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Geomorphology, Shallow Subbottom Structure, and Sediments of the Atlantic Inner Continental Shelf Off Long Island, New York

by
S. Jeffress Williams

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<p>About 800 square miles of the Atlantic Inner Continental Shelf off Long Island, New York, were studied by CERC to obtain information on the sea floor morphology, sediment distribution, and shallow subbottom stratigraphy and structure. This information is used for delineating sand and gravel resources and deciphering shelf geologic history. Basic survey data by CERC consist of 735 miles of high-resolution continuous seismic profiles and 70 vibratory cores; additional data were available from 82 sediment cores and 225 miles of</p> <p>(continued)</p>		

seismic records. Data coverage extends from Atlantic Beach east to Montauk and in Gardiners Bay; and from the shoreface seaward about 10 miles to water depths of 105 feet.

Three primary acoustic horizons are evident on the seismic profiles and have been identified by correlation with cores, land borings, and surface exposures of the reflectors. Granitic bedrock is the oldest and deepest horizon underlying Long Island, but its recognition on the seismic records, due to limited subbottom penetration, is confined to northern Gardiners Bay. The bedrock surface slopes southeast and exhibits considerable relief where glacial ice has enlarged pre-Pleistocene drainage channels. Upper Cretaceous and Tertiary semiconsolidated clastic sediments overlie the bedrock and dip and thicken to the southeast. The surfaces of these strata, which are present throughout the study area and project north under Long Island, are the second major horizon. The third seismic horizon is a Pleistocene erosion surface cut by fluvial and glacial agents into the older rock units. Depth of this surface varies from -50 to -300 feet MSL off the western and eastern Long Island shelf to sea floor outcropping in parts of the central Long Island inner shelf. Pleistocene detritus consists primarily of blanketlike deposits of outwash sand and gravel; however, radiocarbon dates show that Holocene-age barrier-lagoonal sequences and estuarine sediments cover parts of the Long Island shelf.

Surficial sediments on the inner shelf are primarily fine to medium quartz sand with secondary occurrences of coarse sand and pea gravel on the Atlantic shelf and silt-clay mixtures in the Gardiners Bay region. The granular facies are relict outwash detritus, carried onto the shelf by ancient rivers and washed and sorted by marine processes since the Holocene rise of sea level. Fine-grained sediments on the shelf originated in early Holocene back-barrier or lacustrine environments; however, those in Gardiners Bay are estuarine or lacustrine deposits from Pleistocene lakes which occupied that region. Glauconitic sands, restricted to a zone off Fire Island Inlet, appear to be residual from the underlying Monmouth Group which, along with other Cretaceous strata, form a cuesta where strata are truncated by the sea floor.

Numerous major buried ancestral drainage channels transect Long Island mainland in a north-south orientation and continue south across the shelf. Thalweg depths of the channels range from -100 to -550 feet MSL and channel widths are often several miles. Many channels on the north shore of Long Island underlie reentrant bays and most were significantly enlarged by Pleistocene glacial ice and later filled with sediment.

Much of the surficial sand on the inner shelf is suitable as fill for beach restoration, except for that of the shoreface region (0 to -30 feet MSL) which contains fine sand and that of major parts of Gardiners Bay which contain organic-rich silt and clay. Topographic highs on the sea floor in the form of linear shoals, and broad deltalike platforms in eastern Long Island appear most suitable for sand recovery. The sea floor in most potential borrow areas is flat and sand occurs as blanket deposits. Potential sand reserves within about 12 feet of the sea floor in the region are estimated to be more than 8 billion cubic yards.

PREFACE

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

The report was prepared by Mr. S. Jeffress Williams, a CERC geologist, under the supervision of Dr. David B. Duane, former Chief, Geological Engineering Branch, and his successors, Dr. William R. James and Mr. Ralph L. Rector. As part of the research program of the Engineering Development Division, the ICONS study is under the general supervision of Mr. George M. Watts, Chief of the Division. The fieldwork (obtaining cores and seismic reflection records) was carried out by Alpine Geophysical Associates, Inc., under Contract No. DACW51-68-C-0044.

Discussions with Mr. Edward C. Rhodehamel and others of the U.S. Geological Survey (USGS), Reston, Virginia, were helpful in deciphering the Coastal Plain stratigraphy; Dr. Walter S. Newman of Queens College, New York, provided guidance on use of the radiocarbon dates; Dr. John E. Sanders of Columbia-Barnard College, New York; and Dr. Michael E. Field of USGS (formerly with CERC) provided helpful reviews of the manuscript. Appreciation is given to Mr. George Tirey of Woodward-Clyde-Sherard Associates, and to the Testing Service Corporation for providing the ancillary data.

Microfilm copy of the CERC seismic data used in this study is stored at the National Solar and Terrestrial Geophysical Data Center (NSTGDC), Rockville, Maryland 20852. Vibratory cores collected during the field survey program are in a repository at the University of Texas, Arlington, Texas 76010. Requests for information relative to these items should be directed to NSTGDC or the University of Texas.

Comments on this publication are invited.

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

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GEOMORPHOLOGY, SHALLOW SUBBOTTOM STRUCTURE, AND SEDIMENTS OF THE ATLANTIC INNER CONTINENTAL SHELF OFF LONG ISLAND, NEW YORK

by
S. Jeffress Williams

I. INTRODUCTION

1. Background.

Ocean beaches and associated dunes provide a necessary and important buffer zone between the sea and fragile coastal wetland areas for many continental land masses. At the same time, beaches provide public recreation areas for millions of people. The construction, improvement, and periodic maintenance of beaches and dunes by placement of suitable sand along the shoreline can be an important means of counteracting coastal erosion by providing stability to shoreline positions and permitting recreational facilities (U.S. Army, Corps of Engineers, 1971). Beach nourishment techniques (Hall, 1952) have gained prominence in coastal engineering largely as a result of the successful beach nourishment test program using a hopper dredge at Sea Girt, New Jersey, in 1966 by the U.S. Army Engineer District, Philadelphia (1967); and the successful completion of the nourishment of Redondo Beach, California, in 1969 by commercial operator under contract to the Corps of Engineers (Fisher, 1970). Artificial beach nourishment using offshore sand was also successfully conducted at five beaches on the southeast coast of Florida (Strock and Noble, 1975). A major restoration of Rockaway Beach on western Long Island, New York, is presently underway. Approximately 4 million cubic yards (3 million cubic meters) of sand has been dredged from East Bank shoal (offshore Coney Island) and transported by pipeline to the beach (G. Nersesian, U.S. Army Engineer District, New York, personal communication, 1975). These projects show that present technology is advanced enough to make sand and gravel on the shallow parts of the shelf a presently exploitable resource (Duane, 1968) and (at some locations) economically competitive with existing methods (truck haul and drag scoop) for sand transport and beach construction.

Plans for initial beach restoration and periodic renourishment usually involve large volumes of suitable sandfill. In recent years it has become increasingly difficult to obtain suitable sand from lagoons and wetlands or from inland sources in sufficient volumes and at an economical cost for beach fill purposes. These difficulties have resulted in part from increased real estate values, concern over environmental and ecological effects of removing such large volumes of sand, diminution or depletion of previously used land sources, and inflated transportation costs of moving the material from areas increasingly remote from final destinations. In addition, sedimentary material comprising the bottoms of wetlands, i.e., lagoons, estuaries, and bays, is mostly fine-grained and rich in organic content, and as a result, is unsuitable for long-term effective shoreline protection. While the loss of some fine-grain material is to be expected as a newly nourished beach attains a new state

of equilibrium with the sea environment, it is possible to minimize the losses through careful selection of the most suitable fill material (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1973).

The problems of locating suitable and economical sand deposits led the U.S. Army, Corps of Engineers, Coastal Engineering Research Center (CERC) to initiate a search for exploitable deposits of sand. Exploration efforts are focused offshore with the intent to locate and inventory deposits suitable for future fill requirements and to later refine techniques for specifying more suitable fill characteristics.

The search for offshore sand deposits, referred to initially as the Sand Inventory Program, started in 1964 with a survey off the New Jersey coast (Duane, 1969). Subsequent data collection surveys have included the Inner Continental Shelf areas off New England, Long Island, Delaware, Maryland, Virginia, the Cape Fear area of North Carolina, the east coast of Florida, and southern California. A survey for eastern Lake Michigan was initiated in August 1975. Since 1971, broader application to the CERC mission of the data collected has been recognized, especially in deciphering the shallow structure of the Continental Shelf, understanding shelf sedimentation and hydraulic processes, unravelling geologic history of the shelves, and finally, evaluating the potential for engineering design of manmade structures on the shelf. This more diversified program is now referred to as the Inner Continental Shelf Sediment and Structure (ICONS) program.

2. Field and Laboratory Procedures.

The field exploration phase of the ICONS program uses continuous high-resolution seismic reflection profiling, supplemented by cores of the sub-bottom sediment. Both of these sources of data are obtained by contractual agreement with ocean industry firms. These data are then analyzed and interpreted by CERC Geological Engineering Branch staff. Support data are obtained from the National Ocean Survey hydrographic boat sheets, pertinent professional papers, and published literature.

a. Data Collection Planning. Geophysical survey tracklines are laid out for the study areas by the CERC staff in two basic patterns: grid and reconnaissance lines. A grid pattern, with variable line spacing depending on regional geologic relationships is used to cover areas where a more detailed picture of sea floor and subbottom geologic conditions is desirable, usually those areas suspected of containing sand and gravel. Reconnaissance lines consist of one or more continuous shore-parallel or zigzag lines which provide minimal coverage for intermediate areas between grids. Reconnaissance lines also provide a correlation of regional geology between grid areas. They normally provide sufficient information to reveal the general morphologic and geologic aspects of the area and to identify sea floor areas where more detailed additional data collection may be advisable.

Selection of individual core sites is based on a continuous inspection of the seismic records as they become available from the contractor during the survey. This procedure of picking core locations based on geologic conditions revealed on the seismic records allows core-site selection to be based on the best available information and thus maximizes usefulness of both sources of data. It also permits the contractor to complete the required work of obtaining geophysics and cores in one area before moving his base of operations to the next area.

b. Seismic Reflection Profiling. Seismic reflection profiling is a technique widely used for delineating subsea floor geologic structures and bedding surfaces in sea floor sediments and rocks. Continuous reflections are obtained by generating repetitive, high-energy, sound pulses near the water surface and recording "echoes" reflected from the sea floor-water interface and subbottom interfaces between acoustically dissimilar materials. In general, the compositional and physical properties (e.g., porosity, water content, relative density) which commonly differentiate sediments and rocks also serve to produce acoustic contrasts which show as dark lines on the geophysical paper records. Thus, a seismic profile is roughly comparable to a geologic cross section.

Seismic reflection surveys of marine areas are made by towing variable energy and frequency sound-generating sources and receiving instruments behind a survey vessel which follows the predetermined survey tracklines. A dual energy source (100- to 200-joule engineering sparker) was used for this survey. In continuous profiling, the acoustic source is fired at a rapid rate (usually 4 pulses per second) and returning echo signals from sea floor and subbottom interfaces are received by an array of towed hydrophones. Returning signals are amplified and fed to a recorder which graphically plots the two-way signal travel time. Assuming a constant velocity for sound in water at 4,800 feet per second and for typical shelf sediments at 5,400 feet per second, a vertical depth scale is constructed to fit the seismic record. Detailed seismic profiling techniques are discussed in several technical publications (Ewing, 1963; Hersey, 1963; van Reenan, 1963; Miller, Tirey, and Mearini, 1967; Moore and Palmer, 1968; Barnes, et al., 1972; Ling, 1972).

Geographic position of the survey vessel is obtained by frequent navigational fixes keyed to the record by an event marker. Navigation for this particular survey was achieved by use of the Alpine Precision Range System, Model 4350. This system uses a Decca Transar for radar rangings, the Alpine Model 4270 X-Band Transponder as a point reflection source, the Precision Range System for measuring the distance of strobe alignment to the reflectors, and a Remote Autotrack Plotter. The plotter was coupled electronically to the range system to provide a real-time true-motion plot of the survey vessel course. Accuracy for this survey was about ± 100 feet in 80 nautical miles.

c. Coring Techniques. The sea floor coring device used in this study was a pneumatic, vibrating piston coring assembly designed to obtain core samples (20-foot or 6-meter maximum length; 4-inch or 10.2-centimeter

diameter) in granular-type Continental Shelf sediments. The apparatus consists of a standard steel core barrel, plastic inner liner, shoe and core catcher, and a pneumatic driving head attached to the upper end of the barrel. These elements are enclosed in a tripodlike frame with articulated legs which allow the assembly to rest on the sea floor during the coring operation. The detachment of the core device from the surface vessel has the advantage of allowing limited motion of the vessel during the actual coring process. Power is supplied to the pneumatic vibrator head by a flexible hose line connected to a large-capacity air compressor mounted on the deck of the ship. After coring is complete, the assembly is winched on board the vessel, the liner containing the core is removed, capped at both ends, adequately marked, and stored. A review of the historical development of vibratory coring equipment is discussed by Tirey (1972).

d. Processing of Data. Seismic records are visually examined to establish the principal bedding and geologic features in the subbottom strata. After analyses are complete, record data are reduced to detailed geologic cross-sectional profiles showing the primary reflective interfaces within the subbottom. Selected acoustic reflectors are then mapped to provide areal continuity of horizons considered significant because of their extent and relationship to the general structure and geology of the study area. Where possible, the topmost reflectors are correlated with cored sediment to provide a measure of continuity between cores.

Cores are visually inspected and described aboard the recovery ship. After delivery to CERC, the cores are sampled at close intervals by drilling through the liners and removing parts of representative material. After preliminary analysis, representative cores are split longitudinally to show details of the bedding and changes in stratigraphy. Cores are split using a wooden trough arrangement fabricated at CERC shop facilities. A circular powersaw, mounted on a base designed to ride along the top of the trough, is adjusted to cut just through the plastic liner and not disturb the core sediment. By making a second longitudinal cut in the opposite direction, a 120°-segment of the liner is cut and can be removed. The sediment above the cut is then scraped away to remove altered and disturbed sediment and the core is carefully logged, sampled at closer intervals, photographed, and resealed.

Samples from the cores are then examined using a plane light binocular microscope and described in terms of gross lithology, color, mineral composition, and the type and abundance of skeletal fragments of marine organisms. Granulometric parameters (e.g., mean size, sorting) for the sand fraction of many samples are also obtained by using the CERC Rapid Sand Analyzer (RSA) which is analogous to that described by Zeigler, Whitney, and Hays (1960) and Schlee (1966).

3. Scope.

The study area (Fig. 1) covers about 800 square miles (2,072 square kilometers) of the Long Island Atlantic inner shelf from East Rockaway

Figure 1. Location map of the New York Bight study area. Map shows extent of seismic and core data coverage (shaded area) and the major submarine physiographic features. Bathymetry from Uchupi (1970).

Inlet (73°45'W.) east to Montauk Point (71°50'W.), and includes parts of Gardiners Bay and Block Island Sound on the eastern end of Long Island (Fig. 2). Actual data coverage extends a maximum of about 10 nautical miles (18.5 kilometers) offshore; however, by extrapolation, shelf areas seaward are included in the discussion of shelf morphology and sediment origin. Collection of field data for this study was conducted during the summer of 1968 under contract with Alpine Geophysical Associates, Incorporated. Data collected consist of approximately 735 statute miles (1,183 kilometers) of high-resolution continuous seismic reflection profiles and 70 vibratory sediment cores with a maximum length of 20 feet (6 meters) and a mean length of 9.7 feet (3 meters). Core and geophysical trackline locations are shown in Figure 2; core descriptions are in Appendix A. CERC data coverage for individual areas includes:

(a) Gardiners Bay: 85 statute miles (137 kilometers) of geophysical records; 14 cores with average length of 12 feet (3.6 meters).

(b) Montauk Point: 152 miles (245 kilometers) of records; 20 cores with average length of 8.5 feet (2.6 meters).

(c) Shinnecock, Moriches Bay, and Jones Beach: 296 miles (476 kilometers) of records; 24 cores with average length of 11 feet (3.4 meters).

(d) Fire Island: 173 miles (278 kilometers) of records; 12 cores with average length of 8 feet (2.5 meters).

(e) Long Beach: 29 miles (46.7 kilometers) of records; no cores.

Additional data available for inclusion in this study (data location plotted in Fig. 2) include:

(a) Approximately 225 miles (362 kilometers) of geophysical records and descriptive logs from 19 vibratory cores off Nassau County from Alpine Geophysical Associates, Incorporated after the conclusion of a preliminary regional study for site selection of an offshore sewer outfall;

(b) logs for two 20-foot soil borings taken on the shelf south of Atlantic and Long Beaches from a technical report by Sieck (1965);

(c) a descriptive log and sample photos of a 240-foot (73.2 meters) boring at Orient Point, Long Island, from a technical report by Woodward-Clyde-Sherard and Associates (1965);

(d) descriptive logs for 15 cores along a 2.5-mile (4 kilometers) offshore transect at a Tobay Beach sewer outfall position from Testing Service Corporation (1969); and

Figure 2. Location of seismic reflection ship tracklines, vibratory cores, and Orient Point boring. See Figure 8 for detail on core spacing along the Nassau and Suffolk County sewer lines, and Figure 12 for detail on 21 shore borings from Fire Island to Montauk. Descriptive logs for each core are in Appendix A; Sediment analyses are in Appendix B.

Figure 2. Location of seismic reflection ship tracklines, vibratory cores, and Orient Point boring.—Continued

(e) descriptions of 26 cores taken along two 5-mile (8 kilometers) transects off Cedar Beach supplied by Alpine Geophysical Associates, Incorporated.

Core descriptions for most of these data are in Appendix A.

4. Geographic Setting.

Long Island, situated within a prominent reentrant (New York Bight) on the Atlantic coast, is an elongated east-west oriented island approximately 120 miles (193 kilometers) long and 25 miles (40.2 kilometers) wide. Long Island is separated on the north from the New England mainland by Long Island Sound, bounded to the east by Block Island Sound and on the south by the Atlantic Ocean. New York City is located to the west. Long Island lies within the Coastal Plain physiographic province and marks the southern boundary of Pleistocene glacial advance in the eastern part of the North American Continent. Two end moraines form the physiographic backbone along the northern part of Long Island and are partly responsible for land relief along the north shore in excess of 350 feet (106.7 meters). The moraines are superimposed along the western half of Long Island but are sharply bifurcated in west-central Long Island. Each moraine forms the core of the two peninsulas of eastern Long Island which diverge around Great Peconic Bay. The northern moraine (Harbor Hill) projects offshore at Orient Point and continues past Plum Island and Fishers Island obliquely toward the Connecticut-Rhode Island coast. These elongate islands are separated by overdeepened waterways. The Ronkonkoma Moraine on the southern peninsula extends parallel to the Connecticut mainland east to Montauk Point and then is submerged by the Atlantic Ocean. Eastward continuation of Ronkonkoma Moraine is responsible for most of the relief and steep cliffs of loose soil on Block Island, Martha's Vineyard, and Nantucket located east of Montauk Point and south of Cape Cod, Massachusetts.

The land surface of Long Island exhibits greatest relief on the northern side and gently slopes southward where it intersects the Atlantic Ocean. Shallow brackish-water lagoons and low relief sandy barrier islands with associated dunes are the dominant landforms along most of the southern shore of Long Island. The flat terrain south of the two moraines originated as glacial outwash plains, and is composed of sand and gravel detritus transported south by melt-water streams during Pleistocene time. The back-barrier lagoons and elongate-barrier islands are geologically very recent features which owe their origins to coastal processes operating during the gradual worldwide rise in sea level. The barrier islands are constructional landforms built up over the past several thousand years by sand from the sea floor and by sand transported westward along the Long Island shoreface by wave-generated longshore currents. This chain of sandy barrier islands extends from the western end of Long Island eastward to Southampton (Fig. 2) and is presently broken in continuity by six tidal inlets. Historically, most inlets on the south shore have migrated westward, some very rapidly such as Fire Island and Rockaway, in response to the predominantly westward longshore transport of littoral materials (Taney, 1961). These inlets

are temporal features in a geologic sense; they migrate with time by erosion on their west bank and backfilling on their east bank, or may eventually fill completely. However, new inlets are periodically created when severe storms cause sufficient water overwash to erode breaches in barrier segments.

The coastline from Southampton east to Montauk Point is a headland region where the Ronkonkoma Moraine and associated outwash sediment are directly eroded by wave action. The small bays and estuaries in the moraine east of Southampton are remnant stream channels which breached the Ronkonkoma Moraine during Pleistocene time and were later sealed on the seaward side by littoral sediments.

The northern coast of Long Island bordering Long Island Sound (Fig. 2) is characterized in the western half by 10 recessed narrow bays or estuaries which project southward and terminate at their intersection with the Harbor Hill Moraine. The irregular coastline resulting from these bays is confined to the western half of the north shore of Long Island; the coast along the eastern half is steep and characterized by cliffs where the Harbor Hill Moraine is directly exposed to wave and wind erosion.

The two Peconic Bays and Gardiners Bay (Fig. 2) in east-central Long Island are flat-bottomed, shallow, brackish bodies of water situated in the intermoraine region. They are bounded on the north by the Harbor Hill Moraine and on the south by the Ronkonkoma Moraine. The eastern side of Gardiners Bay is open to Block Island Sound except for the presence of Gardiners Island. East of Gardiners Bay, the sea floor deepens rapidly and is marked by a series of overdeepened northwest-southeast trending sea floor depressions, some at depths of greater than -300 feet (-91.4 meters) mean sea level (MSL).

5. Geologic Setting and Regional Stratigraphy.

Long Island, a glacial-depositional landform located within the Coastal Plain, marks the most southerly advance by Pleistocene continental glaciers in eastern North America. Geologic data from numerous deepwater well borings show that Precambrian or early Paleozoic metamorphic bedrock, composing much of the New England land surface, underlies the entire length of Long Island. These well data indicate the bedrock surface is relatively flat, apparently the result of extensive regional erosion before Cretaceous time, and exhibits a southeast slope of approximately 1 on 55. Information on the physical nature of the bedrock is limited because it is not a usable water aquifer; hence, most water-well bore holes terminate at the bedrock surface. However, some well data show that saprolite (a rock chemically decomposed *in situ*) overlies fresh, high-grade, metamorphic rock of granitic composition. The altitude of the bedrock surface varies from less than 200 feet (61 meters) below sea level on the north shore of Long Island in Queens County to approximately -1,100 feet (-335 meters) MSL at the eastern end of Rockaway Beach (Fig. 3). In east-central Long Island the bedrock surface lies about 2,000 feet (610 meters) below Fire Island beach; in northern Long Island Sound, bedrock directly underlies

Western Long Island showing the bedrock-Coastal Plain framework and an oblique section of a major buried channel. Note the low relief of Long Island except for the Harbor Hill moraine (Soren, 1971).

East-central Long Island showing the low relief bedrock surface and offlapping Cretaceous strata which dip and thicken to the southeast (modified from De Leguna, 1963). See Figure 4, profiles B and C, for detailed shallow stratigraphy of Fire Island.

Figure 3. Transverse sections showing detailed stratigraphy along western and east-central Long Island.

variable thicknesses of glacial deposits or thin overburden of Holocene mud (Fig. 3) (Taney, 1961; Williams, in preparation, 1976).

Reddish-brown sandstones, siltstone and claystones, and extrusive basalts of Triassic-Jurassic age crop out in a broad, north-south oriented, half-graben structure from Massachusetts south through Connecticut to Long Island Sound at New Haven. Because the Triassic province in New Jersey is characterized by a complementary half-graben structure filled with similar reddish-brown clastic rocks, Sanders (1960, 1963) has suggested that Triassic strata are buried under parts of the western Long Island and New Jersey Inner Continental Shelf.

Upper Cretaceous-age semiconsolidated strata overlie the granitic bedrock and dip and thicken to the southeast along the entire length of Long Island. These formations (Table 1) consist primarily of silt, clay, sand, and sandy gravels which were deposited in both marine and nonmarine environments. The oldest unit is the Raritan Formation which is composed of the basal Lloyd Sand Member and the Raritan Clay Member. In Nassau County (western Long Island) the Lloyd Sand ranges in thickness from 60 to 300 feet (18.3 to 91.4 meters) (Suter, De Laguna, and Perlmuter, 1949). The Lloyd Sand consists primarily of thin strata of fine to coarse sand and gravel, and also contains thin noncontinuous lamina of clay and silt. The sand and gravel is generally white, gray, and yellow. Because it is both porous and permeable, the Lloyd Sand is

Table 1. Generalized stratigraphy of Long Island.

Era	Period	Epoch	Unit	Character and origin of deposits
Cenozoic	Quaternary	Holocene (Recent)		Quartzose sand, beach and dune deposits and fine-grained lagoon sediments.
		Pleistocene	Harbor Hill Moraine Ronkonkoma Moraine	Ground and terminal moraine; stratified deposits of sand and gravel, cobbles, and silt and clay.
			20-foot clay	Grayish-green, silty clayey, glauconitic fine sand (marine).
			Gardiners Clay	Grayish-green, silty clay (marine).
			Jameco Gravel Mannetto Gravel	Fine to very coarse sand and gravel; scattered beds of silt and clay (fluvial or glacial outwash).
Mesozoic	Cretaceous	Upper Cretaceous	Monmouth Group Matawan Group Magothy Formation	Quartzose sand interbedded with silt and clay.
			Raritan Formation Raritan Clay	Silty, sandy, brownish-gray clay with thin beds of sand and gravel.
			Lloyd Sand	Quartzose fine to coarse sand and gravel; interbedded clay and silty sand is common.
Precambrian or Paleozoic			Crystalline Bedrock	Undifferentiated, consolidated, metamorphic granite.

an important freshwater aquifer in the Long Island area. The Clay Member directly overlies the Lloyd Sand and is composed primarily of variegated silts and clays. Fragments of lignitic material, pyrite, and iron-oxide nodules are throughout. Deep borings indicate the Clay Member varies in thickness from 30 to 300 feet (9.2 to 91.4 meters), with thicker values in southern Long Island. Because of the physical properties of silt and clay minerals, the Clay Member generally exhibits low permeability and acts as an aquiclude by effectively capping the Lloyd Sand and preventing the interchange of water between the Lloyd Sand and the overlying Magothy Formation. The Clay Member also retards natural freshwater recharging of the Lloyd Sand by reducing downward percolation of ground water, except in northwestern Long Island where glacial processes have eroded the Clay Member and the permeable Harbor Hill Moraine lies directly on the Lloyd Sand.

The Magothy Formation, chiefly a nonmarine deposit, was considered the uppermost Cretaceous unit underlying the Long Island mainland until 1965 (Perlmutter and Todd, 1965). Boring logs reveal its surface is highly irregular and in places gaps exist where the Magothy has been removed by erosion. Removal of Magothy by erosion is especially evident near the buried ancestral stream channels which characterize northwestern parts of Long Island. Lubke (1964) reported that the Magothy exhibits relief of more than 500 feet (152.4 meters) in northern parts of Suffolk County. Magothy strata crop out in places along the north shore; Fuller (1914) reported several locations where the strata exhibit broad folds and small displacement faults as the result of glacial ice pressure. Most of the topographic highs on the Long Island north shore peninsulas correspond in position with the Harbor Hill Moraine, but Magothy material forms the core for many of the high areas. Upper parts of the Magothy Formation are composed of stratified fine to medium quartz sand, with interbedded lenses of clay and silt. Sandy gravel strata are present but they are generally thin and limited in areal extent. The lower part of the Magothy is significantly coarser in texture and marked by a greater abundance of gravelly layers, e.g., the base of the Magothy in many areas consists of thick gravel layers intercalated with fine sands. Because of the nature of this basal zone, it is the most important source of freshwater within the formation.

Examination of the microfauna and mineralogy from sediment from 31 deep cores in southern Suffolk County by Perlmutter and Todd (1965) (Fig. 4) has led to reevaluation of Long Island stratigraphy, and has enabled correlations to be made with similar stratigraphic sequences in New Jersey (Table 2). Perlmutter and Todd (1965) combine the Magothy Formation and the Matawan Group as an undifferentiated unit which they correlate with the Matawan Group of New Jersey studied by Owens and Minard (1960). In upper parts of the post-Raritan Cretaceous deposit, Perlmutter and Todd (1965) identified highly glauconitic marine strata which, based on mineral composition and micropaleontologic content, are correlated with the Monmouth Group of New Jersey. Figure 4 shows Monmouth sediments are apparently limited to the extreme southern coast and offshore shelf of

Figure 4. Geologic cross sections showing detailed stratigraphy along the central Long Island coast (modified from Perlmutter and Todd, 1965).

Table 2. Correlation of stratigraphy from New Jersey and Long Island.

Series	New Jersey ¹		Long Island ²
Upper Cretaceous	Monmouth Group	Tinton Sand Red Bank Sand Navesink Formation Mount Laurel Sand (marine origin, glauconite abundant)	Monmouth Group (undifferentiated) (marine origin, glauconite abundant)
	Matawan Group	Wenonah Formation Marshalltown Formation Englishtown Formation Woodbury Clay Merchantville Formation (marine origin, glauconite abundant)	Matawan Group (undifferentiated) (nonmarine origin, glauconite absent) Magothy Formation
		Magothy Formation (marine and nonmarine origin)	(nonmarine origin, glauconite absent)
		-----Unconformity-----	-----Unconformity-----
		Raritan Formation (nonmarine)	Raritan Formation (nonmarine)
Precambrian, Paleozoic and Mesozoic		-----Unconformity----- Igneous, metamorphic, and sedimentary bedrock	-----Unconformity----- Igneous and metamorphic bedrock

1. After Owens and Minard (1960)

2. After Perlmutter and Todd (1965), Sirkin (1974)

central Long Island; profile C shows that Monmouth strata are absent west of Gilgo Beach and very thin east of Westhampton Beach. To the north they pinch out under Great South Bay.

Recent palynologic analyses by Sirkin (1974) have further defined the Late Cretaceous stratigraphy in southern Long Island. He basically agreed with the work of Perlmutter and Todd (1965), but was able to correlate basal Cretaceous sediments under Fire Island with the South Amboy Fire Clay Member from New Jersey. Liebling and Scherp (1975) used detailed clay mineral analyses to study Cretaceous stratigraphy under Nassau County, New York; Perry, et al. (1975) provided an up-to-date summary of results on pre-Quaternary Coastal Plain stratigraphy in the mid-Atlantic region.

Crosby (1910) and Fuller (1914) applied the name Mannetto Gravel (Table 1) to anomalous gravel deposits in the hills of eastern Nassau

County. Crosby (1910) considered the Mannetto to be of probable Pliocene age, whereas Fuller (1914) thought the deposits were remnants of an early Pleistocene outwash sheet. Suter, De Laguna, and Perlmutter (1949), Swarzenski (1963), and Lubke (1964), either rejected the idea that the Mannetto is of Tertiary age or failed to support either interpretation of the age for this unit because of a lack of definitive evidence.

The Jameco Gravel (Table 1) is considered by many Long Island stratigraphers to be an early Pleistocene deposit. The Jameco underlies the Mannetto Gravel in parts of western Long Island but in other areas where it occurs as stream channel fill the Jameco unconformably overlies the Magothy Formation or older strata. In extreme northwestern Long Island, the Jameco directly overlies metamorphic bedrock. The lithologic character of the Jameco varies considerably over wide areas; its composition is apparently dependent on the nature of its source rock. In western Long Island the Jameco is composed of fresh well-rounded fragments of various igneous and metamorphic rocks with varying amounts of shale and sandstone. However, farther east the principal parent rocks were apparently Cretaceous formations, resulting in less compositional variety (Swarzenski, 1963). Fuller (1914) felt the Jameco Gravel was an outwash deposit resulting from melt-water discharge which accompanied a pre-Wisconsin continental ice sheet which had its ice front north of the Long Island mainland. The Jameco, usually between 100 to 200 feet (30.5 to 61 meters) thick, is found along the northern edge of Long Island or buried in the deep channels which underlie the reentrant bays on the northwestern coast of Long Island (Swarzenski, 1963). Age of the Jameco is still unknown, and the only certainty is that it is pre-Sangamon; however, it is thought to be of Illinoian age.

There is a sharp lithologic break between both the Upper Cretaceous formations and Jameco Gravel and the overlying Gardiners Clay. Present data suggest the Gardiners Clay is of Sangamon age, deposited under a low-energy lagoonal-estuarine environment, possibly similar to present conditions in Great South Bay, Long Island (Weiss, 1954). The Gardiners Clay is characterized by dark gray or green-gray glauconitic silty clay with lenses of sand and gravel. Some of the silt layers contain rich assemblages of foraminifera which may be correlated over a significant area by the microfossil content (Donner, 1964). According to Fuller (1914), the maximum elevation of occurrence for Gardiners Clay, excluding elevation due to ice-pressure deformation, is 50 feet (15.2 meters) below present sea level, which may indicate that sea level was at least 50 feet lower than present in the immediate area before the commencement of Wisconsin glaciation. The thickness and areal continuity of the Gardiners Formation vary greatly; Athearn (1957) identified Gardiners-type material from a deep boring sample, retrieved in connection with site foundation studies for a proposed Air Force Texas Tower, 60 miles (96.5 kilometers) south of Moriches Bay, Long Island. The sample was retrieved 70 feet (21.3 meters) below sea floor (overlain by coarse sand and fine gravel) under a water depth of 185 feet (56.4 meters). Recent studies by Gustavson (1976) suggest that the environment of deposition for the Gardiners Clay was considerably more complex than previously thought.

Perlmutter and Todd (1965) showed that the landward limit of the Gardiners Clay is about 8 miles (12.9 kilometers) north of Fire Island beach (Fig. 2). The thickness of the formation is 10 to 25 feet (3 to 7.6 meters) with a surface elevation of 50 to 100 feet (15.2 to 30.5 meters) below sea level. Further possible extension of the Gardiners Clay and upper Pleistocene-Holocene stratigraphy offshore across the Long Island inner shelf is covered later in this report.

Most investigators of Long Island stratigraphy agree that late Wisconsin glaciation is represented by two prominent ice margin moraines. Both deposits consist primarily of stratified sand, silt, and gravel; however, sediments from lacustrine and fluvial environments are also common (Fleming, 1935). The two moraines are difficult to differentiate in western Long Island because the Ronkonkoma is absent or the Harbor Hill covers it; however, observations from eastern Long Island, where the moraines bifurcate, show that the Harbor Hill Moraine is separate from and younger than the Ronkonkoma Moraine. The land south of these moraines is comprised primarily of outwash sand and gravel which was carried southward over the exposed shelf by the numerous, melt-water fed, braided streams during Pleistocene. The time marking the end of Pleistocene continental glaciation and the start of the Holocene transgression of the sea back over the shelf is variable depending on geographic location and degree of isostatic rebound, but Newman (1966) and Schaffel (1971) felt that an approximate date for commencement of the marine transgression for the western Long Island region is 10 to 12 thousand years Before Present (B.P.).

6. Water Movement and Littoral Drift.

The motion and seasonal circulation patterns of the surface and bottom water masses of the nearshore Long Island region have been studied only to a limited extent. Areas receiving greatest attention are the inner New York Bight (western Long Island) and Long Island Sound. Information for the south shore inner shelf of Long Island is sparse except for estimated longshore transport rates and some water motion and current velocity measurements near the barrier inlets.

Tides for the Long Island south shore region are semidiurnal and range in height from 4.7 feet (1.4 meters) at Rockaway Inlet to 4.2 feet (1.3 meters) at Fire Island Inlet, and 2 feet (0.6 meter) at Montauk Point (Panuzio, 1968). Tidal ranges for the lagoons are generally less than values for the open ocean, averaging 2 feet.

Because Long Island is oriented east-west in the Atlantic Ocean and separated from the New England mainland by 10 to 20 miles (16.1 to 32.2 kilometers), it is most affected by wind-generated waves from the south and southeast. Tidal forces are influential in the Block Island region of eastern Long Island and around the six inlets on the south shore; otherwise tidal effects appear secondary. Wind blowing over the large fetches of open ocean from the southwest and southeast quadrants can produce large waves. According to Panuzio (1968), a statistical study

of deepwater wave heights based on wind-casting techniques, showed that almost three quarters of all deepwater waves approached Long Island from the directions east-northeast through south-southeast. The largest deepwater waves computed from the wind data were from 25 to 30 feet (7.6 to 9.2 meters) in height. These wave heights would be considerably reduced as water depths decreased toward shore; however, the wave period and direction would generally remain the same. It is the constant impingement of waves from the southeast which results in the observed net westward longshore drift of beach sand. Longshore sand transport results when ocean waves intersect the coast at oblique angles. The drift direction and volume of detritus moved vary greatly depending on seasonal weather conditions; the net longshore drift for the south shore of Long Island is predominantly from east to west. The net volume of sand moved is estimated from 300,000 to 600,000 cubic yards (229 to 458×10^3 cubic meters) per year (Taney, 1961; Panuzio, 1968; U.S. Army, Corps of Engineers, 1971). Net littoral drift for eastern Long Island (Shinnecock region) is 300,000 cubic yards (229,000 cubic meters) per year, increases to about 600,000 cubic yards (458,000 cubic meters) at Fire Island, and then drops to 400,000 cubic yards (306,000 cubic meters) per year at Rockaway Inlet on western Long Island (Panuzio, 1968).

II. SHELF GEOMORPHOLOGY, SHALLOW STRUCTURE, AND STRATIGRAPHY

1. Continental Shelf Morphology.

The New York Bight Continental Shelf (Fig. 1) has probably received more scientific study over a longer period than any other sea floor area. Dana (1890) was one of the first to explore the Atlantic shelf in 1863, documenting the existence of both the Hudson and Block (submarine) Channels on the shelf by fairly detailed bathymetric surveys. Based on these surveys, Dana suggested that these channels originated during periods of global glaciation when sea level was depressed several hundred feet and the Hudson and Connecticut Rivers flowed in these channels across the exposed shelf to the canyons at the shelf edge. A complete discussion of the history of research on the Atlantic shelf channels and canyons is provided by Shepard and Dill (1966). Research by Lindenkohl (1885), Gulliver (1899), Alexander (1934), Johnson (1939), Veatch and Smith (1939), Garrison and McMaster (1966), Knott and Hoskins (1968), McKinney and Friedman (1970), Uchupi (1970), Garrison (1970), and McMaster and Asraf (1973) has added significantly to knowledge of the Atlantic shelf morphology, substructure, and geologic history. However, there are still many sea floor features of unknown origin and many features whose origins may be explained by conflicting hypotheses.

The Continental Shelf south of Long Island (Fig. 5) is a gently seaward-sloping plain, about 80 miles (129 kilometers) wide from the coast seaward to the shelf edge (Fig. 1). This shelf is a discrete compartment bound on the west by the deeply incised Hudson (shelf) Channel (Fig. 5) and bound on the east by the broader, but equally prominent Block (shelf) Channel (Fig. 1). There are several other linear depressions on the shelf which also appear to be ancestral drainage channels but these are of

Figure 5. Bathymetric map of the Long Island shelf. The density of finger shoals off Fire Island to Jones Beach is defined by the 60-, 90-, and 120-foot contours. The submerged delta-like protuberances off eastern Long Island are residual sand deltas from ancestral rivers which flowed south during lower sea levels.

second-order magnitude compared to the larger and better defined Hudson and Block Channels. The 60-, 90-, and 120-foot shelf contours (Fig. 5) widen to the southeast and show a pronounced ridge and swale morphologic fabric with a northwest-southeast crestal orientation. These crenulations in the contour lines (ridge and swale morphology) are especially evident shoreward of the 120-foot (36.6 meters) depth contour, whereas seaward they are more widely spaced and more subdued. This bathymetric fabric for the Long Island shelf shows marked contrast in orientation to the ridge and swale morphology on the New Jersey shelf west of the Hudson Channel. The New Jersey shelf fabric is oriented northeast-southwest, almost normal to Long Island fabric. Several authors have expressed different hypotheses explaining the origins of ridge and swale morphology and the contrasting shelf fabrics on either side of the Hudson Channel. McKinney and Friedman (1970) suggested that present shelf topography is relict from Pleistocene subaerial exposure during lowered sea level, and that the ridges and swales are the remainder of an intricate fluvial drainage system. Swift, et al. (1972) and Duane, et al. (1972), attributed this morphology to interaction of relict shelf sediment with modern hydraulic forces on the sea floor. If this were true, then the features are modern in the sense that they are presently being actively modified by sea floor currents. Detailed discussions are provided by Knott and Hoskins (1968), Uchupi (1968), McKinney and Friedman (1970), Swift, et al. (1972), Duane, et al. (1972), and Stubblefield, et al. (1975).

Eastern Long Island contains several flat-bottomed basins (Fig. 5) which exhibit minor relief and resemble ancient lakes. These basins are presently interconnected and filled with brackish water as a result of Holocene submergence. The larger basins lie between the northern Harbor Hill and southern Ronkonkoma Moraines. Great Peconic Bay is the westernmost basin in the area and consists of numerous smaller embayments. Gardiners Bay lies between Orient Point and Gardiners Island, exhibits a flat sea floor to a depth of 60 feet (18.3 meters), and then deepens abruptly on the eastern side. Between Orient Point and Plum Island a northwest-trending steep-sided trough, called "Plum Gut," extends about 150 feet (45.7 meters) deep (Figs. 5 and 6). To the east, another trough exceeds 300 feet (91.4 meters) in water depth and separates Plum Island from Fishers Island. These overdeepened waterways were apparently scoured by late Wisconsin glaciers or fluvial agents. Since the Holocene transgression, the waterways have been swept by high-velocity tidal currents which flow between Block Island and Long Island Sounds, preventing significant sedimentation.

2. Shallow Subbottom Structure and Stratigraphy.

Four different geologic units were found to characterize the shallow subbottom shelf of Long Island on the basis of the seismic records which allow a maximum of about 300 feet of resolution of the sea floor, and sediment descriptions from the cores and borings.

a. Bedrock. The deepest and most obscure unit in the study area is the basement or bedrock surface. Because subsea elevation of the basement

Figure 6. Reduction of seismic line 5 showing cross section of major buried channels J and K which transect eastern Long Island and trend southeast. Dashline is possible contact between bedrock and Cretaceous strata. Detailed stratigraphy in channel K is provided by Orient Point boring (Table 3).

surface often exceeds the limited penetration of the CERC seismic records, observations of bedrock are limited to eastern Long Island in the Gardiners Bay region. The physical character of the bedrock is different from the overlying sediment so the acoustic contrast is easily recognized on the seismic records as darker lines. Samples of bedrock soil were never recovered in any of the cores; however, surface outcrops on the Connecticut mainland to the north and logs from deepwater wells on eastern Long Island confirm that the bedrock is a massive, crystalline, metamorphic rock of granitic composition, which exhibits a regional southeast dip of about 1 on 55. The bedrock surface in eastern Long Island Sound shows considerable local relief which is the result of massive glacial carving within previously existing drainage channels. These conclusions agree with similar evidence of massive local downcutting reported by Grim, Drake, and Heirtzler (1970) for Long Island Sound, and by McMaster and Ashraf (1973) for the inner New England shelf from eastern Long Island to Martha's Vineyard.

b. Coastal Plain Strata. The second geologic unit within the Long Island shelf consists of Coastal Plain sedimentary strata of late Cretaceous or early Tertiary age. These consist of semiconsolidated strata composed of glauconitic sand and gravel, poorly sorted sand, and in some instances, fine sand, silt, and clay. They directly overlie the bedrock surface and according to well boring and seismic data, apparently overlap the basement along an east-west line extending through Long Island Sound (Garrison, 1970) and east past Orient Point and Block Island to Martha's Vineyard (McMaster and Ashraf, 1973). Coastal Plain strata dip and progressively thicken to the southeast: under Rockaway Beach the strata are almost 1,000 feet (305 meters) thick; under Fire Island Beach (Fig. 3), about 1,800 feet thick (549 meters); and under Montauk, nearly 800 feet (244 meters) thick (McMaster and Ashraf, 1973). Because the seismic records used in this study are limited in depth resolution to about 300 feet (91.4 meters), Gardiners Bay is the only area where Coastal Plain strata in contact with underlying bedrock may be seen on the records (Fig. 6).

Lithologic variation within the Coastal Plain stratigraphic sequence is limited; therefore, there is little acoustic contrast between strata. Consequently, mappable Coastal Plain reflectors from the seismic records are difficult to identify. However, the reflectors show a low angle, monoclinical, southeast dip with no apparent breaks or dislocations resulting from faulting or slumping, or any evidence of ice-shove deformation. The only structural deformation evident on any of the seismic records is shown in Figure 7. The reflectors on line F show that Coastal Plain strata have been folded into a single asymmetric anticline and subsequently truncated by erosion at the sea floor. The strike of the anticline is oriented generally north-south and the folding with depth is apparently symmetrical to at least -200 feet (-61 meters) MSL, the maximum depth of record resolution. Strata at the crest of the anticline and along the eastern flank crop out on the sea floor and form an erosional cuesta. To the west, closer to the Hudson Channel, the erosion surface on Coastal Plain strata is covered by about 50 feet

Figure 7. Reduction of seismic line F (Fig. 2) shows both an asymmetric anticline involving Late Cretaceous or Tertiary strata and an ancestral river channel. The truncated cuesta of Coastal Plain strata extends northeast from Long Branch, New Jersey to Fire Island, and probably continues under the Long Island mainland.

(15.2 meters) of Quaternary sediments. Because this anticlinal structure is close to strike alignment with the Tertiary-Cretaceous formational contact on New Jersey, and also with the position of the Shrewsbury Rocks shoals off the New Jersey coast (suggested by Williams and Duane (1974) as areas where Coastal Plain strata crop out on the sea floor), the anticline in Figure 7 is thought to be either proximal to the contact or a flexure involving Monmouth Group strata or Tertiary strata. The structural condition shown on the right side of Figure 7 where Coastal Plain strata have been evenly truncated at the sea floor and thinly covered by loose residual detritus, and on the left side of the figure where the Coastal Plain erosion surface is more deeply buried beneath variable thicknesses of Quaternary sediment, seems characteristic of the general subbottom structure for much of the Long Island inner shelf. Acoustic reflectors on the seismic records and presence of the diagnostic mineral glauconite in many of the cores suggest the northern limit of the erosional cuesta of Coastal Plain strata cropping out on the sea floor extends from the northern New Jersey shoreface at Shrewsbury River, offshore in a north-east direction and apparently intersects the Long Island coast near Fire Island. The cuesta underlies the Long Island mainland and McMaster and Ashraf (1973) showed that the cuesta continues eastward from Plum Island across Block Island and Rhode Island Sounds toward Cape Cod. The Coastal Plain erosion surface landward of the cuesta has been scoured in some areas to several hundred feet below sea level and subsequently covered by younger sediments averaging 50 feet (15.2 meters) in thickness except for the ancestral river channels where sediment fill is sometimes greater than 300 feet (91.4 meters) thick.

c. Pleistocene Sediments. Examination and study of the 41 offshore Nassau and Suffolk County sewer outfall cores (Fig. 8) have provided the means of extending Long Island stratigraphy from the mainland across the Long Island shoreface and inner shelf. These cores, located along three nearly shore-normal transects seaward to -108 feet (-33 meters) MSL, show the sea floor consists of gray and tan, fine to medium, clean quartzose sand and gravel, overlying similar sand and dark gray clay and silt. Glauconite is a relatively common mineral in many of the cores both at the surface and with depth which suggests that either the Gardiners Clay Formation or the Monmouth Group, the only two highly glauconitic units in the Long Island Coastal Plain sequence, is present in the shallow sub-bottom. The 15 cores along the Nassau County transect (Fig. 9) extend about 2.5 miles (4 kilometers) offshore from Tobay Beach and several contain 15 to 20 feet (4.6 to 6 meters) of late Pleistocene and Holocene silt-clay and sand sediments overlying a clay-silt surface at -66 feet (-20 meters) MSL which correlates in elevation and stratigraphy with the Gardiners Clay (Fig. 4, profile A-A'). Cores 241, 249, and 251 appear to have penetrated the Gardiners (average thickness 10 feet or 3 meters) and continued into underlying Upper Cretaceous strata of the highly glauconitic Monmouth Group, or Pleistocene sediments derived from the Monmouth. The 26 cores along the two Suffolk County sewer outfall transects (Fig. 9) show a similar stratigraphic sequence as the Nassau County cores, except the Gardiners Clay is apparently thicker and its surface is lower in elevation indicating a slope or dip to the east. The Suffolk County west core

Figure 8. Forty-one vibrocore locations across the shoreface-inner shelf zone were used to delineate subbottom stratigraphy, and to define Late Pleistocene-Holocene geologic history. Visual logs are shown in Figure 9 and sediment descriptions are in Appendix A.

Figure 9. Major lithologies comprising the inner shelf from the shore seaward to the -70-foot depth contour. Core locations are shown in Figure 8. Proposed contact between Pleistocene deposits and Gardiners Clay Formation slopes east and varies from about -66 to -82 feet. All depths are in feet below mean sea level.

transect (Fig. 9) contains 15 cores which extend a maximum of 108 feet (33 meters) below sea level. Seaward of core V-3, the Pleistocene-Holocene sequence is about 20 feet (6.1 meters) thick and the Gardiners surface is at -76 feet (-23.2 meters) MSL. None of the cores appear to penetrate Monmouth strata. The east transect (Fig. 9) contains 11 shorter cores which extend a maximum of 94 feet (28.7 meters) below sea level. Most of the cores show marked variations in sediment types and all but the three inshore cores contain abundant glauconite, suggesting sediment derivation from underlying Monmouth strata. The top of the Gardiners Formation along this line is placed at -82 feet (-25 meters) MSL from cores V-22, V-23, and V-24. Rampino's (1973) study of the landward continuation of these borings revealed basically the same stratigraphy reported here except that he found evidence of a clay-silt stratum (Wantagh Formation) between glacial outwash sands and overlying the Gardiners Clay. He attributed this stratum to an interglacial period of high sea level. His interpretation is supported by U.S. Geological Survey (USGS) investigation of Pleistocene-Holocene stratigraphy in the mid-Atlantic region.

Seismic data and some CERC cores indicate that the shelf geology from Fire Island Inlet east to Shinnecock Inlet is similar in structure and stratigraphy to that described above; i.e., Upper Cretaceous strata of the Monmouth-Matawan Group exhibit some deformation and a truncated upper surface. These strata are overlain by the Gardiners Clay and a relatively thin overburden of late Pleistocene interglacial silts and sand and gravel outwash detritus. Holocene back-barrier estuarine muds and marine sands are also present. Exceptions to this geologic framework are shelf areas where ancestral river channels have deeply eroded the Coastal Plain surface and subsequently been filled with outwash sand and gravel. From Shinnecock Inlet eastward to Montauk Point the Coastal Plain surface becomes progressively deeper and covered by thicker Quaternary sediments, analogous to the western Long Island shelf. The Coastal Plain surface is more deeply eroded under the eastern Long Island shelf than in the central Long Island shelf region for the same reasons that apply to the western Long Island inner New York Bight shelf. Eight major north-south river channels dissect the eastern mainland and shelf of Long Island and at least six are present in western Long Island. This contrasts with the central Long Island region where only two ancestral channels are identified. These channels are discussed later, but basically the higher density of buried river channels found in western and eastern Long Island provides explanation for the deeply eroded Coastal Plain surface and for thicker accumulations of Pleistocene sediments.

Pleistocene sediments were found to vary considerably in thickness and lithology in the Long Island region. Because of similar lithologies with both overlying Holocene sediments and underlying Cretaceous strata, it is often difficult to accurately identify upper and lower Pleistocene contacts from the seismic records or from the sediments in the cores. Thus, the regional extent and abundance of definite Pleistocene sediments are uncertain. The most definitive evidence for the Cretaceous-Pleistocene contact is an undulatory dark line on the seismic records directly overlying southeast-dipping flat reflectors. Presence of

abundant glauconite (black grains) in some of the cores also provides some insight into locating the base of Pleistocene deposits. Evidence for identifying the Pleistocene-Holocene contact is based on core data, except in certain areas where the seismic records show the Pleistocene surface is irregular or the contact is acoustically different from overlying Holocene materials. Sediments at the Pleistocene surface are generally oxidized medium to coarse sand with varying amounts of gravel and may show some degree of compaction. Pleistocene units generally appear stratified and either flat lying or with a low-angle seaward dip. Pleistocene sediments along the Long Island south shore inner shelf vary considerably in thickness depending on both proximity to source and the relief of the pre-Pleistocene surface. However, the sediment descriptions from the cores show the predominant sediments presently covering the shelf are relict or palimpsest Pleistocene-age sand and gravel, spread across the shelf in the form of outwash plains south of the Ronkonkoma and Harbor Hill Moraines and river deltas. During Pleistocene time when sea level was depressed several hundred feet, several southward-flowing melt-water rivers were the primary agents in eroding, transporting, and spreading outwash detritus south of the Long Island ice margin moraines. As the glaciers melted and sea level rose to its present position, the moraines on the Long Island and New England inner shelves were greatly influenced by direct action from waves and marine processes of erosion and deposition. The interaction of direct marine erosion on morainal materials is still evident at Montauk Point on eastern Long Island and on Block Island, Nantucket, and Martha's Vineyard. The sand fraction of the morainal cliff material eroded at Montauk Point is thought to be a major source of littoral material for the Long Island longshore transport system (Taney, 1961; Panuzio, 1968).

Maximum thicknesses of Pleistocene sediment occur in the buried ancestral river channels which, at least on the northern parts of Long Island, were occupied and scoured directly by glaciers. These same channels later acted as conduits for melt-water runoff. The nature, distribution, and ages of these channels are discussed later. The nature of the Pleistocene sediment in many of the channels is unknown; however, several cores which penetrate the channels along the eastern Long Island south shore (Fig. 10) indicate that the upper part of the fill is composed of fine to medium sand with rounded pebbles. Additional information on deeper stratigraphy in a channel in eastern Long Island is provided by the log for the 240-foot (73.2 meters) boring at Orient Point (Table 3). The boring, made for an engineering study for a proposed bridge, is on the extreme northeast prong of Long Island (Fig. 2) and was drilled fortuitously into the Orient Point buried channel which bisects Long Island and Plum Island (Fig. 6). The descriptive log in Table 3 shows the top 41 feet (12.5 meters) is typical Pleistocene outwash or moraine-derived sand and gravel which is yellowish brown and poorly sorted. The remainder of the boring log indicates a general fining downward with typical varve sequences (proglacial lacustrine seasonal deposits) present from 146 feet (44.5 meters) to the bottom of the hole at 240 feet (73.2 meters) (Fig. 11). Figure 6 shows the Orient Point channel thalweg depth exceeds -500 feet (-152.4 meters) MSL but record resolution makes it impossible to tell whether the varve sequence in Table 3

Reduction of seismic line 18 (Fig. 2) exhibiting the eroded Coastal Plain surface at -150 feet (-46 meters) MSL and the broad Three Mile buried channel which is traceable northward into Long Island Sound. The three cores indicate the channel fill is clean, fine to medium, quartzose sand.

Reduction of seismic line 14 (Fig. 2) showing three buried channels which transect the southern fork of Long Island. The sand waves off Montauk Point have amplitudes of 20 feet (6 meters) and probably originate from high-velocity tidal currents. The four cores show the subbottom is composed of a mixture of fine to coarse, sand and gravel. Shading identifies Quaternary sediments.

Figure 10. Geologic profiles of seismic reflection lines 14 and 18.

ORIENT POINT
SAMPLE: 17
DEPTH: 60'-162'

ORIENT POINT
SAMPLE: 19
DEPTH: 170'-172'

ORIENT POINT
SAMPLE: 20
DEPTH: 178'-180'

ORIENT POINT
SAMPLE: 22
DEPTH: 188'-190'

Figure 11. Photos of apparent varve sediments retrieved in the Orient Point boring (described in Table 3) drilled into the Orient Point buried channel. These suggest a major glacial lake occupied the Long Island Sound-Block Island Sound region during Pleistocene time. Each pair of light and dark lines represents a summer and winter episode of lacustrine deposition.

ORIENT POINT
SAMPLE: 25
DEPTH: 208'-210'

ORIENT POINT
SAMPLE: 26
DEPTH: 218'-220'

ORIENT POINT
SAMPLE: 27
DEPTH: 228'-230'

Figure 11. Photos of apparent varve sediments retrieved in the Orient Point boring drilled into the Orient Point buried channel.—Continued

Table 3. Log of the Orient Point, Long Island boring.¹

Boring interval ² (feet)	Description
0 to 41	Medium dense to dense, yellow-brown sandy gravel. Poorly sorted. Individual sand grains are angular to subangular and gravel materials are rounded to subrounded.
41 to 146	Very dense micaceous, silty, fine sand becoming finer with depth grading into a micaceous, fine sandy silt at -70 feet.
146 to 240	Very stiff, brown silty clay interfingered with layers of clayey silt and occasional fine sand partings. The upper part consists of equal amounts of clay and silt in 1/8- to 1/2-inch layer thicknesses. Lower part contains more clay layers than silt and is up to 2 inches thick. Mass property tests indicate that these clays have been preconsolidated in the past under loads greater than presently exist.

1. Data from Woodward-Clyde-Sherard and Associates (1965). (See Figure 2 for location.)

2. Surface elevation at boring is approximately +20 feet (Mr. Henry Miller, Alpine Geophysical Associates, Incorporated, personal communication, 1973).

continues to the channel floor or whether the varves overlie Coastal Plain strata or older glacial materials. Existence of varve deposits at the Orient Point location is consistent with other occurrences of fine-grain sands and muds in CERC cores from the Gardiners Bay-Napeague Harbor-Peconic Bay region of eastern Long Island. Such a broad occurrence of these sediments supports the hypothesis that a large freshwater lake occupied this region during Pleistocene time. Frankel and Thomas (1966) found evidence of lacustrine sediments in the Fishers Island region east of Long Island which appear to correlate with the lake deposits reported here and by Coch (1974). Varve strata in the Orient Point Channel (Fig. 6) show some evidence of deformation but no scour on the seismic records is evident. Therefore, the lake must have postdated the glacial advance responsible for the Ronkonkoma Moraine. Since this moraine is thought to be of Wisconsin age by most workers, the lacustrine phase is inferred to be late Wisconsin in age intermediate between times of the Ronkonkoma advance and the Harbor Hill advance.

d. Holocene Sediments. The fourth stratigraphic unit recognizable from the cores and geophysical records is Holocene sediment. Definitive recognition of these materials is difficult because they closely resemble, and many times are derived from underlying Pleistocene or Cretaceous-Tertiary strata. Holocene stratigraphy is best identified on the seismic records when the acoustic returns are good quality and the records show a complete sequence of southeast-dipping Coastal Plain strata, overlain by flat-lying or slightly dipping Pleistocene strata, which often exhibit an irregular upper surface, and then thin evenly bedded Holocene strata on top. The most definitive proof for the presence of Holocene sediments is the radiometric carbon-14 (C^{14}) dates for cores 39, 67, and 73 off Fire Island and cores 1, 2, and 14 in the Gardiners Bay-Napeague Harbor area of eastern Long Island. The thickness and distribution of Holocene sediment vary considerably depending on present and past environmental history and sea floor morphology. CERC cores indicate that Holocene sediments are most abundant (or most easily recognized) in the shelf region between Fire Island Inlet and Shinnecock Inlet. Many cores in that shelf area exhibit

typical back barrier-beach sedimentary sequences where modern marine sands overlie compact, organic-rich muds. Figure 12 shows the typical areal and vertical variation of the major Holocene sediment types for the shoreline from Fire Island east to Montauk Point. These same sediment sequences in the cores offshore indicate that barrier-spit complexes existed offshore in the past, the same as they do today for that area, and that as sea level rose the barriers moved toward the mainland. Thickness of the Holocene sediments along this segment of the south shore is difficult to determine; several cores show an excess of 10 feet (3 meters) with a general decrease in thickness offshore.

Eastern Long Island between Orient Point and Montauk Point is the second area where Holocene sediments (confirmed by C^{14} dates) were retrieved in cores. In many places, possible estuarine or lake sediments are exposed on the sea floor or covered by several feet of medium to coarse, reddish-brown sand.

3. Major Surface and Buried Paleodrainage Channels.

Locating, identifying, and tracing ancestral stream and river channels and flood plain erosion surfaces have been of considerable interest to geomorphologists, geologists, and foundation and mining engineers for many years. Such channels are elongated geomorphic depressions resulting from normal fluvial and glacial erosional and depositional processes. The channels may be exposed at the land surface or be buried under thick overburden composed of more recent sediments. If the channels are buried, present land surface morphology may provide only subtle clues to their existence. Until the last few decades, study of fluvial channels on land was limited to areas with natural exposures and the use of bore holes. The possibility of submerged channels existing on the continental shelves was surmised but remained unproven until Lindenkohl (1885) discovered the morphologically expressed Hudson (submarine) Channel seaward of New York Bay during a 1842-44 hydrographic survey. The significance of this discovery was first described in 1863 in professional literature by Dana, 1890. Dana was apparently one of the first scientists to hypothesize that the Hudson submarine channel represented a conduit through which the Hudson River flowed in earlier geologic times when sea level was significantly lower and the shelves were dry land. This astute observation provided the stimulus for other researchers to initiate detailed surveys of the Atlantic shelf to examine the Hudson and other channel-canyon systems found to cut the shelf. Later development of sophisticated echo sounders and navigation equipment was instrumental in providing data for compiling accurate physiographic maps of the shelf surface. Detailed information on various features of the Atlantic shelf was presented by Veatch and Smith (1939) and Smith (1939); a very interesting history of exploration was summarized by Stearns (1969). The technological development of high-power continuous seismic reflection equipment was important in allowing researchers to examine and map the shelves and accompanying submarine channels in the third (vertical) dimension. This equipment showed completely buried fluvial channels were present where no hint was suggested by sea floor topography, and for the first time submarine channels on the

Figure 12. Visual logs for 21 borings on the Atlantic coast showing typical stratigraphic sequences of littoral sands and lagoonal muds. The lack of stratigraphic continuity between borings suggests a varied and complex geologic history for the south shore coast. Sediment descriptions are given in Appendix A (Taney, 1961).

shelves (both buried and not buried) were shown to be identical in relief, profile, and cross section to channel features on land. These observations proved that the channels were formed by fluvial processes. Results of these studies using seismic equipment are covered by Ewing, Pichon, and Ewing (1963), Knott and Hoskins (1968), Garrison (1970), and Uchupi (1970). Use of sophisticated high-resolution seismic reflection equipment enabled Grim, Drake, and Heirtzler (1970) to accurately map and delineate the intricate drainage channel network in Long Island Sound; McMaster and Ashraf (1973) provided valuable information on the paleodrainage configuration on the southern New England inner shelf; and Williams and Duane (1974) showed that a buried channel 300 feet (91.4 meters) in depth underlies the geomorphic sea floor expression of the Hudson Channel seaward of New York Lower Bay. Williams (1975) showed that ocean dumping of assorted wastes has filled and significantly modified the Hudson Channel since about 1890.

The seismic records from the south shore and eastern shelf of Long Island show that a more intricate system of major ancestral drainage channels is present than is suggested by the sea floor morphology. Figure 13 shows the channels generally trend northwest-southeast and on the records they exhibit considerable differences in width, depth, and profile form. In the figure, each channel is designated a letter for easy reference in this discussion. In several instances, channels identified on the Atlantic shelf were traced by projection, similarity of profile, and thalweg depth to buried channels reported on the Long Island mainland in various professional papers.

The most westerly buried channel A (Fig. 13) is the ancestral Raritan Channel first reported by MacClintock and Richards (1936) from examination of test borings taken along a north-south proposed bridge line connecting northern New Jersey to Staten Island. Raritan Channel is about 1 mile (1.6 kilometers) wide, cut 170 feet (52 meters) into the Upper Cretaceous-age Raritan Formation, and filled almost level to the present bay floor by fine-grained estuarine sediments. The channel was probably primarily excavated by Pleistocene melt-water runoff from upland glaciers and possibly secondarily eroded by isolated glacial ice lobes which reached south of the main ice front. Subsequently, the channel was filled by lacustrine deposits from Lakes Passaic or Hackensack which occupied the area west of present-day Raritan Bay (MacClintock and Richards, 1936) and by Holocene estuarine deposits as sea level rose. Williams and Duane (1974) reported an elongate buried basin, with the sediment fill characterized by large-scale and very complex cross-stratification, immediately east of Sandy Hook spit. The basin is oriented north-south, measures about 2 miles (3.2 kilometers) wide and 5 miles (8 kilometers) long, and is cut about 120 feet (36.6 meters) into Cretaceous strata. The crossbed strata filling the basin are composed primarily of fine to very coarse sand and pea gravel. Williams and Duane (1974) suggested this buried basin is a complex of two or more major channel networks, possibly the confluence of the ancestral Hudson and Raritan Rivers. If this interpretation is correct, then the Raritan Channel underlies the length of Raritan Bay and is covered by Sandy Hook spit, which has accreted due to littoral processes northward during Holocene time.

Figure 13. Network of major buried channels transecting subbottom Long Island inferred from water well borings on land and from seismic records and vibratory cores on the shelf. Overdeepening of channels under the north shore reentrant bays is due to glacial ice scour. Position of the Coastal Plain cuesta corresponds to the positive sea floor relief of Shrewsbury rocks in New Jersey (Williams and Duane, 1974) and is traceable on seismic records and cores northeast to the Fire Island region.

Channel B, projecting southeast from the present Hudson estuary through the Verrazano Narrows (between Brooklyn and Staten Island) and onto the inner shelf, owes its origin to late Pleistocene glacial and fluvial erosion by the Hudson River. According to Lovegreen (1974), the channel at the Verrazano Narrows is about 1 mile wide and is cut to a depth of -330 feet (-100.6 meters) MSL into Paleozoic bedrock. Worzel and Drake (1959) studied subsurface data and found the base of the Hudson Channel was at -725 feet (-221 meters) MSL at Tarrytown, New York. Williams and Duane (1974) reported seismic profile evidence of a probable extension of the same buried channel with a thalweg depth of -300 feet (-91.4 meters) MSL underlying the topographically expressed Hudson Shelf Channel about 8 miles (12.9 kilometers) east of Sandy Hook (Fig. 13). They ascribe its origin in late Pleistocene time to scour by isolated ice lobes, rapid but massive erosion by glacial lake debouchment and fluvial erosion by the melt water enlarged Hudson River.

Buried channel C, east of the Hudson Channel (Fig. 13), underlies Coney Island and was recognized on only one seismic profile of marginal quality. Exact channel orientation is difficult to determine, but it is apparently north-south; the channel floor is cut into Cretaceous strata to a depth of at least -275 feet (-84 meters) MSL. Position and dimensions indicate the channel may be an older course of the Hudson River.

Presence of channel D (Fig. 13) has been determined from evidence contained on subsurface ground water maps of Queens County, Long Island, compiled by Soren (1971). Channel D appears on the western part of Figure 14 as a broad depression, more than 2 miles (3.2 kilometers) wide, a maximum depth of -250 feet (-76 meters) MSL, and cut into the Raritan Clay (Cretaceous age). The channel has been filled with Jameco Gravel and Gardiners Clay. Projection of the channel southeast under Jamaica Bay and the eastern end of Rockaway Beach is based on evidence shown in Figure 3 where the Coastal Plain surface slopes seaward under far Rockaway Beach more than -200 feet (-61 meters) MSL. Projection of channel D northward indicates it underlies the small reentrant estuary immediately west of Flushing Bay on the Long Island north shore (Fig. 13). The superpositional relationship of ancestral buried channels under reentrant estuaries seems characteristic of most buried channels crossing central and western Long Island.

Channel E (Fig. 13), underlies Flushing Bay, and is described by Soren (1971); the profile and cross section (Figs. 3 and 14) indicate it trends southeast. Channel E (Fig. 14) is about 1.5 miles (2.4 kilometers) wide, reaches a maximum depth of about -450 feet (-137 meters) MSL, and exhibits a broad U-shaped cross section for the upper 175 feet (53.3 meters) and a steeper incised cross section for the lower 275 feet (84 meters). These differences in channel shape suggest that the upper part was eroded by Pleistocene glacial ice during glacial advance stages responsible for the Harbor Hill and Ronkonkoma Moraines. Based on the presence of Jameco Gravel on the bottom of the channel, Soren (1971) suggested the channel was initially eroded by fluvial processes in Cretaceous or early Pleistocene time and enlarged and deepened by ice scour during one or more phases of Pleistocene glacial advance. These same observations and attendant

Two major north-south channels cut into Cretaceous strata and filled and covered with Pleistocene sediment. The Flushing Bay channel shows evidence of both fluvial erosion and subsequent widening due to glacial scour (modified from Soren, 1971).

Reduction of seismic line RR (Fig. 2) depicting two major buried channels and the westward deepening of the Coastal Plain erosion surface. Nassau County cores are described in Appendix A.

Figure 14. Geologic profiles from the Long Island mainland and shelf showing the three major ancestral channels and a regional erosion surface.

conclusions were made by McMaster and Ashraf (1973) from their studies of buried drainage channels on the New England shelf east of Long Island. The Flushing Bay channel E (Fig. 13) projects southeast, crosses the Long Island coast at the west end of Long Beach, and continues its southeast trend across the inner shelf. The lower part of Figure 14 shows channel E cross section from reduced seismic profile line RR located about 5 miles (8 kilometers) off the coast; the limited record penetration prohibits knowing the exact channel depth but it probably exceeds -350 feet (-106.7 meters) MSL. The eastern channel wall is relatively steep and clearly defined; the absence of any confining channel wall on the west indicates that fluvial erosion was more pervasive there. Nearly the entire inner New York Bight landward of the Coastal Plain cuesta (Fig. 13) exhibits evidence that the Coastal Plain surface was eroded 100 to 300 feet (30.5 to 91.4 meters) below sea level and subsequently covered by Pleistocene outwash sand and gravel. This same geologic condition is shown on the seismic profile reduction (Fig. 7) located about 10 miles (16.1 kilometers) offshore, close to the cuesta.

Ground water studies by Swarzenski (1963) showed that channel F consists of several adjacent channels separated by topographic highs of the Cretaceous-age Magothy Formation. The relationship of these channels to the subbottom geology is shown in the top part of Figure 15. The channel underlying Little Neck Bay (Fig. 13) is about 1.5 miles (2.4 kilometers) wide, 200 feet (61 meters) deep, and filled with Jameco Gravel, Gardiners Clay, and Wisconsin-age moraine material. Swarzenski (1963) showed (Fig. 15) that three secondary channels in the Manhasset Bay area were about 160 feet (49 meters) deep and one-half mile (0.8 kilometer) wide. Because of the proximity of the channels it is likely the channels coalesced farther south and eroded the broad, low relief, 280-foot-deep (85.3 meters) channel to the east (channel F in Fig. 14).

The 260-foot-deep (79.3 meters) channel G underlying Hempstead Harbor (Fig. 13) was discussed by Swarzenski (1963) and is shown in cross section in Figure 15. The southern projection of this channel underlies the western end of Jones Beach and lies east of seismic line RR (Fig. 14). However, an inshore seismic line about 5 miles (8 kilometers) from shore (Fig. 2) shows some acoustic signals at -275 feet (-84 meters) MSL which may be the channel floor.

The Huntington and Centerport channels H crossing northern Long Island were discussed in a ground water paper by Lubke (1964). These channels (cross-sectioned in Fig. 15), underlie the reentrant harbors in Huntington Bay on the Long Island north shore. The Huntington buried channel, one of the largest drainage channels underlying the Long Island terrain, is a maximum of 3.3 miles (5.3 kilometers) wide, exhibits a symmetrical cross section, and the thalweg extends to a depth of -475 feet (-144.8 meters) MSL. The Centerport buried channel (Fig. 15) has an asymmetric shape and is separated from the Huntington channel by a topographic high composed of apparent Magothy strata. It is a minimum of 1.5 miles (2.4 kilometers) wide and extends to -100 feet (-30.5 meters) MSL. The southward projection of these two channels (Fig. 13) is based on seismic profile evidence of

Channel cross sections along the Long Island north shore. Note that surface topography is due to relief of a combination of Pleistocene Moraine deposits and Magothy strata (modified from Swarzenski, 1963).

Cross sections of a major and minor buried channel (Fig. 13) through the Magothy Formation and into the Raritan Clay (modified from Lubke, 1964).

Figure 15. Subbottom profiles of major buried channels on northern Long Island.

an apparent major channel almost 10 miles (16.1 kilometers) offshore Fire Island. This possible Huntington channel extension is shown to the west in Figure 16 as a broad depression a minimum of 275 feet (84 meters) deep (the maximum energy penetration for seismic line V). Evidence that channel H crosses central Fire Island is also supported by channellike depressions in the Cretaceous surface shown in Figure 4, profile C.

Channel I in central Long Island (Fig. 13) is based on analyses of seismic reflection and magnetic data by Grim, Drake, and Heirtzler (1970) in Long Island Sound; Figure 12 in their study shows that a channel cut into the pre-Tertiary surface north of Smithtown Bay exceeds 700 feet (213.4 meters) in depth and appears to project southeast and decrease in depth as the channel approaches the Long Island north shore. The over-deepening of many of the channels north of the Harbor Hill Moraine is attributed to repeated ice scour by Pleistocene glaciers. Channel I is comparable in depth to the former Hudson fjord at Tarrytown, New York, which was scoured by glacial ice to -725 feet (-221 meters) MSL (Worzel and Drake, 1959). The more shallow continuation of channel I across Long Island to the coast (Fig. 13) is based on seismic evidence of a 205-foot (62.5 meters) channel 3 miles seaward of Moriches Inlet, and also by channellike depressions in Cretaceous strata in Figure 4, profile C. The channel has an apparent reversed gradient because glacial scour was limited to the north shore.

A 40-mile-wide (64.4 kilometers) area (Fig. 13) in east-central Long Island (73°20'W. to about 72°40'W.) has no major buried channels crossing either the Long Island mainland or the Atlantic inner shelf. This lack of channeling is explained by Grim, Drake, and Heirtzler (1970) in a contour map of the pre-Tertiary surface under Long Island Sound which shows a steep-sided east-west oriented buried channel reaching depths of -800 feet (-244 meters) MSL north of this nonchanneled area. They commented on the lack of continuity of pre-Tertiary contours between mainland Long Island and the Sound in this area. Apparently, this deep east-west channel in the Sound was a major drainage system before Pleistocene glaciation and it effectively intersected any streams flowing south from New England across the Sound and diverted their discharges east toward Block Island Sound. Then, with the advent of continental glaciation, the channel was overdeepened by ice scour as the main glacier body impinged on the Long Island north shore. The position and orientation of this channel would suggest that it was controlled by the Coastal Plain cuesta.

The eastern Long Island shelf subbottom is extensively channeled (Fig. 13). Two primary buried channels (J and K) appear to trend south-southeast from Long Island Sound and have thalweg depths exceeding -500 feet (-152.4 meters) MSL. These channels lie on the western margin of the complex of buried channels shown by McMaster and Ashraf (1973) to underlie the southern New England shelf. Cross sections in Figure 6 of the Three Mile (J) and Orient Point (K) channels show they are cut into bedrock and Coastal Plain strata and are filled with horizontal or slightly undulatory more recent sedimentary strata. Clues to the vertical

Figure 16. Reduction of seismic line V showing a major buried channel on the west and two linear shoals to the east underlain by a featureless nearly horizontal reflector. Logs for CERC cores are given in Appendix A; shading identifies Quaternary sediments.

lithology and history of filling for the Orient Point Channel are provided by a 240-foot (73.2 meters) foundation boring (Figs. 2 and 6) at the tip of Orient Point which penetrated the western part of channel K. The descriptive log (Table 3) shows that the channel fill lithology consists of three major groupings down to -220 feet (-68 meters) MSL. The top 41 feet (12.5 meters) is fairly dense, poorly sorted sandy gravel, which is either outwash detritus from the Harbor Hill Moraine (late Wisconsin age) or actual parent moraine material. From 41 feet (12.5 meters) down to 146 feet (44.5 meters) the sediment is compact, micaceous, silty, fine sand which becomes finer with depth. Below 146 feet to the bottom of the boring, the material has the appearance of glacial lake varves consisting of alternating layers of light and dark clayey silt and fine sand (Fig. 11). The compact nature of these materials suggests that they were under greater consolidation pressures in the past than in the present, which may be the result of ice loading or subjection to subaerial exposure. The remaining 300 feet (91.4 meters) of sediments in the channel from the end of the boring to the channel bottom may be a continuation of the varve deposits, or possibly glacial sediment or remnants of Cretaceous or Tertiary strata. Presence of lake sediments in the Orient Point Channel is consistent with occurrences of lake deposits from Long Island Sound, and the Fishers Island region of Block Island Sound as discussed before. These widespread occurrences support suggestions that large freshwater lakes periodically occupied this region. The age and regional extent of the lake deposits are difficult to determine because of gross lithological similarities between Holocene estuarine deposits and the Gardiners Clay (also widespread but Sangamon in age and of marine origin). A detailed study of the lithologies and paleontologic contents of the various units is needed before accurate stratigraphic correlations can be made. Three Mile Channel (Fig. 6) is west of the Orient Point Channel and separated from it by a pinnacle of Cretaceous rock which projects within 90 feet (27.4 meters) of the sea floor. The depth of channel J exceeds -500 feet (-152.4 meters) MSL and the sediment filling the channel is inclined westward and probably similar in sediment character to the description in Table 3 for the Orient Point Channel. Channels J and K bifurcate to the south into seven smaller distributary channels which breached the southern leg of Long Island and continued onto the shelf where they probably intersected the Block Channel. The southward continuation of Three Mile Channel is -225 feet (-68.6 meters) deep (MSL) immediately north of Three Mile Harbor; it is cut to -195 feet (-59.4 meters) MSL and over 3 miles (4.8 kilometers) wide on the south shore shelf (Fig. 10). This anomalous northward channel thalweg gradient is apparently due to over-deepening on the north by glacial scour. Three Mile Harbor is an estuary resulting from submergence of the incompletely filled remnant channel depression by the sea. Expression of many of these channels as present-day lakes and estuaries is common for the eastern part of Long Island, and is the same for the northwest coast of Long Island where the large embayed estuaries superpose nearly buried channels.

Three channels on the shelf south of the Montauk area of eastern Long Island are shown in Figure 10. The two westernmost channels are fairly steep-sided, compared to other channels also cut into Cretaceous material,

and exhibit thalweg depths of -155 and -185 feet (-47.2 and -56.4 meters) MSL. The broad channel to the east has a thalweg depth of -120 feet (-36.6 meters) MSL and seems to either intersect or underlie the Ronkonkoma Moraine at Montauk Point. Cores 16, 18, 19, and 21 in Figure 10 show that upper parts of the channels are filled with fine to coarse sand and pebbles. This sediment composition contrasts with onshore borings 1 and 2 in the Montauk Harbor area (a submerged remnant channel depression) which exhibit 25 to 30 feet (7.6 to 9.2 meters) of cohesive silt and clay (Fig. 12; App. A). These fine-grain sediments presently filling Montauk Harbor are probably Holocene estuarine deposits.

Projecting these Long Island buried channels north across Long Island Sound and connecting them with present-day surface drainage systems in New England is speculative without further information. The Hudson is the only river in western Long Island which is presently large enough to be capable of eroding the six channels which have been shown to cross western Long Island. Lovegreen (1974) documented the existence of three ancestral Hudson channels in New Jersey west of the present channel which are less than 300 feet (91.4 meters) deep and situated within 5 miles (8 kilometers) of the present river channel. Based on stratigraphy, Lovegreen suggested that one of the channels is Cretaceous age, whereas the other two are of Pleistocene age; these bracket the probable ages of all the western Long Island channels reported here. Ascribing all nine channels to erosion by the Hudson River would suggest the river has shifted channel position over a considerable area (~30 miles; 48.3 kilometers) during the past 100 million years. Such lateral channel migration may result from crustal warping due to tectonism or from glacial loading and unloading. An alternative explanation to ascribing all the channels to the Hudson River is that during earlier geologic periods surface water runoff was greater (i.e., Pleistocene interglacial stages) and a number of major rivers occupied the region which have since disappeared. If this were true, evidence of major channels should exist in the bedrock for the eastern New York and southwestern Connecticut mainland on the Long Island Sound north shore.

The pre-Tertiary surface contour map by Grim, Drake, and Heirtzler (1970) gives some indications that the channels crossing central Long Island may be related to the ancestral Housatonic and Quinnipiac Rivers in central Connecticut. Three Mile and Orient Point Channels appear to connect with the deep east-west channel in southern Long Island Sound extending from 73°20'W. to 72°40'W., and with the present course of the Connecticut River, respectively. Study of the intricate subbottom drainage history and further attempts to trace these channels across Long Island Sound and onto the Connecticut and New York mainland are being made by Williams (in preparation, 1976).

III. SURFACE AND SUBSURFACE SEDIMENT CHARACTER AND DISTRIBUTION

Information on the character and areal distribution for Long Island shelf sediment (Fig. 17) was derived from sediment analyses of the cores in Figure 2. Granulometric and textural data were derived solely from the CERC cores, but visual descriptions were obtained from the other data

Figure 17. Surface sediment distribution for five primary sediment facies on the Long Island inner shelf. Data based on core sediment analyses and by extrapolation between cores by seismic profiles identified in Figure 2.

sources in Figure 2. Core coverage is fairly well distributed along the entire Long Island south shore, around Montauk Point, and in the Gardiners Bay and Block Island region of eastern Long Island. Maximum coverage seaward varies from 3 miles (4.8 kilometers) to about 12 miles (19.3 kilometers) with an average limit of about 4 miles (6.4 kilometers). Based on examination of these sediment data, the sea floor of the inner shelf region can be characterized by five distinct sediment lithologies.

1. Primary Sediment Classes.

a. Sediment Type I. This sediment consists of generally clean, fine to medium to coarse (0.125 to 1 millimeter; 3 to 0 phi) white, quartz sand (Fig. 18) mixed with rounded pea gravel (2 to 15 millimeters; -1 to -4 phi) and distinctive green or black grains of sand and silt-size glauconite. Sediment type I is restricted to the sea floor corridor which intersects the shoreline near the Fire Island Inlet and extends southwest toward Long Branch, New Jersey. The northwestern (inshore) boundary of the region is clearly defined by cores V-5 and V-17 in Figure 9, and appears to mark an abrupt transition into fine to medium sands containing little or no glauconite. The southeastern (offshore) boundary is more arbitrary and may be farther southeast than shown in Figure 17. Occurrence of glauconitic sands in the cores appears to coincide on the seismic records with a Coastal Plain erosion surface underlain by highly glauconitic strata (possibly the Monmouth Group) covered by a variable thickness of an admixture of outwash sand and residual detritus from marine erosion of the underlying Coastal Plain substrate. Presence of the shallow Coastal Plain surface is also evident in several of the Suffolk County (sewer outfall) cores (Fig. 9). Williams and Duane (1974) reported that a Coastal Plain cuesta projects southwest from the Long Island shelf, intersects the Hudson Channel, and then projects toward the New Jersey coast on line with Shrewsbury Rocks, which they showed from seismic evidence to be a bathymetric expression of the Coastal Plain cuesta. Presence of this subsurface cuesta of glauconitic strata across the inner shelf is matched by the overlying residual shelf sediments which also contain high percentages of glauconite.

b. Sediment Type II. Type II sediment (≥ 0.5 millimeter; ≤ 1 phi) consists of clean coarse sand and rounded pea gravel which is commonly reddish brown (10YR 7/4; Munsell Soil Color classification, App. A) in surface coloration (Fig. 19). The material occurs primarily on the eastern half of the Long Island shelf in discrete patches and appears related to the proximity of the Ronkonkoma Moraine. This relation of sediment distribution with proximity to glacial moraine deposits agrees with similar sediment distributions reported by McMaster and Ashraf (1973) for the southern New England shelf. The westernmost surface occurrence of type II sediment is in cores 34 and 35 (Fig. 2) seaward and east of Shinnecock Inlet (Fig. 17). Both cores exhibit clean medium to coarse sand with rounded pebbles for their entire lengths of 10 and 10.5 feet (3 and 3.2 meters), respectively. Core 24 (Fig. 2) contains type II sediment for the first foot below the sea floor and then grades into fine to medium quartzose sand (type III sediment). The shoreface region around Montauk Point is primarily type II

Figure 18. Photos of typical shelf sediment. Grid size in millimeters.

Figure 19. Photos of typical shelf sediment. Grid size in millimeters.

sediment (Fig. 17) as evidenced by the composition of cores 18 and 19 (Fig. 2). Core 18 contains 15.3 feet (4.7 meters) of type II material; core 19 contains 4.2 feet (1.3 meters), its entire length of type II material. This suggests the type II lithology may continue with depth. Cores seaward of this region contain medium sand as a primary sediment constituent which tends to become finer with increasing distance from both shore and the Ronkonkoma Moraine. Because the Ronkonkoma Moraine continued east from Montauk Point before Holocene rise in sea level and consequent marine erosion, it is likely that type II sediment also continues east as an erosional lag deposit. This contention is supported by McMaster and Ashraf (1973) who reported patches of coarse bottom sediment on the southern New England shelf at several locations east of Block Island and on line with moraine projections. The only other surface occurrence of type II sediment was found in cores 13 and 14 in Block Island Sound east of Gardiners Island. Core 13 contains type II sediment for the entire length of 6.6 feet (2 meters). Core 14 contains type II sediment for the top 7.5 feet (2.3 meters) overlying 4.5 feet (1.4 meters) of Holocene organic-rich mud. The organic mud underlying type II sediment in core 14 appears from the seismic records to crop out as type V sediment to the south and west. Based on this evidence it appears that much of the coarse surficial sediment in Block Island Sound may be underlain at variable depths by fine-grained Holocene muds.

c. Type III Sediment. This sediment is fine to medium sand (0.125 to 0.5 millimeter; 3 to 1 phi) (Fig. 20), and is the predominant sediment lithology comprising both the inner shelf floor of south shore Long Island and the adjacent barrier islands (Figs. 12 and 17). Type III sediment is predominantly quartz with minor percentages of opaque heavy materials. The quartz grains generally have a yellowish cast (2.5Y 7/4) except for the grains in several cores at variable depths below the sea floor which exhibit a dusky, reddish-brown color (7.5YR 7/8) as a result of staining by iron oxide. The iron staining appears to be a surface coating occupying cracks and surface depressions on the grains and is apparently abraded off when the sand is exposed to active wave and current forces on the sea floor. Textural trends for type III sediment are subtle, but the mean grain-size diameter for surface shelf sediment from 43 cores decreases from Montauk Point west to Long Beach (Fig. 21). The figure also shows that a greater occurrence of very coarse sand or larger material (>1 millimeter, <0 phi) is contained in cores from eastern Long Island than in cores from western Long Island. These observations support work by Taney (1961) and Panuzio (1968) who propose that shoreline erosion of the headland region of eastern Long Island supplies a significant percentage of sediment available for littoral transport westward along the south shore barrier beaches. The predominance of fine to medium sand (type III) on the inner shelf appears to continue across the shelf to the shelf-slope transition where sediments become significantly finer (Schlee, 1973). Occurrence of type III sediment in Gardiners Bay and Block Island Sound is more restricted than on the open shelf to the south of Long Island (Fig. 17). Figure 17 shows that sand mantles sea floor areas adjacent to moraine-covered headlands. Several cores show a transition with depth from clean, well-sorted type III material down to either Pleistocene outwash

Figure 20. Photos of typical shelf sediment. Grid size in millimeters.

Figure 21. Surface textural trend from 43 cores along western Long Island showing subtle fining of sediment from Montauk west to Fire Island. Circled data points denote presence of coarse sediment not included in size results.

detritus or to Holocene fine-grained organic-rich muds (core 39). In either case, type III sands appear to be relict or palimpsest sediments being winnowed and acted upon by modern marine processes. Core 1, directly south of Plum Island (Fig. 2) is 13.5 feet (4.2 meters) long and shows 11 feet (3.4 meters) of pebbly, fine to coarse sand overlying 1 foot (0.3 meter) of peat. The peat is underlain by gray compact clay extending to the bottom of the core. The 11 feet of sand probably originated from erosion of the Harbor Hill Moraine corssing Orient Point and Plum Island, and was deposited on the type V sediment surface which underlies much of the shelf of eastern Long Island. The other six cores in the Gardiners Island region which contain type III sediments (cores 3, 6, 7, 9, 11, and 12) at the surface range in length from 4.7 feet (1.4 meters) (core 12) to 14 feet (4.2 meters) (core 9) and contain typical reworked outwash detritus (fine to coarse sand with rounded pebbles of varying composition) for their tal lengths.

d. Type IV Sediment. The granular material in this sediment is in the very fine sand to silt-size range (0.0625 to 0.125 millimeter; 4 to 3 phi) (Fig. 22). Cores indicate this sediment is restricted to four areas on the south shore, two on the shoreface off Fire Island, one directly seaward of Moriches Inlet, and one seaward of Shinnecock Inlet. Other areas of type IV sediment probably exist but present core coverage precludes more precise definition of their location and extent. The most westerly exposure of type IV sediment is defined by cores 65 and 67 (Fig. 2). Core 65 contains nearly 6 feet (1.8 meters) of clean, well-sorted, very fine sand for its total length; core 67, only about 1 mile (1.6 kilometers) south, exhibits more variable stratigraphy for its length of 17.2 feet (5.3 meters). Core 67 contains a top one-half foot (15.2 centimeters) of dark silt-clay overlying 8.5 feet (2.6 meters) of clean types II and III sediment (medium to coarse sand with rounded pebbles); it then grades into compact clay with a peat stratum 13 feet (4 meters) down the core. Below the peat, sediment texture becomes increasingly coarser to where the bottom 0.3 foot (10.2 centimeters) is medium sand. Core 72, located about 6 miles (9.7 kilometers) east of the type IV sediment locality, is in 30 feet (9.2 meters) of water on the shoreface and exhibits 4 feet (1.2 meters) of type IV material overlying 1 foot (0.3 meter) to the core bottom) of clean type III sediments. The next easterly occurrence of type IV sediment is in core 73, 1.5 miles (2.4 kilometers) offshore from Moriches Inlet. This core is 15 feet (4.6 meters) long and contains 5 feet (1.5 meters) of type IV sediment overlying 1 foot of peat. Below the peat, type IV sediment continues for another 6.5 feet (2 meters) and grades into silty fine sand with wood fragments for the bottom 2.5 feet (0.8 meter). The shoreface region off the western spit adjacent to Shinnecock Inlet contains marginal quantities of type IV sediment as defined by core 37. This core is 5.3 feet (1.6 meters) long, in 32 feet (9.8 meters) of water, and contains 2.5 feet of very fine to fine quartzose sand overlying 1.5 feet (0.5 meter) of poorly sorted, very fine to coarse sand with rounded pebbles and large shell valves. The bottom 1.3 feet (0.4 meter) of sediment grades finer again into very fine to fine sand. Occurrence of type IV sediment in the study area appears to be restricted to the south shore of Long Island, specifically the shoreface

Figure 22. Photos of typical shelf sediment. Grid size in millimeters.

region where sea floor sediment is constantly being agitated and winnowed by wind and tide-induced bottom currents. Type IV sediment appears to lack significance as a sea floor lithology in the Gardiners Bay-Block Island Sound region of eastern Long Island. This omission can be explained by the lack of adequate core spacing (only 12 cores available for this area) needed to locate and define areas containing this sediment, or alternately by the possibility that type IV sediment is indeed absent. Omission may result because the sediment was not available in the source material or the original environment of deposition was not conducive to sedimentation of fine sand and silt.

e. Type V Sediment. This last primary sediment class found in the study area consists of fine-grained, uniformly textured mixtures of silt and clay (<0.0625 millimeter; >4 phi) (Fig. 23). The sediment, generally gray or brown in color (5Y 6/2), is plastic and highly cohesive when moist, and frequently exhibits an abundance of small mica plates. Type V sediment is limited to two large areas in the Gardiners Bay and Block Island Sound region where it was found at the top of cores 2, 4, 5, 8, and 10. Presence of silt and clay west of Gardiners Island is supported by cores 2, 4, 5, and 8 and by clear recognition of these sediment acoustic signatures on the seismic records. These fine-grained, flat-lying sediments show no discernible internal structures or sedimentary features on the seismic records and the sequence always overlies an erosional disconformity interpreted to be a Pleistocene erosion surface. This relationship is evident in Figure 6 which allows extrapolation of the area of type V sediments from western Gardiners Bay north to Plum Gut. The fine sediments continue northeast of Plum Gut but as shown in core 1, they are covered by an overburden of sand and gravel eroded from the Harbor Hill Moraine crossing Plum Island. Fine-grained, organic-rich sediments of a similar nature have been reported by Frankel and Thomas (1966) south of Fishers Island, and by Antevis (1928) and Coch (1974) in Block Island Sound. These sediments have been postulated as being remnants of extensive Pleistocene freshwater lakes which occupied the region when sea level was significantly lower than at present. Possibly the same origins also apply to type V sediments in the Gardiners Bay area.

2. Radiometric Dating and Land-Sea Relationships.

Organic-rich layers (peat) closely associated with type V sediments were encountered at varying depths in six cores (Fig. 24) and were radiometrically age-dated by laboratory C^{14} techniques (Table 4). Core 39 near Moriches Inlet contains 2 feet of type III sediment overlying almost 3 feet of type V sediment. A peat layer 4 feet (1.2 meters) below the sea floor was dated at 5,585 $\pm$ 110 years B.P. Nearly 3 feet of pebbly type III sediment underlies the peat to the bottom of the core. Core 73 off Moriches Inlet contains type V sediment for the top 12.5 feet (3.8 meters) with 1 foot of peat 5 feet (1.5 meters) below the sea floor which was dated at 7,585 $\pm$ 125 years B.P. (Kumar, 1973; Sanders and Kumar, 1975). The bottom

Figure 23. Photos of typical shelf sediment. Grid size in millimeters.

Figure 24. Map showing six CERC cores containing organic material dated by radiometric methods to obtain the Holocene sea level curve in Figure 25.

Table 4. Carbon-14 dates from CERC Long Island vibratory cores.¹

Core	Location	Depth to top of peat (MSL)		Coordinates	Age in years (B.P.)
		(feet)	(meters)		
1	Plum Island	-50.0	(-15.15)	41°09'N. 72°11'W.	8,120 ± 125 and 8,665 ± 145
2	Gardiners Bay	-39.8	(-12.0)	41°04'N. 72°13'W.	6,575 ± 125
14	Block Island Sound	-52.5	(-15.9)	41°05'N. 72°02'W.	5,600 ± 180
39	Moriches Inlet	-36.0	(-10.9)	40°45'N. 72°47'W.	5,585 ± 110
67	Fire Island	-61.0	(-18.5)	40°40'N. 73°00'W.	7,750 ± 125
73	Moriches Inlet	-54.0	(-16.36)	40°45'N. 72°45'W.	7,585 ± 125

1. Shown in Figures 2 and 24.

2.5 feet (0.8 meter) is silty type III sediment. Core 67 off central Fire Island contains one-half foot of mud over about 9 feet of sand. Type V sediment underlies the sand down to 13 feet (4 meters) and includes a small layer of peat which was dated at 7,750 ± 125 years B.P. (Kumar, 1973; Sanders and Kumar, 1975). Four feet of silty type III sediment completes the bottom of the core. In Gardiners Bay, core 1 contains 2.5 feet of type V sediment at the core bottom with a 1-foot-thick peat layer dated at 8,665 ± 145 years B.P. and 8,120 ± 125 years B.P. (Caldwell and Sanders, 1973). Core 2 contains almost 7 feet of type V sediment, including about 2 feet of peat dated at 6,575 ± 125 years B.P., overlying 4 feet of medium to coarse sand. In Block Island Sound, core 14 contains 4.5 feet (1.4 meters) of organic-rich type V sediment with 7.5 feet (2.3 meters) of medium to coarse sand on top and 1 foot of type III sediment underneath. The organic content in the mud was dated at 5,600 ± 180 years B.P.

Since 1949, radiocarbon dating techniques have been widely accepted as a useful tool in determining approximate ages of organic material. These methods give reasonably accurate ages when compared with tree-ring dating, except for organic materials older than 30 to 40 thousand years B.P. because the short half-life of C¹⁴ limits detection beyond these cutoff dates. Carbon-14 dating methods have greatly expanded man's knowledge of history and are used in this study to gather clues to the history of eustatic sea level rise and sedimentation during the past several thousand years; this submergence has had profound effects on the Long Island shelf and coastal geology. Based on the assumption that the peat material dated once lived at or near the sea-land intersection and that insignificant compaction of the underlying sediment has taken place, it is possible to plot these dates and to construct a curve showing the relative rate and magnitude of sea level rise. Figure 25 is a plot of the seven dates from this study (Table 4) shown in relation to sea level curves for Cape Cod, New Jersey, and Iona Island. Dates for both Cape Cod and Iona Island are considerably younger and beyond the scope of this data; however, two dates from New Jersey extend the curve past 6,000 years B.P. and into the realm of dates from this report. The best-fit curve for

Figure 25. Sea level curves for the Holocene transgression constructed from dates reported in the literature and from radiocarbon dates of CERC cores in the Long Island region shown in Figure 24.

the Long Island dates has the same general slope as the curve for Iona Island and is reasonably close to the extrapolated curves for both Cape Cod and New Jersey. The date for core 14 plots far below the curve and is probably spurious due to inherent problems in accurately dating bulk samples of organic mud. The two dates for core 1 and the date for core 2 plot above the curve, but because both cores are from Gardiners Bay, close to the Pleistocene ice margin, they may indicate that consequent to retreat of the glaciers the land area rebounded a maximum of 15 feet (4.6 meters) before mid-Holocene time. The curves in Figure 25 also indicate that although sea level may have fluctuated slightly, there is an overall indication of a progressive marine transgression during the past 8,500 years.

IV. SANDFILL NEEDS AND RESOURCE POTENTIAL

1. Sandfill Requirements for Area Beaches.

The shoreline along the Atlantic coast of Long Island is one of the most heavily attended recreation areas in the United States. The total annual attendance for the major beaches along the south shore of Long Island is about 57 million people, but these same beach areas are experiencing critical erosion problems (U.S. Army, Corps of Engineers, 1971). This same report indicates that 300 miles (483 kilometers) of Atlantic coastline in New York State have been categorized as having undergone critical erosion. Shore erosion is defined as critical when the magnitude of shoreline recession is significant and when the benefits expected from corrective actions needed to curtail erosion would justify costs of such improvements. For the south shore alone the estimated annual change to public and private property and development from shore erosion is \$9 million (U.S. Army, Corps of Engineers, 1971).

Several Federal Beach Erosion Control and Hurricane Protection projects for the south shore of Long Island are authorized or have been recommended to the Congress by the Corps of Engineers. Figure 26 shows the project segments by order of priority set by the U.S. Army Engineer District, New York. The Jones Beach and Montauk sectors are the only areas where shoreline recession is not considered to be critical at present and no priority has been set. Since the needs and availability for sand at Rockaway Beach are considered by Williams and Duane (1974), they are not discussed in this report. The numbers for each segment are the sandfill volumes thought to be necessary to satisfy the dune and beach-fill requirements for that part of the project. A project generally involves an initial fill and then periodic renourishment during a 50-year period estimated as the reasonable economic life over which to amortize costs and compare benefits. The total sand needed at present to initiate all these projects (excluding Rockaway) is more than 61 million cubic yards (47 million cubic meters), and that needed to complete the 50-year projects is an additional 75 million cubic yards (60 million cubic meters). Thus, the total volume of sand necessary to complete all projects for the south shore is estimated to be 136 million cubic yards (107 million cubic meters).

* $\frac{\text{X}10^6 \text{ Cubic Yards}}{\text{Initial Fill}}$
 * $\frac{\text{X}10^6 \text{ Cubic Yards}}{\text{Annual Fill}}$

Figure 26. Sandfill requirements for beach restoration for seven coastal compartments in order of priority. Numerator is initial fill volume and denominator is anticipated annual fill volume for a project life of 50 years. Volumes given in millions of cubic yards (U.S. Army Engineer District, New York).

2. Suitability of Sand for Beach Nourishment.

Sand should meet certain important criteria to be useful as borrow material for beach restoration and protection projects. Factors to consider are the: (a) population mean grain size and total size distribution, (b) mineralogic composition, (c) economics of sand recovery, and (d) placement and distribution on the beach. The borrow material should be of at least the same size and, preferably, slightly coarser than native material on the beach to be nourished. If borrow material was significantly smaller in particle size than indigenous sand it would be expected to be less stable and out of equilibrium with the wave and current regime. Consequently, it would be rapidly eroded and either carried offshore by wave-induced currents or transported parallel to the beach by longshore currents. In either case the net effect is accelerated retreat of the fill to readjust nearshore profiles, thus requiring considerably larger total volumes of initial fill and more frequent periodic replenishment. If the borrow sand does not have the same grain-size characteristics as the native beach sand, the grain-size population of the borrow sand should preferably be more poorly sorted, i.e., a greater variation in size classes than the native beach sand, and initial overfill relative to the required volume of fill for sand having the same characteristics as that of the native beach would be necessary for comparable performance.

Borrow material should be composed of hard, chemically and physically resistant minerals, such as quartz, which will not readily degrade in the high-energy nearshore-beach-dune environment.

The subject of beach fill and its design is covered in detail by Krumbein and James (1965), U.S. Army, Corps of Engineers, Coastal Engineering Research Center (1973), James (1974), and James (1975).

3. Potential Borrow Areas and Sand Volumes.

Results of this regional study using vibratory cores and high-resolution seismic records indicate that large volumes of clean sand ubiquitously mantel the Atlantic inner shelf of Long Island from Atlantic Beach east to Montauk Point. Availability of suitable beach fill is less easily documented for eastern Long Island in the Gardiners and Napeague Bays region; however, data indicate large volumes are present in limited areas. Based on visual examination of the cored sediment and lateral extrapolation of subsurface stratigraphy on the seismic profiles, 14 sea floor areas are judged to contain detritus suitable for restoration and nourishment of area beaches (Figs. 27, 28, and 29). Individual borrow areas are letter-designated and cover the shelf area from the shoreface (~30-foot depth; 9.2 meters) seaward to an arbitrary limit of data coverage. Normally this seaward limit is the 90-foot (27.4 meters) depth contour; however, in area I off Moriches Inlet the area extends out to the 120-foot (36.6 meters) depth. The cores shown in Figures 27, 28, and 29 were closely examined for sand character; the number adjacent to the symbol identifies the core and the parenthetical expression is the minimum

Figure 27. Sand borrow areas for the eastern Long Island shelf. Minimum sand thicknesses in feet in parentheses adjacent to the cores. Boundary dashlines are indefinite for lack of data.

Figure 28. Sand borrow areas for the central Long Island shelf.
See Figure 27 for further explanation.

Figure 29. Sand borrow areas for western Long Island. See Figure 27 for further explanation. Detail on borrow area M is shown in Figure 30.

continuous sand thickness in feet for each respective core. Sediment descriptions and some granulometric analyses for these cores are in Appendixes A and B. The sediment thickness values shown in Figures 27, 28, and 29 were then extrapolated to peripheral parts of the borrow areas by sea floor sediment trends and by correlation of the sediment stratigraphy in the cores with stratification lines on the seismic profile records. Based on these data, minimum sand thicknesses and potential thickness were calculated for each borrow area. The potential thickness is considered to be a reasonable value for which limited core data exist; however, based on the seismic profiles it is highly probable that these potential sand volumes are less than what could be proven available if longer cores were taken. Because the cores used for this report are a maximum of 20 feet (6 meters) long (except area M), 20 feet is the maximum potential thickness. However, the seismic profiles, especially along the eastern Long Island Atlantic shelf, indicate that greater thicknesses of sand exist below the limits of core recovery. Much deeper cores would be necessary to substantiate the presence of deeper sand, but volumes calculated from cores in this report indicate that further exploration may be unnecessary to satisfy presently anticipated needs for beach restoration.

Each of the 14 borrow areas was planimetered to calculate the area in square yards and this figure was multiplied by both the minimum and potential sand thicknesses to yield the sand volumes in Table 5.

a. Area A (Gardiners Bay). Area A is small and circular and is located immediately west of Three Mile Harbor (Fig. 27). The sea floor surface dips gently northeast beyond the 30-foot (9.2 meters) depth contour. Only core 3 is in area A, but it shows the entire length (9 feet; 2.7 meters) is clean, fine to medium sand. The seismic records show the sediments are flat lying but pinch out abruptly at the eastern boundary where muds cover the upper parts of the ancestral Three Mile River channel.

b. Area B. Area B lies east of Three Mile Harbor and is slightly smaller than area A (Fig. 27). Core 6, the only core in area B, contains clean medium sand overlying coarse sand with pebbles down to a depth of 8.5 feet (2.6 meters) below the sea floor. Deeper core penetration was probably prohibited by the coarse sediment, and the seismic records show no apparent change in lithology down to 15 feet (4.6 meters). The boundary limits for this area are arbitrary but the four surrounding cores show that this is an isolated pocket of sand surrounded by muds (type V sediment).

c. Area C. This area is on the northern side of Gardiners Bay immediately south of Plum Island (Fig. 27). Core 1, the only core available, contains 6.7 feet (2.1 meters) of sand overlying very fine silty sand, organic peat, and cohesive clay. It is in 39 feet (12 meters) of water on the east bank of the submerged Plum Gut depression. Since the seismic records show the sand layer thickens toward Plum Island, it is possible that more than the indicated 3 yards (2.7 meters) (Table 5) are present and that suitable sand extends farther east than is shown by the boundary.

Table 5. Sand availability for borrow areas.¹

Area	Sand thickness		Sand volume	
	Minimum ² (yards)	Potential ³ (yards)	Minimum ($\times 10^6$ cubic yards)	Potential ($\times 10^6$ cubic yards)
A	3	3.0	24.30	24.30
B	3	5.0	19.41	32.35
C	2	3.0	14.32	21.48
D	3	5.0	65.64	109.40
E	2	2.5	38.64	48.21
F	3	5.0	672.00	1,120.00
G	4	4.3	241.04	259.11
H	3	4.3	480.00	688.00
I	4	5.0	518.68	648.35
J	3	6.0	756.00	1,512.00
K	2	3.0	950.06	1,425.09
L	3	3.0	698.01	698.01
M	6	6.0	960.30	960.30
N	2	3.5	399.04	698.32
Total			5,837.42	8,244.98

1. See Figures 27, 28, and 29.

2. Values based on core data.

3. Values derived from extrapolation of core data by seismic reflection records.

d. Area D. Area D is an elongate region between Gardiners Island and the southern Long Island peninsula (Fig. 27). Cores 9, 11, and 12 contain suitable sand for their entire lengths, which means a minimum sand thickness of 3 yards. The sand appears on the seismic records to be flat bedded and continuous with depth; therefore, 5 yards (4.6 meters) is judged to be a reasonable potential thickness. The eastern boundary shows a sharp contact where fine-grained (type V) sediments overlie the older sand deposits. The western boundary is tentative because data are lacking; it possibly continues farther west to the line of islands stringing south from Gardiners Island.

e. Area E. This area projects southeast from the eastern shore of Gardiners Island (Fig. 27). The sea floor slopes gently east from the shore at Gardiners Island to the 60-foot (18.3 meters) depth contour. Core 13 contains clean, medium to coarse sand for the entire length of 6.6 feet (2 meters) while core 14, to the southeast, contains 7.5 feet

(2.3 meters) of medium to coarse sand overlying 4.5 feet (1.4 meters) of organic mud which in turn overlies clean fine sand to the bottom of the core at 13 feet (4 meters). Based on these core data, the sand thickness is judged to be between 2 and 2.5 yards (1.8 and 2.3 meters).

f. Area F. Area F extends along the south shore of eastern Long Island from Montauk Point to Napeague Harbor and offshore from about 3.5 miles (5.6 kilometers) to the limits of data coverage (Fig. 27). The area contains 14 cores which are fairly evenly distributed, and all except core 23 exhibit suitable sand for their entire lengths. Based on core data, the minimum sand thickness is judged to be 3 yards (2.7 meters) and the potential thickness is thought to be 5 yards (4.6 meters). The seismic records show the sea floor in the eastern quarter is covered by large amplitude sand waves and the central part includes a lobate delta-like positive feature defined by the 60-foot (18.3 meters) depth contour; both of these features are especially promising. However, the seismic records show possible sand thicknesses of 13 yards (11.9 meters); true determinations cannot be made without aid of deeper cores. Also, it must be emphasized again that the seaward boundaries for all the borrow areas along the Long Island coast are only approximate and the indicated boundaries extend seaward only to the limits of data coverage. In all potential borrow areas the seismic records indicate that the sand lithologies continue seaward beyond data coverage.

g. Area G. This area is more narrow than other borrow sites and contains cores 29, 30, and 119 in the actual borrow area and cores 120 and 121 on the seaward side (Fig. 27). Cores 120 and 121 contain unsuitable silty, very fine to fine sand. The three cores within the borrow area contain clean sand for their total lengths; seismic records support a minimum thickness of 4 yards (3.7 meters) and a potential thickness of 4.3 yards (3.9 meters).

h. Area H. This area is rectangular in shape with a flat and gently seaward-sloping sea floor to the 90-foot (27.4 meters) depth contour (Fig. 27). It contains five cores (31 through 34, and 118) all of which have clean sand for their entire lengths. The minimum surficial sand cover is 3 yards with a reasonable potential of 4.3 yards.

i. Area I. A trapezoidal-shaped region immediately east of Moriches Inlet (Fig. 27), area I owes its shape to a southward extension of data along seismic line 51 (Fig. 2). The five cores (35, 36, 115, 116, and 117) in this area penetrated a minimum of 9 feet (2.7 meters) at core 36, and a maximum of 19 feet (5.8 meters) at core 116; all five cores showed continuous sand sequences for their entire lengths. Based on these values the minimum sand thickness is 4 yards and the potential thickness is 5 yards. Presence of shoal (ridge and swale) topography in the southern part of the area may have considerable influence on sand availability because data from other geographic shelf areas indicate that shoals may be important sand repositories (Duane, et al., 1972; Williams and Duane, 1972). The western boundary for area I was established because core 79, seaward of Moriches Inlet, contains gray, very fine sand silt overlying

overlying and mixed with medium sand and pea gravel. These fine materials may be older Holocene back-barrier sediments which are being reexposed as barrier migration progresses landward, or they may result from contemporary fine detritus being flushed out of Moriches Inlet during intense storms or strong ebb tides. In either case, this area should be avoided as a borrow site until more detailed data are available.

j. Area J. Area J occupies the shelf region between Moriches Inlet and Shinnecock Inlet and extends seaward about 4 miles (6.4 kilometers) to the 90-foot (27.4 meters) depth contour, which expresses several northwest-trending shoals (Fig. 28). This area contains seven cores (37, 38, and 74 through 78) which are evenly distributed, and exhibit sand for their entire lengths; the minimum length is 3.5 feet (1.1 meters) at core 76, and the maximum length is 18 feet (5.5 meters) at core 77. Based on these core data and on the seismic records the minimum thickness is 3 yards (2.7 meters) and the potential thickness is 6 yards (5.5 meters) of sand blanketing the area. Thus, this area contains the largest volume of potential sand (Table 5), all within the 90-foot depth contour. The western boundary marks the transition from clean sand to the gray silt and clay (core 73) which overlies older peat materials derived from a lagoon which occupied this region about 7,500 years B.P. (Table 5). These lagoonal sediments are too fine and organically rich to be suited for beach fill; their presence should be anticipated beneath the modern shelf sand cover in other areas.

k. Area K. Area K covers the largest shelf area and extends offshore a maximum of 8 miles (12.9 kilometers) (Fig. 28). The tentative seaward limit parallels the 90-foot depth contour and includes the areas where seismic lines U and V are located (Fig. 2). Twelve cores are positioned within this area, nine cores within 3 miles (4.8 kilometers) of the coast and the other three closely spaced along seismic line V (Figs. 2 and 16) normal to a linear shoal. While the core coverage is not ideally distributed, the seismic records show the stratigraphy in the cores probably extends throughout the area. Based on sand recovered in the cores and by extrapolation on seismic records the minimum sand thickness is judged to be 2 yards (1.8 meters) while the potential is 3 yards.

l. Area L. This area is a rectangular region extending more than 7 miles (11.3 kilometers) off Fire Island (Fig. 29). It is covered by a 1-mile-grid (1.6 kilometers) spacing of seismic records and contains cores 8, 9, 20, 61, and 114. The sea floor has a gentle seaward slope with a pronounced northwest ridge and swale surface fabric. Presence of shoal topography seaward of area L may warrant extending the southern boundary; however, data are only available for the western section, and use of an area with greater than 10-mile (16.1 kilometers) distance from shore would probably be economically prohibitive because proven sand resources from adjacent area M are closer to project beaches. Of the five cores in area L, four contain suitable sand for their entire lengths; the exception, core 114 (Fig. 2), contains 8 feet (2.5 meters) of suitable sand underlain by 3 feet (0.9 meter) of clean but very fine sand. Based on this core information, the minimum sand thickness is 3 yards and because

Cretaceous strata of varied and possibly fine lithologies are close to cropping out on the sea floor, the potential thickness is also 3 yards.

m. Area M. Area M is unique because it contains the greatest number of cores of any potential borrow area (Figs. 29 and 30). A total of 41 cores are located along three shore-normal transects which were established to determine engineering conditions for two sewer outfall pipes, one for Nassau County, which has since been constructed, and one planned for Suffolk County. The 15 cores along the Nassau County line (Fig. 9) are spaced about 300 yards (274 meters) apart and extend to a maximum of -80 feet (-24.4 meters) MSL and provide excellent lithologic correlation. All but one of the cores (core 250) show that the upper 12 to 30 feet (3.6 to 9.2 meters) of shelf sediment in this region is composed of fine to medium sand with lesser amounts of coarse detritus and minimal fine silt and clay (Fig. 9; App. A). A continuous clay-silt surface (Gardiners Clay) is present at -50 feet (-15.2 meters) MSL inshore in core 241 and seems to slope offshore and then level off at about -66 feet (-20 meters) MSL between cores 247 and 253. This surface provides the lower limits of potential sand for this area and thus the minimum and potential thickness (Table 5) is 6 yards (5.5 meters).

The two core transects for the Suffolk County sewer outfall (Fig. 30) are about 5 miles (8 kilometers) long, 1.25 miles (2 kilometers) apart, and contain 26 cores, a maximum of 40 feet (12.2 meters) long. The 15 cores in the western transect (Fig. 30) are about one-third mile (0.5 kilometers) apart and extend down the shoreface slope and across a subdued shoreface linear shoal.

Most cores shoreward of the 50-foot (15.2 meters) bathymetric contour contain a varied stratigraphic sequence of fine to medium to coarse sand above and below silt-clay lenses, except cores V-13, V-7, and V-6 which contain continuous sand sequences (Fig. 9; App. A). All of the eight cores seaward of the 50-foot depth contour show 10 to 23 feet (3 to 7 meters) of sand overlying a flat, featureless, silt-clay horizon (Gardiners Clay) at about -73 feet (-22.3 meters) MSL (Fig. 9). This horizon is continuous under the shoal which is analogous to data reported by Duane, et al., (1972) for similar shoals studied along other parts of the Atlantic inner shelf. Incomplete descriptive logs for some cores yield gaps in the stratigraphic information; however, the information loss is generally minimal except for core V-2. The shelf in this region is underlain at shallow depths (relative to eastern and western Long Island) by Upper Cretaceous strata (Monmouth Group) which show an anticlinal southeast dip on the seismic records and are characterized by compact glauconitic, sandy, silty gravels (Figs. 7 and 14). Based on the presence of glauconite (dark greenish grains) in the core descriptions from Appendix A, an assumed Coastal Plain surface has been plotted in Figure 9. The silt-clay horizon which underlies shelf sands seaward of the 50-foot-depth contour is apparently the Gardiners Clay Formation (Sangamon age) which marks the lowermost limit of sediment that may be considered suitable for borrow.

The 11 cores along the eastern transect in Suffolk County (Fig. 30) are approximately one-half mile apart and vary in length from 10 to 27

Figure 30. Map showing sand thicknesses in feet for borrow area M (Fig. 29). Visual logs for the three core transects are shown in Figure 9. Sand volumes are in parentheses adjoining core number. Detailed core descriptions are in Appendix A.

feet (3 to 8.2 meters). These cores display a stratigraphic sequence across the shoreface (Fig. 9) similar to that shown by the cores along the west transect (Fig. 9). The east transect passes slightly seaward of the shoal (Fig. 30) and a silt-clay horizon is present at -80 feet (-24.4 meters) MSL (cores V-22, V-23, and V-24) which is correlative with the Gardiners Clay described above for the west transect. Based on the sediment descriptions from cores along the three transect lines, a potential sand thickness for area M is judged to be 6 yards (5.5 meters).

n. Area N. Area N at the western end of the study adjoins the shelf region studied by Williams and Duane (1974) (Fig. 29). It lies within the 60-foot (18.3 meters) depth contour and contains 11 cores which show considerable variation in continuous sand content (App. A). Part of the stratigraphic variation may be explained by the presence of three major buried river channels which trend north-south (Fig. 13) and reach dimensions of several thousand yards in width and over 350 feet (106.7 meters) in depth. The textural and mineralogic nature of the channel-fill detritus is uncertain but information on channels from other areas indicates the fill may be quite variable depending on composition of the original source rock and hydraulic competence of the rivers. The minimum sand thickness is judged to be 2 yards (1.8 meters), while the potential recovery is 3.5 yards (3.2 meters).

Since the borrow sites discussed above are based on a regional study of sediment distribution, additional exploration by seismic profiling and coring in the offshore sites is necessary to accurately delimit the borrow material size parameters and volumes. For example, a detailed followup study was conducted by the U.S. Army Engineer District, New York, before initiation of the Rockaway Beach nourishment project where an offshore sand source at East Bank Shoal seaward of Coney Island and west of Rockaway Inlet was used. A similar data collection program is underway off Westhampton Beach and will be completed in late 1975.

V. SUMMARY

The study area covers about 800 square miles (2,072 square kilometers) of the Long Island Atlantic Inner Continental Shelf from Atlantic Beach east 110 miles (177 kilometers) to Montauk Point and includes the Gardiners Bay-Block Island Sound region in eastern Long Island. Basic ICONS survey data consist of 735 miles (1,183 kilometers) of seismic reflection records and 70 vibratory cores (average length: 9.7 feet; 3 meters). Supplemental data consist of 82 cores and borings and 225 miles (362 kilometers) of seismic records. All these data were obtained on the inner shelf between the beach and water depths of 105 feet (32 meters), about 10 miles (16.1 kilometers) offshore.

The shelf south of Long Island is a submerged continuation of the surface underlying the Long Island mainland. Long Island is underlain at depths of about 1,100 feet (335 meters) at the south coast by a southeast-sloping metamorphic bedrock surface which is overlain by unconsolidated and semiconsolidated Cretaceous-Tertiary, and Quaternary

strata. These dip and thicken to the southeast. Long Island originated as a glacial depositional land mass made up of the Harbor Hill and Ronkonkoma Moraines and seaward-sloping outwash plains which coalesce to the south coast and extend onto the shelf. Shelf sediments are primarily stratified blanketlike deposits of quartzose sand and gravel which are discontinuous in areal extent. Most of the shelf sediments are relict Pleistocene outwash deposits; however, parts of the west-central shelf contain residual material from Coastal Plain strata which crop out on the sea floor. Also, C^{14} radiometric-age dates from six cores show that Holocene barrier island-lagoon sedimentary sequences comprise minor parts of the shelf, primarily east-central shoreface parts of the shelf and the regions around Gardiners Bay and Block Island Sound.

About 15 major buried drainage channels have been found to transect the Long Island mainland and adjacent shelf. Channel thalweg depths range from -100 to -700 feet (-30.5 to -213.4 meters) MSL and channel widths from hundreds of feet to several miles. Most of the channels at the Long Island north shore exhibit evidence of significant overdeepening by Pleistocene glacial lobes which selectively followed preexisting stream channels. The channels are filled with assorted Pleistocene sediments and influence much of the present Long Island topography, but fluvial and marine processes have obliterated any bathymetric clues to their existence on the shelf surface, except for the Hudson and Block Channels.

Fine to medium quartzose sand is the primary sediment type on the Long Island Atlantic shelf with secondary quantities of coarse sand and gravel; in the Gardiners Bay-Block Island region mixtures of fine-grain sandy silts and clays predominate.

Large quantities of sand suitable for beach restoration and nourishment are present on the Atlantic shelf in water depths suitable for recovery by present dredge technology. Sea floor relief is fairly regular and the sand occurs as evenly bedded, flat-lying, blanket deposits. An estimated 8 billion cubic yards (6 billion cubic meters) of sand is available for recovery.

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APPENDIX A

CORE SEDIMENT DESCRIPTIONS

Appendix A contains visual descriptions of sediment from cores in the study area. Except where noted, sample locations are shown in Figure 2.

Visual descriptions for the CERC cores are based on both megascopic and microscopic examination. Sediment color is based on dry sample per Munsell Soil Color Charts (Munsell Color Company, Incorporated, Baltimore, Maryland, 1954 Edition).

Sediment descriptions for the other three groups of cores off Nassau and Suffolk Counties were obtained from reports and logs.

Sediment names are based on the Wentworth size-scale as follows:

Sediment	Size (mm)	Phi
gravel	> 2	< -1
very coarse sand	1.0 to 2.0	0 to -1
coarse sand	0.5 to 1.0	1 to 0-
medium sand	0.25 to 0.5	2 to 1-
fine sand	0.125 to 0.25	3 to 2-
very fine sand	0.0625 to 0.125	4 to 3-
silt and mud	< 0.0625	> 4

Sorting Terms*	Phi
very well-sorted	0.35
well-sorted	0.50
moderately well-sorted	0.80
moderately sorted	1.40
poorly sorted	2.00
very poorly sorted	2.60
extremely poorly sorted	

*Verbal sorting terms from Friedman (1962).

Table A-1. Sediment description of Coastal Engineering Research Center cores from Long Island south shore.

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Color code	Description
1	39	13.5	0.0 to 0.5	5Y 6/1 gray	Silty, medium, poorly sorted sand with small pebbles and shell fragments.
			0.5 to 1.0	10YR 7/2 brown	Clean, fine to medium, moderately sorted sand with small pebbles and shell fragments.
			1.0 to 1.5	10YR 7/2 brown	Clean, fine to medium sand with rounded pebbles ≤ 0.75 -inch diameter.
			1.5 to 5.1	2.5Y 7/2 gray	Clean, medium to coarse sand with abundant dark mica flakes.
			5.1 to 6.4	5Y 7/2 gray	Silty, medium to coarse sand.
			6.4 to 6.7	5Y 6/2 gray	Silty, medium, poorly sorted sand and rounded gravel.
			6.7 to 11.0	5Y 7/1 gray	Silty, very fine to fine, poorly sorted, micaceous sand.
			11.0 to 12.0		Organic peat (see Table 4 for radiocarbon date).
			12.0 to 13.5	5Y 7/1 gray	Cohesive clay.
2	33	11.1	0 to 5.0	5Y 6/1 gray	Silt to clay, with shells.
			5.0 to 6.8		Peat (see Table 4 for radiocarbon date).
			6.8 to 11.1	10YR 6/4 brown	Slightly silty, medium to coarse, moderately sorted sand.
3	29	9.0	0 to 1.0	5Y 7/1 gray	Silty, fine to medium sand.
			1.0 to 4.0	2.5Y 8/2 white	Clean, fine, moderately well-sorted sand.
			4.0 to 9.0	5Y 8/2 gray	Clean, fine to medium sand with shell fragments.
4	35	15.4	0 to 9.0	5Y 6/1 gray	Micaceous mud.
			9.0 to 13.5	2.5Y 6/2 gray	Silty, fine sand.
			13.5 to 15.4	10YR 6/4 brown	Clean, fine, well-sorted sand.
5	38	15.8	0 to 1.0	5Y 6/2 gray	Cohesive clay.
			1.0 to 2.1	5Y 7/2 gray	Very fine sand or silt.
			2.1 to 15.8	5Y 6/2 gray	Cohesive clay.

Table A-1. Sediment description of Coastal Engineering Research Center cores from Long Island south shore.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Color code	Description
6	21	8.5	0 to 0.5	5Y 6/2 gray	Medium, moderately sorted sand.
			0.5 to 1.5	5Y 7/1 gray	Silty, medium sand mixed with shell hash and rounded $\leq$ 1-inch diameter pebbles.
			1.5 to 3.5	5Y 7/2 gray	Clean, fine to medium, gray to brown sand with shell fragments.
			3.5 to 8.5	10YR 6/4 reddish-brown	Medium to coarse sand mixed with rounded pebbles $\leq$ 1.5-inch diameter (pebble composition: red silt, stone, quartz, gneiss).
7	25	13.4	0 to 3.3	5Y 7/1 gray	Fine, poorly sorted, micaceous sand, silt and clay.
			3.3 to 6.0	2.5Y 8/2 brown	Clean, fine to medium sand with rounded pebbles.
			6.0 to 13.4	10YR 6/6 reddish-brown	Clean, medium to coarse sand with rounded pebbles.
8	25	15.9	0 to 3.8	5Y 7/1 gray	Silt.
			3.8 to 6.0	5Y 5/1 gray	Micaceous cohesive mud.
			6.0 to 15.9	10YR 7/1 gray	Clean, fine to medium, moderately sorted sand.
9	30	14.0	0 to 8.0	5Y 7/2 gray	Clean, fine, moderately well-sorted sand.
			8.0 to 10.0	5Y 8/2 gray	Clean, medium to coarse sand.
			10.0 to 14.0	2.5Y 6/4 reddish-brown	Medium to coarse, poorly sorted sand.
10	45	10.0	0 to 10.0	10YR 6/1 gray	Silty micaceous mud.
11	37	7.5	0 to 4.0	5Y 8/2 gray	Clean, fine sand.
			4.0 to 6.0	5Y 6/2 gray	Fine, micaceous sand.
			6.0 to 7.5	5Y 6/1 gray	Silty, medium to coarse, moderately sorted sand.
12	23	4.7	0 to 3.0	2.5Y 7/2 gray	Clean, medium to coarse, moderately well-sorted sand.
			3.0 to 4.0	5Y 8/2 gray	Slightly silty, fine sand.
			4.0 to 4.7	5Y 7/2 gray	Silty, medium sand with fine shell fragments and mica.
13	20	6.6	0 to 1.0	10YR 8/3 brown	Medium to very coarse sand.
			1.0 to 6.6	10YR 7/6 reddish-brown	Medium to coarse, moderately well-sorted sand.

Table A-1. Sediment description of Coastal Engineering Research Center cores from Long Island south shore.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Color code	Description
14	45	13.0	0 to 1.0		Medium to coarse sand with armoured mudballs and small pebbles.
			1.0 to 3.0	10YR 7/6 yellowish-brown	Medium to coarse sand.
			3.0 to 5.0	2.5Y 8/4 yellow	Medium sand.
			5.0 to 7.5	2.5Y 8/6 yellow	Medium to coarse, moderately well-sorted sand.
			7.5 to 12.0		Organic mud (see Table 4 for radiocarbon date).
			12.0 to 13.0	2.5Y 8/4 yellow	Clean, fine sand.
15	52	6.3	0 to 6.3	2.5Y 8/4 yellow	Clean, medium, moderately well- to well-sorted sand.
16	46	6.3	0 to 6.3	2.5Y 8/4 yellow	Clean, medium, well-sorted sand.
17	51	10.0	0 to 6.0	2.5Y 8/2 white	Clean, fine to medium, well-sorted sand.
			6.0 to 10.0	10YR 8/2 white	Clean, fine, well-sorted sand.
18	63	15.3	0 to 1.5	10YR 6/2 light brown	Fine to coarse sand with rounded pebbles.
			1.5 to 6.0	10YR 6/3 brown	Medium to coarse sand.
			6.0 to 12.0	10YR 6/3 brown	Coarse sand.
			12.0 to 15.3	2.5Y 7/6 yellow	Fine to coarse, moderately sorted sand.
19	30	4.2	0 to 2.0	10YR 6/6 brown	Coarse, moderately well-sorted sand and pebbles.
			2.0 to 4.2	7.5YR 5/8 brown	Medium to coarse sand.
20	30 to 35	2.0	0 to 1.0	10YR 8/3 pale brown	Clean, fine, well-sorted sand.
			1.0 to 2.0	10YR 8/4 pale brown	Clean, fine to coarse sand with rounded pebbles.
21	52	7.0	0 to 7.0	2.5Y 8/4 pale yellow	Clean, medium, moderately well-sorted sand.
22	59	10.3	0 to 1.0	2.5Y 8/4 yellow	Clean, medium to coarse sand.
			1.0 to 2.0	10YR 6/6 brownish-yellow	Medium to coarse sand.
			2.0 to 10.3	10YR 7/8 yellow	Fine to medium, moderately well-sorted sand.

Table A-1. Sediment description of Coastal Engineering Research Center cores from Long Island south shore.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Color code	Description
23	47	11.7	0 to 5.0	2.5Y 6/2 brown	Clean, medium to coarse sand with few pebbles of gneiss, quartz composition.
			5.0 to 10.0	2.5Y 8/2 white	Clean, moderately well-sorted, medium sand.
			10.0 to 10.1	5Y 5/1 gray	Cohesive clay.
			10.1 to 11.7	10YR 6/4 brown	Silty, coarse sand with pebbles ≤ 1.25 -inch diameter.
24	56	10.0	0 to 1.0	2.5Y 7/4 yellow	Clean, medium to coarse sand with rounded pebbles.
			1.0 to 5.0	10YR 7/8 yellow	Medium sand.
			5.0 to 7.0	2.5Y 7/2 gray	Fine to medium, moderately well-sorted sand with isolated clay patches.
			7.0 to 10.0	10YR 8/2 white	Clean, fine to medium sand.
25	75	7.0	0 to 1.0	2.5Y 7/2 light gray	Clean, medium, moderately well-sorted sand.
			1.0 to 2.0	5Y 6/1 gray	Silty, medium to coarse sand.
			2.0 to 4.0	10YR 6/6 brown	Clean, coarse sand with large shell fragments.
			4.0 to 6.0	5Y 8/4 yellowish-green	Fine to medium sand.
26	63	9.2	6.0 to 7.0	10YR 5/1 brown	Silty, fine to medium sand.
			0 to 1.0	2.5Y 7/4 yellow	Clean, fine to medium, well-sorted sand.
			1.0 to 9.2	2.5Y 8/4 yellow	Silty, fine sand.
27	44	11.0	0 to 11.0	2.5Y 8/2 white	Clean, fine to medium, moderately well-sorted sand.
28	32	5.0	0 to 0.5	5Y 6/2 gray	Medium sand with clay balls.
			0.5 to 1.5	10YR 7/2 gray	Clean, fine to medium sand.
			1.5 to 2.0	7.5YR 5/8 brown	Clean, medium to coarse sand.
			2.0 to 3.3	10YR 6/3 gray	Fine to very coarse sand with rounded pebbles.
			3.3 to 5.0	2.5Y 8/2 white	Clean, medium, moderately well-sorted sand.
29	40	11.0	0 to 1.0	2.5Y 7/2 gray	Clean, fine sand.
			1.0 to 10.5	10YR 8/2 gray	Clean, medium to coarse, moderately well-sorted sand.
			10.5 to 11.0	2.5Y 8/2 white	Clean, fine sand.

Table A-1. Sediment description of Coastal Engineering Research Center cores from Long Island south shore.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Color code	Description
30	36	13.0	0 to 13.0	2.5Y 8/2 white	Clean, fine to medium, moderately sorted sand.
31	47	11.4	0 to 11.4	10YR 8/2 white	Clean, fine to medium sand.
32	19	7.0	0 to 5.0	10YR 8/2 white	Clean, medium to coarse sand.
			5.0 to 7.0	5Y 6/3 gray	Silty, fine to coarse sand with quartz pebbles.
33	54	6.0	0 to 6.0	2.5Y 8/2 white	Clean, fine to medium, moderately well-sorted sand.
34	51	10.0	0 to 10.0	10YR 8/2 white	Clean, medium to coarse sand with rounded gravel.
35	30	10.5	0 to 2.0	10YR 8/3 white	Clean, coarse to very coarse sand with gravel $\leq$ 1-inch diameter.
			2.0 to 6.0	2.5Y 8/2 white	Clean, medium to coarse sand.
			6.0 to 10.5	10YR 8/6 yellow	Medium to coarse sand with gravel $\leq$ 1-inch diameter.
36	44	9.0	0 to 3.0	10YR 7/2 gray	Clean, fine, moderately sorted sand.
			3.0 to 6.0	10YR 6/1 gray	Silty, fine sand.
			6.0 to 8.0	5Y 7/1 gray	Clean, fine to medium sand.
			8.0 to 9.0	5Y 8/1 white	Clean, fine to very coarse sand.
37	32	5.3	0 to 2.5	5Y 6/1 gray	Very fine to fine sand with abundant opaque heavy minerals.
			2.5 to 4.0	2.5Y 7/2 light gray	Very fine to very coarse sand, rounded pebbles, large shells at —4 feet.
			4.0 to 5.3	10YR 8/1 white	Clean, very fine to fine sand.
38	45	9.2	0 to 1.0	5Y 8/3 yellow	Clean, fine to medium sand.
			1.0 to 5.0	5Y 7/1 gray	Silty to very fine sand.
			5.0 to 6.0	5Y 6/1 gray	Silty, medium to coarse sand.
			6.0 to 7.0	5Y 7/1 gray	Silty to very fine sand.
			7.0 to 9.2	2.5Y 8/2 white	Clean, fine to medium, moderately well-sorted sand.
39	32	8.0	0 to 2.0	5Y 6/1 gray	Silty, fine to medium sand.
			2.0 to 4.0	10YR 6/1 gray	Silt.
			4.0 to 4.7		Organic peat (see Table 4 for radiocarbon date).
			4.7 to 8.0	10YR 7/1 gray	Silty, fine to medium sand with scattered pebbles from 5.3 to 6.1 feet.

Table A-1. Sediment description of Coastal Engineering Research Center cores from Long Island south shore.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Color code	Description
61	68	6.0	0 to 6.0	5Y 7/2 gray	Clean, fine, well-sorted sand.
62	44	4.8	0 to 4.8	2.5Y 8/2 white	Clean, medium to coarse sand.
63	42	6.5	0 to 6.5	10YR 8/1 white	Clean, medium, well-sorted sand.
64	45	5.0	0 to 5.0	2.5Y 7/2 light gray	Clean, fine to medium, moderately well-sorted sand.
65	31	5.8	0 to 5.8	10YR 8/1 white	Clean, very fine to fine, well-sorted sand.
66	44	2.7	0 to 1.0	2.5Y 8/2 yellow	Clean, fine to medium, well-sorted sand.
			1.0 to 1.5	2.5Y 6/2 gray	Silty, very fine to fine sand.
			1.5 to 2.7	2.5Y 8/6 yellowish-gray	Clean, fine to medium sand.
67	48	17.2	0 to 0.5	5Y 5/1 gray	Silty mud.
			0.5 to 2.0	5Y 6/2 light gray	Clean, medium to coarse sand with small rounded rock fragments.
			2.0 to 9.0	5Y 7/2 gray	Clean, medium sand.
			9.0 to 9.8	5Y 5/1 gray	Silty, very fine to fine sand.
			9.8 to 12.9	5Y 6/1 gray	Cohesive clay.
			12.9 to 13.2		Organic peat (see Table 4 for radiocarbon date).
			13.2 to 17.2	5Y 5/1 gray	Silt grading to medium sand for bottom 0.3 foot.
68	84	6.0	0 to 1.0	5Y 5/3 gray	Medium to coarse, moderately sorted sand with some pea gravel $\leq$ 1-inch diameter.
			1.0 to 3.0	10YR 6/6 light brown	Fine to coarse sand with rounded gravel.
			3.0 to 6.0	5Y 7/1 gray	Very fine to fine sand with abundant mica plates.
69	95	17.3	0 to 2.0		Clean, fine to medium sand.
			2.0 to 2.1	5Y 5/1 gray	Clay to very fine sand.
			2.1 to 17.3	10YR 7/3 brown	Clean, fine to medium sand.
70	90	12.0	0 to 1.0	2.5Y 7/3 yellow	Clean, fine, poorly sorted sand.
			1.0 to 2.0	2.5Y 8/2 white	Slightly silty, coarse to very coarse sand.
			2.0 to 12.0	10YR 8/3 white	Clean, silty, very fine, moderately well-sorted sand.

Table A-1. Sediment description of Coastal Engineering Research Center cores from Long Island south shore.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Color code	Description
71	52	8.4	0 to 0.5	5Y 5/3 gray	Silty, fine to coarse sand with rounded pebbles $\leq$ 1-inch diameter.
			0.5 to 5.0	5Y 8/2 white	Clean, medium to coarse, very well-sorted sand.
			5.0 to 8.4	2.5Y 8/3 white	Clean, medium to very coarse sand.
72	30	5.0	0 to 4.0	5Y 7/2 gray	Silty, very fine to fine sand.
			4.0 to 5.0	2.5Y 8/6 yellow	Clean, fine to medium sand.
73	50	15.0	0 to 5.0	5Y 6/1 gray	Silt and clay.
			5.0 to 6.0		Organic peat (see Table 4 for radiocarbon date).
			6.0 to 12.5	5Y 6/2 gray	Silt to clay.
			12.5 to 15.0	5Y 6/2 gray	Silty, fine sand with wood fragments.
74	63	4.0	0 to 1.0	5Y 6/2 gray	Silty, fine sand.
			1.0 to 4.0	5Y 8/2 white	Clean, medium to coarse sand.
75	73	10.0	0 to 10.0	5Y 8/2 white	Clean, fine to medium sand.
76	69	3.5	0 to 1.0	5Y 6/2 gray	Fine sand and mud mixture.
			1.0 to 3.5	5Y 7/2 gray	Clean, very fine to fine sand.
77	72	18.0	0 to 18.0	2.5Y 8/2 white	Clean, fine to medium sand.
78	42	5.8	0 to 5.8	2.5Y 8/2 white	Clean, fine to medium, moderately well-sorted sand.
79	50	17.0	0 to 1.0	5Y 7/2 gray	Very fine to fine sand.
			1.0 to 2.0	5Y 6/1 gray	Micaceous silt or clay with rounded pebbles.
			2.0 to 6.0	5Y 6/1 gray	Silt to fine sand.
			6.0 to 15.0	5Y 6/1 gray	Micaceous silt.
			15.0 to 17.0	5Y 6/2 gray	Fine to medium sand with rounded pea gravel.
110	60	16.5	0 to 8.0	5Y 8/2 white	Clean, very fine to fine sand.
			8.0 to 16.0	5Y 6/1 gray	Silt.
			16.0 to 16.5	10YR 6/6 brown	Fine sand.

Table A-1. Sediment description of Coastal Engineering Research Center cores from Long Island south shore.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Color code	Description
111	82	6.7	0 to 1.7	5Y 5/3 gray	Fine to medium sand with rounded pea gravel.
			1.7 to 2.3	5Y 6/2 light green	Very fine to fine, glauconitic sand.
			2.3 to 5.0	5Y 6/2 light green	Fine to very coarse, glauconitic sand and rounded quartz gravel.
			5.0 to 6.7	5Y 8/1 white	Fine to medium sand and rounded quartz gravel.
112	80	4.7	0 to 4.7	10YR 7/4 brown	Clean, fine to medium, moderately well-sorted sand.
113	82	15.3	0 to 2.9	10YR 7/3 brown	Clean, fine to medium sand.
			2.9 to 15.3	5Y 5/6 green	Medium, glauconitic sand.
114	68	11.0	0 to 6.0	2.5Y 8/2 white	Clean, fine to medium sand.
			6.0 to 8.0	2.5Y 8/2 white	Clean, fine to coarse sand.
			8.0 to 11.0	5Y 8/2 white	Clean, very fine to fine, well-sorted sand.
115	92	15.0	0 to 14.0	2.5Y 8/2 white	Clean, fine to medium sand.
			14.0 to 15.0	2.5Y 6/4 brown	Medium to very coarse sand with rounded pea gravel at bottom.
116	105	19.0	0 to 4.0	5Y 7/2 olive	Silty, fine to medium, moderately well-sorted sand.
			4.0 to 7.0	5Y 6/3 gray	Clean, coarse to very coarse sand and pea gravel.
			7.0 to 10.0	5Y 7/1 gray	Fine to medium sand.
			10.0 to 19.0	2.5Y 8/2 white	Clean, fine to medium, moderately sorted sand.
117	68	12.2	0 to 12.2	5Y 7/2 gray	Clean, very fine to fine, moderately well-sorted sand.
118	81	13.0	0 to 4.0	2.5Y 7/2 gray	Fine to medium sand.
			4.0 to 11.0	10YR 8/6 yellowish-brown	Fine to medium sand.
			11.0 to 13.0	10YR 6/5 brown	Fine to medium sand with rounded gravel.
119	66	5.0	0 to 1.0	2.5Y 8/2 white	Clean, fine to medium sand.
			1.0 to 3.0	5Y 6/3 gray	Fine to medium, moderately well- to well-sorted sand.
			3.0 to 5.0	10YR 8/2 white	Clean, fine to medium sand.
120	63	6.3	0 to 6.3	10YR 7/3 brown	Clean, very fine to fine, well-sorted sand.
121	68	7.0	0 to 7.0	5Y 7/2 gray	Silty, very fine to fine sand with mica.

Table A-2. Sediment description from Nassau County cores.¹

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Description
1	53	8.5	2.5	Coarse sand.
			5.0	Coarse sand.
			7.5	Fine sand.
2	36	8.3	0 to 4.0	Brown, medium sand with shell fragment.
			4.0 to 7.0	Gray-brown, fine sand.
			7.0 to 8.3	Coarse sand.
3	45	10.5	0 to 1.0	Brown, medium sand.
			1.0 to 6.0	Gray, medium sand with shell fragment.
			6.0 to 10.5	Greenish-gray, silty clay.
4	56	11.5	0 to 9.0	Medium sand.
			2.0 to 11.5	Clay and silt.
5	52	11.4	0 to 3.0	Brown, medium sand.
			3.0 to 6.0	Gray, medium sand with shell fragment.
			6.0 to 10.0	Gray, coarse sand with shell fragment.
			10.0 to 11.4	Dark green, silty glauconitic sand.
6	58	10.8	2.5	Medium sand.
			5.0	Fine sand.
			6.7 to 10.8	Clay and silt.
7	62	7.2	0 to 0.5	Brown, medium sand.
			0.5 to 7.2	Greenish-gray, glauconitic clay.
8	63	6.3	0 to 4.5	Grayish-brown, coarse sand.
			4.5 to 6.3	Light brown, medium sand.
9	34	14.2	0 to 2.5	Light brown, fine sand.
			2.5 to 6.0	Gray, fine sand.
			6.0 to 14.2	Brown, medium sand.
10	56	8.0	2.5	Medium sand.
			5.0	Fine sand.
			6.0 to 6.7	Very coarse sand.
			7.5	Medium sand.
11	47	9.2	0 to 2.0	Brown, medium sand.
			2.0 to 9.2	Dark greenish-gray, glauconitic clay.

Table A-2. Sediment description from Nassau County cores.—Continued¹

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Description
14	52	8.3	2.5	Coarse sand with pebbles.
			5.0	Coarse sand with pebbles.
			7.5	Very coarse sand with pebbles.
15A	38	11.3	0 to 1.0	Brown, medium sand.
			1.0 to 11.3	Gray, medium sand.
16	45	5.3	2.5 to 5.0	Medium sand.
17	65	5.4	0 to 2.0	Brown, medium sand with shells.
			2.0 to 5.4	Clay.
18	74	5.8	0 to 5.8	Grayish-brown, medium sand.
19	77	10.0	0 to 1.5	Brown, medium sand.
			1.5 to 3.5	Brown and black, medium sand.
			3.5 to 4.5	Brown, medium sand.
			4.5 to 5.5	Coarse sand with pebbles.
			5.5 to 8.0	Brown, fine sand.
			8.0 to 10.0	Clay.
20	78	6.1	2.5 to 5.0	Medium sand.
21	60	6.2	0 to 4.0	Gray, coarse sand.
			4.0 to 6.2	Gray, medium sand.

1. The Nassau County, Long Island, cores (Fig. 2) were obtained in 1966 by Alpine Geophysical Associates, Incorporated for an engineering study of a sewer outfall offshore from Jones Beach. Only incomplete log descriptions were provided CERC by Alpine. Water depths (derived from map location of each core) are approximate.

Table A-3. Sediment description from Nassau County cores.¹

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Description
239	+2.5	65.0	0 to 10.0 10.0 to 65.0	Loose, white, fine sand with shells. Very dense, white, fine sand with shells and small gravel.
240	-18.8	45.0	0 to 12.0 12.0 to 44.0 44.0 to 45.0	Dense, gray, fine to medium sand with shells, silt, and gravel. Dense to firm, gray, fine to medium sand with silt. Firm, dark brown to gray, clayey sand; trace of gravel.
241	-21.9	55.0	0 to 12.0 12.0 to 22.0 22.0 to 29.0 29.0 to 35.0 35.0 to 37.0 37.0 to 41.5 41.5 to 49.0 49.0 to 55.0	Firm, gray and brown, fine to medium sand with silt and shells. Firm, gray, fine to coarse sand with gravel and shells. Firm, brown, fine to coarse sand with shell and gravel. Firm, gray, fine sand with silt. Gray, silty clay with some sand and gravel. Dark gray, silty clay with layers of fine sand. Firm, brown, fine-coarse sand; trace of small gravel. Very stiff, black and gray, silty clay.
242	-28.0	30.3	0 to 0.5 0.5 to 1.1 1.1 to 2.5 2.5 to 30.3	Black, silty clay. Gray, fine-coarse sand with shells. White, medium-coarse sand. White, fine sand.
243	-31.0	30.3	0 to 1.5 1.5 to 1.8 1.8 to 15.2 15.2 to 15.6 15.6 to 19.8 19.8 to 20.2 20.2 to 30.3	White, fine sand. White, fine sand with shells. White, fine sand. White, fine sand with shells. White, fine sand. Gray, fine sand. White, fine sand.
244	-33.4	30.3	0 to 7.8 7.8 to 11.2 11.2 to 11.9 11.9 to 13.3 13.3 to 19.7 19.7 to 20.1 20.1 to 20.5 20.5 to 23.0 23.0 to 24.4 24.4 to 26.6 26.6 to 30.3	Light gray to white, fine sand with shell fragments. White, fine sand. Light gray to white, fine sand with shell fragments. Black, clayey silt. Black clay. Black sand with some organic matter. Light gray, coarse to medium sand; trace of small gravel. Dark gray, medium sand with layers of small to large gravel. Brown sand and small gravel. Light brown, fine sand. White, fine sand.
245	-34.5	30.3	0 to 0.5 0.5 to 10.8 10.8 to 11.0 11.0 to 16.0 16.0 to 16.6 16.6 to 18.0 18.0 to 21.4 21.4 to 23.1 23.1 to 23.9 23.9 to 26.0 26.0 to 29.5 29.5 to 29.7 29.7 to 30.3	Light gray, fine to medium sand with some shell fragments. White, fine sand. Light gray, fine sand with seashell fragments. Black, soft to stiff clay. Light brown, fine sand. White sand and gravel up to ¾-inch diameter. Light brown to white sand with some gravel. Light brown, fine to medium sand; trace of gravel. Brown sand and small gravel. Light brown to white, fine sand. Black clay. Black, fine sand. Black clay.

Table A-3. Sediment description from Nassau County cores.—Continued¹

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Description
246	-36.4	30.2	0 to 17.0 17.0 to 25.0 25.0 to 26.0 26.0 to 29.0 29.0 to 30.2	Light gray, fine sand. Black clay. White, fine sand. White, fine to coarse sand with some gravel. White, fine to coarse sand.
247	-40.8	30.0	0 to 21.0 21.0 to 24.0 24.0 to 30.0	White, fine sand. No samples available. Black clay.
248	-44.6	30.3	0 to 2.9 2.9 to 10.1 10.1 to 10.6 10.6 to 12.5 12.5 to 13.3 13.3 to 21.2 21.2 to 22.2 22.2 to 24.7 24.7 to 30.3	Black sand with shells. White, fine sand. White, fine sand with large shells. Gray sand. Gray sand with shells. White, fine sand. Black clay. Black clay. Black clay.
249	-49.0	28.5	0 to 1.7 1.7 to 14.7 14.7 to 19.0 19.0 to 27.5 27.5 to 28.5	Black and white sand, layered with shells. White, fine sand. Gray, silty, fine sand; trace of seashells. Gray clay; trace of fine sand. Gray, silty, fine sand; trace of clay.
250	-48.0	28.0	0 to 0.4 0.4 to 3.4 3.4 to 3.9 3.9 to 5.4 5.4 to 18.6 18.6 to 21.3 21.3 to 26.3 26.3 to 28.0	Black, fine sand. Black, sandy clay. Brown and gray clay; evidence of previous exposure to weathering above water table. Black and gray clay. White, fine sand. Black clay. Black clay. Black, fine to medium sand.
251	-50.1	30.0	0 to 18.0 18.0 to 29.6 29.6 to 30.0	White, fine sand. Black and gray clay. Black, fine to medium sand.
252	-51.4	29.0	0 to 2.6 2.6 to 6.3 6.3 to 16.0 16.0 to 29.0	White sand and seashells; black inclusions at 0.5 to 10 feet. White, fine sand. White, fine sand with layers of shells from -8.7 to -13.7 feet. Black and gray clay.
253	47.2	30.0	0 to 0.8 0.8 to 19.5 19.5 to 24.7 24.7 to 28.3 28.3 to 30.3	Gray, fine sand with shells. White, fine sand; layer of shells from -5.7 to -8.8 feet. Black clay. Black, fine sand with layers of black clay; layer thicknesses vary from less than ¼ to over 2 inches. Gray clay.

1. These cores (locations given in Figure 8) were taken along a proposed sewer outfall line in Nassau County off Tobay Beach. Descriptions were obtained from the Testing Service Corporation (1969). Visual logs of the cores are shown in Figure 9C.

Table A-4. Sediment description from Suffolk County sewer outfall cores.¹

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Description
V-26	18	9.3	0 to 1.2	Light gray, very fine to fine sand.
			1.2 to 1.5	Black, clayey silt.
			1.5 to 3.5	Light gray to tan, medium, gravelly sand.
			3.5 to 4.5	Medium sand with shells.
			4.5 to 4.6	Black, silty clay.
			4.6 to 7.0	Medium, pebbly sand with shells.
			7.0 to 9.3	Fine sand.
V-25	28	22.0	0 to 3.0	Silty, fine to medium sand.
			3.0 to 4.0	Medium to coarse sand.
			4.0 to 5.0	Light gray, medium sand and gravel with shells.
			5.0 to 8.0	Fine to medium sand.
			8.0 to 9.0	Silty clay with abundant mica; occasional very fine sand layers.
			9.0 to 11.2	Fine to medium sand.
			11.2 to 12.0	Fine to medium sand.
			12.0 to 17.0	Fine to coarse sand; shelly at top and gravelly at bottom; occasional clay balls between 14 and 15 feet.
			17.0 to 19.0	Medium, gravelly sand.
			19.0 to 20.7	Light gray, fine to medium sand.
			20.7 to 22.0	Light gray, fine to medium sand with gravel at bottom.
V-16	35	21.0	0 to 1.1	Greenish-black, fine sand with mica.
			1.1 to 1.5	Gray, medium sand with shells.
			1.5 to 2.5	Gray, fine sand.
			2.5 to 8.6	Dark gray, sandy silt.
			8.6 to 9.3	Black, organic clayey silt.
			9.3 to 15.8	Gray, fine to medium sand.
			17.0 to 21.0	Light gray, fine to coarse sand.
			21.0 to 21.6	Coarse sand and small gravel.
V-17	42	19.0	0 to 0.5	Tan, medium sand.
			0.5 to 0.7	Black, silty sand.
			0.7 to 1.0	Gray, fine to medium sand.
			1.0 to 1.7	Sandy gravel with large shell fragments.
			1.7 to 3.1	Light gray, fine to medium sand with shells.
			3.1 to 3.9	Dark gray, sandy silt.
			3.9 to 6.8	Tan, fine to medium sand with thin clay lenses.
			8.8 to 8.8	Brown, silty sand.
			8.8 to 9.0	Brown, compact clay.
			9.0 to 17.8	Fine to medium sand with scattered pebbles.
			17.8 to 19.0	Fine to medium sand with layering of dark minerals.

1. These cores (Fig. 8) are located along two nearly shore-normal transects in Suffolk County off Tobay and Cedar Beaches. Sediment descriptions were obtained from Alpine Geophysical Associates, Incorporated. Visual logs of the cores are shown in Figures 9A and 9B. Water depths, based on map location of each core, are approximate.

Table A-4. Sediment description from Suffolk County sewer outfall cores.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Description
V-18	49	21.0	0 to 6.8 6.8 to 21.0	Light to dark gray, fine to medium sand with pebbles and shells. Tan, compact sand with layers of dark minerals.
V-19	52	18.5	0 to 0.5 0.5 to 1.5 1.5 to 12.5 12.5 to 12.8 12.8 to 18.5	Yellowish-brown, medium sand. Dark gray, silty sand. Sand with gray clay lenses. Brown sand with dark brown clay lenses. Tannish-gray, fine to medium sand with layers of dark minerals.
V-20	55	21.1	0 to 0.6 0.6 to 15.0 15.0 to 21.1	Gray, medium to coarse sand with large shells. Gray, fine to medium compact sand with mica and dark minerals. Medium sand with dispersed dark minerals.
V-21	57	17.0	0 to 1.8 1.8 to 2.4 2.4 to 12.5 12.5 to 17.0	Gray, fine sand. Gray, medium to coarse sand with shells. Gray, fine sand with organic clay layer at 6.9 feet. Yellowish-brown, fine sand with thin layer of dark minerals (glauconitic?).
V-22	59	26.8	0 to 4.8 4.8 to 10.0 10.0 to 16.0 16.0 to 21.8 21.8 to 25.0 25.0 to 26.0 26.0 to 26.9	Gray, fine to medium sand with shell hash layers. Fine to coarse sand. No sample available. Gray, medium to coarse sand with occasional wood fragments. Dark gray, stiff clay; possibly overconsolidated. Sandy, pebbly gravel. Greenish, glauconite sand.
V-23	65	22.0	0 to 14.9 14.9 to 17.5 17.5 to 18.0 18.0 to 22.0	Light gray, fine to medium sand. Mottled gray and black, overconsolidated clay. Sandy, pebbly gravel with shell hash. Dark green to black, micaceous silt.
V-24	73	20.7	0 to 1.4 1.4 to 3.8 3.8 to 8.0 8.0 to 12.8 12.8 to 12.9 12.9 to 13.5 13.5 to 20.7	Gray to brown, medium sand. Gray, medium sand with large shells. Gray, fine to medium sand. Dark gray, compact, silty clay. Large, pebbly gravel. Dark green to black, very compact, silty, micaceous sand. Dark green to black, silty sand with some gravel.
V-15	17	35.3	0 to 0.5 0.5 to 11.0 11.0 to 11.5 11.5 to 17.7 17.7 to 19.5 19.5 to 22.6 22.6 to 28.8 28.8 to 35.3	White, fine to medium sand with few pebbles. Light gray, fine to medium sand. Medium sand with shells and few pebbles. Light gray, fine sand. Dark gray sand with possible erosion of surface. Dark gray, fine to medium sand. Yellowish-brown sand and small gravel. Light gray, fine, compact sand with thin bands of dark minerals.

Table A-4. Sediment description from Suffolk County sewer outfall cores.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Description
V-1	26	39.4	0 to 1.2	Light brown, medium to coarse sand.
			1.2 to 1.3	Black, silty clay.
			1.3 to 1.8	Medium to coarse sand with shell and gravel.
			1.8 to 8.8	Light gray, fine to medium sand.
			8.8 to 9.3	Gray, sandy silt with shells.
			9.3 to 11.2	Silty clay with thin, sandy lenses.
			11.2 to 12.0	Fine, sandy silt.
			12.0 to 13.5	Gray, silty, fine sand.
			13.5 to 15.0	Fine to medium sand with shells.
			15.0 to 16.0	Sandy, silty, small gravel.
			16.0 to 18.4	Light gray, fine to medium, silty sand.
			18.4 to 19.4	Sandy, small gravel.
			19.4 to 37.0	Gray, fine to medium sand.
			37.0 to 38.0	Sandy, fine gravel.
			38.0 to 38.4	Dark gray, stiff clay.
			38.4 to 39.4	Gray, medium to coarse sand.
V-14	32	37.8	0 to 2.7	Gray, medium sand.
			2.7 to 3.3	Dark gray, fine sand with mica.
			3.3 to 3.8	Dark gray clay.
			3.8 to 9.2	Dark gray, fine sand.
			9.2 to 9.6	Dark gray clay.
			9.6 to 16.0	Dark gray, fine sand.
			16.0 to 18.9	Dark gray, compact clay.
			18.9 to 21.4	Dark gray, fine to medium sand.
			21.4 to 23.3	Dark gray, medium sand with gravel.
			23.3 to 27.9	Gray, fine to medium sand.
			27.9 to 30.7	No sample available.
			30.7 to 37.8	Gray, fine to medium sand.
V-13	38	33.7	0 to 1.1	Gray, medium sand with shells.
			1.1 to 16.3	Light gray, fine to medium sand.
			16.3 to 20.0	No sample available.
			20.0 to 24.0	Light gray, fine to medium sand.
			24.0 to 28.3	No sample available.
			28.3 to 33.7	Gray, fine to medium sand with silt lenses.
V-7	42	36.6	0 to 0.8	Gray, fine to medium sand with large shell fragments.
			0.8 to 25.5	Gray, fine to medium sand.
			25.5 to 32.0	No sample available.
			32.0 to 35.4	Gray, fine to medium sand.
			35.4 to 36.6	Dark green to black, fine to medium sand.

Table A-4. Sediment description from Suffolk County sewer outfall cores.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Description
V-6	45	37.5	0 to 0.7	Fine to medium sand.
			0.7 to 0.8	Black, soft, inorganic silt.
			0.8 to 9.0	Light, fine to medium sand with shell fragments.
			9.0 to 11.3	No sample available.
			11.3 to 12.4	Light gray, medium sand with shell fragments.
			12.4 to 18.5	Sand with lenses of dark brown peat.
			18.5 to 23.9	Light gray, fine to medium sand.
			23.9 to 26.3	No sample available.
			26.3 to 27.0	Tan, fine to medium sand with pebbles and shells.
			27.0 to 32.5	Gray, fine to medium sand.
			32.5 to 33.5	No sample available.
			33.5 to 36.0	Gray, fine to medium sand with shell fragments.
			36.0 to 36.3	Brown to black silt.
			36.3 to 37.5	Dark gray, fine to medium sand.
V-2	48	40.0	0 to 36.5	No sample available.
			36.5 to 36.9	Gray, gravelly sand.
			36.9 to 40.0	Black, silty clay.
V-3	52	36.8	0 to 1.75	Dark gray, compact clay.
			1.8 to 11.2	Tan, fine to medium sand with gravel.
			11.2 to 21.3	Gray, fine to medium sand with thin layers of dark minerals.
			21.3 to 31.9	Gray, very compact clay.
			31.9 to 35.0	Dark gray to black, fine to medium sand.
			35.0 to 35.3	Poorly sorted gravel.
V-4	55	40.0	35.3 to 36.8	Black, very compact clay with abundant mica.
			0 to 1.0	Gray, medium sand.
			1.0 to 2.0	Gray, medium to coarse sand with shell fragments.
			2.0 to 12.0	Gray, medium sand with shell.
			12.0 to 13.5	Fine to medium, clean sand.
			13.5 to 14.5	No sample available.
			14.5 to 18.5	Gray, fine to medium sand with thin layers of silty, micaceous sand.
			18.5 to 22.6	No sample available.
			22.6 to 23.5	Medium sand.
			23.5 to 25.3	Dark gray, silty clay.
			25.3 to 27.0	No sample available.
			27.0 to 27.5	Dark gray, silty clay.
			27.5 to 29.8	Fine sand with silt lenses.
			29.8 to 30.2	Sandy gravel with some clay.
			30.2 to 40.0	Dark green to brown, silty, sandy, micaceous clay.

Table A-4. Sediment description from Suffolk County sewer outfall cores.—Continued

Core no.	Water depth (feet)	Core length (feet)	Interval (feet)	Description
V-5	58	40.0	0 to 16.2	Light gray, medium sand with shell fragments and thin layers of mica.
			16.2 to 17.8	Gray to black, silty clay.
			17.8 to 21.0	No sample available.
			21.0 to 25.2	Gray to black, silty clay.
			25.2 to 26.0	Dark green to black, medium sand.
			26.0 to 27.8	No sample available.
			27.8 to 28.4	Black, silty, sandy gravel.
			28.4 to 40.0	Dark green to black, silty clay.
V-8	60	35.9	0 to 4.1	Brown, silty sand.
			4.1 to 12.0	Light gray, fine to medium sand with occasional thin clay layers.
			12.0 to 14.4	Gray, compact clay.
			14.4 to 19.2	Greenish-black, fine to coarse sand.
			19.2 to 20.6	Greenish-black, sandy gravel.
			20.6 to 35.9	Greenish-black, very compact clay.
V-9	55	38.2	0 to 13.5	Gray, fine to medium sand with thin clay-silt layers.
			13.5 to 18.0	Gray, fine to medium sand.
			18.0 to 18.7	Gray, compact clay.
			18.7 to 19.0	Greenish-black, medium sand.
			19.0 to 20.3	No sample available.
			20.3 to 20.7	Greenish-black, fine to medium sand.
			20.7 to 21.0	Greenish-black sand and gravel.
			21.0 to 31.0	No sample available.
V-10	53	38.2	31.0 to 38.2	Greenish-black, compact clay.
			0 to 14.0	Tannish-gray, fine to medium sand with occasional layers of silty, fine sand.
			14.0 to 19.4	No sample available.
			19.4 to 23.0	Gray, fine to medium sand.
			23.0 to 28.6	Gray, compact clay.
			28.6 to 28.8	Dark gray gravel.
			28.8 to 33.8	No sample available.
			33.8 to 38.2	Greenish-black, compact clay.
V-11	60	29.6	0 to 13.3	Fine to medium sand.
			13.3 to 13.8	Greenish-black, fine to medium sand with 1- to 2-inch gravel.
			13.8 to 29.6	Greenish-black, silty clay with abundant mica.
V-12	71	36.8	0 to 1.3	Gray sand with shell fragments and gravel.
			1.3 to 7.3	Gray, fine to medium sand becoming coarser with depth.
			7.3 to 9.1	Greenish-black sandy gravel; some gravel 2 inches in diameter.
			9.1 to 36.8	Greenish-black very fine sand and silty clay.

Table A-5. Description of beach borings shown in Figure 12.

Boring number	Location	Elevation (feet)	Sediment thickness (feet)	Horizon depth below MSL (feet)	Horizon thickness (feet)	Classification	Median diameter (millimeters)
1	South end, Lake Montauk Harbor	-2.6	26.5	-2.6 to -29.1	26.5	Silt or clay	
2	West side, Fort Pond	-0.9	26.0	-0.9 to -26.9	26.0	Silt or clay	
3	East side, Napeague Harbor	-2.1	25.5	-2.1 to 27.6	25.5	Uniform medium sand	0.6 to 0.3
4	West side, Napeague Harbor	-2.0	25.0	-2.0 to -27.0	25.0	Uniform medium sand	0.6 to 0.3
5	West end, Hook Pond	+1.1	25.0	+1.1 to -0.4	1.5	Medium to coarse sand with gravel	2.0 to 0.4
				-0.4 to -3.6	3.2	Uniform medium sand	0.6 to 0.3
				-3.6 to -10.8	7.2	Silt or clay	
				-10.8 to -15.9	5.1	Uniform medium sand	0.6 to 0.3
				-15.9 to -20.9	5.0	Medium to coarse sand with gravel	2.0 to 0.4
				-20.9 to -23.9	3.0	Uniform medium sand	0.6 to 0.3
6	Georgica Pond	-1.0	26.5	-1.0 to -9.5	8.5	Uniform medium sand	0.6 to 0.3
				-9.5 to -27.5	18.0	Silt or clay	
7	Center of Sagaponack Lake	-0.7	27.5	-0.7 to -4.9	4.2	Uniform medium sand	0.6 to 0.3
				-4.9 to -6.4	1.5	Silt or clay	
				-6.4 to -28.2	21.8	Medium to coarse sand with gravel	2.0 to 0.4
8	South end, Mecox Bay	-1.9	27.0	-1.9 to -10.7	8.8	Uniform medium sand	0.6 to 0.3
				-10.7 to -28.9	18.2	Silt or clay	
9	2.5 miles east of Shinnecock Inlet, Shinnecock Bay	-3.3	28.1	-3.3 to -6.8	3.5	Uniform medium sand	0.6 to 0.3
				-6.8 to -10.6	3.8	Medium to coarse sand with gravel	2.0 to 0.4
				-10.6 to -15.8	5.2	Uniform medium sand	0.6 to 0.3
				-15.8 to -28.8	13.0	Medium to coarse sand with gravel	2.0 to 0.4
				-28.8 to -31.4	2.6	Uniform medium sand	0.6 to 0.3
10	0.3-mile west of Shinnecock Inlet, Shinnecock Bay	-0.6	25.0	-0.6 to -1.7	1.1	Silt or clay	
				-1.7 to -19.6	17.9	Uniform medium sand	0.6 to 0.3
				-19.6 to -25.6	6.0	Medium to coarse sand with gravel	2.0 to 0.4
11	1.2 miles west of Shinnecock Inlet, Shinnecock Bay	-1.9	26.5	-1.9 to -23.0	21.1	Silt or clay	
				-23.0 to -28.4	5.4	Uniform medium sand	0.6 to 0.3
12	West end of Shinnecock Bay	-1.1	25.0	-1.1 to -26.1	25.0	Uniform medium sand	0.6 to 0.3
13	East side, Quantuck Bay	-2.2	26.7	-2.2 to -15.4	13.2	Uniform medium sand	0.6 to 0.3
				-15.4 to -26.3	10.9	Silt or clay	
				-26.3 to -28.9	2.6	Medium to coarse sand with gravel	2.0 to 0.4

Table A-5. Description of beach borings shown in Figure 13.—Continued

Boring number	Location	Elevation (feet)	Sediment thickness (feet)	Horizon depth below MSL (feet)	Horizon thickness (feet)	Classification	Median diameter (millimeters)
14	West side, Quantuck Bay	-1.3	28.0	-1.3 to -4.5 -4.5 to -20.4 -20.4 to -29.3	3.2 15.9 8.9	Fine to medium sand Silt or clay Uniform medium sand	0.4 to 0.06 0.6 to 0.3
15	3.8 miles east of Moriches Inlet, Moriches Bay	-2.5	29.0	-2.5 to -3.8 -3.8 to -5.5 -5.5 to -8.0 -8.0 to -14.5 -14.5 to -19.5 -19.5 to -24.0 -24.0 to -31.5	1.3 1.7 2.5 6.5 5.0 4.5 7.5	Uniform medium sand Silt or clay Uniform medium sand Fine to medium sand Uniform medium sand Fine to medium sand Uniform medium sand	0.6 to 0.3 0.6 to 0.3 0.4 to 0.06 0.6 to 0.3 0.4 to 0.06 0.6 to 0.3
16	3.7 miles west of Moriches Inlet, Moriches Bay	-1.6	27.0	-1.6 to -18.5 -18.5 to -28.6	16.9 10.1	Uniform medium sand Fine to medium sand	0.6 to 0.3 0.4 to 0.06
17	Narrow Bay off Mastie Beach	-2.0	27.0	-2.0 to -7.5 -7.3 to -29.0	5.3 21.7	Silt or clay Uniform medium sand	0.6 to 0.3
18	Great South Bay	-2.0	25.5	-2.0 to -7.5 -7.5 to -9.9 -9.9 to -20.8 -20.8 to -27.5	5.5 2.4 10.9 6.7	Uniform medium sand Silt or clay Fine to medium sand Uniform medium sand	0.6 to 0.3 0.4 to 0.06 0.6 to 0.3
19	Great South Bay	-4.0	25.5	-4.0 to -21.3 -21.3 to -26.4 -26.4 to -29.5	17.3 5.1 3.1	Fine to medium sand Silt or clay Uniform medium sand	0.4 to 0.06 0.6 to 0.3
20	Great South Bay	-1.9	26.0	-1.9 to -27.9	26.0	Uniform medium sand	0.6 to 0.3
21	6.5 miles east of the western tip of Fire Island	-5.4	27.5	-5.4 to -12.3 -12.3 to -32.4	7.2 20.3	Silt or clay Fine to medium sand	0.4 to 0.06

Taney (1961)

Table A-6. Descriptive logs of two borings located south of Atlantic and Long Beaches, Long Island¹
(locations in Figure 2).

Boring 56-½	Boring 116
<p>Longitude: 73° 44' 22.38" W. Latitude: 40° 33' 52.93" N. Water depth: 40.8 feet (12.4 meters) Boring interval in feet</p>	<p>Longitude: 73° 39' 44.35" W. Latitude: 40° 34' 07.42" N. Water depth: 27.8 feet (8.5 meters) Boring interval in feet</p>
<p>0 to 3.8 gray, fine to coarse sand with pea gravel.</p> <p>3.8 to 6.0 pea gravel with brown, coarse sand.</p> <p>6.0 to 13.0 gray, firm, stiff, silty clay.</p> <p>13.0 to 14.5 fine, sandy clay with clay seams and pockets.</p> <p>14.5 to 18.0 gray, fine sand.</p> <p>18.0 to 20.0 intermixed clay, silt, and sand.</p>	<p>0 to 1.0 brown, medium sand.</p> <p>1.0 to 3.0 gray, coarse sand with pea gravel.</p> <p>3.0 to 9.5 light gray, medium to coarse sand with shell and pea gravel.</p> <p>9.5 to 13.0 silty clay.</p> <p>13.0 to 18.0 gray and tan clay.</p> <p>18.0 to 20.0 tan, silty clay.</p>

1. These logs result from a foundation investigation authorized by Transcontinental Gas Pipe Line Company, Sieck (1965).

APPENDIX B

GRANULOMETRIC DATA

Appendix B contains the results of Rapid Sand Analyzer (RSA) size analyses of selected sediment samples from CERC cores in the study area. Analyses are based on sand-size fraction only.

The samples are identified by core number, CERC identification, and sample interval below top of the core. These samples are plotted by core number in Figure 2.

Data include mean ($\bar{X}$) size values (ϕ and millimeter) and standard deviation or sorting coefficient (σ) from direct RSA analyses.

CERC has determined empirical relations for converting RSA means and standard deviation to sieve analyses equivalents. The relationships, developed from RSA and sieve analyses at a 0.25- ϕ interval, are:

$$\text{means: } \bar{X}_{\phi \text{ sieve}} = 1.0735 \bar{X}_{\phi \text{ RSA}} + 0.1876$$

Sieve millimeter values were derived by means of a conversion table.

RSA standard deviation values were converted to sieve sorting equivalents by the formula:

$$\text{standard deviation: } \sigma_{\phi \text{ sieve}} = 1.4535 \sigma_{\phi \text{ RSA}} - 0.146$$

Cumulative curves of selected samples from CERC cores are presented graphically. Sample locations are shown in Figure 2. Data are derived from RSA analyses.

Table B. Granulometric Data.

Number			Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.	Depth (ft)	Mean (phi)	Standard deviation (phi)	Mean (mm)	Mean (phi)	Standard deviation (phi)	Mean (mm)
1	1	0.0	1.32	1.23	0.400	1.60	1.64	0.330
1	1	0.8	1.23	0.67	0.426	1.51	0.83	0.351
1	1	1.5	0.82	0.82	0.568	1.07	1.05	0.476
1	1	2.8	1.10	0.65	0.467	1.37	0.80	0.387
1	1	6.0	0.20	0.68	0.871	0.40	0.84	0.758
1	1	6.6	1.42	1.35	0.373	1.72	1.82	0.304
1	1	8.8	2.62	1.31	0.162	3.00	1.76	0.125
1	1	12.5	2.03	1.40	0.244	2.37	1.89	0.193
2	2	7.0	1.41	0.81	0.377	1.70	1.03	0.308
2	2	10.0	1.83	0.43	0.281	2.15	0.48	0.225
3	3	1.0	1.42	1.02	0.373	1.71	1.34	0.306
3	3	3.0	1.87	0.49	0.274	2.20	0.57	0.218
3	3	8.5	2.01	0.70	0.249	2.35	0.87	0.196
4	4	14.0	2.11	0.40	0.232	2.45	0.44	0.183
4	4	15.3	1.96	0.35	0.258	2.29	0.36	0.205
5	5	1.6	2.13	1.42	0.229	3.55	1.92	0.85
5	5	13.8	2.82	0.95	0.141	3.21	1.23	0.108
6	6	0.0	1.17	0.78	0.445	1.44	0.99	0.369
6	6	0.8	0.55	0.81	0.682	0.78	1.03	0.582
6	6	1.5	1.16	0.59	0.446	1.43	0.71	0.371
6	6	2.0	2.51	1.06	0.176	2.88	1.39	0.136
6	6	2.8	1.25	0.62	0.420	1.53	0.76	0.346
6	6	6.5	0.81	0.94	0.570	1.06	1.22	0.480
6	6	8.3	0.79	0.52	0.578	1.04	0.61	0.486
7	7	0.0	2.29	1.15	0.204	2.65	1.53	0.159
7	7	4.0	1.36	0.89	0.388	1.65	1.15	0.319
7	7	7.0	1.01	0.60	0.496	1.27	0.73	0.415

Table B. Granulometric Data.—Continued

Number			Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.	Depth (ft)	Mean (phi)	Standard deviation (phi)	Mean (mm)	Mean (phi)	Standard deviation (phi)	Mean (mm)
7	7	9.0	1.51	0.79	0.351	1.81	1.00	0.285
7	7	13.0	1.37	0.83	0.388	1.66	1.06	0.316
8	8	5.0	2.40	1.30	0.189	2.76	1.74	0.148
8	8	9.5	1.66	0.78	0.316	1.97	0.99	0.255
8	8	11.0	1.88	0.69	0.272	2.21	0.86	0.216
8	8	15.0	2.35	0.59	0.196	2.71	0.71	0.153
9	9	0.0	2.10	0.52	0.234	2.44	0.66	0.184
9	9	7.0	1.80	0.87	0.287	2.12	1.12	0.230
9	9	14.0	1.37	0.83	0.387	1.66	1.06	0.316
10	10	3.0	2.66	0.64	0.158	3.04	0.78	0.122
11	11	0.0	2.05	0.55	0.242	2.39	0.65	0.191
11	11	7.5	0.76	0.98	0.591	1.00	1.28	0.500
12	12	0.0	1.14	0.47	0.453	1.41	0.54	0.376
12	12	4.7	1.24	1.05	0.425	1.52	1.38	0.349
13	13	1.0	1.07	0.61	0.477	1.34	0.74	0.395
13	13	6.6	1.36	0.61	0.390	1.65	0.74	0.319
14	14	0.0	0.51	0.68	0.703	0.74	0.84	0.599
14	14	6.8	1.26	0.56	0.416	1.54	0.67	0.344
14	14	13.0	2.33	0.71	0.198	2.69	0.87	0.155
15	15	0.0	1.49	0.49	0.356	1.79	0.57	0.289
15	15	1.0	1.54	0.43	0.344	1.84	0.48	0.279
15	15	3.0	1.42	0.42	0.373	1.71	0.46	0.306
15	15	5.0	1.04	0.56	0.485	1.30	0.67	0.406
15	15	6.3	1.29	0.61	0.409	1.57	0.74	0.337
16	16	0.0	1.42	0.42	0.373	1.71	0.46	0.306
16	16	1.0	1.41	0.47	0.377	1.70	0.54	0.309
16	16	6.3	1.36	0.49	0.389	1.65	0.57	0.319

Table B. Granulometric Data.—Continued

Number		Depth	Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.		Mean	Standard deviation	Mean	Mean	Standard deviation	Mean
		(ft)	(phi)	(phi)	(mm)	(phi)	(phi)	(mm)
17	17	0.0	1.71	0.40	0.305	2.02	0.44	0.247
17	17	1.0	1.74	0.42	0.300	2.06	0.46	0.240
17	17	3.0	1.60	0.45	0.331	1.91	0.51	0.266
17	17	6.0	2.00	0.43	0.250	2.33	0.48	0.199
17	17	9.0	2.08	0.40	0.237	2.42	0.44	0.187
17	17	10.0	2.07	0.35	0.238	2.41	0.36	0.188
18	18	0.0	0.61	0.76	0.655	0.84	0.96	0.559
18	18	1.0	1.33	0.70	0.398	1.62	0.87	0.325
18	18	1.5	1.19	0.71	0.437	1.47	0.89	0.361
18	18	2.0	1.36	0.81	0.390	1.65	1.03	0.319
18	18	5.0	0.99	0.71	0.505	1.25	0.87	0.420
18	18	7.0	0.41	0.61	0.751	0.63	0.74	0.646
18	18	8.0	0.71	0.97	0.612	0.95	1.26	0.518
18	18	9.0	0.64	0.58	0.641	0.88	0.70	0.543
18	18	12.0	0.76	0.70	0.589	1.00	0.87	0.500
18	18	14.0	1.54	0.53	0.343	1.84	0.62	0.279
18	18	15.0	1.35	0.50	0.393	1.64	0.58	0.321
19	19	0.0	0.27	0.59	0.829	0.48	0.71	0.717
19	19	1.0	0.67	0.66	0.628	0.91	0.83	0.532
19	19	2.0	0.62	0.78	0.649	0.85	0.99	0.555
19	19	3.0	0.59	0.64	0.666	0.82	0.78	0.566
19	19	4.2	1.03	0.70	0.491	1.29	0.87	0.409
20	111	0.0	1.94	0.43	0.261	2.27	0.48	0.207
20	111	1.0	1.70	0.67	0.308	2.01	0.83	0.248
20	111	1.8	1.34	0.93	0.395	1.63	1.21	0.323
21	20	0.0	0.88	0.58	0.542	1.13	0.70	0.457
21	20	1.0	0.94	0.58	0.522	1.20	0.70	0.435

Table B. Granulometric Data.—Continued

Number		Depth (ft)	Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.		Mean (phi)	Standard deviation (phi)	Mean (mm)	Mean (phi)	Standard deviation (phi)	Mean (mm)
21	20	4.0	1.36	0.51	0.389	1.65	0.60	0.319
21	20	7.0	1.08	0.55	0.472	1.35	0.65	0.392
22	21	0.0	1.09	0.56	0.471	1.36	0.67	0.390
22	21	1.0	0.60	0.67	0.660	0.83	0.83	0.563
22	21	2.0	1.02	0.65	0.493	1.28	0.80	0.412
22	21	3.0	1.35	0.41	0.392	1.64	0.45	0.321
22	21	4.0	1.07	0.53	0.475	1.34	0.62	0.395
22	21	7.0	1.33	0.64	0.399	1.62	0.78	0.325
22	21	9.0	1.22	0.50	0.430	1.50	0.58	0.354
22	21	10.3	1.53	0.71	0.346	1.82	0.87	0.283
23	22	3.0	0.63	0.73	0.648	0.86	0.92	0.551
23	22	4.0	1.03	0.94	0.489	1.29	1.22	0.409
23	22	6.0	1.18	0.56	0.443	1.45	0.67	0.366
23	22	11.0	0.52	0.87	0.697	0.75	1.12	0.595
24	23	0.0	0.76	0.64	0.591	1.00	0.78	0.500
24	23	1.0	0.79	0.49	0.580	1.04	0.57	0.486
24	23	4.0	1.10	0.70	0.467	1.37	0.87	0.387
24	23	7.0	1.28	0.60	0.411	1.56	0.73	0.339
24	23	8.0	1.24	0.51	0.423	1.52	0.60	0.349
24	23	9.0	1.23	0.70	0.425	1.51	0.87	0.351
24	23	10.0	1.02	0.51	0.493	1.28	0.60	0.412
25	24	0.0	1.25	0.61	0.421	1.53	0.74	0.346
25	24	1.0	2.10	0.47	0.233	2.44	0.54	0.184
25	24	2.0	1.24	1.10	0.424	1.52	1.45	0.349
25	24	3.0	0.57	0.64	0.674	0.80	0.78	0.514
25	24	4.0	1.36	0.54	0.389	1.65	0.64	0.319
25	24	6.0	1.41	0.53	0.376	1.70	0.62	0.308

Table B. Granulometric Data.—Continued

Number			Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.	Depth (ft)	Mean (phi)	Standard deviation (phi)	Mean (mm)	Mean (phi)	Standard deviation (phi)	Mean (mm)
25	24	7.0	1.59	0.75	0.332	1.89	0.94	0.270
26	25	0.0	1.34	0.42	0.394	1.63	0.46	0.323
26	25	1.0	1.56	0.48	0.339	1.86	0.55	0.276
26	25	1.3	1.24	0.65	0.424	1.52	0.80	0.349
26	25	1.5	2.21	0.40	0.217	2.56	0.44	0.170
26	25	2.0	2.49	0.56	0.178	2.86	0.07	0.138
26	25	2.5	1.35	0.80	0.393	1.64	1.02	0.321
26	25	3.0	1.67	0.49	0.315	1.98	0.57	0.254
26	25	4.0	1.95	0.41	0.260	2.28	0.45	0.206
26	25	8.0	1.66	0.47	0.316	1.97	0.54	0.255
26	25	9.2	1.62	0.66	0.325	1.93	0.81	0.262
27	26	0.0	1.47	0.61	0.361	1.77	0.74	0.293
27	26	8.0	1.19	0.81	0.440	1.47	1.03	0.361
27	26	11.0	1.85	0.42	0.227	2.17	0.46	0.222
28	27	0.5	1.42	0.50	0.373	1.71	0.58	0.306
28	27	4.0	1.33	0.51	0.398	1.62	0.60	0.325
29	28	1.0	0.74	0.59	0.599	0.98	0.71	0.507
29	28	11.1	1.81	0.46	0.286	2.13	0.52	0.229
30	29	0.0	1.48	0.81	0.359	1.78	1.03	0.291
30	29	11.0	1.08	0.67	0.473	1.35	0.83	0.392
31	30	0.0	1.81	0.48	0.284	2.13	0.55	0.229
31	3.0	11.3	1.18	0.49	0.441	1.45	0.57	0.366
32	31	0.0	1.25	0.63	0.421	1.53	0.77	0.346
32	31	5.0	1.89	0.47	0.270	2.22	0.54	0.215
32	31	6.8	1.03	1.18	0.490	1.29	1.46	0.409
33	32	0.0	1.61	0.52	0.328	1.92	0.61	0.264
33	32	6.0	1.52	0.05	0.348	1.82	0.55	0.283

Table B. Granulometric Data.—Continued

Number			Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.	Depth (ft)	Mean (phi)	Standard deviation (phi)	Mean (mm)	Mean (phi)	Standard deviation (phi)	Mean (mm)
34	33	0.0	0.77	0.54	0.586	1.01	0.64	0.497
34	33	9.0	1.01	0.54	0.496	1.27	0.64	0.415
35	34	2.0	0.56	0.68	0.680	0.79	0.84	0.578
35	34	5.0	1.11	0.47	0.464	1.38	0.54	0.384
35	34	10.0	1.05	0.59	0.483	1.31	0.71	0.403
36	35	0.0	1.82	0.76	0.284	2.14	0.96	0.227
36	35	2.0	2.14	0.53	0.227	2.48	0.62	0.179
36	35	9.0	0.69	0.57	0.619	0.93	0.68	0.525
37	36	0.0	2.58	0.54	0.167	2.96	0.64	0.129
37	36	2.5	2.71	0.38	0.152	3.10	0.41	0.117
37	36	5.5	2.00	0.70	0.249	2.33	0.87	0.199
38	37	0.0	1.67	0.72	0.314	1.98	0.90	0.254
38	37	9.0	1.48	0.49	0.358	1.78	0.57	0.291
39	38	0.0	1.69	0.90	0.311	2.00	1.16	0.250
39	38	5.0	1.61	0.90	0.328	1.92	1.16	0.264
39	38	7.0	1.52	0.43	0.349	1.82	0.48	0.283
61	60	0.0	2.09	0.44	0.234	2.43	0.49	0.186
61	60	3.5	1.09	0.77	0.469	1.36	0.97	0.390
61	60	5.0	1.79	0.48	0.290	2.11	0.55	0.232
62	61	0.0	0.99	0.41	0.503	1.25	0.45	0.420
62	61	4.8	1.36	0.64	0.388	1.65	0.78	0.319
63	62	0.0	1.19	0.48	0.438	1.47	0.55	0.361
63	62	6.5	1.20	0.43	0.434	1.48	0.48	0.359
64	63	0.0	1.25	0.48	0.420	1.53	0.55	0.346
64	63	1.0	1.35	0.45	0.394	1.64	0.51	0.321
64	63	1.5	1.53	0.48	0.346	1.83	0.55	0.281
64	63	3.5	1.49	0.56	0.357	1.79	0.67	0.289

Table B. Granulometric Data.—Continued

Number			Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.	Depth (ft)	Mean (phi)	Standard deviation (phi)	Mean (mm)	Mean (phi)	Standard deviation (phi)	Mean (mm)
65	64	0.0	2.74	0.44	0.150	3.13	0.49	0.114
65	64	3.0	2.87	0.39	0.137	3.27	0.42	0.104
65	64	5.0	2.31	0.48	0.202	2.67	0.55	0.157
65	64	5.7	1.26	1.18	0.418	1.54	1.57	0.344
66	65	0.0	1.24	0.48	0.423	1.52	0.55	0.349
66	65	0.5	1.60	0.60	0.329	1.91	0.73	0.266
66	65	1.0	1.72	0.96	0.303	2.03	1.25	0.245
66	65	2.0	1.41	0.48	0.375	1.70	0.55	0.308
66	65	2.7	1.41	0.37	0.376	1.70	0.39	0.308
67	66	0.8	1.26	0.76	0.419	1.54	0.96	0.344
67	66	1.0	1.24	0.79	0.424	1.52	1.00	0.349
67	66	1.5	0.54	0.78	0.688	0.77	0.99	0.586
67	66	2.0	1.00	0.62	0.499	1.26	0.76	0.418
67	66	3.0	1.36	0.56	0.389	1.65	0.67	0.319
67	66	5.0	0.98	0.45	0.506	1.24	0.51	0.423
67	66	8.0	0.87	0.41	0.547	1.12	0.45	0.460
67	66	8.5	0.81	0.53	0.571	1.06	0.62	0.480
67	66	8.8	1.21	0.70	0.432	1.49	0.87	0.356
67	66	9.0	2.61	0.79	0.163	2.99	1.00	0.126
67	66	9.3	2.62	0.66	0.163	3.00	0.81	0.125
67	66	15.0	1.90	0.50	0.269	2.23	0.58	0.213
67	66	17.2	1.09	0.64	0.469	1.36	0.78	0.390
68	67	0.0	0.96	0.68	0.513	1.22	0.84	0.429
68	67	1.0	1.49	0.92	0.356	1.79	1.19	0.289
68	67	3.0	2.30	0.47	0.203	2.66	0.54	0.158
68	67	5.0	2.33	0.51	0.199	2.69	0.60	0.155
69	68	7.0	1.93	0.46	0.263	2.26	0.52	0.209

Table B. Granulometric Data.—Continued

Number			Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.	Depth (ft)	Mean (phi)	Standard deviation (phi)	Mean (mm)	Mean (phi)	Standard deviation (phi)	Mean (mm)
70	69	0.0	1.70	1.07	0.309	2.01	1.41	0.248
70	69	2.0	1.89	1.36	0.270	2.22	1.83	0.215
70	69	6.0	2.31	0.61	0.201	2.67	0.74	0.157
70	69	9.0	2.64	0.53	0.161	3.02	0.62	0.123
70	69	12.0	1.55	0.87	0.341	1.85	1.12	0.277
71	70	1.0	0.70	0.31	0.617	0.94	0.31	0.521
71	70	5.0	1.00	0.60	0.500	1.26	0.73	0.418
71	70	8.3	0.65	0.57	0.635	0.89	0.68	0.540
72	71	0.0	2.63	0.51	0.161	3.01	0.60	0.124
72	71	1.0	2.70	0.45	0.154	3.09	0.51	0.117
72	71	3.0	2.27	0.87	0.207	2.62	1.12	0.163
72	71	5.0	1.26	0.74	0.418	1.54	0.93	0.344
73	72	0.0	----- ¹	----- ¹	----- ¹	----- ¹	----- ¹	----- ¹
73	72	15.0	1.34	0.71	0.394	1.63	0.87	0.323
74	73	0.0	2.03	1.12	0.244	2.37	1.48	0.193
74	73	1.0	1.02	0.84	0.494	1.28	1.07	0.412
74	73	3.0	2.37	0.57	0.194	2.73	0.68	0.151
74	73	4.0	1.95	0.53	0.259	2.28	0.62	0.206
75	74	0.0	1.31	0.50	0.403	1.59	0.58	0.332
75	74	1.0	1.80	0.56	0.286	2.12	0.67	0.230
75	74	4.0	2.25	0.56	0.210	2.60	0.67	0.165
75	74	7.0	1.99	0.52	0.252	2.32	0.61	0.200
75	74	10.0	1.71	0.58	0.305	2.02	0.70	0.247
76	75	0.0	2.14	0.76	0.226	2.48	0.96	0.179
76	75	3.5	2.18	0.51	0.221	2.53	0.60	0.173
77	76	0.0	1.22	0.55	0.428	1.50	0.65	0.354
77	76	7.0	1.83	0.51	0.281	2.15	0.60	0.225

1. Too fine.

Table B. Granulometric Data.—Continued

Number			Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.	Depth	Mean	Standard deviation	Mean	Mean	Standard deviation	Mean
		(ft)	(phi)	(phi)	(mm)	(phi)	(phi)	(mm)
77	76	18.0	2.04	0.50	0.244	2.38	0.58	0.192
78	77	1.0	1.34	0.59	0.395	1.63	0.71	0.323
79	78	0.0	2.20	0.66	0.217	2.55	0.81	0.171
79	78	17.0	1.48	0.54	0.357	1.78	0.64	0.291
110	97	0.0	2.08	0.46	0.237	2.42	0.52	0.187
110	97	1.0	2.01	0.52	0.248	2.35	0.61	0.196
110	97	7.0	2.49	0.46	0.178	2.86	0.52	0.138
110	97	16.5	1.80	0.45	0.287	2.12	0.51	0.230
111	98	0.0	1.82	0.88	0.284	2.14	1.13	0.227
111	98	1.0	1.35	0.80	0.393	1.64	1.02	0.321
111	98	2.3	0.59	0.82	0.663	0.82	1.05	0.566
111	98	6.0	1.01	0.58	0.496	1.27	0.70	0.415
111	98	6.7	0.96	0.55	0.514	1.22	0.65	0.429
112	99	0.0	1.69	0.50	0.309	2.00	0.58	0.250
112	99	2.5	2.35	0.42	0.196	2.71	0.46	0.153
112	99	4.7	2.23	0.62	0.214	2.58	0.76	0.167
113	100	0.0	1.47	0.47	0.361	1.77	0.54	0.293
113	100	1.0	1.41	0.56	0.377	1.70	0.67	0.308
113	100	2.3	1.66	0.63	0.317	1.97	0.77	0.128
113	100	3.0	1.58	0.39	0.336	1.88	0.42	0.272
113	100	4.0	1.42	0.69	0.373	1.71	0.86	0.306
113	100	6.0	1.49	0.43	0.357	1.79	0.48	0.289
113	100	15.3	1.58	0.44	0.335	1.88	0.49	0.272
114	102	5.0	1.12	0.49	0.461	1.39	0.57	0.382
114	102	8.0	0.99	0.63	0.504	1.25	0.77	0.420
114	102	9.5	2.02	0.38	0.247	2.36	0.41	0.195
115	103	0.0	1.88	0.69	0.272	2.21	0.86	0.216

Table B. Granulometric Data.—Continued

Number			Rapid Sand Analyzer (RSA)			Sieve analyses		
Core	CERC I.D.	Depth (ft)	Mean (phi)	Standard deviation (phi)	Mean (mm)	Mean (phi)	Standard deviation (phi)	Mean (mm)
115	103	14.0	0.68	0.53	0.623	0.92	0.62	0.529
116	104	0.0	1.71	0.58	0.307	2.02	0.70	0.247
116	104	0.5	0.85	0.79	0.555	1.10	1.00	0.467
116	104	10.0	1.76	0.60	0.296	2.08	0.73	0.237
116	104	19.0	1.20	0.63	0.436	1.48	0.77	0.359
117	105	0.0	2.14	0.47	0.227	2.48	0.54	0.179
117	105	12.2	2.08	0.50	0.237	2.42	0.58	0.187
118	106	0.0	1.69	0.59	0.311	2.00	0.71	0.250
118	106	7.0	1.55	0.54	0.341	1.85	0.64	0.277
118	106	13.0	1.10	0.46	0.465	1.37	0.52	0.387
119	107	0.0	1.26	0.45	0.417	1.54	0.51	0.344
119	107	1.0	1.70	0.64	0.307	2.01	0.78	0.248
119	107	3.0	1.34	0.58	0.395	1.63	0.70	0.323
119	107	5.0	1.40	0.59	0.378	1.69	0.71	0.310
120	108	0.0	2.07	0.43	0.238	2.41	0.48	0.188
120	108	1.0	2.53	0.62	0.173	2.90	0.76	0.134
120	108	3.0	2.76	0.62	0.148	3.15	0.76	0.113
120	108	5.0	2.64	0.57	0.161	3.02	0.68	0.123
120	108	6.3	2.27	0.57	0.207	2.62	0.68	0.163
120	108	7.0	2.38	0.34	0.193	2.74	0.35	0.150
121	109	0.0	2.47	0.50	0.181	2.84	0.58	0.140
121	109	1.0	2.35	0.48	0.196	2.71	0.55	0.153
121	109	3.0	1.78	0.47	0.292	2.10	0.54	0.233
121	109	5.0	1.98	0.64	0.254	2.31	0.78	0.202
121	109	7.0	1.49	0.76	0.357	1.79	0.96	0.289

Borrow area F (Fig. 27).

Curve	Core	Depth (feet)	Mean value	
			(phi)	(millimeters)
(1)	15	-1.0	1.54	0.344
(2)	18	top	0.61	0.655
(3)	20	top	1.94	0.261
(4)	28	-0.5	1.42	0.373

Borrow area I (Fig. 27).

Curve	Core	Depth (feet)	Mean value	
			(phi)	(millimeters)
(1)	35	-2.0	0.56	0.680
(2)	177	top	2.14	0.227

Borrow area J (Fig. 28).

Curve	Core	Depth (feet)	Mean value	
			(phi)	(millimeters)
(1)	37	top	2.58	0.167
(2)	38	top	1.67	0.314
(3)	78	-1.0	1.34	0.395

Borrow area K (Fig. 28).

Curve	Core	Depth (feet)	Mean value (phi)	Mean value (millimeters)
(1)	63	top	1.19	0.438
(2)	71	-1.0	0.70	0.617
(3)	72	top	2.63	0.161

Borrow area L (Fig. 29).

Curve	Core	Depth (feet)	Mean value	
			(phi)	(millimeters)
(1)	114	-5.0	1.12	0.461
(2)	61	top	2.09	0.234

<p>Williams, S. Jeffress Geomorphology, shallow subbottom structure, and sediments of the Atlantic inner continental shelf off Long Island, New York / S. Jeffress Williams. - Fort Belvoir, Va. : Coastal Engineering Research Center, 1976. 123 p. : ill. (Technical paper - Coastal Engineering Research Center ; no. 76-2) (Contract - Coastal Engineering Research Center ; DACW51-68-0044) Bibliography : p. 79. The Atlantic Inner Continental Shelf off Long Island was surveyed for data on bottom morphology and sediments, subbottom structure, and sand deposits suitable for beach nourishment. Survey data consist of 960 miles of seismic reflection profiles and 152 vibratory cores. 1. Continental shelf. 2. Beach nourishment. 3. Geomorphology. 4. Sediments. 5. Seismic reflection. I. Title. II. Series : U.S. Coastal Engineering Research Center. Technical paper no. 76-2. III. Series : U.S. Coastal Engineering Research Center. Contract DACW51-68-0044). TC203 no. 76-2 627 .U581tp .U581tp</p>	<p>Williams, S. Jeffress Geomorphology, shallow subbottom structure, and sediments of the Atlantic inner continental shelf off Long Island, New York / S. Jeffress Williams. - Fort Belvoir, Va. : Coastal Engineering Research Center, 1976. 123 p. : ill. (Technical paper - Coastal Engineering Research Center ; no. 76-2) (Contract - Coastal Engineering Research Center ; DACW51-68-0044) Bibliography : p. 79. The Atlantic Inner Continental Shelf off Long Island was surveyed for data on bottom morphology and sediments, subbottom structure, and sand deposits suitable for beach nourishment. Survey data consist of 960 miles of seismic reflection profiles and 152 vibratory cores. 1. Continental shelf. 2. Beach nourishment. 3. Geomorphology. 4. Sediments. 5. Seismic reflection. I. Title. II. Series : U.S. Coastal Engineering Research Center. Technical paper no. 76-2. III. Series : U.S. Coastal Engineering Research Center. Contract DACW51-68-0044). TC203 no. 76-2 627 .U581tp .U581tp</p>
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