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SAND SOURCES FOR THE TRANSGRESSIVE BARRIER COAST OF LONG ISLAND, NEW YORK: EVIDENCE FOR LANDWARD TRANSPORT OF SHELF SEDIMENTS

S. J. WILLIAMS[1/]

E. P. MEISBURGER[2/]

ABSTRACT

Long Island, a glacial depositional landform marking the southern limit of Pleistocene ice sheet advance, is composed of at least two end moraines. Glaciofluvial outwash deltas and sand sheets associated with the moraines underlie the coast and continental shelf. The southern most and older Ronkonkoma Moraine intersects the Atlantic coast along the eastern quarter of Long Island. Marine erosion of the Montauk headlands is an important source of sediment for the construction and maintenance of the barrier beaches, dunes, and tidal inlet deltas to the west along the rest of Long Island during the late Holocene transgression. However, computations of the littoral sediment budget along the coast demonstrate that generally the sediment volumes increase to the west in the direction of net longshore transport, and that the volumes exceed the sand supply available from erosion of the headlands and the updrift beaches. The continental shelf south of Long Island is reputed to be the source of the additional sediment to the coastal sand budget; however, this deduction is contradicted by the Brunn Rule and has been difficult to verify.

During investigations of the regional geologic framework of the Long Island shelf by means of seismic-reflection profiles and cores, Williams (1976) identified a rather limited area on the shelf off Jones Beach where Upper Cretaceous or early Tertiary age glauconite-rich lithosomes subcrop at the seabed, seaward of the shoreface. A suite of beach samples from Montauk Point to Rockaway Beach, cores from the shelf that penetrated the glauconitic strata, and grab samples along a shore-normal transect from the shelf to the beach were analyzed to determine if shelf sediments are being eroded and transported landward, and are contributing to the littoral sand budget along the Long Island coast.

Results of this study using glauconite as a natural tracer of sediment transport show that under present oceanographic conditions, and probably throughout the Holocene transgression, the inner continental shelf has been an important source of sediment for the Long Island barrier beaches.

[1/] U.S. Geological Survey, 914 National Center, Reston, VA 22092

[2/] USAE, Waterways Experiment Station, Coastal Engineering Research Center, Box 631, Vicksburg, MS 39180

INTRODUCTION

The identification of sources for the large volumes of sedimentary materials comprising beaches and coastal landforms is a topic of keen interest to many coastal investigators. Such information is fundamental to understanding the origins and evolutionary development of modern coasts. By knowing the sources and transport paths as well as the oceanographic processes that control them, sediment budgets using quantitative methods can be computed for almost any stretch of coastline. The models resulting from modern coastal systems can be used to decipher and reconstruct ancient coastal environments with which economic deposits of hydrocarbons and marine hard minerals are frequently associated. Engineers responsible for designing coastal structures or mining minerals in nearshore waters also need to be keenly aware of coastal sedimentary processes. Incorporating such information into the initial design of engineering projects will improve the efficacy of the engineering works and reduce the risk of adverse affects to coastal environments.

Many factors are involved in the natural processes that provide sandy sediment to the coast where it accumulates as beaches and dunes. Often the sand sources are local and transport distances are short; however, sometimes sediments are carried great distances before deposition occurs. There are five general sources of beach sediment, and their contributions to a total sediment budget vary with geographic location:

(1) Terrestrial erosion and runoff provide large quantities of sediment of widely varying grain size and composition to rivers. These sediments are carried seaward and may eventually reach the coast and be dispersed to adjacent beaches by littoral transport. For rivers to be significant sources of sand, their gradients must be fairly high. Many of the rivers along the Pacific Coast of the United States have been major contributors of sand to the coast. In contrast, most rivers along the Atlantic and Gulf Coasts have low gradients and, therefore, very limited sediment transport capacities. Any sand entering these rivers and transported seaward is likely to be deposited in their flood plains or estuaries and not reach the coast.

(2) The beach and shoreface itself are a second sediment source. Waves, and in some cases, wind action erode sand from the beach and shoreface and longshore currents transport it to downdrift beaches through the surf and intertidal zones.

(3) Headland areas on the coast offer another major source of beach sand. Bedrock and glacial-till headlands often exhibit considerable relief; wave undercutting and slumping make large volumes of sediment available for winnowing by wave action. Sand-size and coarser materials are carried alongshore, while silts and clays are transported seaward or may be deposited in back-barrier environments if inlets are present.

(4) Biogenic carbonate materials account for most beach sand production in lower latitude regions, and can be an important contributor in middle and high latitude areas as well. In most cases, the shell debris is provided by organisms living in shallow shelf areas close to the beach; however, some beaches contain shell derived from older estuarine or lagoonal deposits that are eroded at the shoreface of transgressing coasts.

(5) The continental shelves may be especially important sources in regions that comprise a wide and gently sloping Coastal Plain with an abundance of sand deposited in fluvial or glacial depositional features. During the Holocene rise in sea level, these sand bodies have been eroded and the sediment distributed by littoral processes. Long-term processes move sand landward on the shelf where it eventually incorporates into the littoral system. The view of the shelf as a sediment source, however, is contrary to the Brunn Rule (1962). This hypothesis, based on two-dimensional conceptual models and experiments in water tanks, proposes that beaches erode and migrate landward with rises in sea level and maintain a dynamic equilibrium with their shoreface parts by a movement of sand offshore. According to the Brunn Rule erosion of the beach is accompanied by proportional aggradation of the shelf. Since being proposed, many tests under field conditions have been made but results supporting the theory have been limited.

Background

The subject of onshore sediment transport from the shelf to the coast has been discussed earlier by McMaster (1954), Van Andel and Poole (1960), Shepard (1963), and Guilcher (1963), who provide convincing evidence for its importance in supplying sand to the coast. Pierce (1969) calculated a sediment budget along part of the North Carolina Outer Banks and concluded that nearly 50 percent of the one million m^3/yr of sand needed to maintain the barrier island coast must be derived from the adjacent shelf.

In 1971, Williams and Field used mineralogic analyses of 23 cores on the shelf off northern New Jersey and western Long Island to show that the sediments at the seafloor to the east and west of the Hudson River shelf valley have quite distinctive compositions. Based on the occurrence of magnetite, feldspar, and glauconite and the textural character of the sand fraction, they concluded that the sediments on the shelf south of Long Island were derived from glacial sources and that the New Jersey shelf sediments resulted from erosion of Coastal Plain formations cropping at the shore and out on the seabed. Their analyses were supported by the early work of Colony (1932), who first recognized the distinct compositional differences of beach sands from northern New Jersey and the south shore of Long Island: New Jersey beach sands have high glauconite content and low values of feldspar and magnetite; Long Island beaches are high in feldspar and magnetite, and glauconite is absent in the moraines and outwash plains and occurs only sporadically in beach sediments.

Pilkey and Field (1972) compared the mineralogic composition of beaches along the southeastern United States with offshore samples and found reasonably close correlations. They too concluded that nearshore parts of the shelf are an important source of sand for the adjacent shore.

Numerous studies have been made on the Atlantic coast of Long Island (Fig. 1) over the last 30 years to mitigate erosion and provide for navigation.

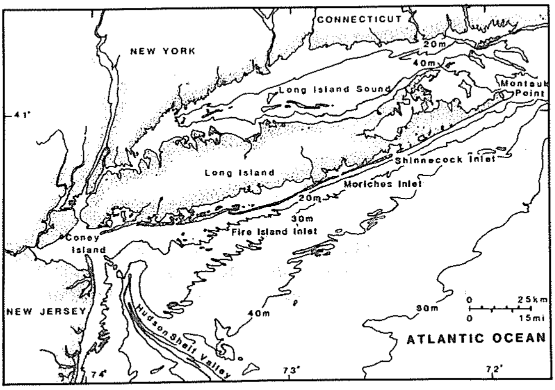

Fig. 1. Location map of Long Island.

Based on volumetric measurements of rates of coastal erosion and sand accumulation at jetties and groins, Saville (1960), Taney (1961a), and Panuzio (1968) found a variable but progressive increase in littoral drift volumes westward along the Long Island coast. The sand volumes could not be balanced by erosion of the Montauk headland or updrift beaches, the two obvious sources. Sediment budget calculations led these investigators to postulate that the surplus in the sediment budget must originate from offshore sources. Ash (1979) used shoreline change and sedimentological data to explain coastal erosion on Long Island and concluded that up to 15 percent of littoral sand budget came from shelf sources. In 1981, McCormick and Toscano used the coastal sediment budget volumes in the literature and compared the present offshore bathymetry with projected Pleistocene outwash slopes. In one-half of the transects selected they found the modern shelf surface exhibiting evidence of erosion, and concluded that erosion of the shelf and landward transport of sand is important in maintaining the Long Island barriers. Panageotou and Powers (1984) also used shelf profiles and calculated that at Fire Island Inlet approximately 11 percent of the sediment budget is derived from the shelf.

In the mid-1970's, high-resolution seismic-reflection profiles and vibracores were analyzed in a study of the shallow structure and stratigraphy of Quaternary sediments on the Long Island shelf (Williams, 1976). Several seismic profiles (Line F, Figs. 2, 3) off western Long Island revealed planar sedimentary reflectors that dip to the southeast and subcrop at the seafloor as cuestas in a zone extending northeast from about Long Branch, N.J., to within 10 km of the Long Island mainland west of Fire Island Inlet (Fig. 2). The cuestas correspond to the location of the New York Bight fault postulated by Hutchinson and Grow (1982, 1985) to displace Coastal Plain strata by 109 m (Fig. 4). The attitude of

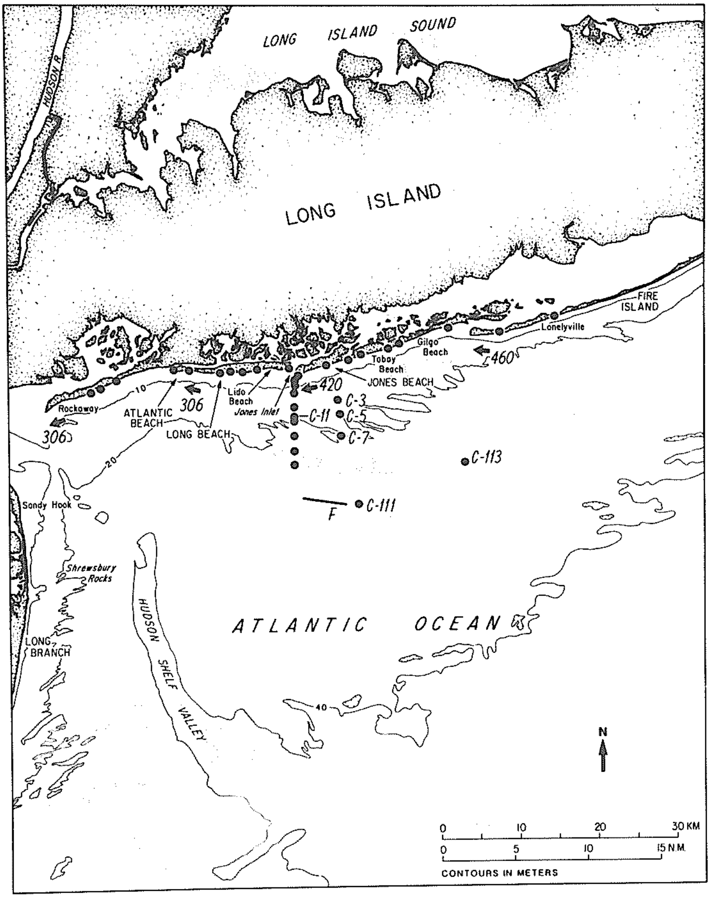

Fig. 2. Map of the western Long Island study area showing the locations of the beach and shelf grab sample stations, the vibracore positions, (e.g., C-3) and seismic profile F. Arrows indicate the direction and volume ($x10^3 m^3$) of net longshore sediment transport.

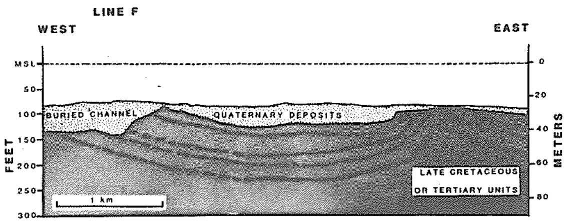

Fig. 3. Geologic cross section of the shelf 17 km off Jones Beach based on interpretations of seismic-reflection profile F and vibracore 111. Locations are shown on Figure 2. (modified from Williams, 1976).

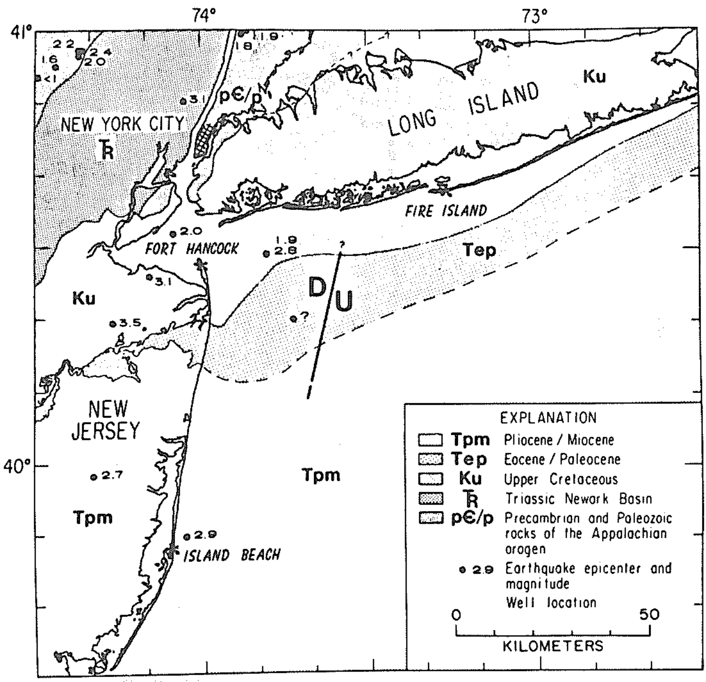

Fig. 4. Map of the pre-Quaterary geology of New York Bight showing the general distribution of Cretaceous and Tertiary sedimentary units on the continental shelf. The location of the New York Bight fault corresponding with the cuestas is the heavy line with up and down relative movement indicated. From Hutchinson and Grow (1982).

the reflectors and their correlation with well logs and subaerial outcrops in northern New Jersey suggests they are Coastal Plain units of Late Cretaceous or early Tertiary age. Vibracores, taken at sites where the seismic profiles show the units at shallow subbottom depths, recovered highly glauconitic sands and sandy muds (Table 1).

Table 1. Selected cores that recovered glauconitic sediments. Locations are shown in Fig. 2, descriptions are from Williams (1976).

Core	Water depth (m)	Interval (cm)	Description
3	13.7	0-31	brown, medium sand
		31-183	gray, shelly medium sand
		183-320	greenish-gray sandy mud
5	15.8	0-93	brown, medium sand
		93-183	gray, shelly medium sand
		183-305	gray, coarse shelly sand
		305-348	dark green, glauconitic muddy sand
7	18.9	0-15	brown, medium sand
		15-220	greenish-gray, glauconitic sandy mud
11	14.3	0-61	brown, medium sand
		61-280	dark greenish-gray, glauconitic clay
111	25	0-52	gray, gravelly fine to medium sand
		52-70	light green, fine glauconitic sand
		70-152	light green, gravelly fine to very coarse sand
		152-204	white, gravelly fine to medium sand
113	25	0-88	brown, fine to medium sand
		88-466	green, glauconitic medium sand

The presence of glauconitic sedimentary units cropping out in restricted areas on the Long Island shelf (Williams, 1976) and the absence of glauconite in the glacial tills and outwash plains on Long Island (Colony, 1932) was the basis for this study on longterm sediment transport. Using a suite of offshore cores and grab samples from the source areas on the shelf to the shore and beach samples from Rockaway Beach to Montauk Point, the authors analyzed for glauconite occurrence. The objective of the study was to use glauconite as a natural trace mineral to provide definitive information on the probability of the continental shelf as a sand source for Long Island beaches.

GEOLOGICAL SETTING

Long Island, a glacial depositional landform at the southern boundary of the New England Coastal Plain Province, marks the southern limit of Pleistocene glaciation in eastern North America (Fig 1.). Long Island is composed of at least two morainal features that extend its length (200 km) and have a maximum relief of nearly 100 m. The southernmost moraine, the Ronkonkoma, has broad and gently south sloping outwash sand plains extending to the coast and south across the shelf (Williams, 1976).

Waves and currents have eroded and shaped the Atlantic coast of Long Island into distinct physiographic environments that are characterized by a variety of coastal geologic features. The headland section on the east extends from Montauk Point west to about Shinnecock Inlet, a distance of 45 km (Fig. 1). It comprises glacial till bluffs almost 20 m high where the Ronkonkoma Moraine intersects the coast. The barrier beach section that extends from Shinnecock Inlet west 150 km to Coney Island consists of two long and continuous barrier islands on the eastern half and four shorter barrier islands from Fire Island Inlet to the Hudson River (Fig 1). Historical data for the south shore coast show a predominately westward migration of the inlets and barrier spits as a consequence of the net westerly longshore littoral transport (Panuzio, 1968).

Crosby (1910) and Fuller (1914) provided early descriptions of the Coastal Plain stratigraphy for the Long Island mainland, while Perlmutter and Todd (1965) and Sirkin (1974) have made minor revisions based on deep cores and modern analyses. Williams (1976) used seismic-reflection profiles and core data from the Long Island inner shelf to decipher its stratigraphic character and identified buried paleofluvial channels. Several channels transected the Long Island mainland and continued south across the shelf as shown to the west in Figure 3. The channels have been filled such that only subtle depressions remain at some places on the mainland and shelf surface. Patches of coarse sediment and lobate highs, primarily on the shelf of eastern Long Island, are remnants of deltaic deposits that were more extensive prior to the Holocene transgression (Williams, 1976).

The Coastal Plain sedimentary units in the region (Table 2) consist of Late Cretaceous interbedded silty sand and gravel of nonmarine origin (e.g., Magothy Fm., Matawan Group) as well as highly glauconitic silt and sand units belonging to the marine Monmouth Group (Fig. 5). The Coastal Plain units, which dip and thicken to the southeast, (Fig. 5) are blanketed on the shelf by Pleistocene and Holocene sediments. The Quaternary sediments vary in thickness from less than one meter on top the Coastal Plain cuestas to 100 m in the large paleofluvial channels of western Long Island (Fig. 3).

About 75 percent of the Long Island coast is transgressive barrier beaches that exhibit a fining-up sedimentary sequence of littoral sands and marsh deposits constructed on the Pleistocene erosion surface. The barriers of western Long Island and those east of Fire Island Inlet overlie the glacial outwash plain. However, section B-B' in Figures 6 and 7 is typical of the central barriers such as Jones Beach. It rests on top of the Coastal Plain cuestas where the late Pleistocene units are thin and Cretaceous glauconitic sands underlie the coast at only -25 m (Rampino and Sanders, 1981).

Nearshore Processes

Tides along the south shore of Long Island are semidiurnal, varying in average height from 1.4 m at Rockaway Inlet, to 1.3 m at Fire Island, and 0.6 m at Montauk Point. The mean spring range is 1.5 m, clearly within the microtidal classification (Panuzio, 1968). Prevailing fair weather winds in the study area are southwest during the summer and northwest in the winter. The largest waves and strongest currents occur during storms that are either hurricanes or extratropical northeasters. The dominant winds from these storms are from the east or northeast and are responsible for the westerly net longshore transport of littoral drift along the south shore. The net littoral drift volumes and directions for western Long Island are shown in Figure 2. The most dramatic evidence of the net westerly transport is the growth of Fire Island spit which has extended

Table 2. Correlation of stratigraphy from New Jersey and Long Island. From Williams (1976).

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

1. After Owens and Minard (1960)
2. After Perlmutter and Todd (1965), Sirkin (1974)

almost 8 km west from 1825 to 1940 and now overlaps the adjacent Cedar Beach barrier. The calculated net annual longshore sediment transport rate is 460 thousand m^3 for Fire Island, decreasing to 420 thousand m^3 along Jones Beach, and just over 300 thousand m^3 along Rockaway (Saville, 1960).

A seabed drifter study by Bumpus (1965) in the middle Atlantic region showed a high seasonal variability in water movement on the seafloor; however, he found the net flow on the western Long Island shelf to be westerly with a dominant onshore component. Beardsley and Butman (1974) have shown that circulation of the New England shelf water mass is dominated by short duration but intense winter storms. More recently, Lavelle and others (1978) used radioisotope tracers and bottom current meters to examine the movement of fine to medium sand at the seabed in 20-m depths within our study area. They too concluded that annual eastward sediment transport from fair weather conditions is more frequent but much less intense than the westward, shore-parallel transport that results from extratropical storms. Similar results reported by Vincent and others (1981) showed net westerly bedload transport across the Long Island shelf to at least 30-m water depths with a strong onshore component landward of the 10-m isobath.

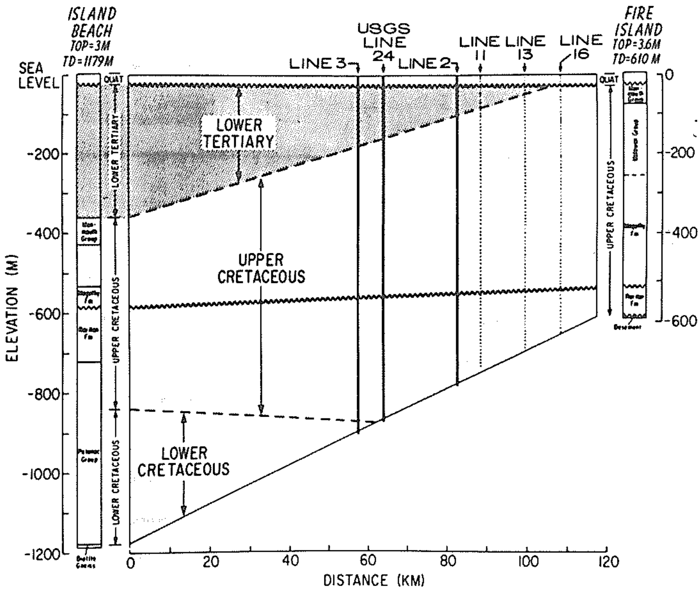

Fig. 5. Geologic cross section of Coastal Plain units between Island Beach, New Jersey and Fire Island, New York based on well data. From Hutchinson and Grow (1982).

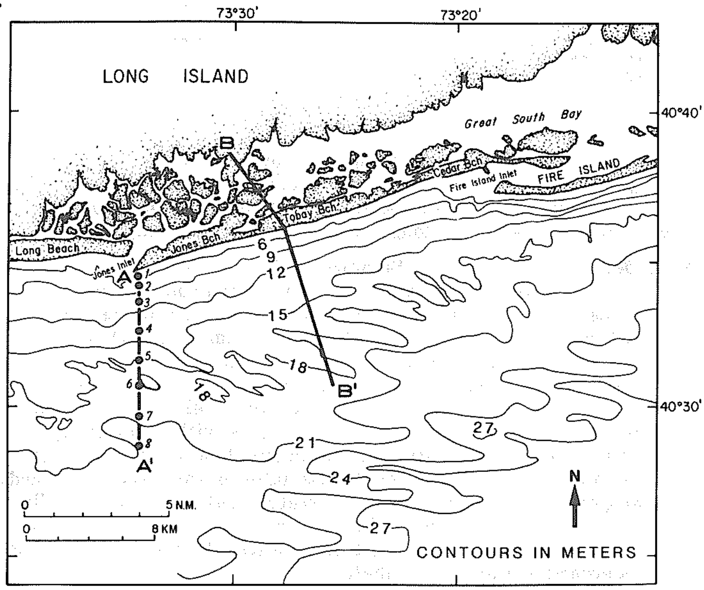

Fig. 6. Locations of grab sample transect A-A'off Jones Beach and geologic cross section B-B' across the Jones Beach-Tobay Beach barrier and shelf.

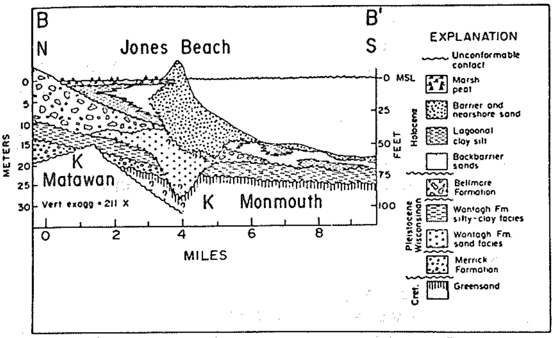

Fig. 7. Geologic cross section of the Jones Beach-Tobay Beach barrier and inner shelf. From Rampino and Sanders (1981).

METHODS

In 1980 and 1981, beach samples were collected at a spacing of 2 to 7 km along the Long Island Atlantic coast from Rockaway Beach east to Montauk Point. The suite of samples from stations 4 (Rockaway Beach) to 22 (Fire Island) discussed here are shown in Figure 2. Examination of these samples revealed that the beaches from Rockaway Beach to Jones Beach contained significant but varying amounts of glauconite; whereas, the beaches to the east including the headland bluffs at Montauk Point - known to be an important source of the beach sediments - contained no glauconite.

Six vibracores, located 5 to 20 km seaward of Jones Beach (Fig. 2) and described by Williams (1976), were used to locate and identify the glauconite source beds (Table 1). To correlate the sedimentology in the cores with the adjacent beach samples, a transect was made consisting of eight grab samples collected at 1.8-km spacing offshore from Jones Inlet (Fig. 6). The most inshore sample was on the upper shoreface at 5 m depth, while the most seaward sample was 10.8 km from the beach at a depth of 20 m (Fig. 6).

Grain-size distributions of the samples were done by sieving at one-half phi intervals or use of a settling tube. Mean grain diameter and standard deviation (sorting) were calculated by method of movement analysis. The samples were examined using a plane-light microscope and were described in terms of color, texture, shell content, and gross mineral composition. The samples were then sieved to separate the 1-3 phi (0.50-0.125 mm) size fraction. This size fraction was used for point counts of glauconite content because it contained the maximum number of well-formed grains.

Because of the small amount of glauconite grains in the sample relative to other particles, it was not practical to count all the grains in the sample to calculate glauconite frequency. Therefore, the frequency was calculated as the number of glauconite grains per 0.25 grams of total sample.

The term glauconite has been used to describe both a specific mineral species and as a morphological term for greenish earthy pellets which resemble but may not correspond to the mineral glauconite. The glauconite pellets described in this study were identified in general field terms for a morphological type and they may or may not contain the mineral glauconite. The glauconite grains contained in the Long Island samples are primarily of a medium to very dark green color; a few have brown exterior surface with a greenish core. In general, the pellets are well rounded and are roughly equal in overall dimensions. Often they have a lobate form. Many grains contain cracks in their surface that are partially filled with a green or brown rugose material. The grains are friable and soft (2 on the Mohs hardness scale) and are easily abraded and broken when transported even short distances in the high energy shelf and littoral environments.

RESULTS AND DISCUSSIONS

Microscopic analyses of the Long Island beach samples from Montauk Point to Rockaway Beach showed wide variations in mean grain size and sorting as well as significant differences in mineralogy. Beach sediments at the base of the Montauk bluffs on eastern Long Island are very coarse, poorly sorted sand with an abundance of pebble to boulder size materials that armor lower parts of the beach. The coarse sediments continue offshore for several kilometers (Williams, 1976). The coarse nature of the beach and inner shelf of eastern Long Island is the result of marine erosion of the till bluffs during the late Holocene transgression. The erosion processes winnow out the silt and clay size fraction and carry it offshore. The gravel is concentrated in the swash zone with little lateral movement, and the sand fraction is transported west by the prevailing longshore currents. Results of this study support Taney's (1961b) findings that the Montauk headlands are a major source of the sand for the beaches to the west along the Long Island south shore. In spite of the variations in grain size, particularly adjacent to relict and modern tidal inlets, mean grain size along the coast is progressively smaller from east to west, and the degree of sorting increases slightly. Figure 8 shows that beach sands of central and western Long Island are composed of moderately to well-sorted medium sands.

Glauconite was not detected in Montauk headland sediments nor any of the beach samples from the eastern two-thirds of Long Island. The plot of glauconite occurrence in Figure 8 shows it was only detected in the three

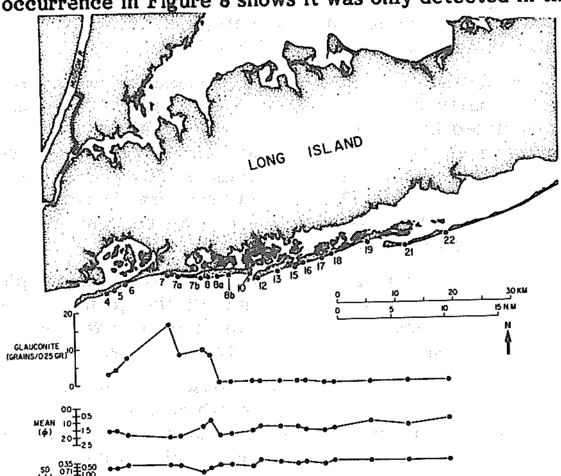

Fig. 8. Display of glauconite frequency and textural characteristics of the beach samples from Fire Island to Rockaway Beach, New York.

western barrier beaches: Jones Beach, Long Beach, and Rockaway Beach. It first appears in trace amounts (<1 grain/0.25 grams) at station 16, in the middle of Jones Beach and remains at low levels until station 8, situated midway along Long Beach, which has a count of nearly 8 grains. The beaches of western Long Beach show a progressive increase in abundance to a maximum value of 16 grains (station 7) on the Atlantic Beach barrier spit adjacent to East Rockaway Inlet (Fig. 8). The three stations (4, 5, 6) on Rockaway Beach show a progressive westward decrease in glauconite. This is likely the result of two factors: Because of the friable and soft nature of the glauconite pellets, they undergo rapid mechanical degradation and reduction in grain size in high energy littoral environments. When the grains are reduced to silt size, they are selectively transported offshore or through tidal inlets to low energy lagoons. The westward decrease in glauconite on Rockaway can also be explained by a succession of beach fills that were completed in the 1970's to nourish the eroded shore. The fill material was obtained from offshore sand bodies having glacial outwash origins. These sediment additions mixed with and diluted the glauconite-bearing littoral sediments coming from adjacent beaches to the east.

The eight samples from shore-normal transect A-A' (Fig. 9) at the western end of Jones Beach provide proof that a transport linkage exists between the shelf and the beach. The textural data plots in Figure 9 show the shelf along transect A-A' is composed fine to medium sands. The samples exhibit remarkable uniformity except for slight coarsening at the toe and just seaward of the shoreface ramp, as well as at the seaward end of the transect. The sorting values also show that most of the samples are moderately well sorted, and that the coarser sands exhibit slightly greater grain-size diversity.

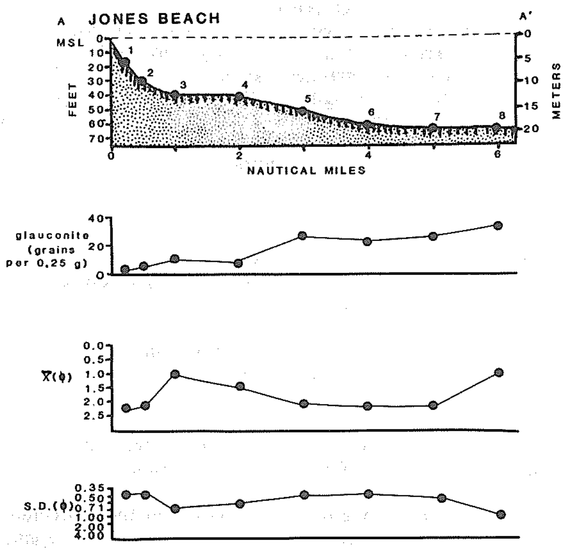

Fig. 9. Plots of sediment textural data and glauconite abundance from eight grab samples along nearshore transect A-A' off Jones Beach. Locations are shown in Figures 2 and 6.

Stations 5, 6, 7, and 8 on transect A-A' are in the shelf area where the cores and seismic profiles show glauconite-rich sediments subcrop at the seafloor. Glauconite counts are very high, 20 to 38 grains/0.25 grams, and the grains in the grab samples have a similar size and morphologic appearance to the parent glauconitic sediments recovered in lower parts of the cores (Table 1). Onshore from station 5 to the beach, glauconite concentrations decrease to trace amounts, agreeing with the analyses of station 12 from the shore suite of samples. The progressive decrease in glauconite frequency along transect A-A' is as might be expected along a transport path from the source to a depositional sink. The reduction in concentration is due to mechanical abrasion of the glauconite grains and dilution by littoral sediments from the east having a glacial origin. This is especially evident along the shoreface (stations 1-4), the zone of maximum littoral transport, in transect A-A' (Fig. 9).

CONCLUSIONS

The results of this study using glauconite as a natural mineral tracer demonstrate that sand-size sediment is being transported from the continental shelf in a landward direction and contributes to the littoral drift budget of Long Island. The Montauk headland bluffs along eastern Long Island are the major source of littoral sediment for the barrier beaches to the west. However, significant additions of sediment along the entire Long Island coast come from marine erosion of offshore glacio-fluvial outwash plains and deltas and residual Coastal Plain sediments that comprise the shelf along the south shore of Long Island.

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