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GEOMORPHOLOGY and SEDIMENTS of the INNER NEW YORK BIGHT CONTINENTAL SHELF

by

S. Jeffress Williams and David B. Duane

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Approximately 445 miles of continuous seismic reflection profiles and 61 vibrating cores were obtained from the Inner New York Bight which encompasses about 250 square miles of the offshore from northern New Jersey and western Long Island. The major physiographic features include Sandy Hook and Rockaway Beach, both prograding barrier islands, Shrewsbury Rocks and the Hudson (submarine) Channel. Shrewsbury Rocks mark the demarcation between two distinct geomorphic provinces. The area north of Shrewsbury Rocks is underlain by Coastal Plain strata

Continued

which have been deeply eroded by Pleistocene glacial processes and covered by sand and gravel outwash. South of Shrewsbury Rocks Coastal Plain strata have been evenly truncated and covered by a veneer of residual material. Three primary types of bedding have been observed on the seismic records. Coastal Plain strata exhibit a monoclinal regional southeast dip; steeply inclined crossbeds are restricted to an elongate basin east of Sandy Hook, considered to be of fluvial origin. The third type is Pleistocene-Holocene stratified fluvial sands and gravels which are regionally discontinuous and exhibit gentle seaward dip. Cores reveal that fine to medium sand is the predominant sediment type on the inner shelf. Isolated patches of coarse sand and rounded pea gravels are present off Long Island where fluvial materials are exposed. Coarse sediment off New Jersey is judged to be residual from sea floor outcrops of Coastal Plain strata. Very fine sand, silt and muds comprise the sea floor at the head of the Hudson Channel and along the body.

Sand suitable for beach nourishment projects is found in abundance throughout the shallow shelf parts of the Inner New York Bight. Sea floor topography is fairly flat and sand occurs as blanket deposits. It is estimated that over 2 billion cubic yards of clean sand is available for retrieval by present dredging techniques.

Comparison of bathymetric maps made from 1845 to 1970 has confirmed that significant parts of the natural Hudson Channel have been filled from ocean disposal of up to 1 billion cubic yards of assorted anthropogenic materials, resulting from early construction in New York City and channel dredging within the estuaries and bays.

PREFACE

This report is one of a continuing series which describes results of the Coastal Engineering Research Center (CERC) Inner Continental Shelf Sediment and Structure (ICONS) Study. One aspect of the ICONS program is locating and delineating offshore sand and gravel deposits suitable for beach nourishment and restoration.

S. Jeffress Williams, a CERC geologist, prepared the report with the assistance and supervision of David B. Duane, Chief, Geology Branch. As part of the research program of the Engineering Development Division the ICONS Study is under the general supervision of Mr. George M. Watts, Chief of the Division. The field work involving coring and continuous seismic profiling was carried out by Alpine Geophysical Associates, Inc., under contracts DA-36-109-CIVENG-64-193, and DACW-51-68-C-0044.

Discussions with Mr. Michael E. Field and Mr. Edward P. Meisburger of the CERC staff were helpful during interpretation of the data. Mrs. Patricia Blackwelder examined sediment samples by electron microscope which aided in interpretation of paleoenvironments.

Microfilm copy of all seismic data used in this study are stored at the National Solar and Terrestrial Geophysical Data Center (NSTGDC), Rockville, Maryland 20852. Vibratory cores collected during the field program are in custody of the National Oceanic and Atmospheric Administration (NOAA), Rockville, Maryland 30852. Requests for information relative to these items should be directed to NSTGDC or NOAA.

NOTE: Comments on this publication are invited.

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

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GEOMORPHOLOGY AND SEDIMENTS OF THE INNER NEW YORK BIGHT CONTINENTAL SHELF

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I. INTRODUCTION

1. Background.

Ocean beaches and associated dunes provide a necessary and important buffer zone between the sea and fragile coastal areas. At the same time they provide public recreation areas for millions of people. The construction, improvement and periodic maintenance of beaches and dunes by placement (nourishment) 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 test program using a hopper dredge at Sea Dirt, New Jersey in 1966 by the U.S. Army, Corps of Engineers (1967); and the successful completion of the nourishment of Redondo Beach, California, in 1969 by a commercial operator under contract to the Corps of Engineers. (Fisher, 1970.) The Redondo Beach project determined that present technology is advanced enough to make sand and gravel on the shallow parts of the shelves a presently exploitable resource (Duane, 1968) and economically competitive at some locations with previous 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 sand fill. 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 are due in part to increased land 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. Also, sedimentary material comprising the bottoms of lagoons, estuaries, and bays is often fine-grained and rich in organics and is unsuitable for long-term effective shoreline protection. While the loss of some fine silt 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. (Krumbein and James, 1965.)

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 were focused offshore with the intent to locate and inventory deposits suitable for future fill requirements, and later refine techniques for specifying most suitable fill characteristics.

The search for 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. During the past two years broader application to the CERC mission of the data collected has been recognized, especially in terms of deciphering the shallow structure of the Continental Shelf, understanding shelf sedimentation and hydraulic processes, unraveling geologic history of the shelves and 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 Program (ICONS).

2. Field and Laboratory Procedures.

The field exploration phase of the ICONS program uses continuous seismic reflection profiling supplemented by cores of the bottom sediment. Both of these sources of data are obtained by contractual agreement with ocean industry firms. These data are analyzed and interpreted by the CERC Geology Branch staff. Support data are obtained from the National Ocean Survey (NOS) (formerly U.S. Coast and Geodetic Survey) hydrographic boat sheets, pertinent professional papers, engineering logs from bore holes and published literature.

a. Data Collection Planning. Geophysical survey tracklines are laid out for the study areas by the CERC Geology Branch staff in two basic patterns: grid and reconnaissance lines. A grid pattern, with variable line spacing depending on regional geology, 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 zigzag lines which provide minimal coverage for intermediate areas between grids, and a means of correlation of geology between grid areas. Reconnaissance lines 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 study 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 of the best information available 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 subbottom 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, an acoustic 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. The energy source used for this survey was a 50- to 200-joule sparker. For continuous profiling, the sound 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 of 5,440 feet per second, a vertical depth scale was constructed to fit the geophysical record. Geographic position of the survey vessel is obtained by frequent navigational fixes keyed to the record by an event marker. Navigation for this project was achieved by use of the Alpine Precision Range System, Model 4350.

More detailed discussions of seismic profiling techniques can be found in a number of technical publications. (Ewing, 1963; Hersey, 1963; van Reenan, 1963; Miller, Tirey and Mecarini, 1967; Moore and Palmer, 1968; Barnes, et al., 1972; and Ling, 1972.)

c. Coring Techniques. The sea floor coring device used in this study is a pneumatic, vibrating piston coring assembly designed to obtain core samples (20-foot maximum length; 4-inch diameter) in Continental Shelf granular-type sediments. The apparatus consists of a standard steel core barrel, plastic inner liner, shoe and core catcher, with a pneumatic driving head attached to the upper end of the barrel. These elements are enclosed in a tripod-like frame with articulated legs, allowing the assembly to rest on the sea floor during the coring operation. The detached state 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 means of a flexible hoseline connected to a large capacity, deck-mounted air compressor. After coring is complete, the assembly is winched on board the vessel; the liner containing the core is removed, capped at both ends and 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 reflective horizons considered significant because of their extent and relationship to the general structure and geology of the study area. Where possible, the uppermost reflectors are correlated with core data 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 portions of representative material. After preliminary analysis, a number of 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 power saw mounted on a base which is designed to ride along the top of the trough is adjusted to cut through the plastic liner and not disturb the core sediment. By making a second logitudinal 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 and photographed and resealed.

Samples from the cores are then examined under a plane light binocular microscope and described in terms of gross lithology, color, mineralogy, and the type and abundance of skeletal fragments of marine organisms. Granulometric parameters (e.g., mean size, sorting) for many of the 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 covered by this report, herein referred to as the Inner New York Bight, is rectangular and extends from eastern Rockaway Beach, Long Island (73°45′W.) southwest to Sandy Hook (74°05′W.) and south to Shrewsbury Rocks, New Jersey (40°20′N.). A map of the area (Fig. 1) shows the major geographic features of the region. Field data collection in support of this study was conducted in 1964 for the Sandy Hook, New Jersey region and in 1968 for the Long Island south shore region and for the area seaward of New York Bay at the head of the Hudson River (submarine) channel. The field work was conducted under contract with Alpine Geophysical Associates, Inc. Data collected consist of about 445 statute (survey) miles of continuous seismic reflection profiles and 61 sediment cores of 20-foot maximum, and 10.7-foot mean length. Core and trackline locations are depicted in Figure 2.

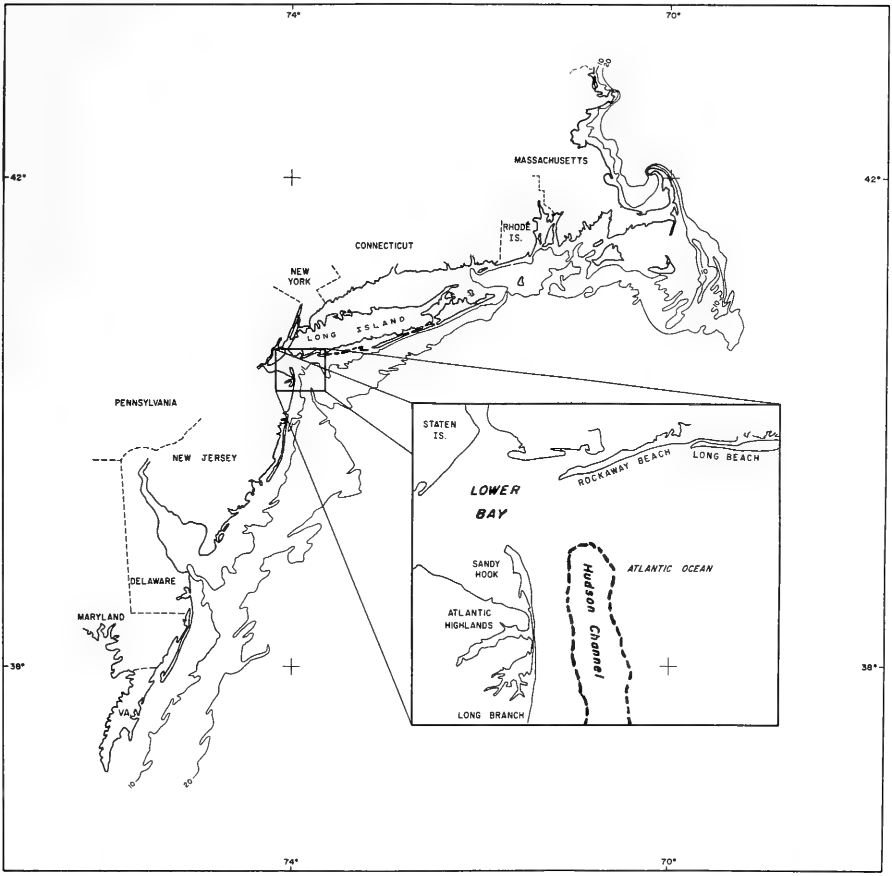

Figure 1. Location map of the Inner New York Bight study area. Map shows the geographic relationship with the northeastern Atlantic coast. Depth contours in 10-fathom intervals indicate the major re-entrants and regional bathymetric fabric of the Continental Shelf surface.

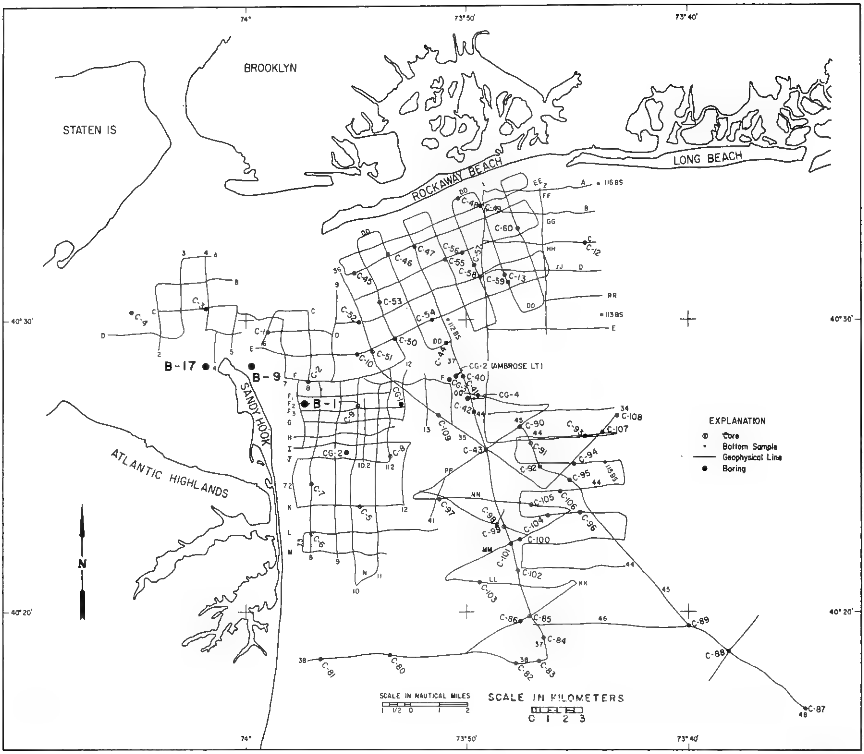

Figure 2. Data coverage of seismic records, vibratory cores, deep borings and grab samples in the Inner New York Bight.

4. Geographic Setting.

The Inner New York Bight is situated just south of the maximum southerly advance of the continental glaciers which periodically covered much of the Northern Hemisphere during the Pleisticene Epoch. Two terminal moraines comprise the northern backbone of Long Island; the southern flank is composed of glaciofluvial outwash derived from the adjacent glacial deposits. The elongate east-west trending barrier islands which extend the 120-mile length of the south shore of Long Island are geologically Recent features resulting from deposition of sandy sediment carried by westward-moving longshore currents. (Taney, 1961.)

Atlantic Highlands, New Jersey is a nonglaciated headland region lying south of maximum glacial advance. Though an area of considerable relief it has a straight and regular coastline and a narrow shoreface including Sandy Hook, a classic example of a recurved spit which has prograded northward toward New York Harbor. This growth is the result of an estimated net longshore sand drift of 500,000 cubic yards per year to the north. (Caldwell, 1966.)

There are four major rivers in the region which have significantly modified the terrain in the past and continue to influence the region today. The Hudson River is the largest of the four and has exerted the most influence in the area. It originates in the foothills of the Adirondack Mountains and flows in a southerly direction for about 200 miles past Manhattan through The Narrows and finally discharges into Lower New York Bay.

The second major river is the Raritan which originates in northern New Jersey and meanders south of the Watchung Mountains until it discharges into Raritan Bay, immediately south of Staten Island.

The Navesink and Shrewsbury Rivers parallel each other in the Atlantic Highlands region of New Jersey. They both trend northeast and their discharges are blocked from entering the sea by a barrier beach; the water is diverted northward into Sandy Hook Bay. In historic time both rivers had direct access to the Atlantic Ocean; however, northward littoral currents constructed a sand barrier which may be breached by future storms and again allow the rivers to flow directly into the Atlantic Ocean.

5. Geologic Setting and Regional Stratigraphy.

The Inner New York Bight lies within the Coastal Plain Physiographic Province which is underlain at shallow depths by Upper Cretaceous, Tertiary and Quaternary semiconsolidated, clastic, sedimentary rocks. This region falls within the northeast corridor which was studied in detail by the U.S. Geological Survey (USGS), (1967) for geological and foundation engineering considerations. Within a 100-mile radius to the north and west a diversity of rock types of various geologic ages are exposed in other physiographic provinces. (See Figure 3.) These older rocks provided major source areas in the past for Coastal Plain and Continental Shelf sediments and are still available for subaerial erosion and subsequent transport of detritus to Continental Shelf areas. A brief account of the primary rock formations is germane to this report.

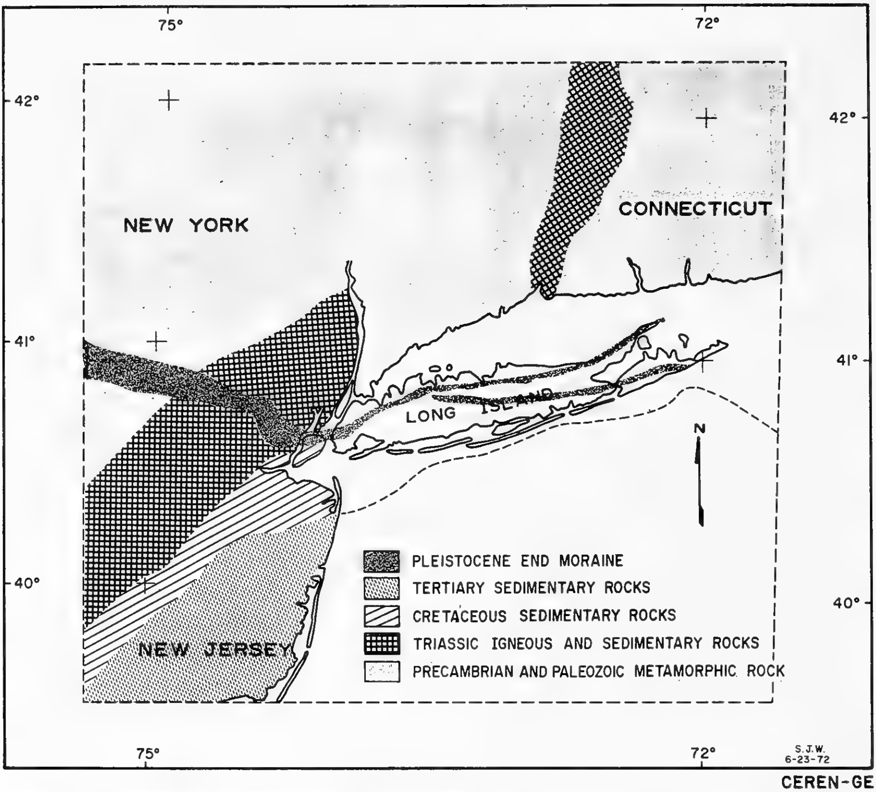

Figure 3. Generalized geologic map of the Inner New York Bight. Long Island is composed of Pleistocene glacial sediment overlying Cretaceous strata. The inferred offshore contact between Tertiary and Cretaceous strata is derived from Garrison (1970) and supported by ICONS data along the Long Island south shore.

The rock formations with greatest exposure in the Piedmont region are the late Precambrian and lower Paleozoic igneous and metamorphic rocks of felsic composition which make up the bulk of northern New Jersey, and most of Connecticut and the New England states. This rock is closely related in age and composition to the basement bedrock beneath Long Island. From outcrops in northwestern Long Island and from water-well bore holes and foundation excavations it is known that the Long Island area is underlain by Precambrian and early Paleozoic metamorphic granitic gneisses and schists. Data from wells reveal that the bedrock surface is deeply weathered and has a fairly regular slope of about 80 feet per mile to the southeast. Depth to bedrock varies from surface outcrop in northwestern Long Island to a reported 1,100 feet under Rockaway Beach. (Suter, deLaguna, and Perlumtter, 1949.) Because of the presence of the deeply weathered surface and fairly even topography it is thought that the bedrock represents a peneplain erosion surface on which Cretaceous sedimentary rock were later deposited subsequent to large-scale regional subsidence. Very little is known about the character of the crystalline bedrock because it is a poor water aquifer, and few drill holes have penetrated below the upper surface. Lower Paleozoic clastic sedimentary rocks of northeastern Pennsylvania, northern New Jersey, and eastern New York are also present.

Rocks of Triassic age are presently exposed in elongate fault structures presently confined to the Connecticut (Connecticut and Massachusetts) and Newark Basins (Pennsylvania, New Jersey, and New York). The rocks consist of argillaceous, red and gray, arkosic, sandstones and siltstones with an abundance of Late Triassic or Early Jurassic basaltic volcanics, intrusive diabase, such as the Palisades Sill which forms the prominent western topographic escarpment on the Hudson River. Metamorphic hornfels are found adjacent to the diabase sills and dikes as a consequence of the thermal alteration. Some authors have suggested (based on similarity of rock types and overall rock stratigraphy and structural framework of the basins) that the Connecticut Basin is actually a half-graben structure and serves as the eastern structural component of a once prominent full-graben structure which would have included the Newark Basin as the western half-graben component. Subsequent erosion has partially removed the strata filling the central position of the graben in New York and Connecticut where older underlying Paleozoic rocks are now exposed. Deposition of thick Coastal Plain strata has buried any possible evidence of Triassic rock under Long Island or New Jersey. If this connected graben hypothesis were true, then most of the central part of the graben would be deeply buried under western Long Island and northern New Jersey. Triassic rock has never been encountered in deep wells drilled through the Coastal Plain strata into Precambrian basement rock on Long Island or New Jersey, but proponents of this hypothesis suggest that the Triassic rock has been removed by extensive subaerial erosion which preceded submergence of the region and deposition of Cretaceous-Tertiary strata. Because of the low density of bore-hole coverage through Coastal Plain rock it is likely that deeply buried remnant pockets of Triassic strata are present in Long Island Sound or under the New York Bight Continental Shelf.

Rocks of Upper Cretaceous and early and late Tertiary age make up the Atlantic Coastal Plain in western Long Island and northern New Jersey. They consist of lithologically similar, semiconsolidated, sandstones and sandy gravels which overlap toward the northwest and have a regional dip of several degrees to the southeast. Regional strike of the Cretaceous strata is approximately North 60° East, whereas strike of the overlying Tertiary formations is more easterly. (Minard, 1969.) The Cretaceous and Tertiary rocks form a wedge-like prism which thickens to the southeast and unconformably overlies the previously mentioned Precambrian, Paleozoic and Triassic rocks of the Piedmont Province. The maximum exposed aggregate thickness of Coastal Plain strata in northern New Jersey is about 500 feet (Minard, 1969); the southern tip of New Jersey and the shelf edge in the Hudson Canyon vicinity have a reported thickness of about 10,000 feet. (Kraft, Sheridan, and Maisano, 1971.)

Exposures of hematite-cemented Cretaceous sandstones form prominent ridges and hills over 240 feet high in the Atlantic Highlands north of the Navesink River in New Jersey. The Shrewsbury Rocks, south of Sandy Hook, exhibit striking bathymetric expression from the shoreface to about 7 miles offshore where they are truncated by the Hudson Channel.

Detailed stratigraphic descriptions of the Cretaceous formations of Long Island are included in papers by Fuller (1914), and Suter (1949); Minard (1969) provides a detailed account of the Coastal Plain stratigraphy of northeastern New Jersey. (See Table 1.)

a. Long Island. Because Pleistocene glacial till, glaciofluvial and glaciomarine outwash occur as thick and pervasive overburden on Long Island, little is known about the exact geologic nature of pre-Pleistocene bedrock. Most of the data available on pre-Pleistocene strata are from samples and logs obtained from the numerous water wells drilled to depths of hundreds of feet. First-hand data are also derived from a limited number of rock exposures on the northern side of the island where the glacial overburden is absent or thin due to either nondeposition or to subsequent erosion by later glacial and nonglacial processes.

The contact between Cretaceous and the overlying early Tertiary strata extends in a northeast direction and appears to run offshore in the vicinity of Long Branch, New Jersey. (See Figure 3.) Eastward projection of this contact and lack of Tertiary-type rock in Long Island drill holes support the hypothesis that the youngest bedrock underlying Long Island is Cretaceous in age.

Upper Cretaceous strata in western Long Island are represented by the Lloyd Sand Member and the Raritan Clay Member, both included in the Raritan Formation and the uppermost Magothy Formation. Porous sand members are excellent reservoirs for ground water in all of the counties of western Long Island, and detailed stratigraphy is presented in several reports by Fuller (1914), Suter (1949), and Soren (1971).

The Lloyd Sand consists primarily of beds of sand and gravel interbedded with thin lenses of silt and clay and was deposited on a moderate relief erosion surface of the underlying Precambrian metamorphics. Consequently, thickness of the sand varies from negligible in northwest Queens County to about 300 feet beneath Rockaway Beach. It is a major source of high quality freshwater in western Long Island.

Table 1. Comparative Stratigraphy of Inner New York Bight.

Era	Period	Epoch	Age (years)	Northern New Jersey	Western Long Island
Cenozoic	Quaternary	Holocene	$<12.0 \times 10^3$	Silt and reworked alluvial detritus	Silt and reworked glaciofluvial detritus
		Pleistocene	$<1.5 \times 10^6$	Alluvial sand and gravel	Harbor Hill Glacial Till Ronkonkoma Glacial Till
				Cape May Sand	Gardiners Silt Jameco Gravel
Cenozoic	Tertiary	Pliocene	6.0×10^6	Cohansey Sand	
		Miocene	17.0×10^6		
		Paleocene	60.0×10^6	Vincentown Sand Hornerstown Sand	
Mesozoic	Cretaceous	Upper Cretaceous	75.0×10^6	Tinton Sand Red Bank Sand Navesink Sand Mt. Laurel Sand Wenonah Sand Marshalltown Sand Englishtown Sand Woodbury Clay Merchantville Sand Magothy Sand	Magothy Sand Raritan Clay Lloyd Sand
Precambrian			$>570.0 \times 10^6$	Undifferentiated metamorphic rock	Undifferentiated metamorphic rock

The Raritan Clay Member consists of beds of dark gray silt and clay with subordinate lenses of sand. Plant remains and lignitized wood are ubiquitous throughout the member and coupled with the complete lack of marine-type fossils indicate that the clay was probably deposited in a fresh- or brackish-water environment. Bore hole data indicate that the Raritan Clay blankets the Lloyd Sand throughout Long Island except for locations at the western end where substantial glacial erosion has removed the clay overburden and permitted moraine material to be deposited directly on top of the Lloyd Sand. These gap areas where the Lloyd Sand is directly overlain by glacial till are thought to be very important for recharging depleted ground water reserves by natural ground water percolation.

The Magothy Formation represents the uppermost Cretaceous beds found on Long Island. The name is applied to strata which closely resemble the Magothy stratigraphy best exposed in parts of New Jersey. The Magothy Formation consists primarily of alternating beds of silty sand, clay and zones of coarse sand and gravel. Because of its porous and permeable character the Magothy is also an important ground water reservoir. (Kimmel, 1971.)

Fuller (1914) considered the Jameco Gravel to be an early Pleistocene (Kansan?) outwash deposit possibly deriving its detritus from a glacial still stand farther to the north which evidently never extended as far south as Long Island. The Jameco is most extensively developed in Queens County and either unconformably overlies the eroded Cretaceous strata as in the northwestern section or lies directly on the crystalline bedrock. The extreme irregularity and high relief surface topography of the Jameco suggests that it was subjected to extensive erosion prior to deposition of the overlying Gardiners Clay. Because of its physical character the Jameco is an important freshwater aquifer in western Long Island.

There is a sharp lithologic break between the Jameco Gravel Formation and the overlying Gardiners Clay Formation. The Gardiners is considered by many to be of Sangamon age and deposited under quiet back bay brackish water environment very similar to present conditions in Great South Bay. (Weiss, 1954.) It is characterized by dark gray or green-gray silty clay with thin lenses of fine sand and contains a rich assemblage of formainifera. The Gardiners is one of the few formations on Long Island which can be correlated over a significant area by virtue of its microfossil content. According to Fuller (1914), the maximum elevation of occurrence for Gardiners Clay, excluding elevation due to ice pressure deformation, is 50 feet below present sea level, which may indicate that sea level was at least 50 feet lower before the commencement of Wisconsin glaciation. Thickness and areal continuity of the Gardiners Formation varies greatly; Athearn (1957) identified Gardiners-type material from a deep boring sample retrieved in connection with site foundation studies for a proposed U.S. Air Force Texas Tower, 60 miles south of Moriches Bay, Long Island. The apparent Gardiners sample was retrieved 70 feet below sea floor (overlain by coarse sand and fine gravel) at a water depth of 185 feet.

It is generally agreed by most investigators of Long Island stratigraphy that Wisconsin glaciation is represented by two prominent terminal moraines. Both deposits consist primarily of terminal moraine till, however, lacustrine and fluvial sedimentary materials are also present. The two moraines are difficult to differentiate in western Long Island because one is nearly superimposed on the other; however, observations from eastern Long Island, where the moraines bifurcate, clearly show that the Harbor Hill Moraine is separate from and younger than the earlier Ronkonkoma Moraine. The flanks of Long Island south of the terminal moraines are composed primarily of outwash sand and gravel which was carried southward over the then exposed shelf by numerous, melt-water fed, braided streams. 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 Schaffel (1971) feels that a date of 10,000 ± 1,000 years, Before Present (B.P.) represents an approximation for commencement of the marine transgression over the western Long Island region.

b. New Jersey. Much of the original mapping, describing and naming of the Coastal Plain strata of New Jersey was complete by the end of the 19^{th}, or beginning of the 20^{th} century. Most of the research effort since then has been to refine paleontological correlations and to reassign various formations to different geologic ages based on new evidence. Because Atlantic Highlands is less urbanized than western Long Island fewer bore holes for ground water have been drilled to provide detailed vertical stratigraphy. In general, the geology of the Atlantic Highlands region is less complex and varied than Long Island because it lies south of maximum glacial advance and was little influenced by the tremendous erosive and depositional effects of the continental ice sheets and their accompanying melt-water streams. The most exhaustive study of the Sandy Hook area was done by Minard (1969). Minard provides detail on the surfical geology of the area and also, by use of deep auger drilling equipment, has provided detailed stratigraphy in the third dimension along Sandy Hook into Lower New York Bay. Consequently, only a summary will be included in this paper.

At least 10 Coastal Plain formations are well exposed in the northern New Jersey area where a highland has developed by differential erosion to a maximum relief of over 240 feet. The strata in northern New Jersey are Upper Cretaceous and Tertiary in age and are stratigraphically higher and therefore geologically more recent than the Coastal Plain formations underlying western Long Island. The aggregate thickness of the exposed Coastal Plain units is about 500 feet (Minard, 1969) but, no deep bore hole data are available to confirm depth to the crystalline bedrock. Total subsurface thickness is based on geophysical refraction data and projection of bedrock from close-in holes. Extrapolation of data from seismic refraction study by Oliver and Drake (1951) to the New Jersey area indicates that the basement surface is perhaps 1,200 feet beneath Sandy Hook and sloping to the southeast.

The Upper Cretaceous formations (Table 1) are lithologically very similar and consist of semiconsolidated clays, silts, glauconitic sands and sandy quartz gravels. Tertiary age Hornerstown and Vincentown consist primarily of glauconitic sands whereas the Cohansey consists of medium to coarse quartz sand. All of the Cretaceous and Tertiary formations are apparently the result of deposition in a marine environment. (Johnson and Richards, 1952), (Carter, 1972.)

Total thickness of Pleistocene and Recent sediments varies greatly in the northern New Jersey area. The Pleistocene sediments, usually assigned to the Cape May Formation (Sangamon Age), consist primarily of mixtures of sand and gravel which are derived from erosion and reworking of older Coastal Plain sediments or the result of fluvial transport and deposition by the ancestral Raritan, Hudson, Navesink, and Shrewsbury Rivers. The Raritan and Hudson Rivers flowed through glaciated terrain to the north during Pleistocene glacial stages and because of the unconsolidated nature of the till, large volumes of assorted detritus were spread as a veneer on the then exposed land areas south of the actual terminal moraines. Recent sediments appear to be a combination of reworked glacial outwash and an almost insignificant contribution of fine silts and clays transported by the local rivers. Probably the largest contemporary source of sediment results from ocean disposal of waste material from the New York metropolitan area (Gross, 1972.)

c. *Water Movement and Circulation Patterns.* Water motion and circulation patterns of the surface and bottom water masses in the New York Bight region have been investigated in the past with limited success. (Ketchum, Redfield, and Ayers, 1951), (Bumpus, 1965.) This region is an extremely complex system involving the interaction of tidal and wind-driven currents being acted upon and modified by freshwater discharge from the Hudson, Raritan, Shrewsbury, and Navesink Rivers. Each of these contributors changes regularly and the whole interacting system adjusts in an attempt to maintain a semiequilibrium condition of water mass movement in and out of the New York estuary. Because winds, tides and freshwater discharges change so frequently it is difficult to obtain an accurate synoptic view of the complete New York Bight water mass circulation system; however, generalized observations can be presented.

Because of the bight orientation the primary direction of floodtide approach is east-southeast. Jeffries (1962), found that floodtides enter the Lower Bay through Ambrose Channel; at initiation of flood, ebb flow exists both at the surface and the bottom of the channel. Jeffries also found that ebbtides exceed floodtides by 10 percent more volume; this is, no doubt, related to freshwater discharge into Lower Bay from the area rivers. Ketchum, Redfield, and Ayers (1951), have estimated the duration of total flushing of bay water to be 6 to 10 days and more dependent on tidal oscillations rather than on river discharges.

Wind-driven currents affect surface water down to variable depths. Because winds predominate from the northwest except during July and August, the net surface water movement is southeast. During these two months the predominate wind directions are from the south and the net water movement is northward. Below an indefinite depth water masses are unaffected by wind stress but, may flow in a direction counter to surface water in order to maintain continuity. In general, Bumpus (1965) found a clockwise circulation in the inner bight. He also found that there was a residual bottom current into the estuary which is an expected consequence of less dense freshwater outflow. This same phenomenon is also found in other estuary-ocean systems which have been studied. Littoral drift or longshore transport forms in response to waves impinging at angles to the shoreface. Volumes of sand carried in the breaker zone vary greatly depending on wind and current energy and directions; however, net volumes over a number of years for the same geographic area are fairly constant. Taney (1961), and the U.S. Army, Corps of Engineers (1971), estimate that 450,000 to 600,000 cubic yards of sand (net volume) annually move from east to west for parts of the south shore of Long Island. Caldwell (1966), estimated that a minimum of 500,000 cubic yards of sand is transported northward along the northern New Jersey coast.

Additional studies on water velocities, directions and overall circulation patterns are being conducted in the Inner New York Bight by the National Oceanic and Atmospheric Administration (NOAA) as a part of a comprehensive oceanographic research program.

II. GEOMORPHOLOGY AND SHALLOW SUBBOTTOM STRUCTURE

1. Natural Effects.

a. Continental Shelf Morphology. Sea floor morphology and the features present are complex and varied; their origins are difficult to attribute to simple geologic processes. The Inner New York Bight region is in a very unusual geologic site–it straddles two major geomorphic provinces. Unlike other areas to the north and to the south, it has been influenced by both differential subaerial erosion of the near surface Coastal Plain strata and by several episodes of Pleistocene glaciation. Primary glacial erosion and deposition had a profound effect on this region. The formation and orientation of Long Island, a glacial depositional feature, has reduced the fetch of northeast winds and modified the water currents, waves and tidal actions. These factors have had and still have a profound influence on modifying the inner shelf morphology and surficial sediment distribution since the last major transgression of the sea about 10,000 years B.P. The area is also unusual because of the influence man has had on modifying natural sea floor morphology by dredging channels for cargo vessels and by large-scale waste disposal in the Hudson Channel region.

A striking feature on the bathymetric chart of the region (Fig. 4) is the Hudson River (submarine) Channel which is a topographic sea floor expression of a deeper buried river channel (shown in the seismic records) connecting the subaerial Hudson River Valley with the deeply incised Hudson Canyon at the Continental Shelf edge. The Hudson Channel system is probably the best defined of all of the channel-canyon systems which dissect the Atlantic Continental Shelf. (Shepard and Dill, 1966.)

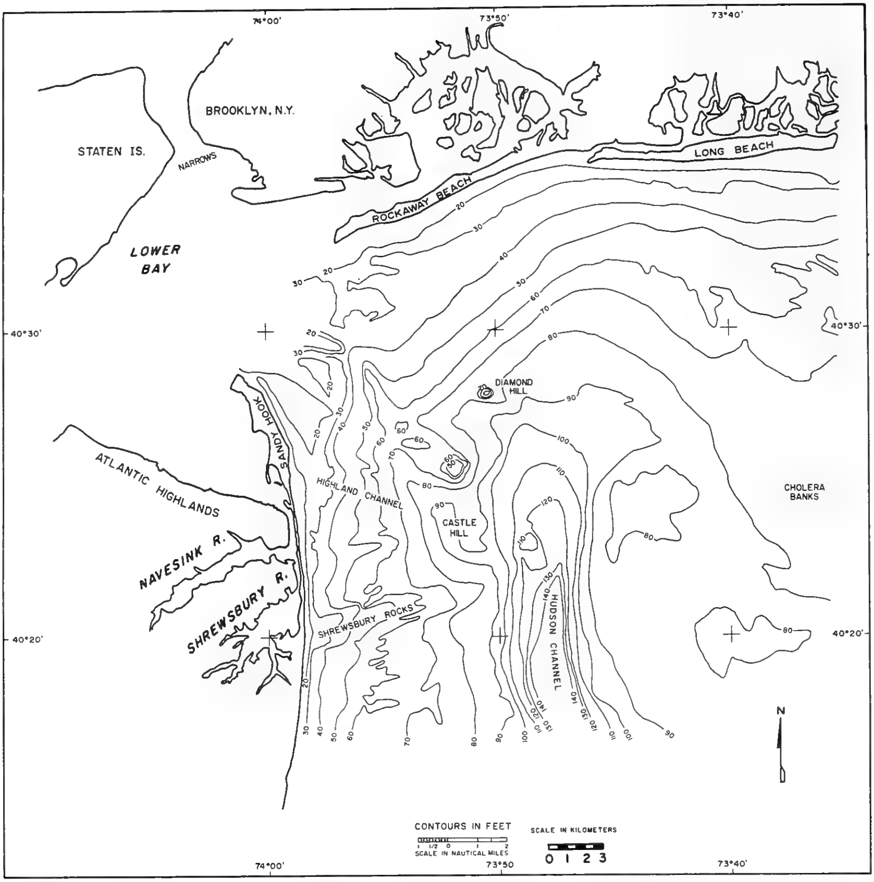

Figure 4. Bathymetric map of the Continental Shelf outside New York Harbor. Depth contours are from the National Ocean Survey Chart 1215 (1970), based on a 1934 survey. Note the northeast-trending expression of Shrewsbury Rocks; the location of a Coastal Plain cuesta. Note also the topographically positive features in the former Hudson (submarine) Channel north of Castle Hill and a similar mound at Diamond Hill to the northeast.

Evidence for the presence of the Hudson (submarine) Channel off Lower New York Bay apparently was first discovered during the 1842-44 hydrographic lead-line surveys (Lindenkohl, 1885), and was first described in professional geologic literature by James D. Dana in 1863. (Dana, 1890.) The area was described by early mariners as a "series of mud holes" but it was Dana who realized the significant alignment of the mud holes with the course of the subaerial Hudson River. It was his hypothesis that the submarine channel represented, during earlier geologic periods, the channel through which the river flowed when either the land surface was higher or sea level was significantly lower. Dana's acute observation provided the impetus for others to carefully survey the Hudson River region and started others examining channel-canyon systems elsewhere and formulating ideas for their origins which is still not resolved. An 1882 survey gives more detailed topographic expression of the channel. A second hypothesis on the channel origin was proposed at this time and suggested that it was produced "by a break in the strata." However, this theory of a fault or zone of crustal weakness projecting southeast from New York was not substantiated by the peripheral geology in either New Jersey or on Long Island, and thus was rejected. Later surveys traced the channel from its head in Lower Bay some 85 nautical miles across the shelf where it leads to the head of the Hudson Canyon at the shelf edge. (Stearns, 1969), (Veatch and Smith, 1939.)

Modifications of the channel by ocean disposal of solid materials from New York City have greatly altered the topography since the first detailed hydrographic chart was produced in 1845. Several anomalous circular mounds at least 20 feet high from the sea floor are situated in the depression of the Hudson Channel just east of Sandy Hook. Similar features are also present to the northeast adjacent Ambrose Light Tower and are referred to as Diamond Hill. (See Figure 4.) These sea floor features are the result of ocean disposal of solid material from the New York metropolitan area and will be discussed later.

A second but smaller submarine channel exhibits bathymetric expression in a southeast orientation from about the midpoint of Sandy Hook. It was named the Highland Channel on a hydrographic chart by Murray, 1888 (Veach and Smith, 1939) and appears to connect with the Hudson Channel in 90 feet of water south of Castle Hill. Considering its relative position the channel is most likely an extension of the ancestral Raritan River which apparently flowed eastward across the exposed shelf during Late Pleistocene, before the growth and accretional development of Sandy Hook. Topographic expression of the channel is lacking west of Sandy Hook in Lower New York Bay; it probably was present and has since been filled by the Holocene redistribution of sediment and especially by sand carried by littoral currents around the tip of Sandy Hook. MacClintock and Richards (1936), reported the presence of the buried Raritan Channel from borings along a proposed bridge route, between New Jersey and Staten Island, and noted that the base of the channel had been excavated 170 feet below sea level into the Raritan Formation. The channel was filled with sand, gravel and silt. The strikingly straight coastline of the Atlantic Highlands (Fig. 4) perhaps owes its origin to lateral stream bank erosion by the Pleistocene Raritan River.

Shrewsbury Rocks are a positive topographic sea floor feature at the southern end of the study area, immediately south of the Shrewsbury River. (See Figure 4.) They trend in a northeast orientation and form a demarcation line separating two markedly different geologic and physiographic provinces. North of Shrewsbury Rocks sea floor morphology is irregular and random except for the obvious submarine channels and the even contour line spacing south of Rockaway Beach. Sea floor topography south of Shrewsbury Rocks follows a similar northeast fabric of alternating ridge and swale structures. Shrewsbury Rocks extend about 6 miles seaward from the shore to where they have been abruptly truncated by the Hudson Channel. It is also interesting (Fig. 4) that the Highland Channel turns sharply east and joins the Hudson Channel immediately north of where the Hudson River has breached Shrewsbury Rocks. Apparently the Shrewsbury Rocks persisted as a barrier during Pleistocene and had a definite influence on diverting the course of drainage of the Raritan River and possibly the Hudson River.

Cholera Banks is another prominent topographic high located about 13 miles east of the New Jersey shore (Fig. 4) on the seaward flank of the Hudson Channel. Because of its northeast strike alignment with Shrewsbury Rocks, it very likely represents an eastward extension of one or more resistant Coastal Plain strata; however, no geophysical data are present in this area to support these conclusions.

2. Shallow Subbottom Structure.

Three distinct types of sedimentary bedding are evident from the geophysical records which allow a maximum of about 300 feet of subsea floor resolution. The first bedding type has the character of Coastal Plain strata which have a regional dip of about 1 on 80 (65 feet per mile) to the southeast. Energy penetration deeper than the first reflecting surface below the water-sediment interface is marginal so it is difficult to delineate detailed vertical stratigraphy. Records south of Shrewsbury Rocks show a buried surface of acoustic contrast, which may correlate with the T1 reflector traced across the shelf south of New England by Garrison (1970). Garrison assumed the T1 to be the contact between the Paleocene Vincentown Formation and the Miocene-Pliocene Cohansey Formation. Based on subsea depth and relative position in Coastal Plain stratigraphy this assumption agrees with our geophysical records.

Seismic profile Line 37 (Figs. 2 and 5) extends south-north from Long Branch, and shows the regional southeasterly dipping nature of the Coastal Plain strata and how they crop out on the sea floor south of Long Branch exhibiting about 15 feet of sea floor relief. This sea floor expression shown on the seismic records matches exactly with the location of Shrewsbury Rocks and is along strike (on line) with Cholera Banks, farther to the northeast. Because Shrewsbury Rocks is in apparent alignment with the Cretaceous-Tertiary contact on land it is reasonable to hypothesize that these outcropping beds are either the uppermost Cretaceous Tinton Formation (an indurated sandstone) or the early Tertiary Hornerstown Formation (a glauconitic sand body).

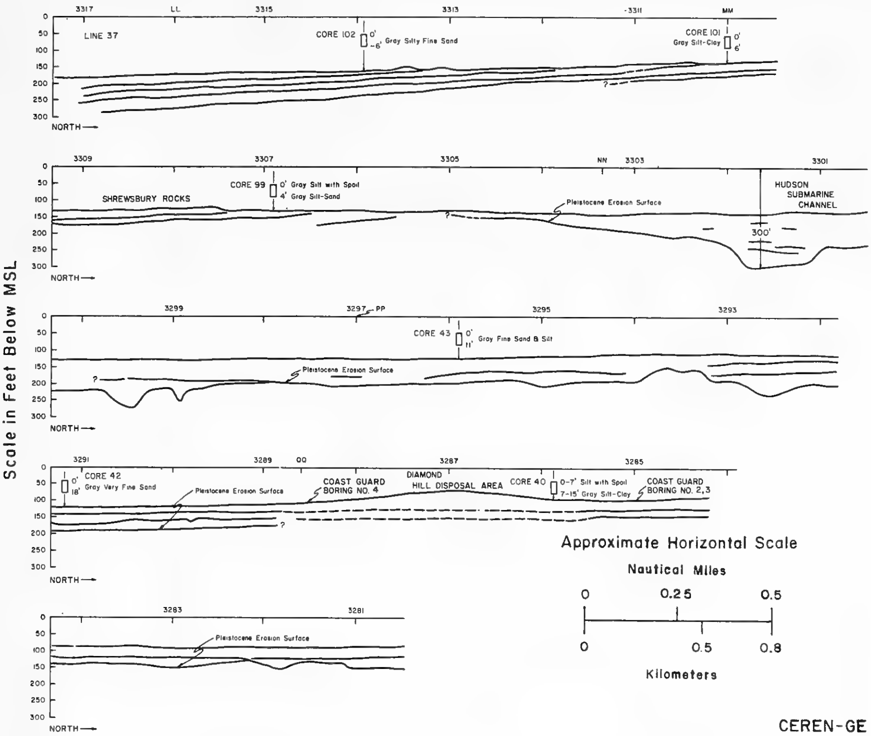

Figure 5. **South-north seismic profile line 37 from Long Beach to the Rockaway shelf.** The sea floor is the topmost continuous irregular line and the Pleistocene erosion surface is the contact between underlying Coastal Plain strata and overlying Pleistocene outwash. The top two profile frames show the Coastal Plain cuesta and abrupt transition to the deeply eroded and filled main Hudson Channel and two smaller channels. The fourth profile frame shows the regular profile of the Diamond Hill mound. Detailed stratigraphy for the Diamond Hill region is provided by the Ambrose Borings No. 2 and 3 shown in Table 2. (Ln. 37 location shown in Figure 2; the numbers refer to navigation fixes and the letters refer to trackline intersections.)

North of Shrewsbury Rocks Coastal Plain strata are buried by up to 100 feet of Pleistocene sediments. (See Table 2.) Considerable relief occurs on the upper surface of the Coastal Plain strata as a result of deep subaerial erosion during Pleistocene lower sea levels. This pervasive downcutting is mostly attributable to the erosive effects of the ancestral Raritan, Hudson, Shrewsbury, and Navesink Rivers and possibly to a southern advance by an outlier of the main glacial ice sheet. An ice prong may have funneled through The Narrows, exceeding the terminal moraine limits crossing Long Island and Staten Island, to transgress several miles south onto the shelf. Further discussion of this idea and evidence for its plausibility will be presented later. The Pleistocine erosion surface on top of the Coastal Plain strata becomes deeper in places northward from Shrewsbury Rock toward Long Island. Seismic profile records immediately south of Rockaway Beach have limited penetration and show a hint of possible Coastal Plain reflections 150 to 180 feet below present sea level. In places east of the head of the Hudson Channel erosional remnants of apparent Coastal Plain rock project within about 50 feet of the sea floor but none of the records in the immediate inner bight exhibit evidence of actual sea floor outcrops of Coastal Plain strata north of the Shrewsbury cuesta.

A second type of sedimentary bedding exhibited on the seismic records are large scale and very complex crossbed features which are restricted to an elongate buried basin, 6 miles long and 2.5 miles wide, parallel to and 1 mile east of Sandy Hook, included in Williams and Field, 1971. (See Figure 6.) Boundaries of the area of cross stratification are identifiable on the seismic records and seemingly grade into flat-lying sediments around the periphery. The boundaries to the north appear to narrow and apparently the crossbed sediment is truncated by the buried shelf extension of the Hudson Channel which has been artifically deepened in the construction of the Ambrose Navigation Channel. Attempts at following the crossbed strata on geophysical records north of the channel to the shelf south of Rockaway Beach have been unsuccessful.

The records indicate that the material underlying the crossbeds dips slightly to the southeast and appears to be more massive and continuous than the overlying sediment. Descriptions of material from Coast Guard bore hole No. 2 (Fig. 6, and Table 3), taken to evaluate foundation conditions for the Scotland Light Navigation Tower, support our conclusions that strata below 100 feet (MLW) are Cretaceous age Coastal Plain sediments which were eroded and subsequently covered by deposition of overlying crossbed sand and gravel. Figures 7 and 8 show five reduced seismic profiles for the trackline locations shown in Figure 6. These profiles are typical of the actual seismic profiles within the crossbed boundaries and show the complexity, size, and structural framework of the sedimentary features.

At the northern limit of the crossbed area, Line A (Fig. 7) shows the topmost 10 to 15 feet of sediment to be flat-lying stratified material of probable Holocene age resting on the truncated tops of planar, massive, crossbed structures. Thickness of the crossbed unit

Table 2. Coast Guard Boring Logs for Holes 2 and 3 from the Flank of Diamond Hill for Ambrose Light Station.*

Boring 2 — TYPE: 3" Shelby tube & 2" split-spoon

Depth, ft	Description of material	Blows per ft	Unit dry wt lb/cu ft
	Water depth: 76 ft (MLW)		
0–27	Brown fine-medium sand becoming dark gray organic silty sand, slightly clayey w/gravel & cobbles @ 0.5'; -gray silty fine sand w/shell fragments @ 1.5'; -some large shells @ 7'; Q-REM (MS) w = 30% γ_d = 95 pcf, ϕ = 36 deg	10, 10, 19	95, 103
27–50	Soft gray clay, w = 62% Q-Und(OB) S = 0.10 tsf; -firm w/imbedded shell @ 37', trace of silt w = 55% UC: S = 0.32 tsf; -more silt w/sand layers below 46' and containing flecks of wood and mica w = 45% Q-UND(OB) S = 0.45 tsf	0	63, 67, 77, 84
50–67	Gray fine-medium sand w/firm gray clay layers, w = 41% UC: S = 0.20 tsf (on clay)		82
67–120	Sand & fine-coarse gravel; -traces of clay 77' to 79'	30, 70, 40, 50	

Boring 3 — TYPE: 3" Shelby & 2" split-spoon & rock core

Depth, ft	Description of material	Blows per ft	Unit dry wt lb/cu ft
	Water depth: 76 ft (MLW)		
0–21	Fine-coarse sand & gravel w/cobbles & brick to 1'; dark gray organic silty fine sand w/some clay. Gray silty fine sand w/shell @ 4'; Q-REM(MS) w = 30% γ_d = 94 pcf, ϕ = 37.5 deg; w = 31%	6, 6, 20	96
21–55	Firm gray clay w/shell, slightly silty, w = 48% UC: S = 0.27 tsf, LL = 51, PL = 30; -more silty @ 38' w = 48% UC: S = 0.14 tsf; w = 46-49% UC: S = 0.22 tsf, Q-Und(OB): S = 0.33 tsf, LL = 53, PL = 28		74, 71, 76, 70
55–120	Gray & brown fine-medium sand w/pea gravel, w = 21; -coarser w/more gravel @ 68'; -gray sand & gravel by 80'	34, 60, 53	102
120–192	Gray silty fine sand, slightly clayey w/traces of wood, w = 33%; -layers of lignite & traces of clay below 131'; -gray fine-medium sand w/lignite layers below 150'; -hard lignitic clay seams @ 189' w = 32%	30/6", 40/6", 50/6", 30*	
192–202	Hard gray shaly clay w/sand layers		
202–212	Hard gray shaly clay w/sand layers; -trace of siltstone @ 210' w = 31%, LL = 53, PL = 25	* 15/4"	
212–253	Soft gray shale w/occasional 1" seams hard limestone, w = 27%, LL = 49, PL = 26, UC: S = 2.1 tsf; w = 28%	**, * 24/3"	

* 680-lb hammer dropped 30-in.
** Rock core, 100% recovery

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*See Figures 2 and 5 for locations.

(Courtesy of U. S. Coast Guard)
(McClelland, 1963)

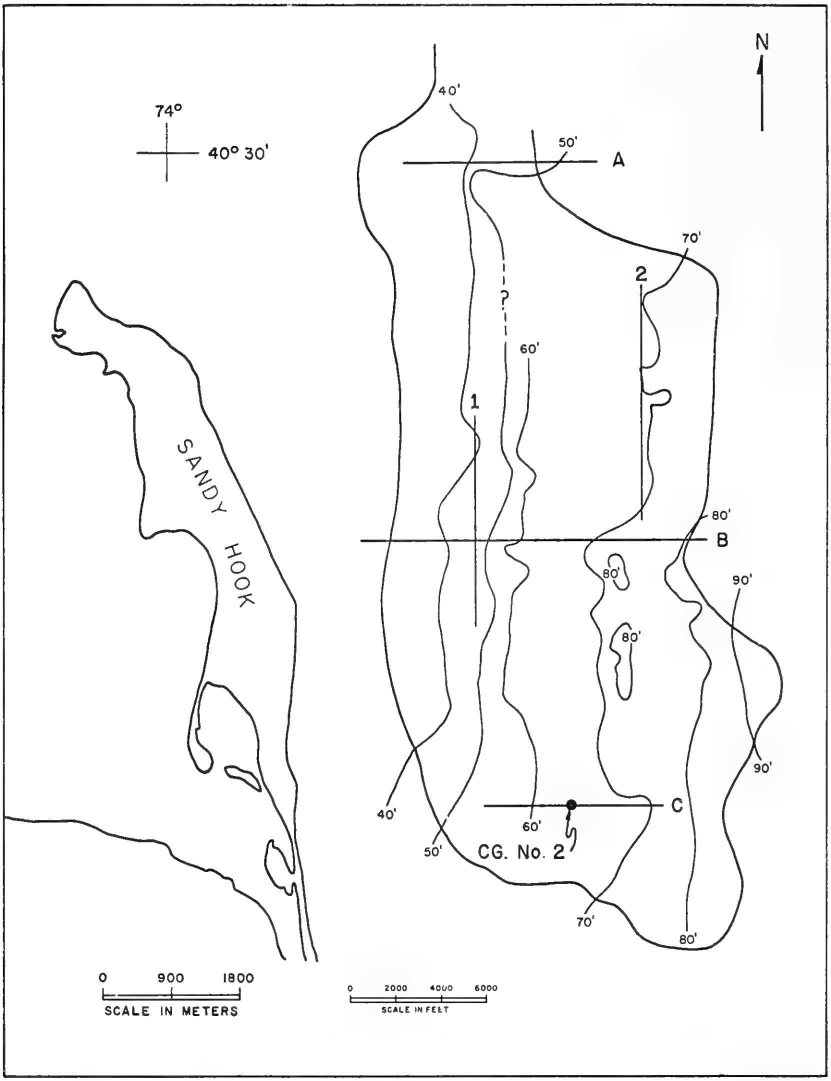

Figure 6. Crossbed surface topography. Map shows the areal limits of the complex crossbed area east of Sandy Hook. Superimposed are subsea contours in 10-foot intervals on the crossbed erosion surface and profile locations for the reduced seismic lines shown in Figures 7 and 8. Stratigraphic control is provided by the log for Coast Guard bore hole No. 2, (Scotland Light) located on line C and shown in Table 3.

Table 3. Coast Guard Boring Logs for Holes 1 and 2 at the Scotland Light Navigation Station East of Sandy Hook, New Jersey.*

Boring 1

TYPE: 3" Shelby & 2" split-spoon

DEPTH, FT	DESCRIPTION OF MATERIAL	BLOWS PER FT	UNIT DRY WT LB/CU FT
	Water depth 51 ft (MLW)		
0	Gray & brown fine to medium sand w/pea gravel & pockets of dark gray clayey silt to 1.5' ω=42%	30	
10	-dark gray clayey silt w/sand & gravel & clay pockets & shells at 1.5'		
20	-mostly dark gray silty fine sand w/shell at 15'		
30	-gray fine sand w/shell at 28'; w = 27%	35	94
40	-some layers rounded pea gravel below 38'	38	
50	-trace clay at 48'	32	
60	w = 24%, Q-REM(MS) γ_d = 102 pcf, ϕ = 39 deg	20	99
70	-gray medium sand at 69'	42	
80	Fine to coarse sand & gravel (rounded)	40	
90	-less gravel below 85'	48	
100		40	

DEPTH, FT	DESCRIPTION OF MATERIAL	BLOWS PER FT	UNIT DRY WT LB/CU FT
100	Medium to coarse sand & gravel		
110	-trace clay by 109'; -much more gravel by 115' w/ some shell	44	
120	-boulders 123' to 124.5'	52	
130	Medium to fine sand w/some pea gravel		
140	-no gravel at 138'; w = 22%, Q-REM(MS) γ_d = 107 pcf, ϕ = 40.5 deg	48	
150			
160	-fine to medium sand by 158'; w = 24%	40	
170			
180		50	
190			
200	Hard gray shaley clay w/sand & silt lenses	50	

Boring 2

TYPE: 3" Shelby & 2" split-spoon

DEPTH, FT	DESCRIPTION OF MATERIAL	BLOWS PER FT	UNIT DRY WT LB/CU FT
	Water depth 49.5 ft (MLW)		
0	Gray fine sand to 1.5', then pea gravel	27	
10		22	
20	Gray fine to medium sand w/some pea gravel to 25'	19	
30	-silty fine sand by 29'; w = 29%, Q-REM(MS) γ_d = 100 pcf, ϕ = 42.5 deg	25	
40	-trace clay at 37'; -gray silty fine sand at 39'	28	
50	w = 34%, LL = 39, PL = 17; Gray very silty clay to clayey silt, becoming stiff to very stiff gray clay, slightly silty w/some shell at 55'	7	
60	w = 39%, LL = 49, PL = 23, UC; S = 1.08 tsf		80
70	Gray silty fine sand w/shell; -w = 25%	22	97
80	w = 34%; -medium to coarse brown sand w/pea gravel 80 to 88.5'	19	
90		23	
100		22/3"	

DEPTH, FT	DESCRIPTION OF MATERIAL	BLOWS PER FT	UNIT DRY WT LB/CU FT
100	Pea gravel (rounded)		
110	-w/medium to coarse sand by 109'	29	
120	Hard gray & tan shaley clay	50	
130	Gray & brown fine to medium sand w/occasional pea gravel		
140	-becomes gray fine sand w/ trace of silt	32	
150			
160		48	
170			
180	-w = 26%, Q-REM(MS) γ_d = 101 pcf, ϕ = 41 deg	55/9"	
190			
200			

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(Courtesy of U. S. Coast Guard)

(McClelland, 1963)

*Log 2 provides the stratigraphic control for Line C shown in Figure 7.

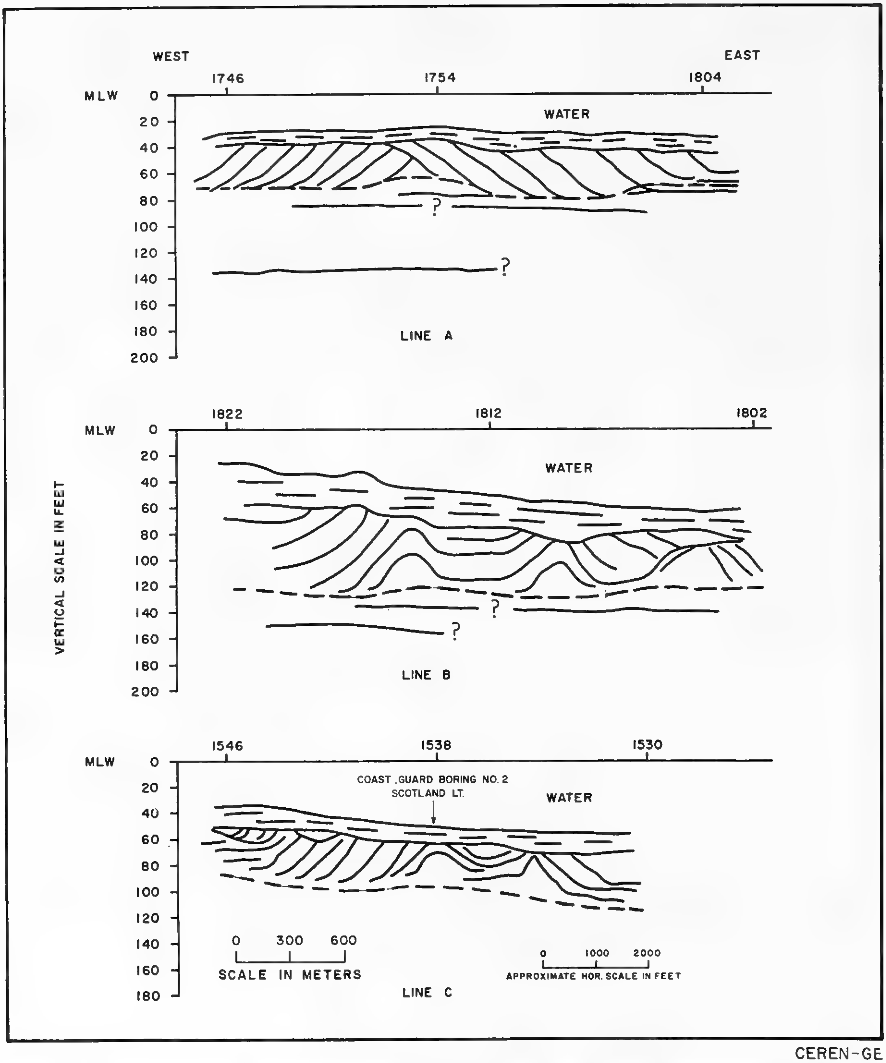

Figure 7. Three reduced east-west seismic profiles from the crossbed area shown in Figure 6. The topmost sediment is inferred to be Holocene age; the crossbed material is Pleistocene fluvial sand and gravel and bore hole No. 2 indicates the dash-line is a Pleistocene erosion surface on top of Coastal Plain strata. Numbers are navigation fixes.

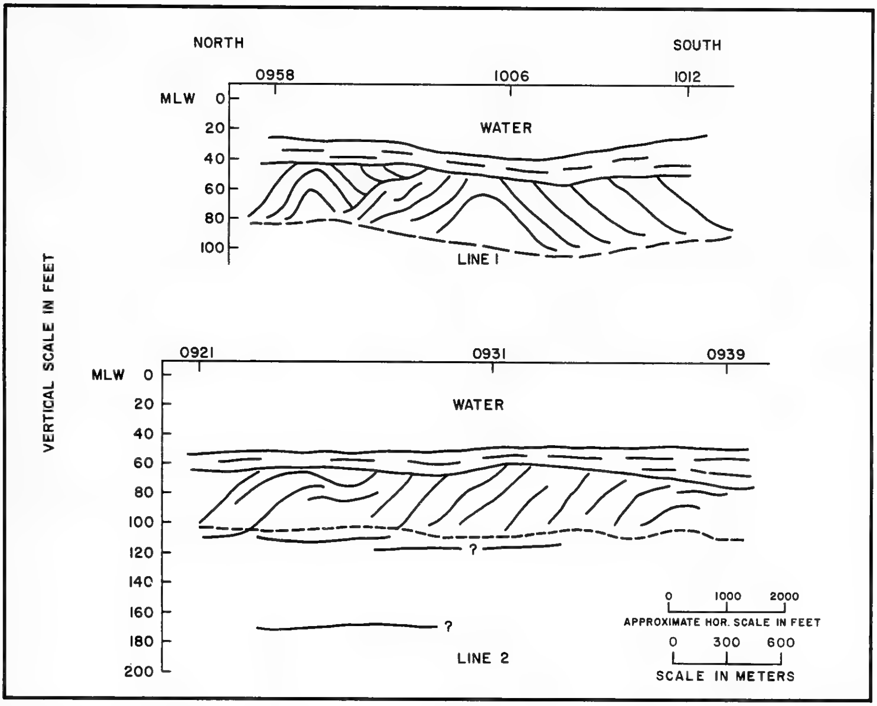

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Figure 8. Two reduced north-south seismic profiles from the crossbed area shown in Figure 6. (See Figure 7 for stratigraphy.)

approximates 35 feet and two primary slope directions are indicated. If these are sedimentary structures, then westerly flow apparently preceded easterly transport. Material underlying the crossbeds is flat-lying or dips slightly easterly and acoustically appears more massive and continuous than overlying sediment.

Horizontally stratified Holocene material is shown in Line B, but of slightly greater thickness, on top of crossbeds which appear to be the result of complex multidirectional stream flow. Smaller scale internal structures within crossbedded units are not discernible on the records. At the southern margin of the crossbed area, Line C is similar to the preceding two lines but, in addition, shows more cut and fill structures thought to represent stream channels buried by later deposition. Such channel-like structures are common on many of the records and some appear to be in continuous alignment over short distances with present-day drainage channels such as the Navesink River. The log of Coast Guard boring No. 2 from Scotland Light (Table 3) agrees with the independent reconstruction of seismic profile C. The log, showing a water depth of 49.5 feet, indicates that from the sea floor down to a subsea depth of about 100 feet the material consists of fine to medium sand with varying percentages of pea gravel. At −100 feet there is a sharp lithologic break which correlates with the Coastal Plain erosion surface shown in Line C. The top 15 feet of Coastal Plain strata from the log description apparently are stiff silts and clays underlain generally by medium to coarse brown sand and pea gravel. Because of the general nature of the log description no correlations with specific Coastal Plain formations are possible.

A horizontally bedded 12-foot thickness of Holocene sands overlying a 40-foot-thick sequence of crossbed material is shown in Line 1, Figure 8. Inclinations of foreset beds at the north indicate a southerly transport direction while the chaotic internal structures to the south are indicative of cut and fill associated with stream channel migrations. The approximate maximum lower limit of crossbed strata is −100 feet MLW, which here represents the Coastal Plain erosion surface. The same stratigraphic sequence (Line 1) is shown in Line 2, except that the Holocene material at the north end is about 10 feet thick and thickens to about 30 feet to the south. The underlying crossbeds are inclined northward and indicate either a northerly transport system or an extraneous component of a southerly directed system. Buried and filled stream channels are evident and their position indicates they postdate the forest beds.

Attempts have been made to determine major stream channel orientations in the crossbed area east of Sandy Hook by plotting crossbed dip directions and by construction of crossbed isopach maps, but the structures are so complex that regional trends are obscure.

A contour map representing the surface topography of the crossbedded sands using mean low water as the datum surface is shown in Figure 6. The contours indicate that the surface has a general north-south strike with a gentle slope to the east. There are smaller variations in relief but difficulty was sometimes encountered in determining the top of the sands on the records because of masking by the bubble pulse. Such a regional surface topography may have resulted from a high degree of marine reworking of the fluvial material by transgressing seas in post-Wisconsin time.

Inclined and seemingly deformed sedimentary features similar to those just described were found by Knott and Hoskins (1968) on the shelf south of Martha's Vineyard. The inclined beds appear (Fig. 13 from Knott and Hoskins, 1968) to be about 125 feet thick and overlain by flat-bedded material 30 to 60 feet thick. Because of apparent folding and overthrusting the authors have attributed the anomalous bedding to ice-push deformation, due to southward-directed glacial transport. Thus, they conclude the strata south of Martha's Vineyard may mark the southern limits of Pleistocene glacial advance in the eastern Long Island region. Fuller (1914) reported the presence of extensive isoclinal folding of Cretaceous strata and the Pleistocene Gardiners Formation on Long Island which he also attributed to ice pressure. Fuller also noted that the clay beds, because they were more coherent and better able to transmit lateral stress, remained intact during compressional folding; incompetent sand and gravel strata were incapable of transmitting stress and were squeezed into structureless masses. Keeping his observations in mind, it is difficult to believe that unconsolidated outwash materials, about 125 feet thick, could transmit the pressures over several kilometers to result in the structures described by Knott and Hoskins (1968) and later by Uchupi (1970). While it is plausible that some glaciers transgressed south of the terminal moraine on Martha's Vineyard and were the cause of local sediment deformation, the presence of apparent buried stream channels and stratified sediment on the Knott and Hoskins (1968) figures strongly suggest that the strata may be sedimentary structures built by outwash-laden meandering streams which drained the glaciers and flowed onto the shelf. However, if structural deformation is truly pervasive, the inclined structures are more likely slump structures, resulting from instability due to rapid depositional loading of sediment on an unstable sloping surface. Some trigger mechanism could then cause gravity slumping. In any case, the inclined bedding structures east of Sandy Hook appear to owe their origin to depositional processes, possibly related to a cataclysmic event, such as rupture of major proglacial dams which periodically occupied the Hudson Valley or to fluvial processes operative at the confluence of the ancestral Raritan and Hudson Rivers. (Connally, 1972.)

A third type of sedimentary bedding shown in Figures 5, 7, and 8, consists of nearly horizontal and sometimes seaward dipping Pleistocene and Holocene silt, sand and gravel sediments. Because of the lack of sharp acoustic contrast between these materials the seismic records show only faint hints of continuous bedding. The bedding surfaces which show on the geophysical records probably mark an interface between two materials with markedly different mass properties. There is a perceptible increase in thickness of the Pleistocene-Holocene sands from the southern part of the study area, offshore from Long Branch toward the south shore of Long Island at Rockaway Beach. (See Figure 5.) Because of the nature of the material and the proximity of the moraines and outwash plains on the north side of Long Island it seems plausible that this material on the shelf is primarily fluvial outwash sediment which during Pleistocene time was deposited on top of the Coastal Plain strata which had been eroded by rivers in the area.

The buried Hudson Channel on the seismic records in the region east of Sandy Hook has a subsea depth of 300 feet (Fig. 5) in contrast to the channel depth of over 700 feet at Tarrytown, New York. (Worzel and Drake, 1959.) Because of the general north-south alignment of the subaerial Hudson Valley and because of both the great width and depth of the entire Hudson River Valley it is reasonable to assume that the valley acted as a conduit for glacial ice during Pleistocene times, at least as far south of the terminal moraines across Staten Island, in which the glaciers advanced and retreated a number of times. The resulting glacial scour was responsible for deepening the Hudson Valley into a fjord which has since been partially filled by typical fluvial and glacial sediments. The base of the Hudson Channel on seismic line 37 (Fig. 5) exhibits a flat-bottomed, U-shaped lateral profile (typical glaciated valley) in contrast to more typical V-shaped profiles (typical fluvial valley) of the channel on the outer shelf. (Knott and Hoskins, 1968.) The channel profile and 300-foot depth suggest the possibility that glaciers transgressed south of the Long Island-Staten Island terminal moraine, were funneled through The Narrows and flowed for an indefinite distance out onto the Continental Shelf. If this suggestion were correct it could provide the mechanism to explain why the Hudson is the best developed of any submarine channel-canyon system on the Atlantic shelf. To provide further evidence to either prove or disprove this idea, and in general to further document the exact course, maximum channel relief, and nature of channel fill, more high resolution seismic records and deep cores are needed on the inner shelf to tie with seismic work done by Ewing, Pichon, and Ewing (1963), and Oser (1969) on parts of the outer shelf.

3. Effects of Man.

a. Ocean Disposal of Spoil Material. An interesting feature on the bathymetric chart of the New York Inner Bight (Fig. 4) is the presence of several conical, topographically positive, sea floor features located in what was a clearly defined Hudson Channel depression on the 1845 chart. (See Figure 9.) These features are situated about 6 miles southeast of the New York Harbor entrance and have about 30 feet of relief relative to the surrounding sea floor. Their isolated nature and circular form in plan view sets them apart from the natural sea floor morphology. The 1845 chart, based on lead-line sounding data, shows clear contour expression of the Hudson (submarine) Channel as it makes its transition from the Continental Shelf to the Lower Bay entrance, and ultimately through The Narrows to connect with the Hudson Valley. Comparison of Figure 4 with Figure 9 shows little net change in contour placement for the inner shelf except for the region around the channel head.

An isopach map (Fig. 10) of bathymetry differences from both the 1845 and 1934 charts shows the location and magnitude of accretion that has taken place during 90 years. The minimum isopach line limits the maximum bathymetrical areal extent of material accumulation and shows an irregular outline, is elongated in a northwest-southeast direction,

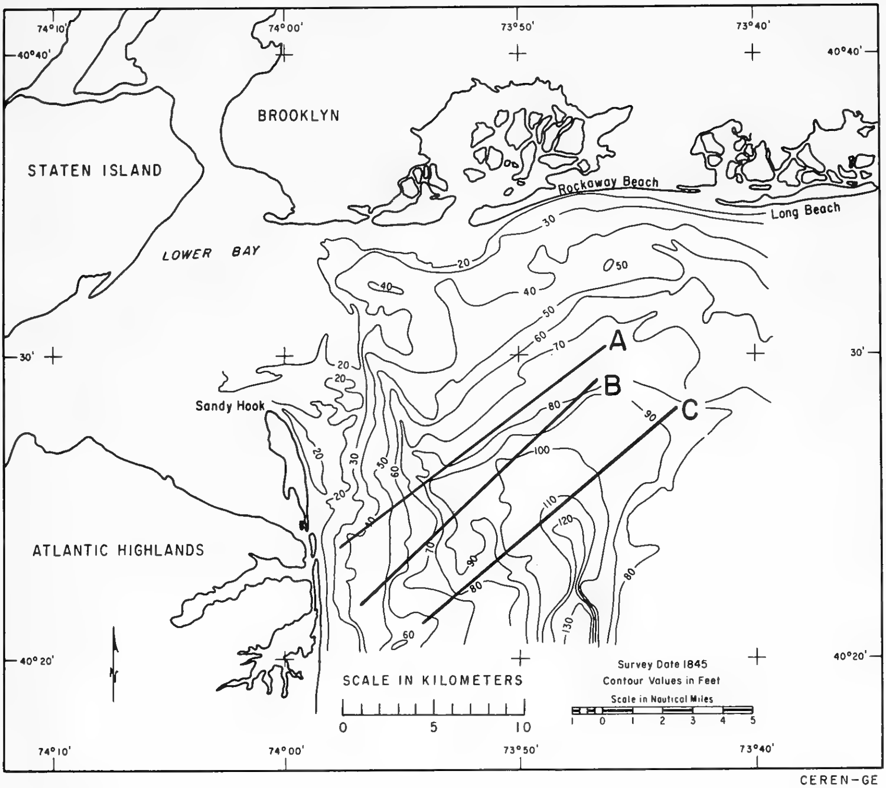

Figure 9. Bottom contour map of the Inner New York Bight using bathymetric data from an 1845 hydrographic survey. Note the bathymetric expression of the Hudson Channel (better defined than the recent map in Figure 4) and the absence of rubble mounds either in the channel or at Diamond Hill. Lines A, B, and C are profile locations shown in Figure 11.

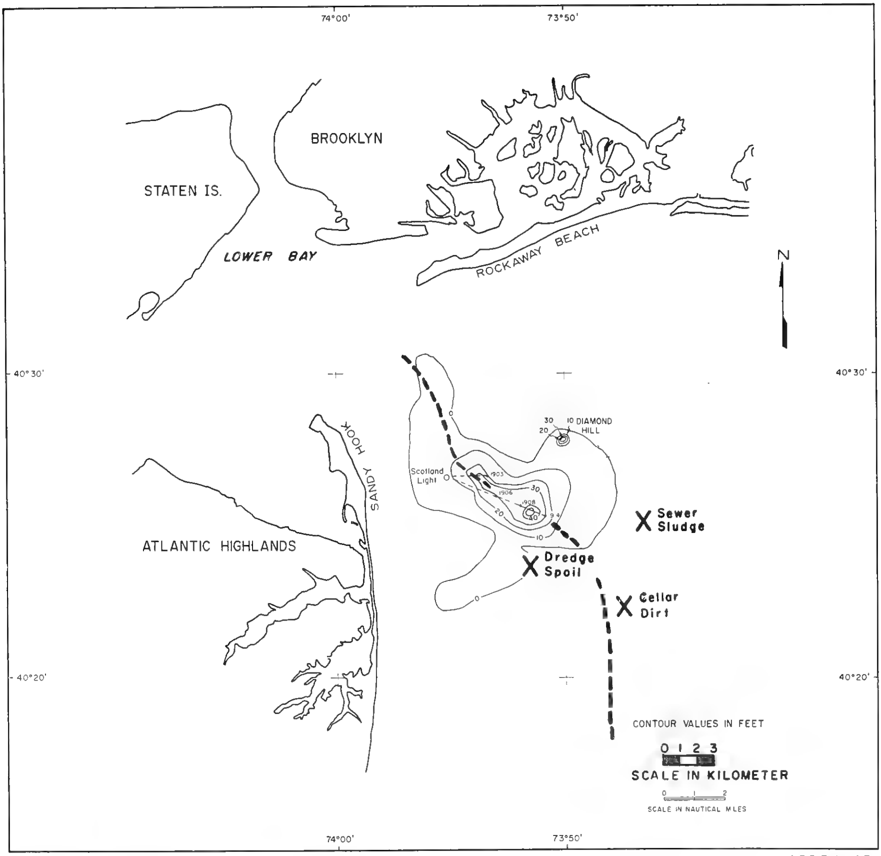

Figure 10. Isopach map of fill materials. Data are based on bathymetric differences between the 1845 hydrographic survey (Fig. 9) and the National Ocean Survey chart 1215. (See Figure 4.) Dash-lines east and southeast of Scotland Light, used as a navigation landmark, show dump sites for the years indicated. Note area of maximum fill is in thalweg of Hudson Channel (heavy dash-line). Crossmarks denote contemporary waste disposal sites.

paralleling the natural topographic expression of the Hudson (submarine) Channel. It measures approximately 7 nautical miles along an east-west axis and 3 nautical miles along a north-south axis. The protrusion of accumulated material extending in a southwest direction toward the New Jersey mainland may be attributed to a lack of close survey control on the 1845 survey due to proximity of Shrewsbury Rocks, which posed a navigation hazard. Another factor contributing to the anomalous protrusion may be natural sedimentary accretion from the Navesink and Shrewsbury Rivers. The rivers at one time flowed directly into the ocean (Fig. 9) before northward growth of the barrier island, which has since diverted their discharge north into Sandy Hook Bay.

The area of maximum thickness, corresponding to the Castle Hill area on the recent chart, is about 5 nautical miles east of New Jersey, and contains more than 50 feet of fill material. The 10-, 20-, and 30-foot isopach lines extend about 4 miles in a northwest direction and include another conical feature. (See Figure 10.) The conical elevation northeast of the channel exhibits more than 30 feet of fill and historically has been referred to as Diamond Hill. Three northeast-southwest oriented sea floor profiles located in Figure 9 are shown in Figure 11. Some of the disparity between the 1845 and 1934 sea floor could be attributed to inaccurate surveys; however, the net aggradation of the sea floor in profiles A and B is unmistakably real. The lack of significant sea floor change along profile C, which passes seaward of the isopached disposal area reported on here, further indicates that the sand, gravel, and stone fractions of the fill along profiles A and B are stable in the present oceanographic environment and have shown little movement southward toward the deeper parts of the Hudson Channel.

Conclusive proof that the Diamond Hill sea floor feature is ocean-disposed fill is available from the log for Coast Guard bore hole 4 (Table 4) taken for a foundation study for the Ambrose Light station. The boring is located on a flank (Fig. 5) about 600 yards southeast of the main sea floor feature. The log (Table 4) describes a mixture of fill material to 16 feet below the sea floor.

Additional proof of the origin of these sea floor features and a perspective history of ocean disposal of fill in waters proximal to New York City is contained in annual reports by the U.S. Army, Corps of Engineers (1885–1930). Part 1 of the 1915 report was helpful in providing the location, volumes and general nature of material disposed in the ocean outside New York Harbor.

To accommodate the increasing need for disposal of assorted materials the Office of Supervisor of New York Harbor was established by an act of Congress in 1888. The Harbor Supervisor, acting through the Office of the Chief of Engineers, was responsible for designation of specific disposal sites and for ensuring that ocean disposal would not be detrimental to navigation or pollute adjacent beaches. A more complete documentation of establishment of authority over ocean disposal in the New York City region is discussed by Pararas-Carayannis (1973).

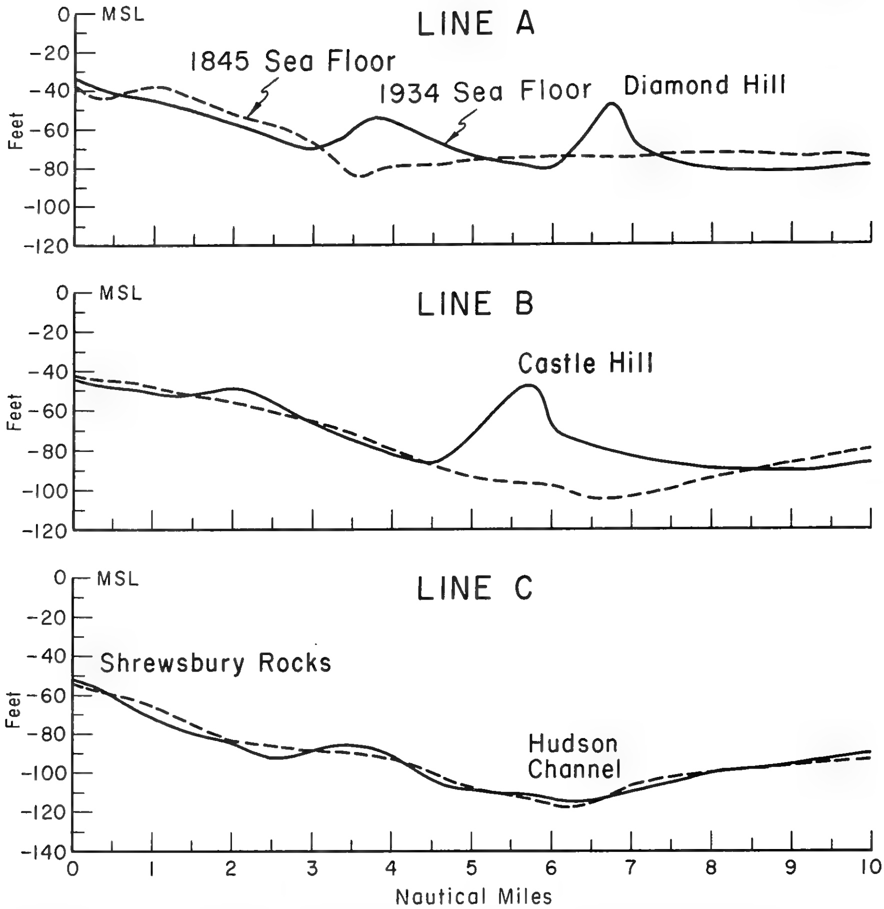

Figure 11. Sea floor profiles from 1845 and 1934 surveys. (Figure 4.) Aggradation in the channel is shown on lines A and B as a result of ocean disposal practices. Line C is seaward of the disposal area and shows little change.

Table 4. Log of Ambrose Boring No. 4* (Diamond Hill Area).

Depth: 72 ft (MLW) Interval (ft)	Description
0 to 16	Fill. Coarse brown sand with pea gravel. Black organic clayey silt 1.5 to 2 feet. Silt, sand and gravel below 2 feet with pieces of brick, roofing paper, wood and miscellaneous materials.
16 to 26	Gray silty fine sand with shell fragments.
26 to 52	Soft gray silty clay with shell. Firm by 30 feet with flecks of wood. Micaceous. Less silty at 48 feet.
52 to 62	Gray fine to medium sand.
62 to 121	Brown fine to coarse sand with pea gravel below 62 feet. Some 1.5-inch gravel below 70 feet. Coarse gravel 94 to 97 feet. Coarse sand with pea gravel below 97 feet.
121 to 196	Lignite layer, 121 to 122 feet, then light gray silty fine sand with traces of lignite and wood. Much decomposed wood at 169 feet.
196 to 250	Hard gray shaly clay with sand seams to 200 feet grades into soft shale by 218 feet, slightly lignitic. Some thin limestone seams below 238 feet.

*Data from McClelland Engineers (1963a.). (See Figure 2 for location.)

A chronology of the locations of official disposal sites follows: (U.S. Army, Corps of Engineers, 1885–1930.)

1888--Mud buoy, 2.5 miles south of Coney Island, for the deposit of all refuse, including garbage and city refuse.

1 Sept. 1900--A point one-half mile southward and eastward of Sandy Hook Lightship.

1 Dec. 1903--A point 1.5 miles to the eastward of Scotland Lightship, in 12 fathoms of water.

1 Jan. 1906--A point 2 miles southeast of Scotland Lightship, in 14 fathoms of water.

17 Apr. 1908--For cellar dirt and floatable material, a point 3 miles southeast of Scotland Lightship.

1 Sept. 1913--Limit of water for deposits, 15 fathoms.

1 May 1914--For material containing floatable matter, not less than 4 nautical miles east-southeast of Scotland Lightship, in not less than 17 fathoms of water.

Each successive designated dump site was relocated farther seaward as the previous site became shoaler and posed a possible hazard to navigation. A bathymetric map, printed in 1888 (Fig. 12), shows the natural sea floor contours before formal designation of disposal sites. Compared with the 1845 chart (Fig 9) it reveals negligible fill in the channel proper.

In searching the summary of annual reports (U.S. Army, Corps of Engineers, 1885–1930), and individual reports from 1880 to 1920 no reference was found to acknowledge the presence of an official dump site in the vicinity of Diamond Hill. It does seem unusual that navigation control of dumping was so good, as evidenced by the compact conical form of Diamond Hill. The origin of the Diamond Hill mound is unknown to the authors but bathymetric differences show it did originate sometime between 1845 and 1888.

The isopach map (Fig. 10) shows close agreement with the above listed records detailing locations of the disposal areas for specific years. Shoaling became so critical in 1914 at the large central mound immediately north of Castle Hill that a memorandum was issued by the Supervisor of New York Harbor—thereafter excavated stone up to a size commonly referred to as "one-man stone" had to be deposited not less than 3 miles southeast of Scotland Light. For larger stone, commonly referred to as "derrick stone," deposition was specified to be not less than 4 miles southeast of the light.

Specific composition of the dump material is difficult to determine from the reports; it mostly consisted of "cellar dirt" or natural rock and soil overburden from construction projects in the city. (See Figure 13.) Mixed with this would be: rubble from the demolition of buildings; street sweepings consisting of light trash, debris and coal ashes; floating debris from the harbor and derelict vessels which posed possible threat to navigation; dredge spoils from removal of bottom sediment during construction of new channels; and normal

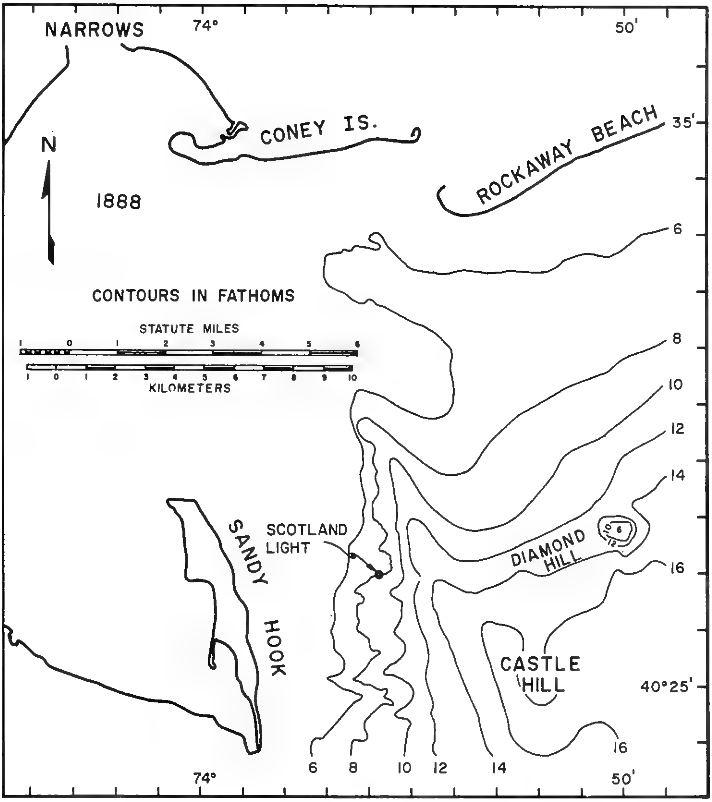

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Figure 12. Bathymetric map based on an 1885-88 hydrographic survey. Map (Veatch and Smith, 1939) shows an apparent natural Hudson Channel, but also the presence of the Diamond Hill waste mound in contrast to its absence in Figure 9 depicting the survey of 1845.

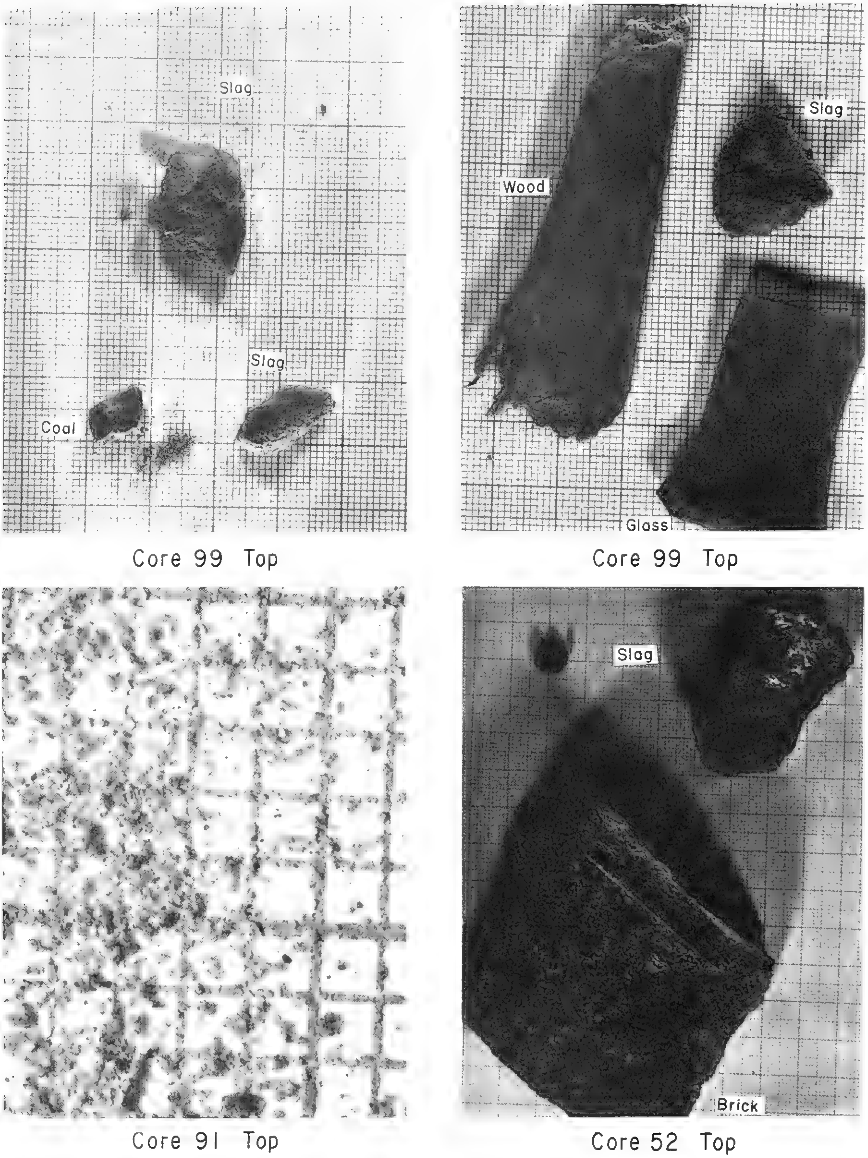


Figure 13. **Photos of typical spoil from the shelf and ocean dump areas.**
(Grid in millimeters).

maintenance and deepening of existing channels in surrounding kills and bays. Another source was garbage, dumped in the ocean until 1897 when a reduction plant was put into operation. The construction of Ambrose navigation channel (1900–07) is one example of a major contribution of ocean-disposed dredge material. During those years about 50 million cubic yards of assorted clean sand and gravel were removed from the sea floor and dumped in the designated disposal area. (See Figure 10); (Wigmore, 1909.)

III. SURFACE AND SUBSURFACE SEDIMENT CHARACTERISTIC AND DISTRIBUTION

Most data on the character of the sea floor sediments in the study area were derived from ICONS vibratory cores, which are fairly evenly spaced throughout the inner bight region and provide a comprehensive overview of the total sediment distribution. (See Figures 2 and 14.) The average length of recovered sediment in the cores is 10.7 feet. Other sediment data were derived from grab samples and from reports submitted by dredge companies in the New York vicinity. Based on examinations of the sediment data the region can be characterized generally by five distinct sediment types.

Sediment Type I (Figs. 14 and 15) occurs in the vicinity of Shrewsbury Rocks, New Jersey where the seismic profiles (Fig. 5) show that Coastal Plain strata project toward the sea floor and in places crop out as a cuesta. (Williams, 1973.) The sea floor consists of reddish brown medium to coarse quartz sand with an abundance of quartzose pea gravel. The coarse material appears to be a thin mantle of residual sediment resulting from erosion of the underlying semiconsolidated Coastal Plain strata. This same sediment type possibly extends along strike of the sea floor cuesta to the east of the Hudson Channel toward the south shore of Long Island.

Sediment Type II consists of coarse to very coarse sand (500 micrometers to 2 millimeters), and pea gravels (5 to 20 millimeters). (See Figure 16.) This material is found in four discrete areas (Fig. 14) but, the cores indicate a much wider areal coverage beneath finer-grained sea floor sediment. The mineralology of the patch of sediment Type II northeast of Sandy Hook resembles glacially derived detritus, which apparently is exposed as a result of removal of overlying recent sediment due to continuous channel dredging. Competent tidal currents, often exceeding 0.5-knot (25.7 centimeters per second) velocities, also effectively scour the sea floor between Sandy Hook and Rockaway Beach leaving a lag of coarser sediment. (Cok, et al., 1973.) The large kidney-shaped area immediately off the northern New Jersey mainland is characterized by Type II reddish brown sand which apparently resulted from subaerial oxidation of iron-bearing minerals. The sedimentary character and configuration of the material indicate that it may represent relict fluvial deposits transported by the Navesink and Shrewsbury Rivers during the Pleistocene when sea level was significantly lower than at present. Another hypothesis is that this sediment is residual material from adjacent outcropping Coastal Plain strata which formed a headland throughout the most recent marine transgression. This material may have since been distributed over wider areas of the sea floor by wave action and longshore sediment transport.

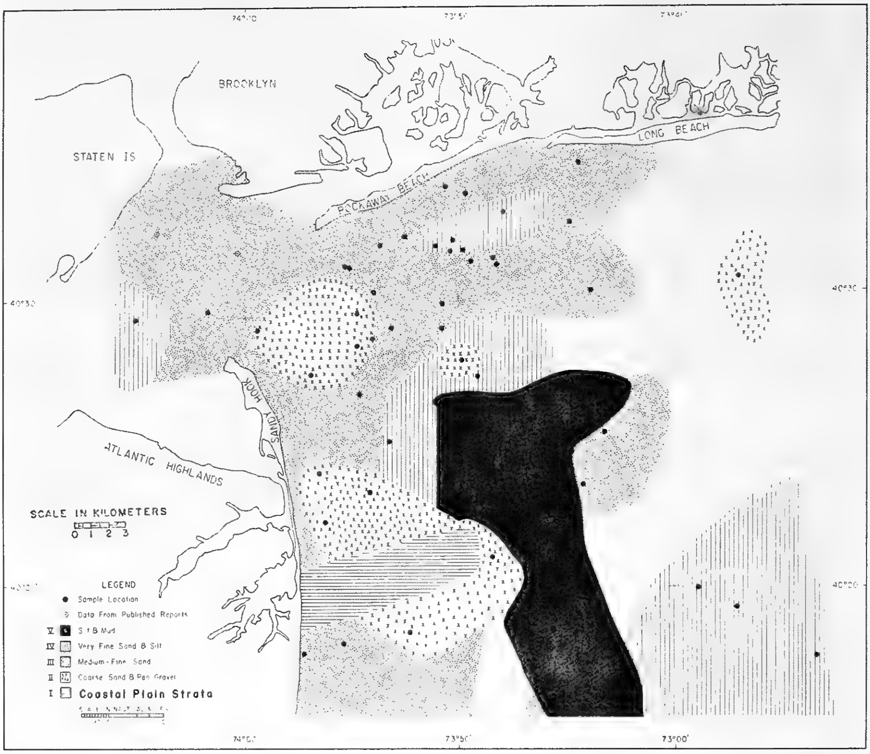


Figure 14. Surface distribution of five major sedimentary facies. Data are based on cores and lateral extrapolation by use of seismic profiles.

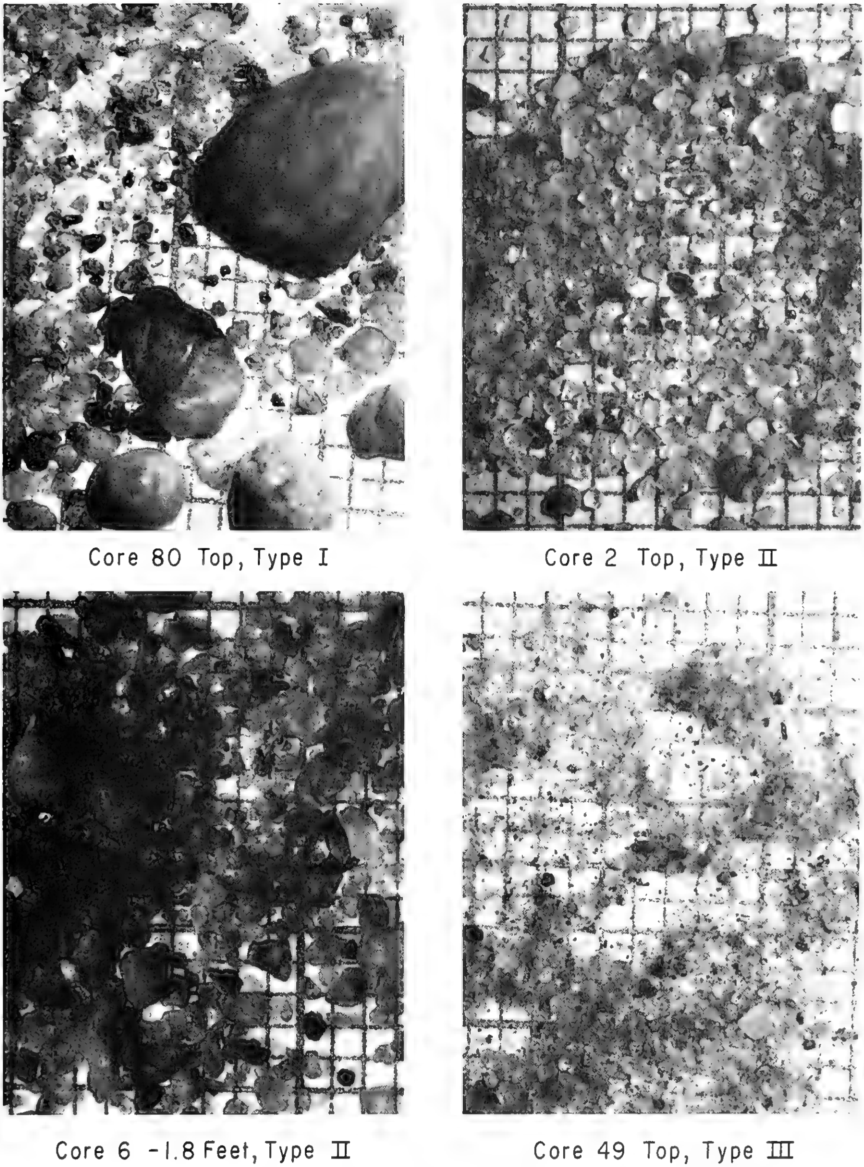


Figure 15. Photos of typical sediment from the shelf. (Grid in millimeters).

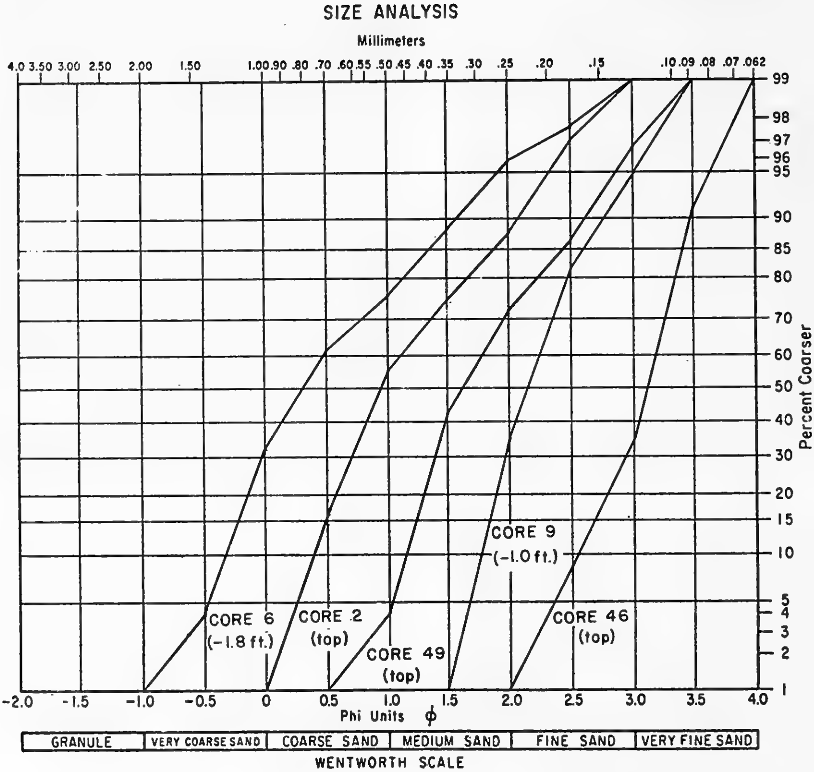


Figure 16. Cumulative size distribution curves for typical Type II (cores 6 and 2), Type III (cores 9 and 49), and Type IV (core 46) sediment from cores shown in Figure 2. Data from Rapid Sand Analyzer analysis.

Mean sieve value for Core 6 = 0.65 phi (0.637 mm)
Mean sieve value for Core 2 = 1.35 phi (0.392 mm)
Mean sieve value for Core 9 = 2.51 phi (0.176 mm)
Mean sieve value for Core 49 = 2.04 phi (0.243 mm)
Mean sieve value for Core 46 = 3.20 phi (0.109 mm)

Sediment Type III (fine to medium sand) is the most predominant facies in the study area. (See Figure 14.) It mantles much of the sea floor from the shore out to about the 80-foot depth contour and appears in most samples to be moderately well- to well-sorted quartzose sand. (See Figures 15 and 16.)

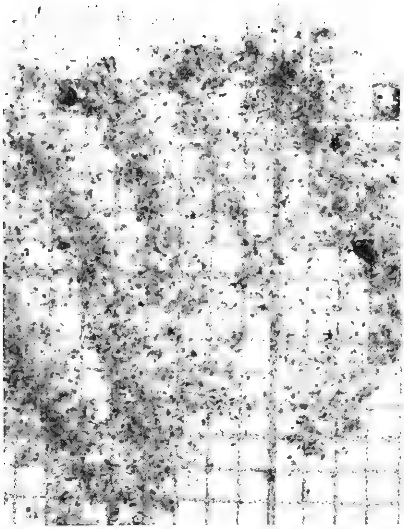
Sediment Type IV is very fine sand and silt (Fig. 17) found in four general areas. (See Figure 14.) The area at the head of the Hudson Channel fringes the seaward edge of the medium sand and possibly represents the finer sediment winnowed out and carried by seasonal bottom currents toward the channel. Some of the fine detritus is disposal material as evidenced by intermittent occurrence of glass shards and coal fragments in the cores. (See Figure 13.) The large area southeast of the study area is mantled by clean, well-sorted, very fine sand to a depth of 15 feet, as evidenced by cores 87, 88, and 89. (See Figures 2 and 14.) The ellipsoidal area about 1.5 miles south of Rockaway Beach is defined by five cores (averaging about 6 feet in length) which show that very fine sand overlies a moderately well-sorted fine to medium sand. The patch of Type IV sediment in Raritan Bay, as shown in core 4, rests on top of medium size reddish brown sand and probably results from recent reworking of underlying relict fluvial sands and deposition of estuarine sediments.

Sediment Type V is silt and mud characterized by high percentages of mica. (See Figure 17.) Distribution is restricted to parts of the Hudson (submarine) Channel and to the disposal areas for sewer sludge and dredge spoil; both are proximal to the head of the Hudson Channel. (See Figure 14.) The mineralology and sedimentary character suggests that sediment Type V is a Pleistocene estuarine facies or represents Coastal Plain facies exposed by erosive downcutting by the Hudson River during Pleistocene lower sea stands. The first contention that sediment Type V is older channel fill which has subsequently been cut by a more recent Hudson drainage channel is supported by Figure 18. It is likely that farther out on the shelf Coastal Plain strata crop out in the channel.

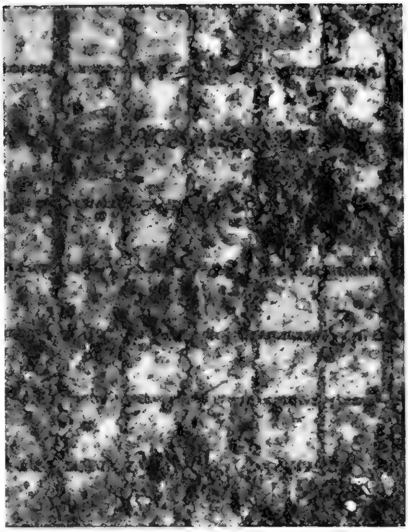
IV. SEDIMENT ORIGINS

A number of investigators have attempted to deciper the origins of Atlantic Continental Shelf sediments. (Colony, 1932), (Alexander, 1934), (McMaster, 1954), (Schlee, 1968), (Ross, 1970), (Schlee and Pratt, 1970), and (Milliman, Pilkey and Ross, 1972.) Several authors recognize the influence glacially derived material has had on total sediment composition of the shelf south of the Long Island terminal moraines (Alexander, 1934; McKinney and Friedman, 1970), but little is known in detail about sediment composition in the inner bight and the role the Hudson River played in influencing sediment distributions.

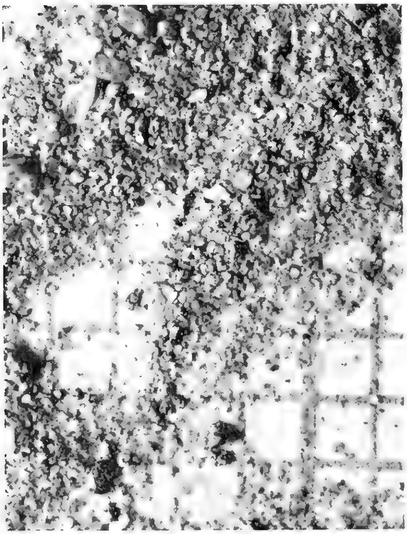
The results of analyses of sediment from the tops of 24 cores taken in the inner bight are shown in Figure 19. Analyses included mineral composition and relative abundance, grain textures and color. To eliminate any significant results which may be attributed to grain size variation only sediment in the 0.125 to 0.250 millimeter (2.0 to 3.0 phi) range were used.



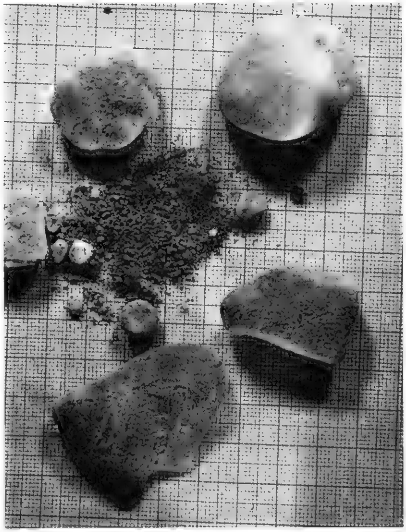
Core 46 Top, Type IV



Core 92 -16.5 Feet, Type V



Core 102 Top, Type V



Core 9 - 8.0 Feet

Figure 17. Photos of typical shelf sediment. Core 9 shows size diversity. (Grid in millimeters).

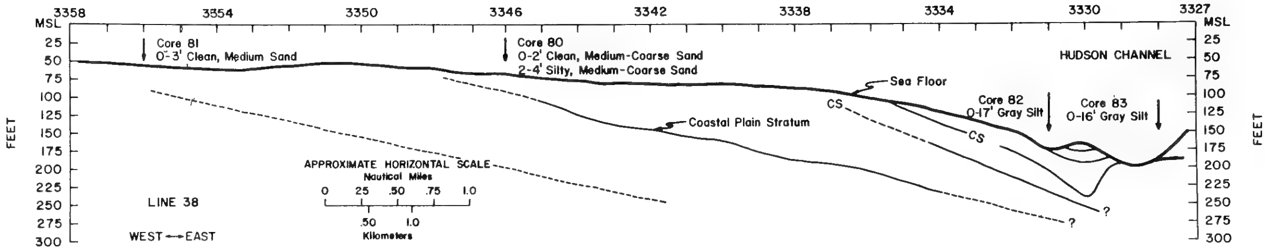


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Figure 18. Reduced seismic profile of geophysical trackline 38 shown in Figure 2. Profile extends east-west from the New Jersey shoreface across the Hudson Channel. The top horizontal line represents sea level and the numbers refer to navigation fixes. The profile shows the region is underlain by Coastal Plain strata having a uniform southeast dip. Lines CS are thought to represent older Hudson Channel surfaces which have steeper dip angles than underlying strata. Cores 82 and 83 also support the conclusion that the most recent submarine channel is cut into older channel-fill deposits rather than Coastal Plain strata.

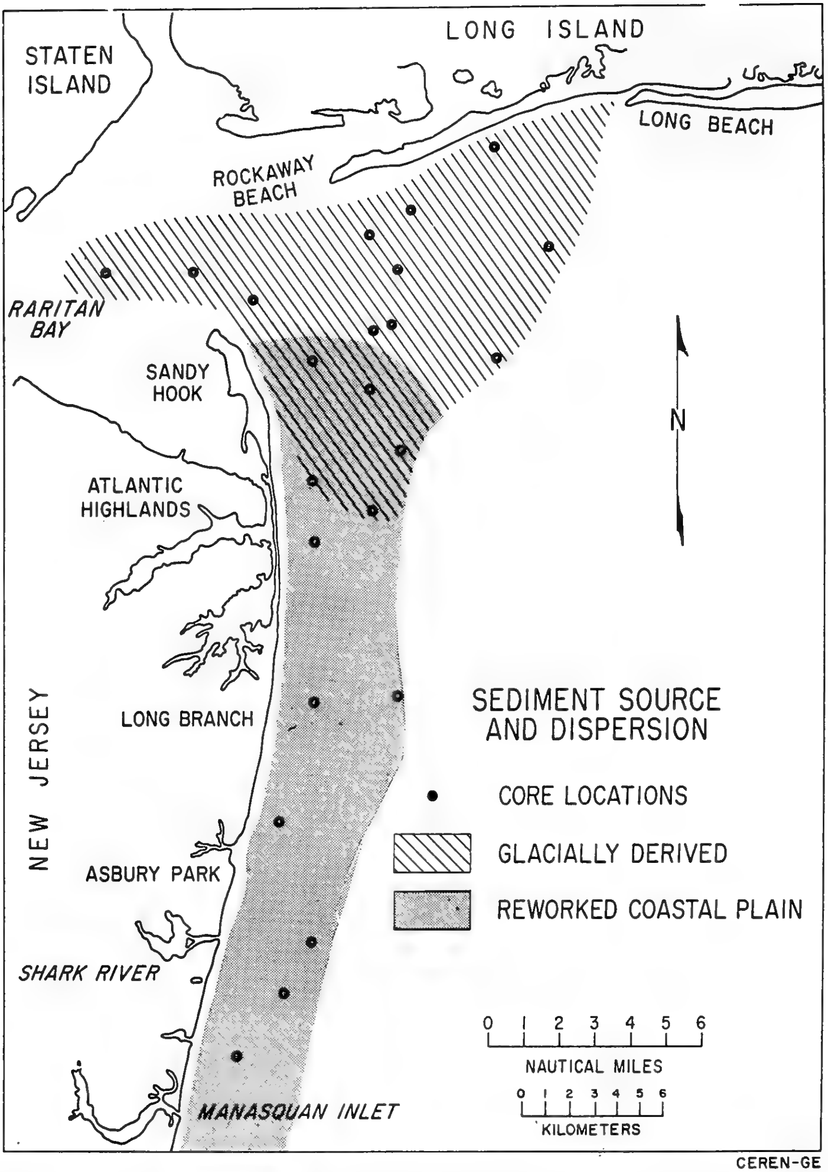


Figure 19. Source and apparent dispersion of surficial sediment. Data based on analyses of the ICONS cores shown. Surficial sediment east of Sandy Hook showed evidence of a zone of mixing. (From Williams and Field, 1971.)

Because of the geographic position of the study area the obvious major sources of marine sediments are the glacial moraine to the north and Coastal Plain strata underlying the shelf and composing the New Jersey landform to the west. Relative mineral abundance was found to be a definitive criteria in distinguishing between these two most likely sources. Colony (1932) determined that both green and black glauconite are an abundant constituent of the Upper Cretaceous and Tertiary formations restricted to New Jersey. Cretaceous beds reportedly underlie Long Island, buried by thick Pleistocene deposits; consequently, glauconite is not found in the beach sands of Long Island. In the cores east of mainland New Jersey glauconite grains averaged about 5 percent of the total population, while the shelf sands east of Sandy Hook contained 1 to 2 percent glauconite. There was a noticeable decrease northward from Long Branch toward Long Island to where no glauconite was present in the cores immediately south of Rockaway Beach.

Of the opaque heavy minerals in the fine sand-size class the abundance of magnetite was an important indicator of source. Magnetite is an ubiquitous constituent in Long Island beach sands, carried south by glacial processes from the igneous and metamorphic terrain to the north. In New Jersey magnetite is nearly absent, except for trace amounts near some coast jetties constructed of blocks of igneous and metamorphic rock. Sediment samples immediately south of Coney Island and Rockaway Beach contained as much as 10 percent opaque heavy minerals while samples south of Sandy Hook contained only about 1 percent.

Feldspar was found to be an equally good source-area indicator. All core-top sediment north of Sandy Hook and on the Rockaway Beach shelf contained at least 8 percent, and some samples as high as 25 percent feldspar. New England Piedmont terrain is characterized by rocks rich in feldspar. Because weathering processes are predominantly mechanical, the rocks tend to disaggregate into constituent minerals with a minimum of decomposition. Core-top samples east of the New Jersey coast were found to average only 2 to 5 percent feldspar. In contrast, Coastal Plain strata have undergone extensive chemical weathering resulting in degradation of the unstable feldspars. This data supports other evidence that the Long Island shelf sediments are from northern glacial deposits and that New Jersey shelf sediments are from Coastal Plain strata.

In samples containing a gravel fraction the pebble compositions supported the other source-area data. Material east of New Jersey consists primarily of rounded, iron-stained milky quartz similar to the gravels found onshore in several Coastal Plain formations. Gravel immediately south of Long Island contained a large percentage of quartz, but also in abundance were rock fragments of igneous and metamorphic origins which ranged from very angular to round. The gravel immediately south of Rockaway Beach is similar to the moraine material covering Long Island and areas to the west.

Grain textures examined by a plane light binocular microscope did not result in any definitive criteria to distinguish source origins. Examination of individual grains by electron microscope has been successfully used by several researchers in determining sediment origins and in some cases modes of transport and ultimate environments of deposition. (Krinsley and Takahashi, 1964.) Sediment samples from several cores in the inner bight were examined by scanning electron microscope (SEM) and surficial textures ascribed to glacial abrasion were recognized in cores 3 and 52. (Figure 20.) Cores 1 and 6 in the study area and two cores farther south had textures indicative of high energy beach conditions. (See Figure 21.) Some cores east of Sandy Hook contained grains exhibiting a superposition of characteristic beach features on distinctive glacial markings, indicating multiple environments. (Patricia Blackwelder, written communication.) The results of these observations supported other data on source and dispersion of sediment shown in Figure 19.

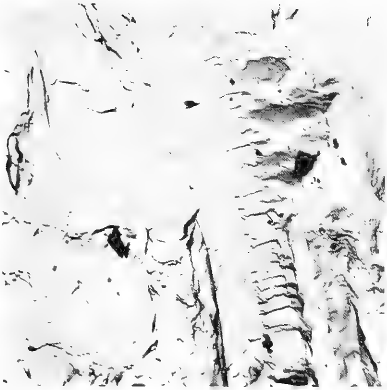
Color of the sediment was of little help in distinguishing glacially derived sediment from Coastal Plain material. Glacial silts and fine sands are light to dark gray, depending on heavy mineral abundance, and the medium and coarse sands are normally reddish brown, probably resulting from oxidation of iron-bearing minerals. Coastal Plain material also ranges in color from greenish gray to reddish brown. Disseminated fine-grained glauconite may be responsible for the greenish cast of some samples.

The sediment limits shown in Figure 19 are based on the above data and are intended to document only the surficial modern sediment. Some glacial material was transported farther south than the boundary indicates but apparently the quantity of material carried south of the Atlantic Highlands was insignificant compared to the volume of sediment contribution from Coastal Plain sources. This sharp demarcation in Holocene sediment source possibly can be attributed to the Hudson Channel which may have acted as an effective barrier to sediment transport during Pleistocene to the present time. It must have funneled glacial detritus farther out on the shelf thus accounting for a large areal spread of outwash across the shelf south of New England. (Knott and Hoskins, 1968.)

V. SAND NEEDS AND RESOURCE POTENTIAL

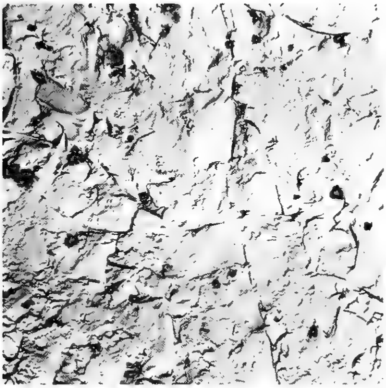
1. Sand Fill Requirements for Area Beaches.

There are several existing and recommended Corps of Engineers Beach Erosion Control and Hurricane Protection projects for parts of Long Island, Staten Island, Raritan-Sandy Hook Bays and the Atlantic coast of northern New Jersey. Sand volumes needed for each area, including the initial fill at inception and the estimated volumes necessary to replace annual erosion over a project life of 50 years, are detailed in Table 5. Total sand needed at present for federally approved projects is over 58 million cubic yards, almost 22 million for initial fill and 36.6 million for periodic maintainance over a 50-year project life. (See Table 5.) This volume estimate is likely to increase significantly if Sandy Hook and selected beaches on parts of western Long Island are designated the Gateway National Recreation Area as proposed.



Core 3 – 2 Feet, Glacial, 6000 X

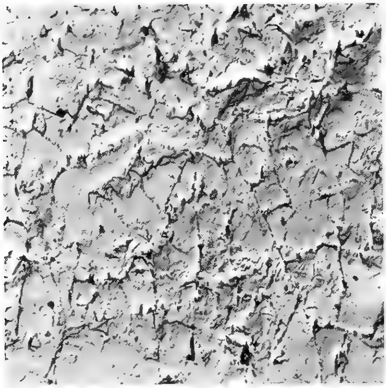
Core 3 – 2 Feet, Glacial, 3800 X



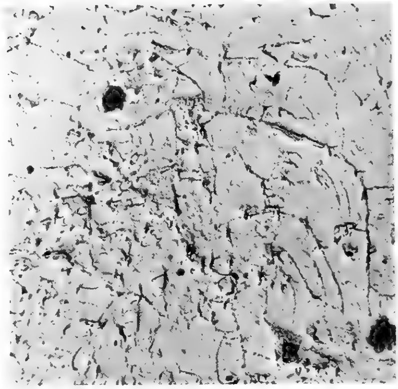
Core 52 – Top, Beach–Glacial, 6000 X

Core 52 – Top, Beach–Glacial, 6000 X

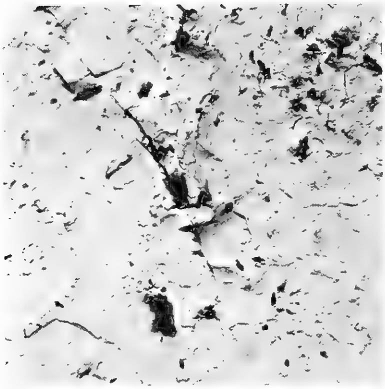
Figure 20. Electron micrograph of quartz sand grains showing glacial and beach surface textures.



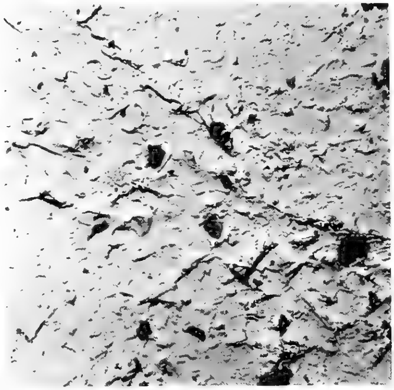
Core 1 – 4 Feet, Beach, 6000 X



Core 1 – 4 Feet, Beach–Dune, 6000 X



Core 6 – 2 Feet, Worn Beach, 6000 X



Core 6 – 2 Feet, Beach, 3800 X

Figure 21. Electron micrograph of quartz sand grains showing beach and dune surface textures.

Table 5. Sand Volume Requirements for Beaches of Inner New York Bight*

Area	Initial Fill	Nourishment	
		Annual	50-Year
	X 10^6	X 10^3	X 10^6
Rockaway	4.20	350.0	17.5
Coney Island	4.50	70.0	3.5
Sandy Hook to Monmouth	6.84	178.0	8.9
Staten Island	2.60	86.3	4.3
Raritan Bay-Sandy Hook Bay	3.61	47.9	2.4
Total	21.75	732.2	36.6

*Cubic Yards

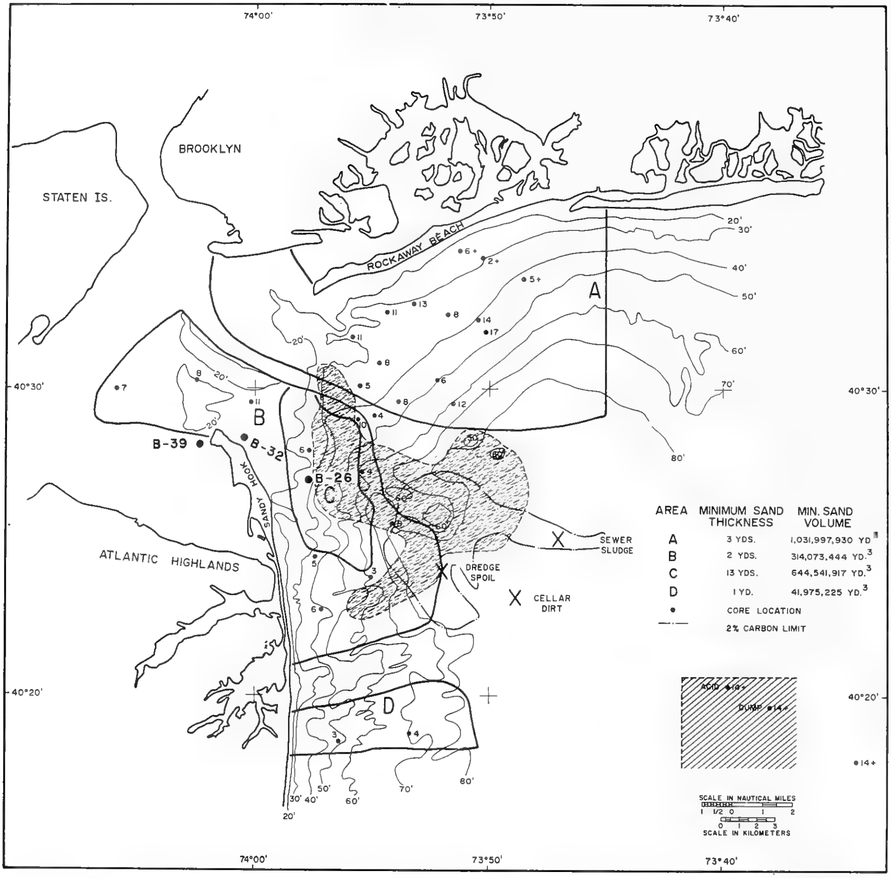
2. Suitability of Sand for Beach Nourishment.

Sand useful as borrow material for beach restoration and protection projects should meet certain important criteria. Factors to consider are: population mean-grain size and total size distribution; mineralologic composition; and economics of recovery, placement and distribution on the beach. Borrow material should be the same size or slightly coarser than native material on the beach to be nourished. If borrow material is significantly smaller in particle size than indigenous sand it will be unstable and out of equilibrium with the wave and current regime. Consequently, it will be eroded and either carried offshore by wave-induced currents or transported parallel to the beach as longshore drift. The net effect in either case is accelerated retreat, and the fill, to readjust nearshore profiles would require large total volumes. Borrow sand without the same size characteristics of the native beach sand should be more poorly sorted (greater size variation), than native beach sand requiring initial overfill. (Krumbien and James, 1965.)

The 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.

3. Potential Borrow Areas and Volumes.

Results of this study indicate that large volumes of clean sand and gravel are widely distributed over the Inner New York Bight shelf region. Based on examination of material in the cores and by lateral extrapolation of stratigraphy on the geophysical profile records, four areas are judged to contain potential material suitable for restoration and nourishment of area beaches. (See Figure 22.) The individual areas are letter-designated and cover the shelf region from the shoreface to about 80-foot depths. Cores in the borrow locations shown in Figure 22 contain clean sand with sedimentary properties suitable as borrow material. Numbers accompanying the core symbols are the minimum continuous sand thicknesses in feet for the respective core. These thickness figures were then extrapolated to peripheral parts of the borrow areas by distribution trends of sea floor sediment and by



CEREN-GE

Figure 22. **Potential borrow areas and representative minimum sand thicknesses from core data.** Areal limits of disposal fill (Fig. 10) and 2 percent contour of total carbon, defining carbon-rich deposits (Gross, 1972) are superimposed. Note the apparent relationship between carbon-rich sediments and locations of contemporary dredge spoil and sewer sludge disposal sites. (marked by X's.)

correlation of the cores with stratification indicated by the seismic profiles. Based on this evidence, minimum sand thicknesses were calculated for each area. Each of the borrow areas was then planimetered to calculate the area in square yards and this figure was multiplied by the blanket thickness in yards. This product represents a total minimum sand volume for each borrow area.

Area A (south of Rockaway Beach) is the largest of the potential borrow areas. The shelf surface is characterized by a gentle seaward dip and exhibits few irregularities. Fourteen cores in this area contain sand with sedimentary properties closely matching native beach material on Rockaway Beach and Coney Island. Based on the cores and geophysical record interpretation a minimum 3-yard thickness of suitable material covers the entire area. From this figure the calculated total volume of sand for Area A is 1.03×10^9 cubic yards. Six of the cores conclusively support this minimum thickness (Fig. 22); the remaining eight cores were limited to less than 9 feet in recovered length but contained good sand through their entirety. Geophysical records near the eight cores show no changes in sediment type at depth which would preclude using the minimum 9-foot-sand thickness. Reasons for the limited penetration of these cores are not evident; small quantities of coarse sand in the bottoms of some cores suggests that localized pockets of coarser material may be present and may have limited core barrel penetration. Quantities of coarse (> 2 millimeters in diameter) sediment are limited.

Geophysical records indicate that the borrow material is stratified, having a gentle seaward dip. Buried stream channels projecting south from the eastern section of Rockaway Beach are found in several of the geophysical records and possibly are filled with sediment having variable sedimentary properties. Most channels are buried below usual dredging depths, and are not a factor in extraction of beach fill but should be considered a factor when planning for foundation design of any offshore engineering structures.

An elongate borrow area extending parallel to shore from the Shrewsbury River north around Sandy Hook to Lower New York Bay is designated Area B. It completely encloses Area C which will be considered separately because of the presence of highly unusual crossbed structures. Area B contains nine cores which reveal that fine to medium sand suitable for placement on adjacent beaches exists for a minimum thickness of 2 yards. Two cores provide some exception to this apparent thickness: cores 5 and 7 (immediately south of Area C) exhibit fine silty sand and coarse sand with pebbles. Because of the proximity of both cores to the Highland Channel these underlying sediment types are probably of fluvial origin. (See Figure 4.) The geophysical records and Coast Guard cores B-9 and B-17 (Table 6) indicate that clean sand is significantly thicker north of Atlantic Highlands than the 2-yard minimum. Using the 2-yard thickness over Area B as a minimum yields a sand volume of over 314×10^6 cubic yards. The northwestern boundary in Lower Bay defines the limits based on data of this report and does not necessarily reflect limits of borrow material in that direction.

Table 6. Coast Guard Core Descriptions*

Core No.	Interval (ft)	Sediment Description
B-1	0 to 9	Sand; gray fine to medium with shells
	9 to 26	Sand; grayish brown, fine to medium with trace of gravel
B-9	0 to 15	Sand; grayish brown, medium to coarse with traces of gravel
	29 to 32	Sand; brown, medium to coarse with traces of gravel
B-17	0 to 5	Sand; dark gray, fine to medium with organic silt and shells
	5 to 18	Sand; dark gray, fine to medium with shells
	18 to 26	Sand; grayish brown, fine to medium, traces of gravel
	26 to 34	Sand; gray, fine to medium
	34 to 39	Sand; yellowish brown, fine to medium

*Data from Alpine Geophysical Associates, Inc. (1969). (See Figure 2 for locations.)

Area C (separate from Area B) is an unusual north-south trending sedimentary basin, described in Section II. Closely spaced geophysical lines show the region underlain by complex crossbed sedimentary structures. (See Figures 7 and 8.) Core 2 reveals that the uppermost 2 yards of sediment (the core length) is fine to coarse clean sand. Boring log 2 (Table 2) for the Coast Guard Scotland Light structure indicates that the entire thickness of crossbed material (mean thickness about 15 yards) consists of alternating fine to medium sand, silt, and pea gravel. Coast Guard core B-1 (Table 6) on the western side of the area shows a sand thickness of 26 feet, the entire core length. Using a figure of 13 yards as a minimum thickness, the computed volume of potential borrow material for Area C is approximately 645×10^6 cubic yards.

Borrow Area D is the southernmost of the four areas, separated from Areas B and C by Shrewsbury Rocks. Shrewsbury Rocks result from Coastal Plain strata cropping out on the sea floor, and in places are covered by only a thin veneer of residual sand and gravel. For this reason, the region between Areas B and D should be avoided as a borrow site. In Area D, Coastal Plain strata are also close to cropping out on the sea floor. The data from cores 80 and 81 indicate a recoverable sand thickness of about 1 yard from the shoreface out to the 80-foot depth contour. The calculated sand volume for Area D is 42×10^6 cubic yards. The southern boundary of Area D is arbitrarily picked as the southernmost limit for this study; it is not intended to necessarily define the actual limit of potential borrow sand.

Gray-shaded areas in Figure 22 mark the approximate limits of disposal material on the sea floor in the inner bight as presented in this report. Detailed discussion is provided in Section II. Cores in the region reveal that much of the disposed fill is indistinguishable from indigenous sea floor sediment. The presence of undesirable detritus (cellar dirt, dredge spoil, etc.), from a beach borrow standpoint, should be anticipated in the eastern parts of borrow Areas B and C and the southwest region of Area A.

4. Contemporary Disposal Sites.

Specific locations are presently designated for the disposal of major types of waste materials. Four of these areas are shown in Figure 22. The areas for dredge spoil and cellar dirt are on line with those originally established in 1888. The disposal area for treated and untreated sewer sludge was established in 1924 and is about 2 miles northeast of the cellar dirt area. The wreck dumping ground is about 13 miles offshore from Sea Girt, New Jersey and is seldom used. The dump zone for toxic chemicals is located outside the study area, about 120 nautical miles southeast of the harbor entrance. Because of excessive transportation costs it is rarely used. The acid waste disposal area was established in 1948 and is an area 8 miles southeast of the sewer sludge area. All of these designated disposal zones are outside the indicated borrow areas except for the overlap of the dredge spoil disposal zone with an eastern fringe of Area B. This same area is also within the 2 percent carbon contour defined by Gross (1972) and therefore should be carefully studied before removal of sand for beach fill.

VI. SUMMARY

The Inner New York Bight covers about 250 square miles in the northern New Jersey and western Long Island region. The major physiographic features include Sandy Hook and Rockaway Beach, both prograding barrier islands, Shrewsbury Rocks and the Hudson (submarine) Channel. ICONS data consist of about 445 miles of seismic data and 61 vibratory cores.

Two major geomorphic provinces characterize this area. The entire region is underlain by Coastal Plain strata which have been differentially eroded by Pleistocene subaerial and glacial processes. Shrewsbury Rocks mark the demarcation between the deeply eroded Coastal Plain surface, filled by Pleistocene sand and gravel to the north, and the evenly truncated Coastal Plain surface, covered by a relatively thin veneer of residual material mixed with small percentages of glacial outwash to the south.

Three primary types of sedimentary bedding have been observed on the seismic records. Coastal Plain strata exhibit a monoclinal regional southeast dip. Steeply inclined complex sedimentary crossbeds are restricted to an elongate basin east of Sandy Hook, considered to be of fluvial origin. The third type is Pleistocene-Holocene stratified fluvial sands and gravels which are regionally discontinuous and exhibit gentle seaward dip.

Cores reveal that fine to medium sand is the most predominate sediment type on the inner shelf. Isolated patches of coarse sand and rounded pea gravels are present in areas where older fluvial materials have been uncovered either by channel dredging or scour by competent bottom currents. The coarse shelf material off New Jersey is judged to be residual from sea floor outcrops of Tertiary strata. Very fine sand, silt and mud comprise the sea floor at the head of the Hudson Channel and along the body; some material is from ocean disposal and some from natural *in situ* estuarine sediments and outcropping fine Coastal Plain facies.

Sand suitable for beach nourishment projects is abundant throughout the shallow shelf parts of the inner bight. Sea floor topography is fairly flat and sand occurs as blanket deposits. It is estimated that over 2 billion cubic yards of clean sand is available for retrieval by present dredging techniques in outlined areas.

Comparison techniques between bathymetric maps dated 1845 to 1970 has confirmed that significant parts of the Hudson Channel have been filled as a result of ocean disposal of up to 1 billion cubic yards of assorted anthropogenic materials, and excavated natural materials resulting from early construction in New York and channel dredging within the estuaries and bays.

LITERATURE CITED

ALEXANDER, A. E., "A Petrographic and Petrologic Study of Some Continental Shelf Sediments," *Journal of Sedimentary Petrology*, Vol. 4, No. 1, Apr. 1934, pp. 12–22.

ALPINE GEOPHYSICAL ASSOCIATES, INC., "Final Report on Data Reduction for CERC New Jersey Offshore Sand Inventory Program," Alpine Geophysical Associates, Inc., Norwood, N. J., June 1969.

ATHEARN, W. D., "Comparison of Clay with the Gardiners Clay," *Journal of Geology*, Vol. 65, No. 4, July 1957, pp. 448–449.

BARNES, B.,et al., "Geologic Prediction: Developing Tools and Techniques for the Geophysical Identification and Classification of Sea Floor Sediments," TR ERL 224-MMTC-2, National Oceanic and Atmospheric Administration, Rockville, Md., 1972.

BUMPUS, D. F., "Residual Drift Along the Bottom on the Continental Shelf in the Middle Atlantic Bight Area," *Limnology and Oceanography*, No. 10, Suppl. 2, 1965, pp. 50–53.

CALDWELL, J. M., "Coastal Processes and Beach Erosion," *Journal of the Society of Civil Engineers*, Vol. 53, No. 2, Apr. 1966, pp. 142–157.

CARTER, C., "Mio-Pliocene Beach and Tidal Flat Sedimentation, Southern New Jersey," Ph.D. Dissertation, Johns Hopkins University, Baltimore, Md., 1972.

COK, A., et al., "Sediment Unmixing in the New York Bight Area," Abstracts with Programs, *Geological Society of America*, Vol. 5, No. 2, 1973, p. 150.

COLONY, R. J., "Source of the Sands on the South Shore of Long Island and the Coast of New Jersey," *Journal of Sedimentary Petrology*, Vol. 2, No. 3, 1932, pp. 150–159.

CONNALLY, G., "Major Proglacial Lakes in the Hudson Valley and Their Rebound History," Abstracts with Programs, *Geological Society of America*, Vol. 4, No. 1, 1972, p. 10.

DANA, J. D., "Long Island Sound in the Quaternary Era, with Observations on the Submarine Hudson River Channel," *The American Journal of Science*, 3rd Series, Vol. 60, No. 240, Dec. 1972, pp. 426–437.

DUANE, D. B., "Sand Deposits on the Continental Shelf, A Presently Exploitable Resource," *Marine Technology Society Regional Meeting*, 1968, pp. 289–297.

DUANE, D. B., "A Study of New Jersey and Northern New England Coastal Waters," *Shore and Beach,* Vol. 37, No. 2, 1969, pp. 12–16.

EWING, J. I., "Elementary Theory of Seismic Refraction and Reflection Measurements," *The Earth Beneath The Sea,* Ch. 1, Vol. 3, Interscience Publication, New York, 1963, pp. 3–19.

EWING, J. I., PICHON, X. L., and **EWING, M.**, "Upper Stratification of Hudson Apron Region," *Journal of Geophysical Research,* Vol. 68, No. 23, Dec. 1963, pp. 6303–6316.

FISHER, C. H., "Mining the Ocean for Beach Sand," *Proceedings, Civil Engineering in the Oceans,* ASCE Conference, 1970, pp. 1–7.

FRIEDMAN, G. M., "On Sorting, Sorting Coefficients, and the Lognormality of the Grain Size Distribution of Sandstones," *Journal of Geology,* Vol. 70, 1962, pp. 737–756.

FULLER, M. L., "Geology of Long Island, New York," Professional Paper 82, U.S. Geological Survey, Washington, D.C., 1914.

GARRISON, L. E., "Development of Continental Shelf South of New England," *The American Association of Petroleum Geologists Bulletin,* Vol. 54, No. 1, Jan. 1970, pp. 109–124.

GROSS, M. G., "Geologic Aspects of Waste Solids and Marine Waste Deposits, New York Metropolitan Region," *Geological Society of America Bulletin,* Vol. 83, Nov. 1972, pp. 3163–3176.

HALL, J. V., "Artificially Nourished and Constructed Beaches," TM-29, U.S. Army, Corps of Engineers, Beach Erosion Board, Washington, D.C., 1952.

HERSEY, J. B., "Continuous Reflection Profiling," *The Earth Beneath the Sea,* Ch. 4, Interscience Publication, New York, 1963, pp. 47–72.

JEFFRIES, H. P., "Environmental Characteristics of Raritan Bay, A Polluted Estuary," *Limnology and Oceanography,* Vol. 7, No. 1, 1962, pp. 21–31.

JOHNSON, M. E., and **RICHARDS, H. G.**, "Stratigraphy of Coastal Plain of New Jersey," *Bulletin of the American Association of Petroleum Geologists,* Vol. 36, No. 11, 1952, pp. 2150–2160.

KETCHUM, B. H., REDFIELD, A. C., and **AYERS, J. C.**, "The Oceanography of the New York Bight," *Physical Oceanographic Meteorology,* MIT-WHOI, Vol. 12, No. 1, 1951.

KIMMEL, G. E., "Water-Level Surfaces in the Aquifers of Western Long Island, New York, in 1959 and 1970," Professional Paper 750-B, U.S. Geological Survey, Washington, D.C., 1971.

KNOTT, S. T., and **HOSKINS, H.**, "Evidence of Pleistocene Events in the Structure of the Continental Shelf off the Northeastern United States," *Marine Geology*, Vol. 6, 1968, pp. 5–43.

KRAFT, J. C., **SHERIDAN, R. E.**, and **MAISANO, M.**, "Time-Stratigraphic Units and Petroleum Entrapment Models in Baltimore Canyon Basin of Atlantic Continental Margin Geosynclines," *American Association of Petroleum Geologists*, Vol. 55, No. 5, 1971, pp. 658–679.

KRINSLEY, D. H., and **TAKAHASHI, T.**, "A Technique for the Study of Surface Textures of Sand Grains with Electron Microscopy," *Journal of Sedimentary Petrology*, Vol. 34, pp. 423–426.

KRUMBEIN, W. C., and **JAMES, W. R.**, "A Lognormal Size Distribution Model for Estimating Stability of Beach Fill Material," TM-16, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Washington, D.C., 1965.

LINDERKOHL, A., "Geology of the Sea-Bottom in the Approaches to New York Bay," *The American Journal of Science*, Vol. 24, No. 174, June 1885, pp. 475–480.

LING, S. C., "State-of-the-Art of Marine Soil Mechanics and Foundation Engineering," Technical Report S-72-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., 1972.

MacCLINTOCK, P., and **RICHARDS, H. G.**, "Correlation of Late Pleistocene Marine and Glacial Deposits of New Jersey and New York," *Geological Society of America Bulletin*, Vol. 47, No. 3, March 1936, pp. 289–337.

McCLELLAND ENGINEERS, "Fathometer Survey and Foundation Investigation Ambrose Light Station, New York Harbor Entrance," Report No. 63-162-1, McClelland Engineers, Houston, Tex., 1963a.

McCLELLAND ENGINEERS, "Fathometer Survey and Foundation Investigation Scotland Light Station, New York Harbor Entrance," Report No. 63-162-1, McClelland Engineers, Houston, Tex., 1963b.

McKINNEY, T. F., and **FRIEDMAN, G. M.**, "Continental Shelf Sediments of Long Island, New York," *Journal of Sedimentary Petrology*, Vol. 40, No. 1, March 1970, pp. 213–24.

McMASTER, R. L., "Petrography and Genesis of the New Jersey Beach Sands," Geologic Series, Bulletin 63, Department of Conservation and Economic Development, State of New Jersey, 1954.

MINARD, J. P., "Geology of the Sandy Hook Quadrangle in Monmouth County, New Jersey," Bulletin 1276, U.S. Geological Survey, Washington, D.C., 1969.

MILLER, H. J., TIREY, G. B., and **MECARINI, G.**, "Mechanics of Mineral Exploration," *Underwater Technology Conference,* American Society of Mechanical Engineers, 1967.

MILLIMAN, J. D., PILKEY, O. H., and **ROSS, D. A.**, "Sediments of the Continental Margin off the Eastern United States," *Geological Society of America Bulletin,* Vol. 83, 1972, pp. 1315–1334.

MOORE, D. G., and **PALMER, H. P.**, "Offshore Seismic Reflection Surveys in Civil Engineering in the Oceans," *American Society of Civil Engineers,* 1968, pp. 780–806.

OLIVER, J. E., and **DRAKE, C. L.**, *Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain, Part VI: The Long Island Area,* Vol. 62, The Geological Society of America, 1951, pp. 1287–1296.

OSER, R. K., "Bottom Environmental Oceanographic Data Report, Hudson Canyon Area, 1967," Informal Report No. 69-8, U.S. Naval Oceanographic Office, Washington, D.C., 1969.

PARARAS-CARAYANNIS, G., "Ocean Dumping in the New York Bight: An Assessment of Environmental Studies," TM-39, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, Va., May 1973.

ROSS, D. A., "Atlantic Continental Shelf and Slope of the United States–Heavy Minerals of the Continental Margin from Southern Nova Scotia to Northern New Jersey," Professional Paper 529-G, U.S. Geological Survey, Washington, D.C., 1970.

SCHAFFEL, S., "Reconstruction of Late-Glacial and Post-Glacial Events in Long Island Sound, New York," Ph.D. Dissertation, New York University, New York, 1971.

SCHLEE, J., "A Modified Woods Hole Rapid Sediment Analyzer," *Journal of Sedimentary Petrology,* Vol. 36, No. 2, 1966, pp. 403–413.

SCHLEE, J., "Sand and Gravel on the Continental Shelf off the Northeastern United States," Circular 602, U.S. Geological Survey, Washington, D.C., 1968.

SCHLEE, J., and PRATT, R. M., "Atlantic Continental Shelf and Slope of the U.S. Gravels of the Northeastern Part," Professional Paper 529H, U.S. Geological Survey, Washington, D.C., 1970.

SHEPARD, F. P., and DILL, R. F., *Submarine Canyons and Other Sea Valleys,* Rand McNally, Chicago, 1966, p. 381.

SOREN, J., "Ground-Water and Geohydrologic Conditions in Queens County, Long Island, New York," Paper 2001-A, U.S. Geological Survey, Washington, D.C., 1971.

STEARNS, F., "Bathymetric Maps and Geomorphology of the Middle Atlantic Continental Shelf," *Fishery Bulletin,* Vol. 68, No. 1, June 1969, pp. 37–66.

SUTER, R., deLAGUNA, W., and PERLUMTTER, N. M., "Mapping of Geologic Formations and Aquifers of Long Island, New York," Bulletin GW-18, Department of Conservation, Water and Power Commission, State of New York, 1949.

TANEY, N. E., "Littoral Materials of the South Shore of Long Island, New York," TM-129, U.S. Army, Corps of Engineers, Beach Erosion Board, Washington, D.C., Nov. 1961.

TIREY, G. B., "Recent Trends in Underwater Soil Sampling Methods," Special Technical Publication 501, American Society for Testing and Materials, 1972.

UCHUPI, E., "Atlantic Continental Shelf and Slope of the United States-Shallow Structure," Professional Paper 529-1, U.S. Geological Survey, Washington, D.C., 1970.

U.S. ARMY, CORPS OF ENGINEERS, "Annual Reports of the Chief of Engineers," Washington, D.C., Annual Reports from 1885 to 1930.

U.S. ARMY, CORPS OF ENGINEERS, "Study on Use of Hopper Dredges for Beach Nourishment," U.S. Army Engineer District, Philadelphia, Pa., 1967.

U.S. ARMY, CORPS OF ENGINEERS, "National Shoreline Study Report," Washington, D.C., 1971.

U.S. GEOLOGICAL SURVEY, "Engineering Geology of the Northeast Corridor Washington, D.C. to Boston, Massachusetts: Coastal Plain and Surficial Deposits," Miscellaneous Geologic Investigations Map I-514-B, Washington, D.C., 1967.

VAN REENAN, E. D., "Subsurface Exploration by Sonic Seismic Systems," *Soil Exploration,* Special Technical Publication No. 351, American Society for Testing and Materials, 1963.

VEATCH, A. C., and SMITH, P. A., "Atlantic Submarine Valleys of the United States and the Congo Submarine Valley," Special Paper No. 7, The Geological Society of America, 1939.

WEISS, L., "Foraminifera and Origin of the Gardiners Clay (Pleistocene), Eastern Long Island, New York," Professional Paper 254-G, U.S. Geological Survey, Washington, D.C., 1954.

WIGMORE, H. L., "Memorandum on Dredging Work in Ambrose Channel," Vol. 1, U.S. Army Professional Memorandum, Engineer Bureau, 1909.

WILLIAMS, S. J., "The Geologic Framework of Inner New York Bight–Its Influence on Positioning Offshore Engineering Structures," Abstracts with Programs, Geological Society of America, Vol. 5, No. 2, 1973, p. 239.

WILLIAMS, S. J., and FIELD, M. E., "Sediments and Shallow Structures of the Inner Continental Shelf off Sandy Hook, New Jersey," Abstracts with Programs, Geological Society of America, Vol. 3, No. 1, 1971, p. 62.

WORZEL, J. L., and DRAKE, C. L., "Structure Section Across the Hudson River at Nyack, New York, from Seismic Observations," New York Academy of Science Annals, Vol. 80, 1959, pp. 1092–1105.

ZEIGLER, J. M., WHITNEY, G. G., and HAYS, C. R., "Woods Hole Rapid Sediment Analyzer," *Journal of Sedimentary Petrology*, Vol. 30, No. 3, 1960, pp. 490–495.

APPENDIX A

SEDIMENT DESCRIPTIONS

Appendix A contains visual descriptions of sediment from cores and grab samples in the study area. Sample locations are shown in Figure 2.

Visual descriptions are based on both megascopic and microscopic examination. Color is based on dry sample.

Sediments 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).

Sediment Description

Core No.	Water Depth (ft)	Core Length (ft)	Interval (ft)	Description
1	24	11.0	top to 8.0	Clean, moderately well-sorted, medium to coarse sand with rock and shell fragments.
			8.0 to 10.0	Medium size, clean sand with few coarse quartz grains and fine silt.
			10.0 to 11.0	Very clean, well-sorted, medium size, many arkose and schist rock fragments.
2	35	6.0	top to 1.0	Medium size, moderately well-sorted, clean sand.
			1.0 to 2.0	Coarse, well-sorted, clean sand.
			2.0 to 3.0	Fine, well-sorted, clean sand.
			3.0 to 6.0	Medium size, well-sorted, clean sand.
3	21	7.7	top to 3.0	Fine to medium, moderately sorted gray sand; some shell fragments.
			3.0 to 5.0	Fine to medium clean sand; abundant mica.
			5.0 to 7.0	Very fine gray silt.
			7.0 to 7.7	Medium to coarse, poorly sorted sand; coarse rock fragments abundant.
4	21	6.8	top to 2.3	Medium gray sand and silt; few coarse grains and shell fragments.
			2.3 to 4.3	Medium to coarse arkosic quartz sand; green and red shale fragments.
			4.3 to 6.0	Medium size brown sand.
			6.0 to 6.8	Medium size reddish brown sand.
5	68	10.0	top to 2.0	Clean, medium size, moderately well-sorted sand.
			2.0 to 4.0	Medium size, clean sand with quartz pebbles and shell fragments.
			4.0 to 10.0	Gray silt and fine sand.
6	50	6.0	top to 2.0	Coarse, moderately well-sorted, clean sand; abundant glauconite.
			2.0 to 3.0	Medium size, brown, moderately well-sorted sand with quartz pebbles; abundant glauconite.
			3.0 to 4.0	Reddish brown, medium size, moderately sorted sand.
			4.0 to 5.0	Reddish brown, coarse, poorly sorted sand.
			5.0 to 6.0	Reddish brown, coarse, poorly sorted sand with quartz pebbles.

Sediment Description—Continued

Core No.	Water Depth (ft)	Core Length (ft)	Interval (ft)	Description
7	30	4.5	top to 1.0	Fine, well-sorted, clean sand; abundant glauconite.
			1.0 to 3.0	Medium size, well-sorted, clean sand; abundant glauconite.
			3.0 to 4.5	Very coarse, poorly sorted pebbly quartz sand; pebbles well-rounded.
8	78	10.3	top to 6.0	Fine, poorly sorted gray silty-clay, with some pea gravel and coal fragments at –4 feet.
			6.0 to 6.4	Red stiff clay.
			6.4 to 8.1	Clean, poorly sorted, coarse sand and rounded pea gravel.
			8.1 to 10.3	Fine, light gray, well-sorted sand; abundant mica.
9	58	7.0	top to 4.0	Clean, well-sorted, fine sand; abundant glauconite.
			4.0 to 7.0	Fine gray silty sand.
10	62	9.3	top to 9.3	Clean, fine, well-sorted sand with abundant opaque heavy minerals.
40	69	15.0	top to 1.0	Medium to coarse, moderately sorted, arkosic sand; abundant rock and quartz pebble fragments, coal fragments, and clinkers.
			1.0 to 3.0	Stiff, gray clay.
			3.0 to 7.0	Gray, silty sand; abundant mica.
			7.0 to 15.0	Stiff gray clay.
41	85	12.0	top to 9.0	Gray, fine, moderately sorted sand.
			9.0 to 12.0	Gray, very fine sand.
42	89	18.0	top to 1.0	Gray, fine sand and silt (possible spoil).
			1.0 to 18.0	Gray, very fine sand; abundant mica.
43	92	11.0	top to 11.0	Gray, fine sand, and silt (possible spoil); shells.
44	55	19.3	top to 7.0	Gray, fine to medium, moderately sorted, clean sand; some shell fragments.
			7.0 to 12.0	Dark brown, fine to medium, well-sorted sand.
			12.0 to 19.0	Gray, fine sand-silt, with some shell fragments.
			19.0 to 19.3	Greenish, clayey, fine sand.

Sediment Description–Continued

Core No.	Water Depth (ft)	Core Length (ft)	Interval (ft)	Description
45	21	10.3	top to 10.3	Very clean, medium size, well-sorted sand.
46	33	11.0	top to 6.0	Very fine to fine, very well-sorted sand.
			6.0 to 8.5	Brown, well-sorted, medium to coarse sand.
			8.5 to 11.0	Reddish brown, medium size, well-sorted sand.
47	30	13.0	top to 6.0	Gray, very fine to fine, well-sorted, clean sand.
			6.0 to 7.0	Medium size gray sand with shell hash.
			7.0 to 13.0	Reddish brown, medium size, well-sorted sand.
48	25	6.0	top to 0.5	Fine to medium, moderately sorted sand.
			0.5 to 6.0	Medium to coarse, clean, well-sorted sand; some shell fragments.
49	30	1.5	top to 1.0	Clean, moderately well-sorted, medium size sand.
			1.0 to 1.5	Clean, moderately sorted, medium to coarse sand; some quartz pebbles.
50	40	8.0	top to 8.0	Brown, fine, well-sorted sand.
51	60	4.0	top to 4.0	Fine to medium, well-sorted clean sand.
52	62	5.0	top to 4.8	Fine to medium, clean, well-sorted sand; evidence of spoil; 3-inch red brick fragments, glass shards, aggregate, and slag fragments.
			4.8 to 5.0	Very coarse, clean, quartz sand.
53	30	7.5	top to 7.5	Brown, clean, fine to medium sand; abundant heavy minerals and mica.
54	45	5.6	top to 3.5	Very fine to fine, moderately sorted sand with some shell fragments.
			3.5 to 5.6	Medium to coarse, clean, moderately sorted sand.
55	34	8.4	top to 1.0	Fine, clean, very well-sorted sand; abundant shell fragments.
			1.0 to 4.0	Gray, fine, clean, well-sorted sand.
			4.0 to 8.4	Fine to medium, well-sorted, reddish brown sand.
56	35	5.6		Not available for sampling.

Sediment Description—Continued

Core No.	Water Depth (ft)	Core Length (ft)	Interval (ft)	Description
57	39	14.4	top to 4.5	Very fine, well-sorted, gray sand.
			4.5 to 5.0	Very fine, moderately sorted sand with shell hash.
			5.0 to 12.0	Fine to medium, clean, well-sorted sand.
			12.0 to 14.4	Medium size, clean, well-sorted sand with small quartz pebbles.
58	44	17.3	top to 1.0	Very fine, well-sorted, clean sand with some shell fragments.
			1.0 to 4.0	Very fine, well-sorted, clean sand with no shells.
			4.0 to 10.0	Very fine, well-sorted, clean sand with shell fragments.
			10.0 to 13.0	Very fine, well-sorted, clean sand with no shells.
			13.0 to 17.3	Brown, medium size, clean, well-sorted sand.
59	57	10.5	top to 7.0	Very fine, greenish gray, moderately sorted sand.
			7.0 to 10.5	Medium size, well-sorted, brown sand; abundant shell fragments.
60	41	5.0	top to 2.0	Very fine to fine, clean, well-sorted sand; some shell fragments.
			2.0 to 5.0	Medium to coarse, clean, well-sorted and rounded sand; some shell and rock fragments.
80	66	4.0	top to 1.0	Medium to coarse, moderately sorted sand with rounded quartz pebbles.
			1.0 to 2.0	Coarse clean sand.
			2.0 to 3.0	Brown, medium to coarse sand.
			3.0 to 4.0	Reddish brown, coarse sand.
81	48	3.0	top to 3.0	Medium size, moderately well-sorted brown sand.
82	152	17.0	top to 17.0	Gray, stiff, silt-clay; abundant mica.
83	172	16.0	top to 16.0	Gray, stiff, silt-clay; abundant mica.
84	126	16.0	top to 4.0	Very fine to fine, gray sand; abundant mica.
			4.0 to 16.0	Gray, stiff, silt-clay; abundant mica.
85	162	12.0	top to 12.0	Gray, stiff, silt-clay; abundant mica.
86	140	12.0	top to 1.0	Gray, stiff clay and possible spoil.
			1.0 to 11.0	Gray, fine sand and silt.
			11.0 to 12.0	Fine to medium sand.

Sediment Description—Continued

Core No.	Water Depth (ft)	Core Length (ft)	Interval (ft)	Description
87	86	18.7	top to 0.5	Razor clam fragments, very fine to fine quartz sand; abundant heavy minerals.
			0.5 to 18.7	Very fine, very well sorted, quartz sand.
88	84	15.0	top to 4.9	Reddish brown, fine to medium, quartz sand.
			4.9 to 15.0	Fine quartz sand; abundant mica.
89	78	15.5	top to 0.2	Fine quartz sand; small shell fragments.
			0.2 to 4.7	Fine quartz sand.
			4.7 to 9.8	Fine quartz sand.
			9.8 to 15.5	Fine sand, shell fragments.
90	90			Not returned from Sandy Hook Marine Laboratory; reported to contain sludge on top.
91	100	16.0	top to 0.4	Gray silt, and apparent spoil (coal, wood, and brick fragments).
			0.4 to 2.6	Gray silt.
			2.6 to 5.4	Gray silt.
			5.4 to 9.7	Dark gray silt.
			9.7 to 16.0	Light gray fine sand and silt.
92	105	18.3	top to 2.0	Brown silt.
			2.0 to 5.1	Light gray silt.
			5.1 to 10.0	Dark gray silt.
			10.0 to 14.5	Gray silt.
			14.5 to 18.3	Gray sandy silt.
93	93	14.5	top to 0.3	Dark gray silty sand; large shell fragments.
			0.3 to 2.3	Gray, very fine sand.
			2.3 to 5.8	Light gray silt.
			5.8 to 8.1	Dark gray silt.
			8.1 to 14.5	Dark gray silt.
94	95			Not returned from Sandy Hook Marine Laboratory; reported to contain sludge on top.
95	87	9.5	top to 0.5	Reddish brown, fine to medium size sand; shell fragments and apparent spoil (clinkers, glass, and coal).
			0.5 to 2.7	Brownish, medium, clean sand.
			2.7 to 4.8	Brownish, gray, fine sand.
			4.8 to 9.5	Gray silt.

Sediment Description—Continued

Core No.	Water Depth (ft)	Core Length (ft)	Interval (ft)	Description
96	76	14.3	top to 0.3	Brown, medium sand; gastropod shells, and coal fragments.
			0.3 to 14.3	Light brown, fine to medium size, clean sand.
97	65	10.0	top to 1.0	Dark gray silt to medium size sand mixture.
			1.0 to 4.0	Medium size, moderately sorted sand; abundant mica.
			4.0 to 9.0	Gray, stiff clay-silt.
			9.0 to 10.0	Red stiff clay; possible spoil.
98	97	6.0	top to 1.0	Poorly sorted mixture of red granular fragments; rounded quartz pebbles and gray silt; possible spoil.
			1.0 to 3.0	Dark gray, medium size sand and rounded pebbles.
			3.0 to 6.0	Very poorly sorted, gray, medium size sand and quartz pebbles.
99	94	4.0	top to 1.0	Gray silt with glass fragments, wood, coal fragments, and cement pebbles.
			1.0 to 4.0	Dark gray, fine sand-silt; abundant mica.
100	105	1.5	top to 1.5	Gray, stiff clay-silt.
101	108	6.0	top to 3.0	Gray, fine sand silt; coal fragments.
			3.0 to 6.0	Gray, stiff clay; abundant mica.
102	100	6.0	top to 6.0	Gray, silty-fine sand.
103	90	18.0	top to 13.0	Medium size, moderately well-sorted shell fragments; clean sand.
			13.0 to 18.0	Reddish brown coarse sand and pea gravel.
104	110	18.0	top to 0.5	Gray silt; wood and coal fragments.
			0.5 to 5.0	Dark gray silt.
			5.0 to 10.0	Dark gray silt-sand.
			10.0 to 13.8	Light gray silt.
			13.8 to 10.0	Dark brownish gray silty sand; abundant mica.
105	120	15.0	top to 5.0	Gray, stiff, silty clay (top 1 foot contained sludge-like materials).
			5.0 to 15.0	Gray, medium size, well-sorted sand.
106	98	15.5	top to 0.5	Coal fragments, light gray silt.
			0.5 to 3.5	Brownish, very fine sand.
			3.5 to 9.0	Dark gray, fine sand.
			9.0 to 15.5	Dark gray, silty sand.

Sediment Description—Continued

Core No.	Water Depth (ft)	Core Length (ft)	Interval (ft)	Description
107	90	13.5	top to 8.0	Gray, silty sand.
			8.0 to 11.0	Gray, silt-clay.
			11.0 to 13.5	Brown, medium size sand.
108	82	14.0	top to 1.0	Gray, fine-medium sand; shell fragments.
			1.0 to 2.0	Gray, stiff clay.
			2.0 to 3.0	Gray, fine-medium sand.
			3.0 to 5.0	Gray, fine-medium sand.
			5.0 to 9.0	Gray, stiff clay.
			9.0 to 10.0	Light gray, fine sand.
			10.0 to 14.0	Dark gray, fine sand.
109	75	15.0	top to 1.0	Gray silt.
			1.0 to 2.4	Gray reddish brown silt and fine sand; possible spoil.
			2.4 to 3.0	Red stiff clay; possible spoil.
			3.0 to 15.0	Gray, silty, medium size sand.
Nassau County Cores				
12	55	10.2	top to 10.2	Brown, medium size sand.
13	50	7.3	top to 4.0	Brown, fine sand.
			4.0 to 5.8	Black, fine sand.
			5.8 to 7.3	Brown, fine sand.
Bottom Grab Samples				
112	52			Gray, fine, well-sorted sand with abundant shell fragments.
113	75			Gray, fine to medium, moderately well-sorted sand.
115	80			Brown, fine to medium, moderately well-sorted sand.
116	30			Brown, fine, moderately well-sorted sand; some shell fragments.

APPENDIX B

GRANULOMETRIC DATA

Appendix B contains the results of Rapid Sand Analyzer (RSA) size analyses of selected sediment samples from the study area.

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

Data include mean ($\bar{X}$) size values (phi 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, from 99 beach samples obtained in New Jersey, Michigan, and California. The relationships, developed from RSA and sieve analyses at a 0.25 phi interval, are:

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

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

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

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

Granulometric Data

Number		Depth	Rapid Sand Analyzer (RSA)			Sieve Analyses		
Core	CERC I.D.	(ft)	Mean (phi)	Standard Deviation (phi)	Mean (mm)	Mean (phi)	Standard Deviation (phi)	Mean (mm)
1	206	top	1.12	0.56	0.461	1.39	0.668	0.382
		–1.0	1.16	0.54	0.448	1.43	0.639	0.371
		–2.0	1.01	0.80	0.496	1.27	1.02	0.415
		–4.0	0.68	0.88	0.624	0.92	1.13	0.529
		–6.0	1.09	0.81	0.469	1.36	1.03	0.390
		–8.0	1.13	0.56	0.456	1.40	0.668	0.379
		–10.0	1.10	0.74	0.466	1.37	0.93	0.387
2	1	top	1.08	0.63	0.472	1.35	0.770	0.392
		–1.0	0.79	0.61	0.580	1.04	0.741	0.486
		–2.0	2.00	0.50	0.250	2.33	0.581	0.199
		–4.0	1.82	0.55	0.283	2.14	0.653	0.227
		–6.0	1.25	1.01	0.420	1.53	1.32	0.346
3	2	top	1.33	1.00	0.397	1.62	1.31	0.325
		–2.0	1.86	1.02	0.276	2.18	1.33	0.221
		–4.0	1.57	0.58	0.336	1.87	0.697	0.274
		–7.0	1.36	0.65	0.389	1.65	0.799	0.319
4	3	–1.8	1.38	0.92	0.383	1.67	1.19	0.314
		–2.8	1.21	0.97	0.433	1.48	1.26	0.359
		–3.7	1.05	0.80	0.482	1.31	1.02	0.403
		–5.7	0.63	0.72	0.646	0.86	0.901	0.551
5	4	top	1.17	0.47	0.446	1.44	0.537	0.369
		–1.0	1.41	0.58	0.376	1.70	0.697	0.308
		–2.0	1.23	0.45	0.426	1.51	0.508	0.351
		–4.0	1.50	0.60	0.353	1.80	0.726	0.287
		–6.0	1.55	0.57	0.341	1.85	0.682	0.277
		–8.0	1.61	0.71	0.327	1.92	0.886	0.264
		–10.0	1.74	0.86	0.299	2.06	1.10	0.240
6	5	–1.8	0.43	0.78	0.741	0.65	0.988	0.637
		–2.1	1.12	0.57	0.460	1.50	0.682	0.354
		–4.0	1.13	0.66	0.456	1.40	0.813	0.379
		–5.8	0.73	0.93	0.602	0.97	1.21	0.511
7	6	top	1.91	0.51	0.267	2.24	0.595	0.213
		–1.0	1.75	0.38	0.297	2.07	0.406	0.238
		–2.0	1.95	0.41	0.258	2.28	0.450	0.206
		–4.0	0.62	0.64	0.648	0.85	0.784	0.555

Granulometric Data—Continued

Number		Depth	Rapid Sand Analyzer (RSA)			Sieve Analyses		
Core	CERC I.D.	(ft)	Mean (phi)	Standard Deviation (phi)	Mean (mm)	Mean (phi)	Standard Deviation (phi)	Mean (mm)
8	7	top	1.94	1.31	0.260	2.27	1.76	0.207
		–2.4*						
		–4.4*						
		–6.1	1.50	0.76	0.355	1.80	0.959	0.287
		–9.6	2.55	0.48	0.170	2.93	0.552	0.131
9	8	–1.0	2.16	0.38	0.223	2.51	0.406	0.176
		–2.0	2.28	0.41	0.206	2.64	0.450	0.160
		–4.0	1.77	0.38	0.293	2.09	0.406	0.235
		–7.0*						
10	9	top	2.21	0.57	0.216	2.56	0.682	0.170
		–1.0	2.35	0.42	0.197	2.71	0.464	0.153
		–2.0	2.58	0.57	0.166	2.96	0.682	0.126
		–4.0	2.08	0.65	0.236	2.42	0.799	0.187
		–6.0	1.61	0.55	0.325	1.92	0.653	0.264
		–8.0	1.58	0.52	0.333	1.88	0.610	0.272
40	39	top	0.97	0.86	0.512	1.23	1.10	0.426
		–1.0	1.09	0.77	0.471	1.36	0.973	0.390
		–3.0	2.55	1.06	0.171	2.93	1.39	0.131
		–4.0	2.33	0.97	0.198	2.69	1.26	0.155
		–7.0	1.67	1.27	0.313	1.98	1.70	0.254
		–10.0	2.18	1.30	0.221	2.53	1.74	0.173
		–15.0	2.59	1.05	0.166	2.97	1.38	0.128
41	40	–1.0	1.99	0.95	0.251	2.32	1.23	0.200
		–2.0	2.29	0.90	0.204	2.65	1.16	0.159
		–3.0	2.01	1.50	0.248	2.35	2.03	0.196
		–6.0	2.85	1.00	0.139	3.25	1.31	0.105
		–9.0	2.20	0.89	0.218	2.55	1.15	0.171
		–12.0	3.16	0.88	0.112	3.58	1.13	0.084
42*	41							

*Too fine for analysis

Granulometric Data—Continued

Number		Depth	Rapid Sand Analyzer (RSA)			Sieve Analyses		
Core	CERC I.D.	(ft)	Mean (phi)	Standard Deviation (phi)	Mean (mm)	Mean (phi)	Standard Deviation (phi)	Mean (mm)
43*	42							
44	43	top	2.05	0.95	0.241	2.39	1.23	0.191
		–1.0	2.15	0.46	0.225	2.50	0.523	0.177
		–4.0	2.16	0.64	0.224	2.51	0.784	0.176
		–7.0	2.32	0.48	0.200	2.68	0.552	0.156
		–9.0	2.34	0.40	0.198	2.70	0.435	0.154
		–10.0	2.64	0.55	0.160	3.02	0.653	0.123
		–12.0	2.71	1.20	0.152	2.52	1.60	0.174
		–13.0	2.72	1.17	0.152	3.11	1.55	0.116
		–16.0	2.20	1.41	2.17	2.55	1.90	0.171
45	44	top	1.61	0.43	0.328	1.92	0.479	0.264
		–1.0	1.91	0.42	0.266	2.24	0.464	0.212
		–4.0	1.97	0.37	0.255	2.30	0.392	0.203
		–7.0	2.17	0.59	0.222	2.52	0.712	0.174
		–8.0	1.96	0.64	0.257	2.29	0.784	0.205
		–9.5	1.96	0.56	0.257	2.29	0.668	0.205
46	45	top	2.81	0.28	0.143	3.20	0.261	0.109
		–1.0	2.77	0.30	0.146	3.16	0.290	0.112
		–6.0	1.64	0.93	0.320	1.95	1.21	0.259
		–8.5	1.46	0.82	0.363	1.75	1.05	0.297
		–11.0	2.14	0.66	0.226	2.48	0.813	0.179
47	46	top	2.66	0.35	0.159	3.04	0.363	0.122
		–1.0	2.64	0.35	0.160	3.02	0.363	0.123
		–4.0	2.41	0.87	0.188	2.77	1.12	0.147
		–6.0	2.04	1.26	0.243	2.36	1.69	0.195
		–9.0	1.95	1.02	0.258	2.28	1.34	0.206
		–13.0	1.84	0.67	0.279	2.16	0.828	0.224
48	47	top	2.32	0.67	0.200	2.68	0.828	0.156
		–1.0	1.60	0.39	0.331	1.91	0.421	0.266
		–2.0	1.17	0.37	0.444	1.44	0.392	0.369
		–4.5	1.58	0.58	0.334	1.88	0.697	0.272
		–6.0	1.51	0.55	0.351	1.81	0.653	0.285
49	48	top	1.73	0.60	0.301	2.04	0.726	0.243
		–1.0	0.94	0.70	0.523	1.20	0.871	0.435

*Too fine for analysis

Granulometric Data—Continued

Number		Depth	Rapid Sand Analyzer (RSA)			Sieve Analyses		
Core	CERC I.D.	(ft)	Mean (phi)	Standard Deviation (phi)	Mean (mm)	Mean (phi)	Standard Deviation (phi)	Mean (mm)
50	49	top	2.46	0.50	0.181	2.83	0.580	0.141
		–1.0	2.41	0.44	0.188	2.77	0.494	0.147
		–2.0	2.16	0.49	0.223	2.51	0.566	0.176
		–4.0	2.33	0.44	0.198	2.69	0.494	0.155
		–6.0	2.12	0.49	0.230	2.46	0.566	0.182
		–8.0	1.57	0.66	0.336	1.87	0.813	0.274
51	50	top	2.32	0.37	0.201	2.68	0.392	0.156
		–1.0	2.07	0.35	0.238	2.41	0.363	0.188
		–4.0	1.26	0.70	0.417	1.54	0.871	0.344
52	51	top	1.01	0.59	0.495	1.27	0.712	0.415
		–1.0	1.69	0.40	0.310	2.00	0.434	0.250
		–3.0	0.72	0.77	0.607	0.96	0.973	0.514
		–5.0	0.59	0.61	0.664	0.82	0.741	0.566
53	52	top	2.31	0.65	0.201	2.67	0.799	0.157
		–4.0	1.70	0.51	0.309	2.01	0.595	0.240
		–7.5	1.55	0.69	0.341	1.85	0.857	0.277
54	53	top	2.64	0.46	0.161	3.02	0.523	0.123
		–1.0	2.68	0.32	0.156	3.06	0.319	0.120
		–3.5	2.79	0.42	0.144	3.18	0.464	0.110
		–5.3	1.33	0.71	0.398	1.62	0.886	0.325
55	54	top	2.18	0.104	0.221	2.53	0.005	0.173
		–1.0	2.94	0.33	0.131	3.34	0.333	0.099
		–2.0	2.87	0.39	0.136	3.27	0.421	0.104
		–4.0	2.40	0.98	0.189	2.76	1.28	0.148
		–6.0	1.36	0.64	0.389	1.65	0.784	0.319
		–8.0	1.76	0.82	0.295	2.08	1.05	0.237
56†								
57	56	top	2.95	0.35	0.130	3.35	0.363	0.098
		–1.0	3.03	0.31	0.122	3.44	0.305	0.092
		–2.0	2.80	0.57	0.143	3.19	0.682	0.110
		–6.0	1.88	0.77	0.271	2.21	0.973	0.216
		–9.0	2.20	0.63	0.217	2.55	0.770	0.171
		–14.0	1.16	1.12	0.447	1.43	1.48	0.371

†Sample not available

Granulometric Data—Continued

Number		Depth	Rapid Sand Analyzer (RSA)			Sieve Analyses		
Core	CERC I.D.	(ft)	Mean (phi)	Standard Deviation (phi)	Mean (mm)	Mean (phi)	Standard Deviation (phi)	Mean (mm)
58	57	top	2.25	0.104	0.210	2.60	0.005	0.165
		–1.0	2.93	0.40	0.132	3.33	0.434	0.099
		–7.0	2.08	1.07	0.237	2.42	1.41	0.187
		–10.0	2.48	0.35	0.180	2.85	0.363	0.139
		–15.0	1.42	0.87	0.373	1.71	1.12	0.306
		–17.0	2.55	0.43	0.170	2.93	0.479	0.131
59	58	top	2.93	0.70	0.132	3.33	0.871	0.099
		–1.0	2.80	0.80	0.143	3.19	1.02	0.110
		–6.0	2.44	1.03	0.184	2.81	1.35	0.143
		–8.0	1.17	0.88	0.444	1.44	1.13	0.369
		–10.0	2.67	0.36	0.157	3.05	0.377	0.121
60	59	top	2.68	0.74	0.156	3.06	0.930	0.120
		–1.0	3.06	0.43	0.120	3.47	0.479	0.90
		–3.0	1.90	0.48	0.267	2.23	0.552	0.213
		–5.0	0.66	1.02	0.632	0.90	1.34	0.536
80	79	top	0.64	0.72	0.640	0.875	0.901	0.543
		–1.0	0.79	0.61	0.579	1.04	0.741	0.486
		–3.0	0.83	0.67	0.562	1.08	0.828	0.473
		–4.0	0.56	0.40	0.678	0.79	0.435	0.578
81	80	top	1.61	0.47	0.328	1.92	0.537	0.264
		–1.0	1.50	0.62	0.353	1.80	0.755	0.287
		–3.0	0.68	1.14	0.624	0.92	1.51	0.529
82*	81							
83*	82							
84	83	top	2.70	0.61	0.154	3.09	0.741	0.117
		–1.0	2.66	0.77	0.159	3.04	0.937	0.122
		–4.0	1.91	1.28	0.267	2.24	1.71	0.212
		–7.0	2.00	1.31	0.250	2.33	1.76	0.199
		–10.0	2.01	1.16	0.248	2.35	1.54	0.196
		–13.0	2.24	1.24	0.211	2.59	1.66	0.166
		–16.0	2.62	0.98	0.162	3.00	1.28	0.125
85*	84							

*Too fine for analysis

†Sample not available

Granulometric Data—Continued

Number		Depth	Rapid Sand Analyzer (RSA)			Sieve Analyses		
Core	CERC I.D.	(ft)	Mean (phi)	Standard Deviation (phi)	Mean (mm)	Mean (phi)	Standard Deviation (phi)	Mean (mm)
86	85	top	2.72	0.83	0.152	3.11	1.06	0.116
		–1.0	2.35	0.98	0.196	1.88	1.28	0.272
		–5.0	2.46	1.13	0.182	2.83	1.50	0.141
		–8.0	2.43	1.22	0.185	2.80	1.63	0.144
		–12.0	2.09	0.74	0.235	2.43	0.930	0.186
87	114	–0.3	2.66	0.40	0.158	3.04	0.434	0.122
		–8.5	3.01	0.34	0.124	3.42	0.348	0.093
		–9.7	3.02	0.34	0.124	3.43	0.348	0.093
		–14.5	2.89	0.48	0.135	3.29	0.552	0.102
		–17.7	2.87	0.34	0.136	3.27	0.348	0.104
88	115	–3.5	2.38	0.57	0.192	2.74	0.682	0.150
		–4.9	2.35	0.50	0.196	2.71	0.581	0.153
		–6.0	2.78	0.38	0.146	3.17	0.406	0.111
		–15.0	2.78	0.43	0.145	3.17	0.479	0.111
89	116	–2.0	2.34	0.57	0.197	2.70	0.682	0.154
		–4.7	2.21	0.49	0.217	2.56	0.566	0.170
		–9.75	2.22	0.54	0.215	2.57	0.639	0.168
		–13.7	2.19	0.54	0.219	2.54	0.639	0.172
		–15.5	2.27	0.52	0.208	2.62	0.610	0.163
90†	117							
91	118	–0.25	2.09	0.80	0.155	3.08	1.02	0.118
		–2.6	2.78	0.83	0.145	3.17	1.06	0.111
		–3.3	2.66	0.88	0.158	3.04	1.13	0.122
		–7.5*						
		–16.5*						
92	119	–1.9	2.82	0.90	0.142	3.21	1.16	0.108
		–5.1	2.82	0.83	0.141	3.21	1.06	0.108
		–10.0*						
		–14.5*						
		–16.5*						
		–18.4*						
93	120	–0.3	2.47	0.67	0.181	2.84	0.828	0.140
		–2.3	2.90	0.41	0.134	3.30	0.450	0.102

*Too fine for analysis

†Sample not available

Granulometric Data—Continued

Number		Depth	Rapid Sand Analyzer (RSA)			Sieve Analyses		
Core	CERC I.D.	(ft)	Mean (phi)	Standard Deviation (phi)	Mean (mm)	Mean (phi)	Standard Deviation (phi)	Mean (mm)
94†	121							
95	122	−0.4	1.83	0.69	0.280	2.15	0.857	0.225
		−2.6	2.10	0.60	0.233	2.44	0.726	0.184
		−4.8	2.26	0.70	0.208	2.61	0.871	0.164
		−6.0*						
		−8.5*						
		−14.3*						
96	123	−0.3	1.46	0.73	0.362	1.75	0.915	0.297
		−4.0*						
		−6.0*						
		−8.5	1.71	0.37	0.306	2.02	0.392	0.120
		−9.7	1.92	0.39	0.265	2.25	0.421	0.210
		−14.3	1.81	0.57	0.286	2.13	0.682	0.229
98	87	top	1.42	0.116	0.374	1.71	0.023	0.306
		−1.0	0.80	0.083	0.574	1.05	1.06	0.484
		−3.0*						
		−6.0*						
99	88	top	1.94	0.123	0.261	2.27	0.033	0.207
		−1.0	1.37	0.105	0.386	1.66	0.007	0.316
		−4.0*						
100*								
101	90	top−1.0	2.36	0.124	0.195	2.72	0.34	0.152
102*	91							
103	92	top	1.62	0.61	0.325	1.93	0.741	0.262
		−1.0	1.63	0.57	0.323	1.94	0.682	0.261
		−4.0	0.98	0.67	0.506	1.24	0.828	0.423
		−7.0	1.05	0.79	0.482	1.31	1.00	0.403
		−10.0	0.72	0.78	0.607	0.96	0.988	0.514
		−13.0	1.33	0.89	0.397	1.62	1.15	0.325
		−18.0	0.30	1.30	0.812	0.51	1.74	0.702
104*								

*Too fine for analysis
†Sample not available

Granulometric Data—Continued

Number		Depth	Rapid Sand Analyzer (RSA)			Sieve Analyses		
Core	CERC I.D.	(ft)	Mean (phi)	Standard Deviation (phi)	Mean (mm)	Mean (phi)	Standard Deviation (phi)	Mean (mm)
105	93	–9.0	1.74	0.52	0.299	2.06	0.610	0.240
		–13.0	1.20	1.08	0.435	1.48	1.42	0.359
		–15.0	1.46	0.71	0.363	1.75	0.886	0.297
106	112	–0.4	2.57	0.65	0.169	2.95	0.799	0.129
		–3.4	2.74	0.62	0.150	3.13	0.755	0.114
		–7.0	2.77	0.71	0.147	3.16	0.886	0.112
		–9.0*						
		–13.5	2.77	0.95	0.147	3.16	1.23	0.112
107	94	top	2.50	0.107	0.177	2.87	0.009	0.137
		–0.4	2.71	0.64	0.153	3.10	0.784	0.117
		–3.0	2.81	0.58	0.142	3.20	0.697	0.109
		–5.0	2.80	0.69	0.144	3.19	0.857	0.110
		–10.0*						
		–12.0	1.03	0.66	0.489	1.29	0.813	0.409
		–13.0	1.09	0.42	0.469	1.36	0.464	0.390
108	95	top	2.45	0.76	0.184	2.82	0.959	0.142
		–1.0	1.90	0.105	0.288	2.23	0.007	0.213
		–3.0*						
		–6.0*						
		–10.0*						
		–14.0*						
109	96	top	2.83	0.90	0.140	3.23	1.16	0.107
		–2.0*						
		–6.5	2.21	1.27	0.217	2.56	1.70	0.170
		–11.0	2.32	1.30	0.200	2.68	1.74	0.156
		–15.0	3.05	0.95	0.121	3.46	1.23	0.091

*Too fine for analysis

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