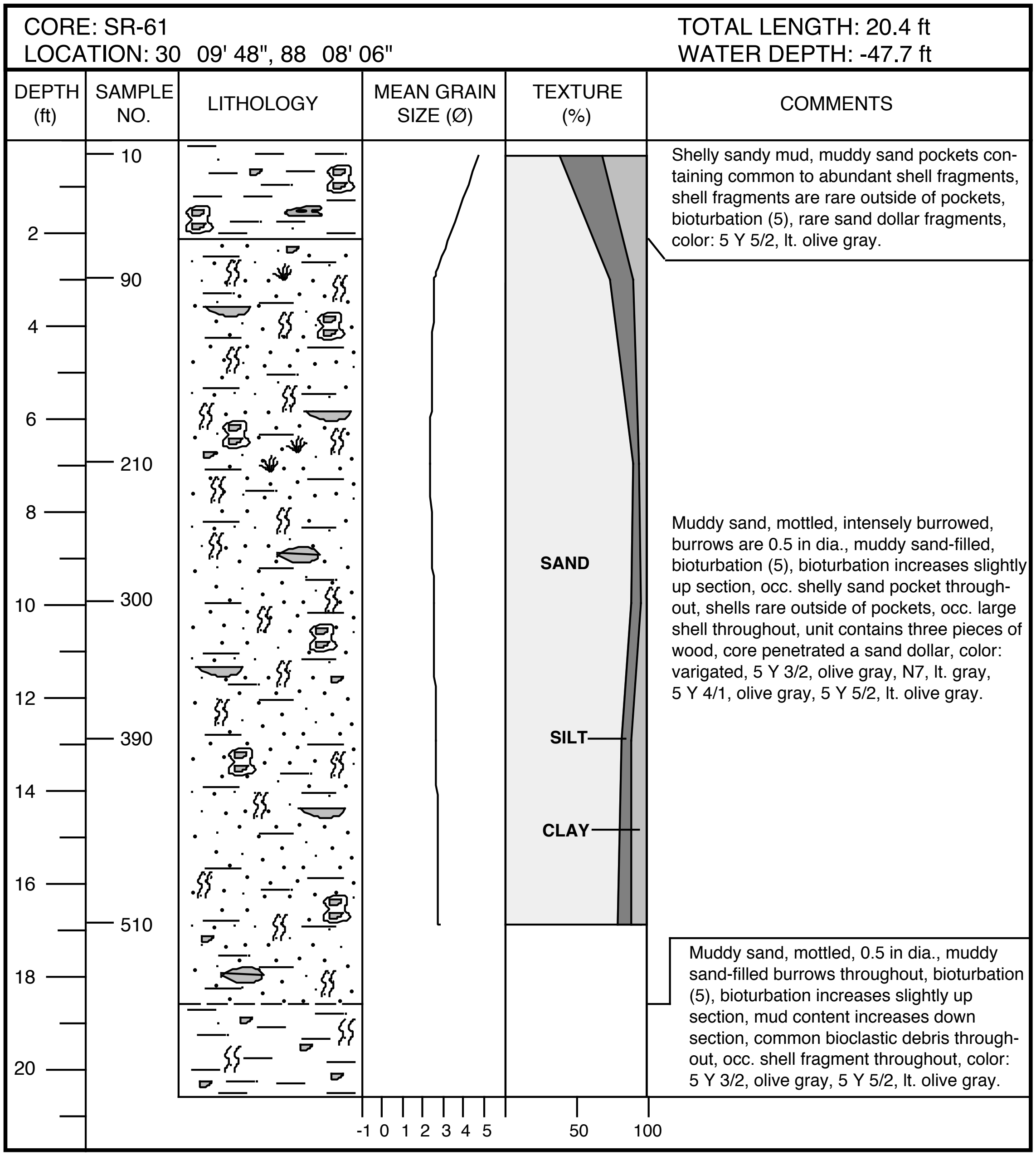


Figure A-12.--Columnar section of EEZ vibracore SR-61.

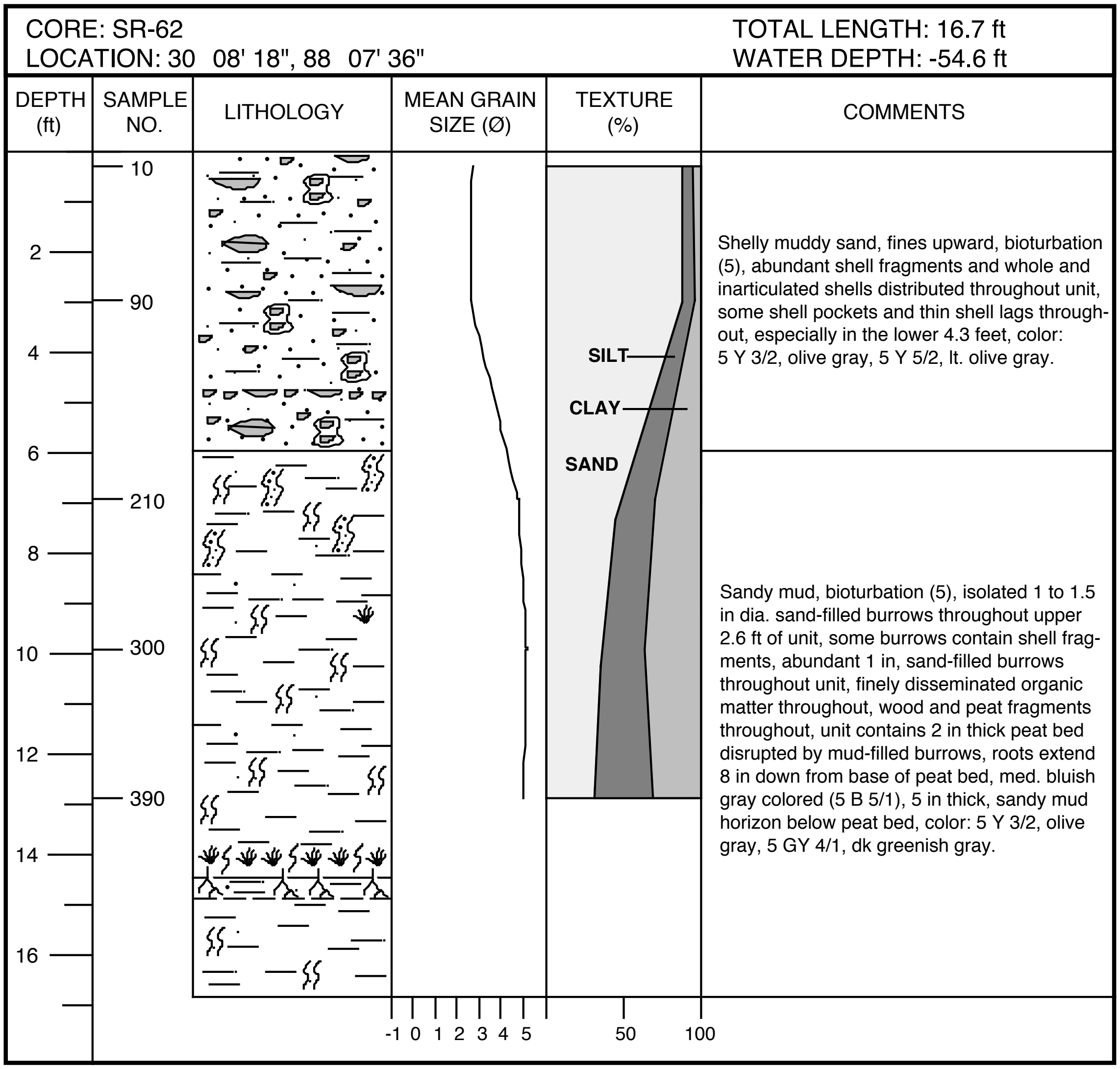


Figure A-13.--Columnar section of EEZ vibracore SR-62.

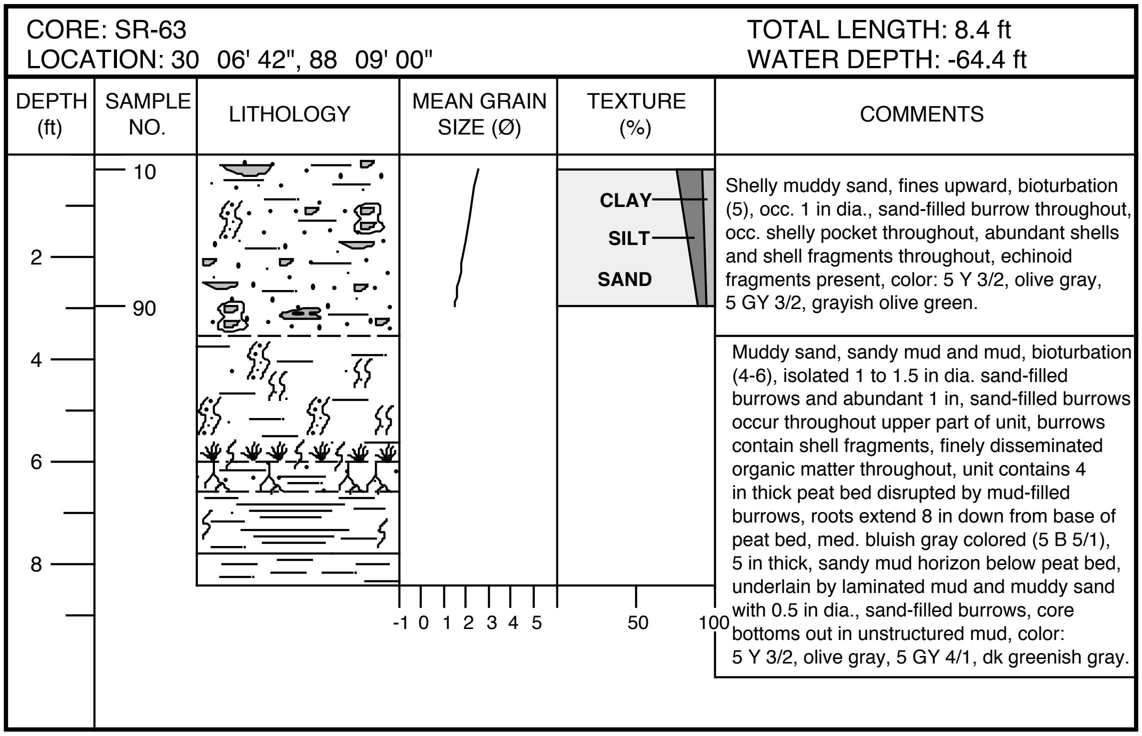


Figure A-14.--Columnar section of EEZ vibracore SR-63.

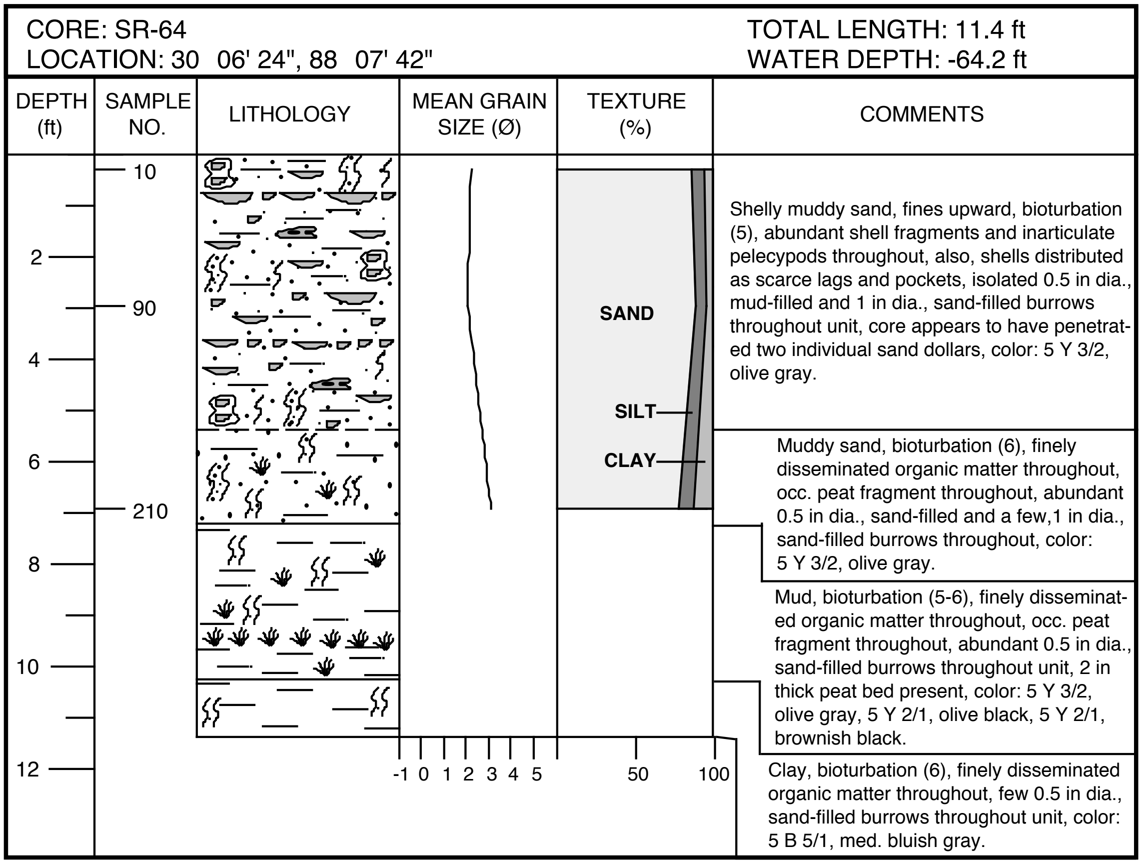


Figure A-15.--Columnar section of EEZ vibracore SR-64.

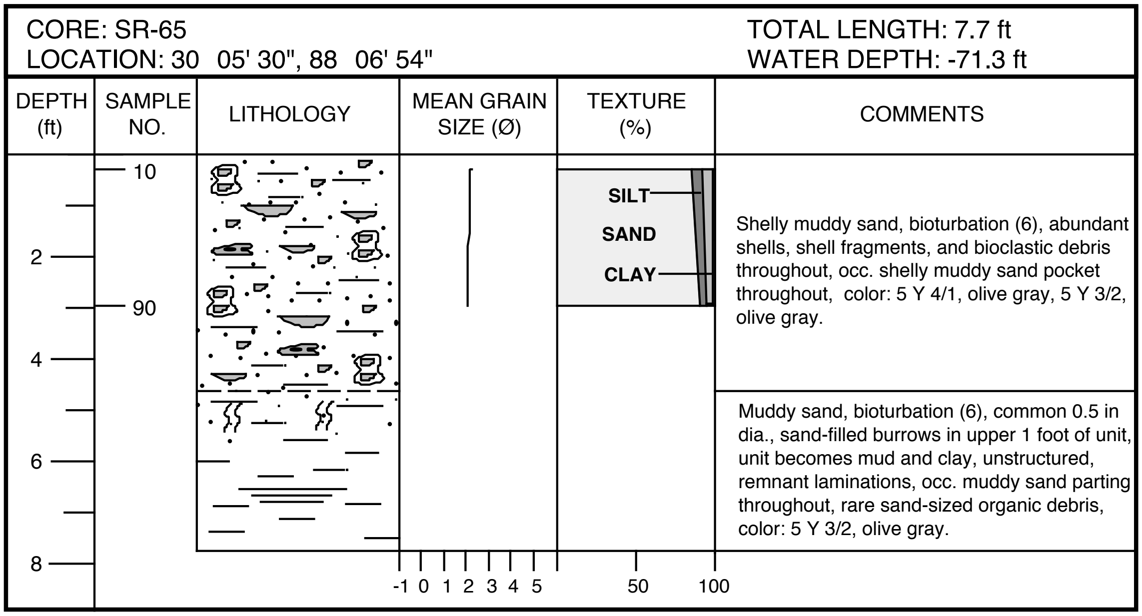


Figure A-16.--Columnar section of EEZ vibracore SR-65.

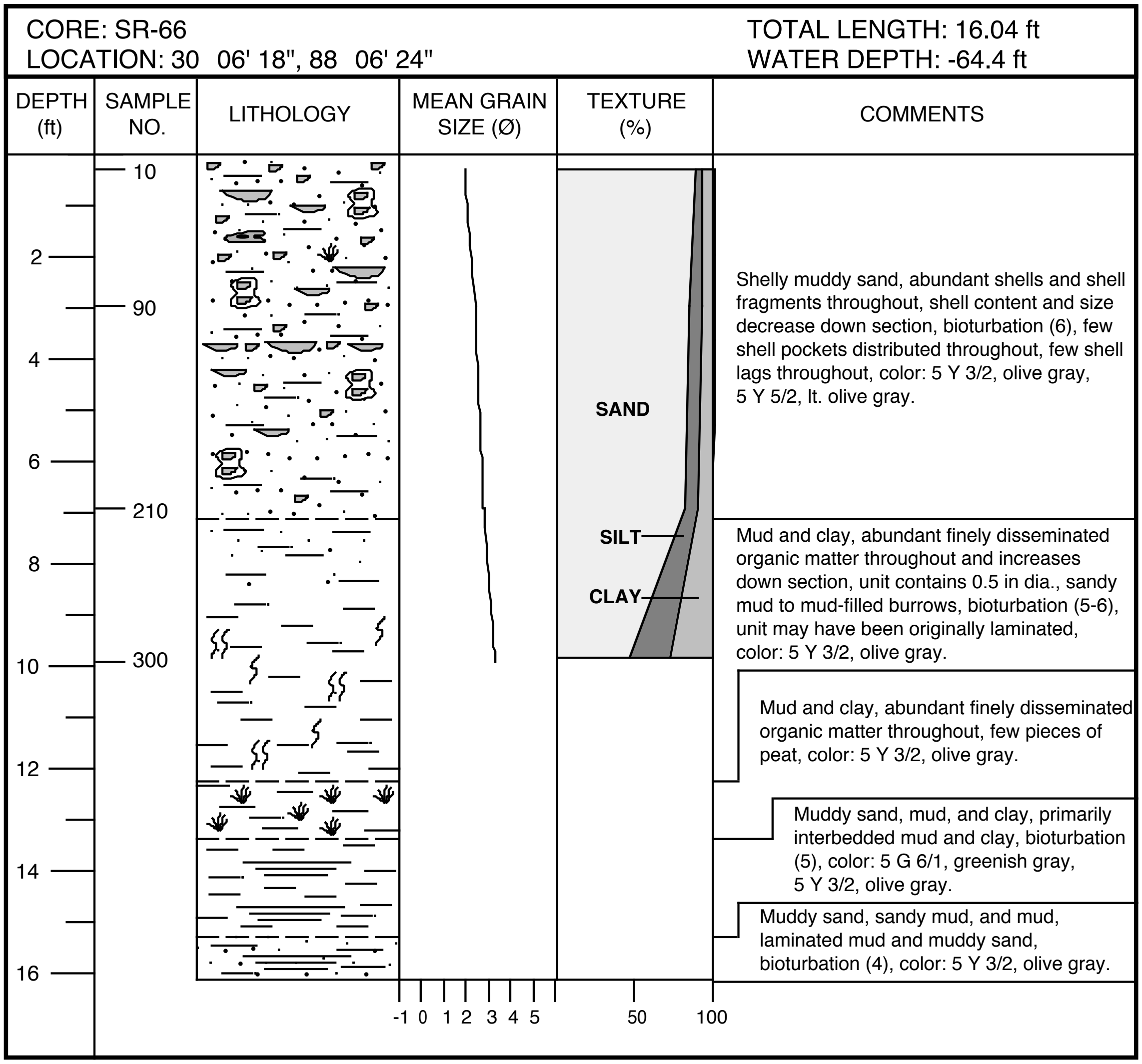


Figure A-17.--Columnar section of EEZ vibracore SR-66.

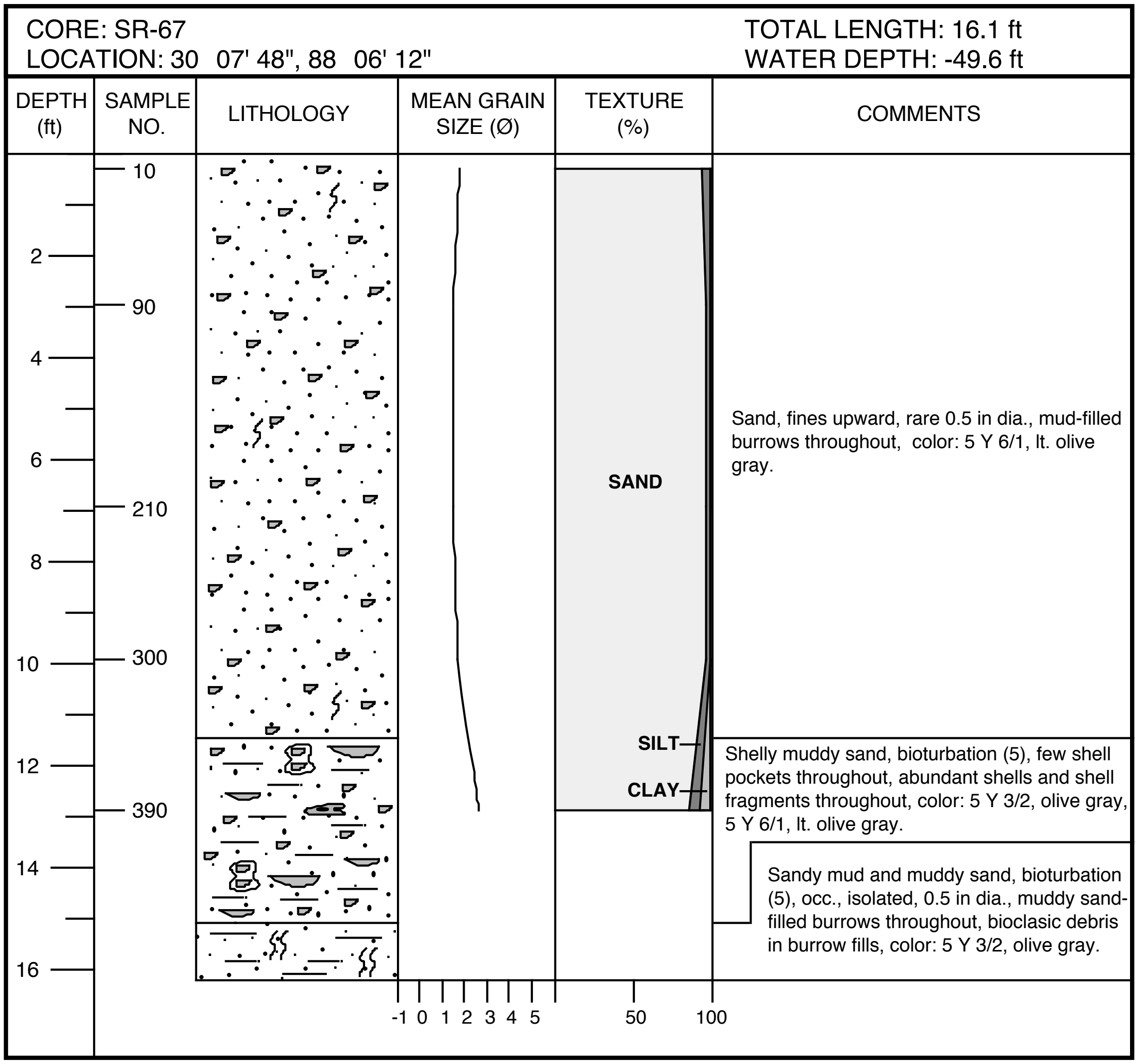


Figure A-18.--Columnar section of EEZ vibracore SR-67.

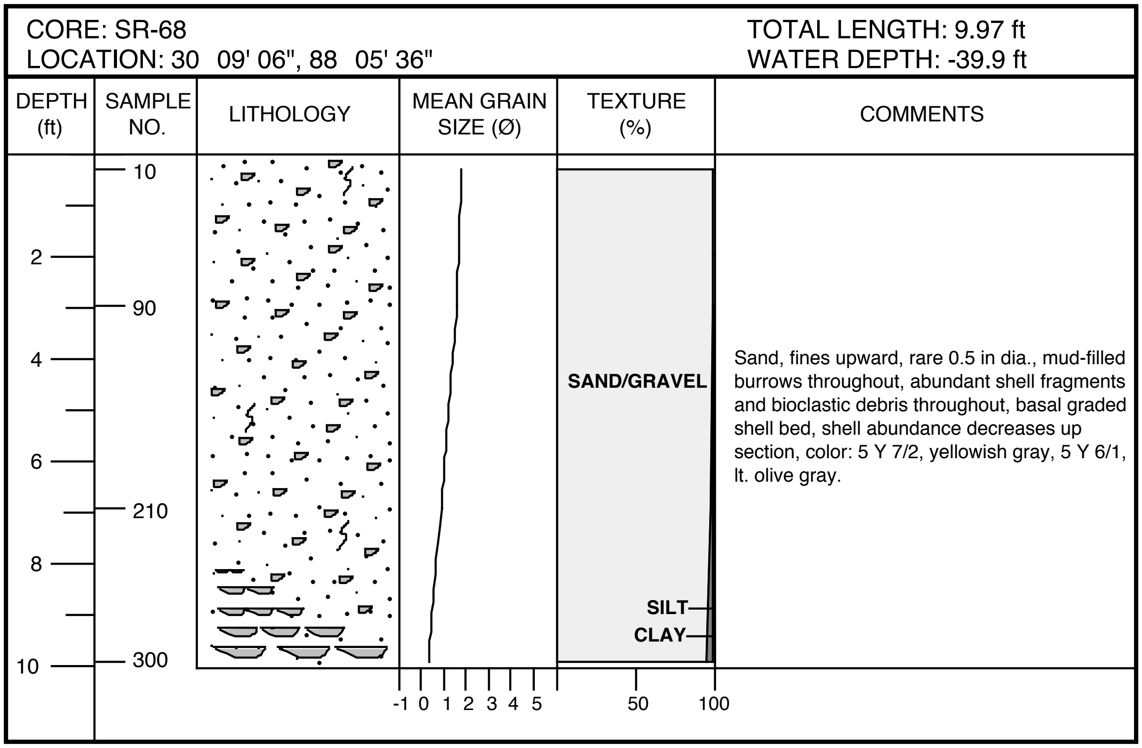


Figure A-19.--Columnar section of EEZ vibracore SR-68.

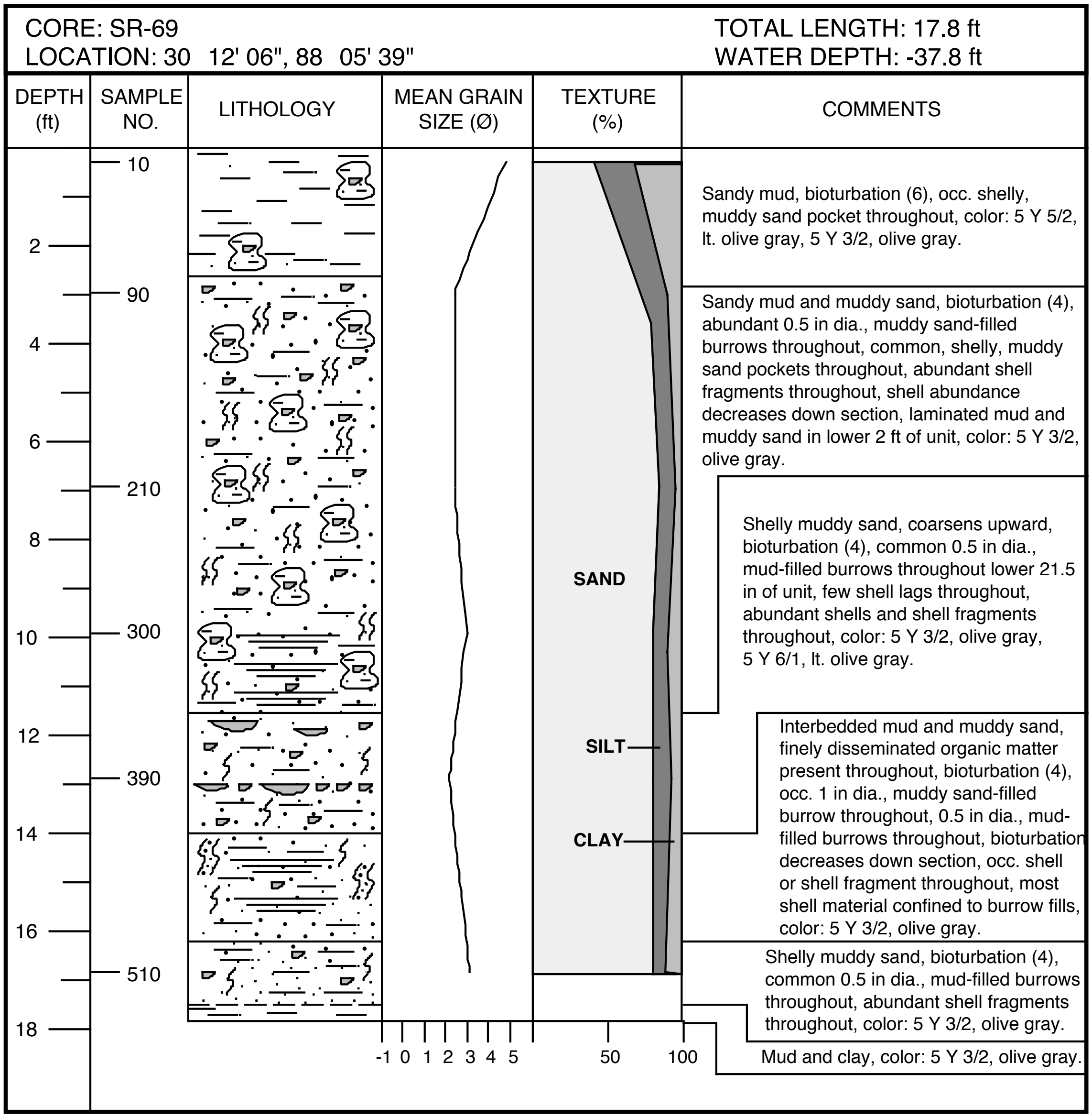


Figure A-20.--Columnar section of EEZ vibracore SR-69.

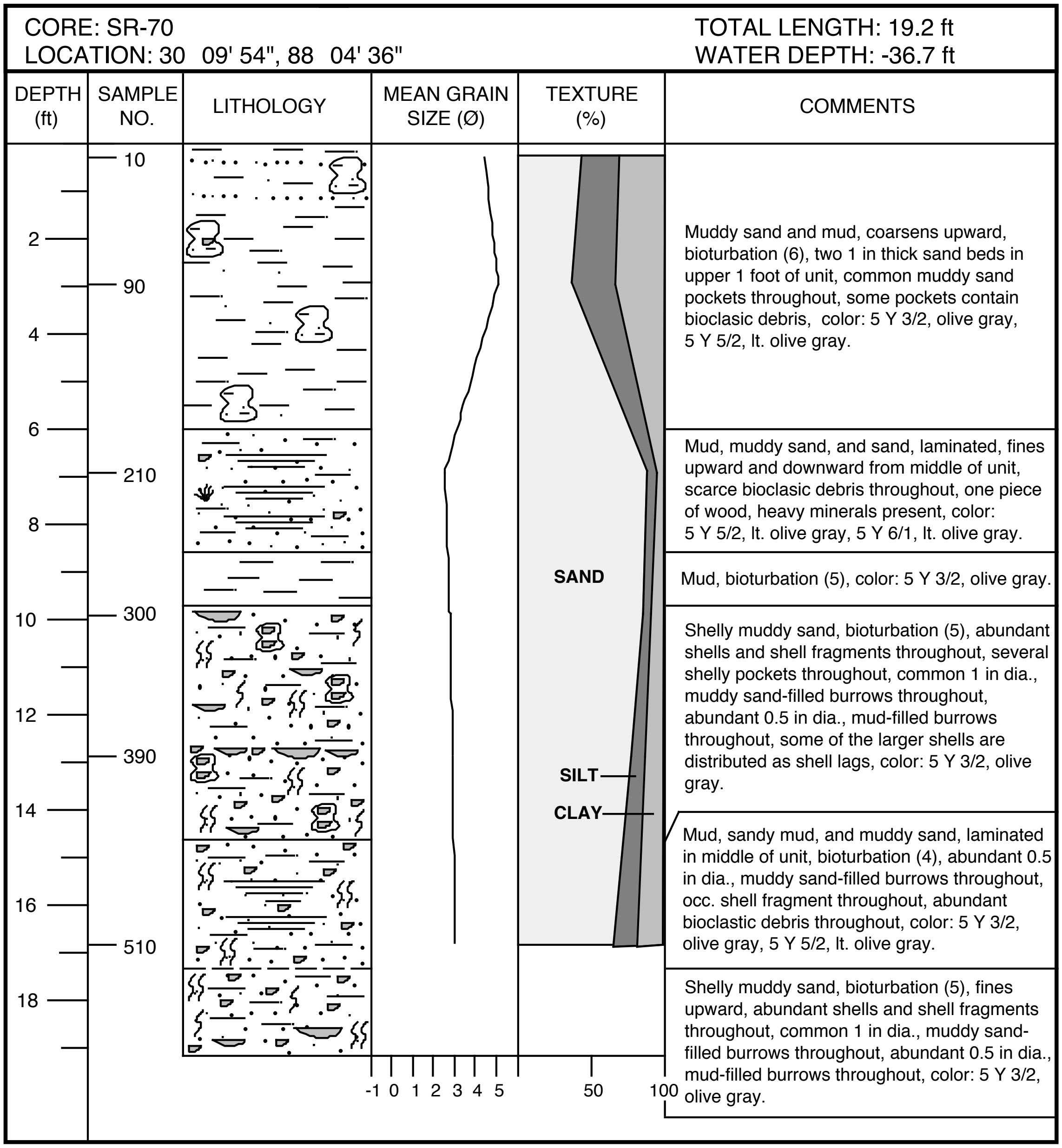


Figure A-21.--Columnar section of EEZ vibracore SR-70.

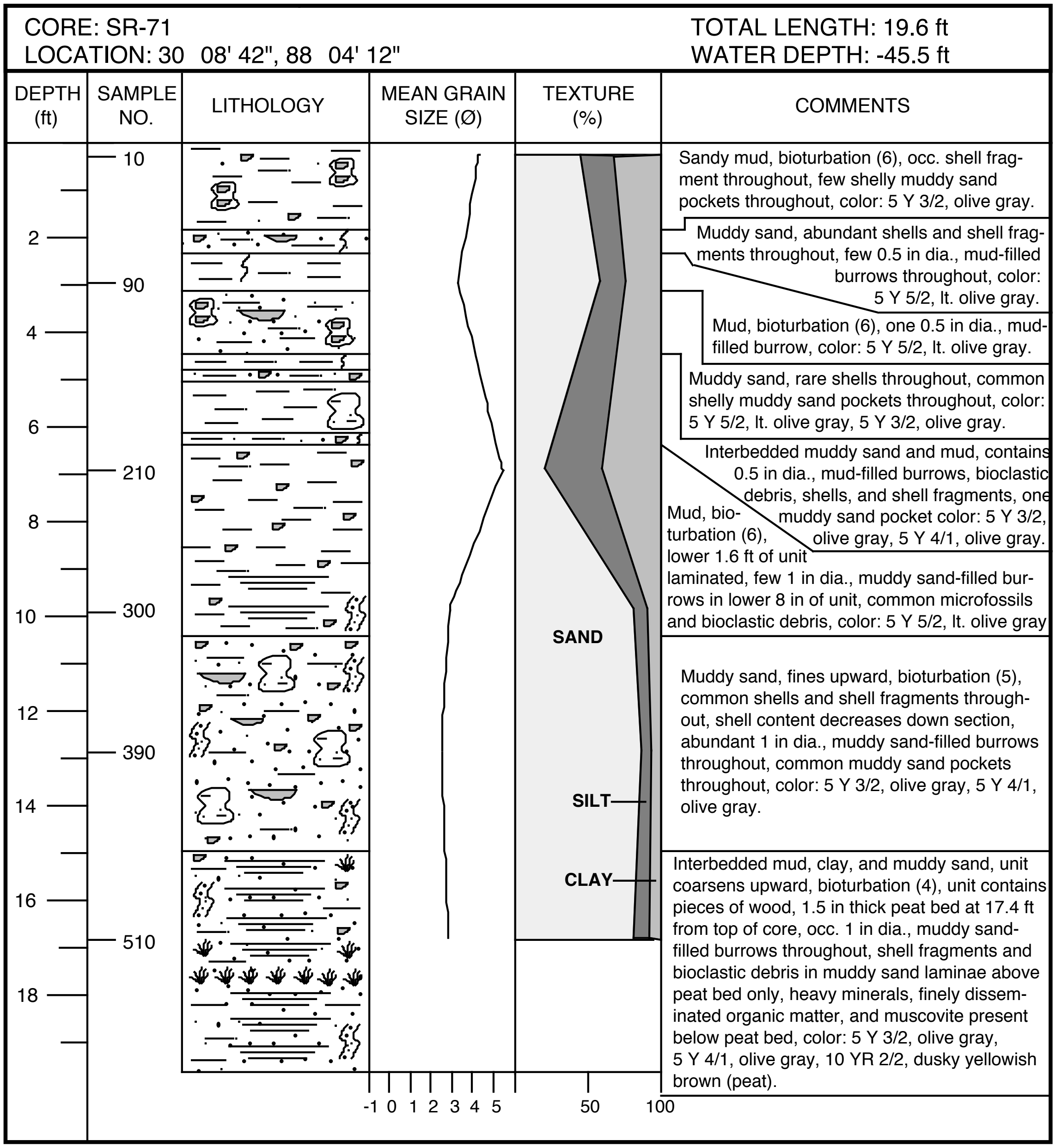


Figure A-22.--Columnar section of EEZ vibracore SR-71.

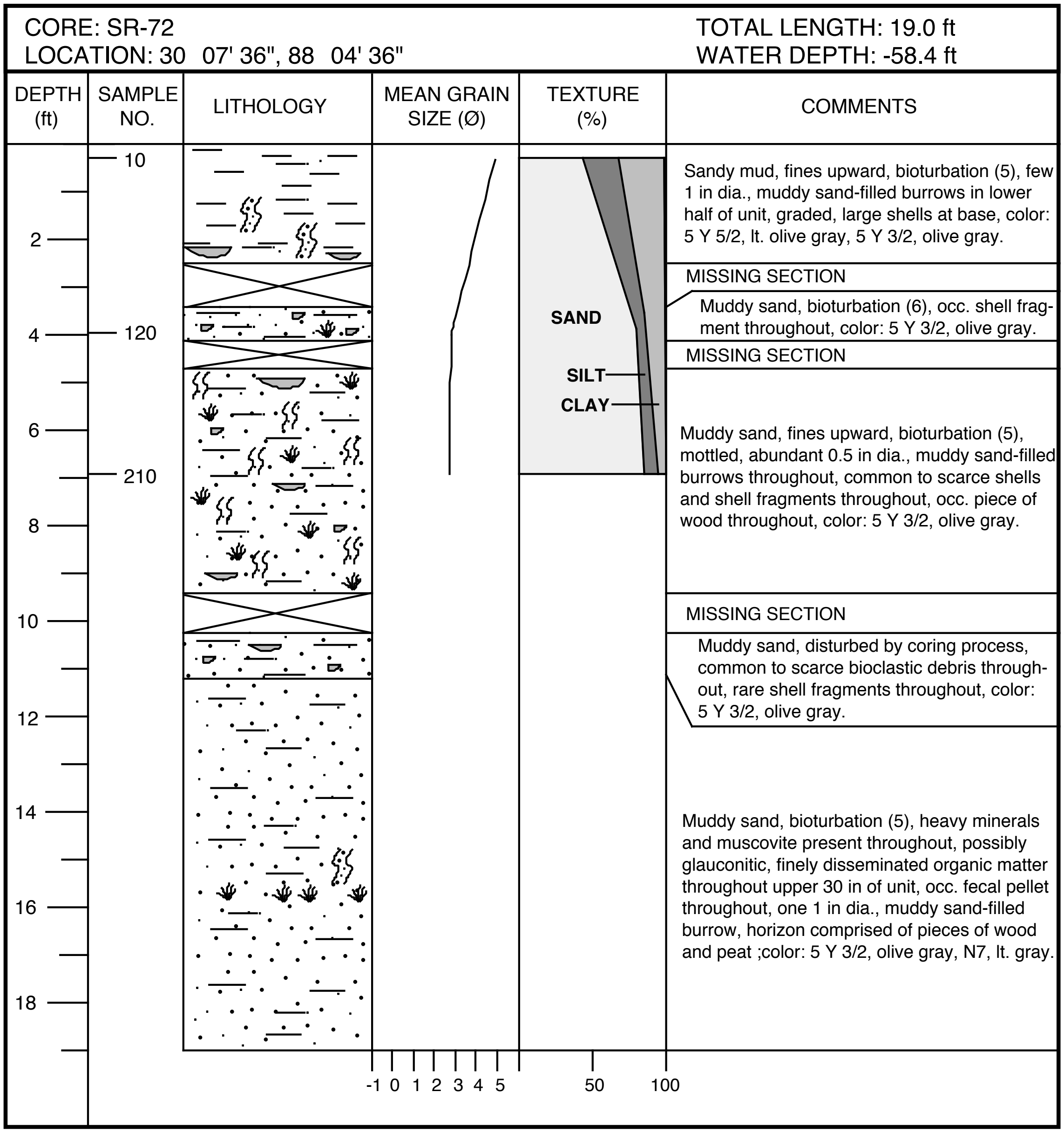


Figure A-23.--Columnar section of EEZ vibracore SR-72.

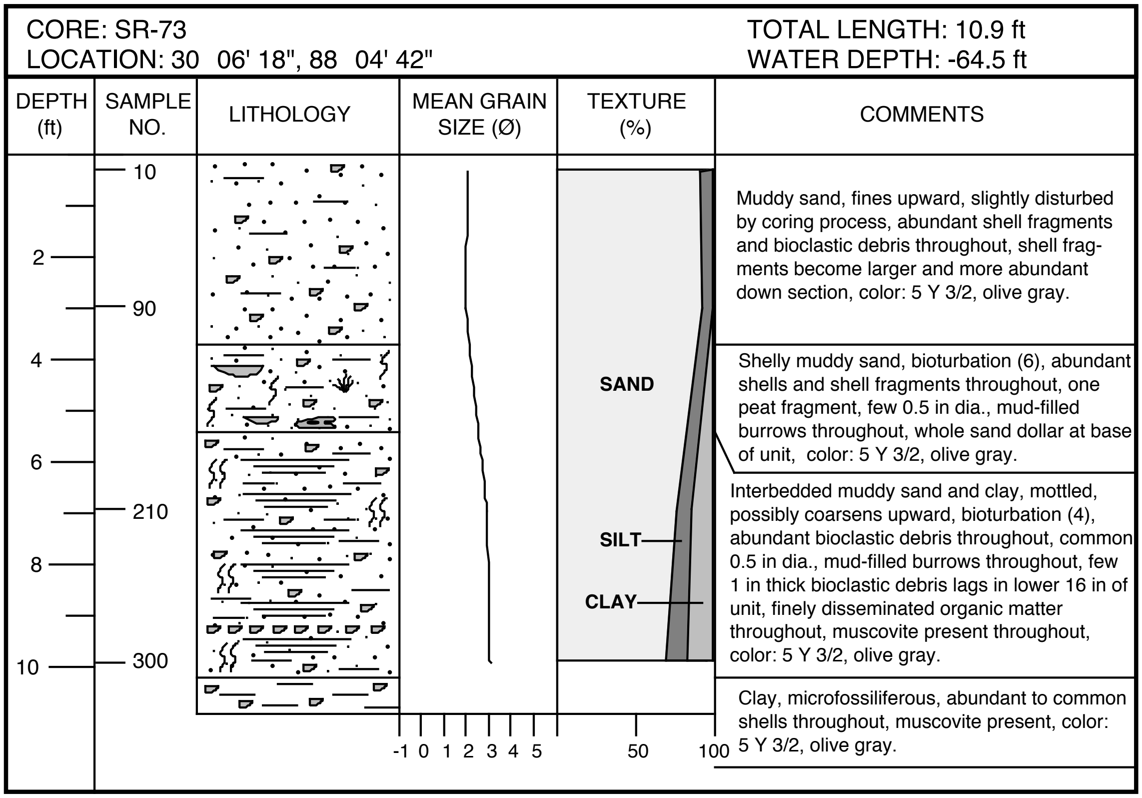


Figure A-24.--Columnar section of EEZ vibracore SR-73.

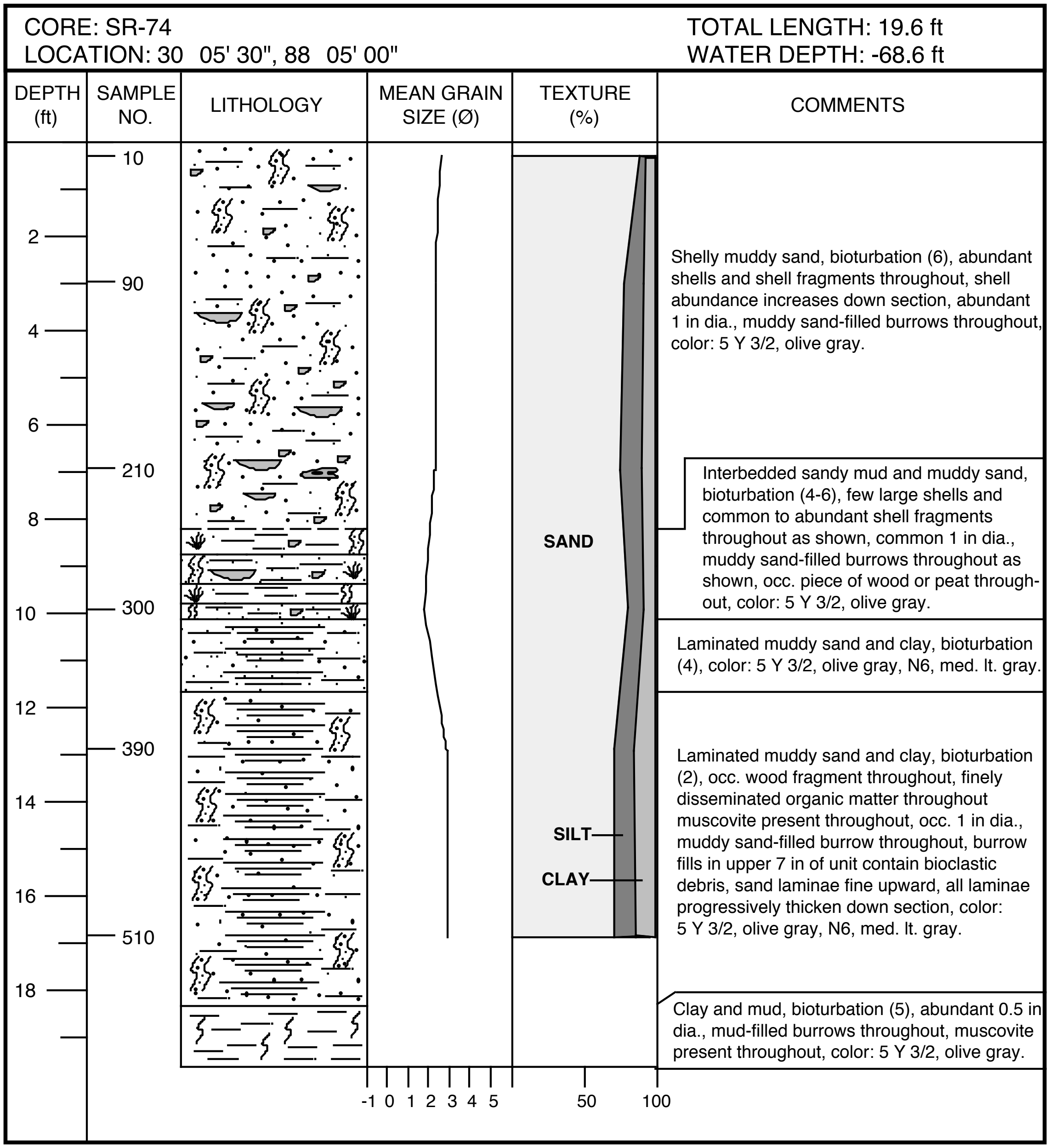


Figure A-25.--Columnar section of EEZ vibracore SR-74.