DUKE GEOLOGICAL LABORATORY

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TRIPS ON THE ROCKS

Guide 01: Robert Moses State Park, Fire Island, New York

Trip 01: 25 September 1988; Trip 07: 17 September 1989

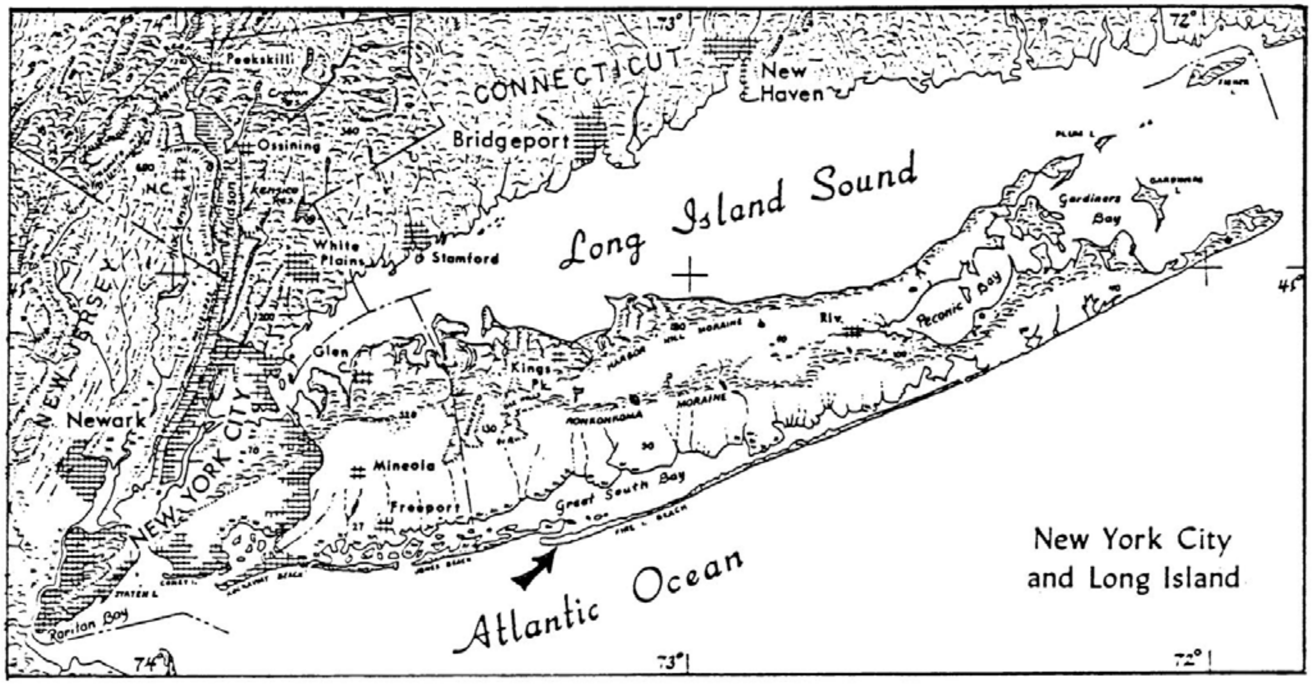

Figure 1 – Index map of Long Island showing the location (arrow) of our field trip.

Field Trip Notes by:

Charles Merguerian and John E. Sanders

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LOGISTICS

0830: Depart NYAS, 2 E. 63rd Street
1000: Arrive Robert Moses State Park, Parking Field 2;
    20-min break for restrooms, cafeteria, etc.
1020: Assemble on cement ramp outside cafeteria; practice pacing.
    Concept of strike and dip.
1100: Board vans to drive to W end of parking lot for walk on beach and to inlet.
1230: Lunch at jetty.
1500: Start back to parking lot.
1600: Board vans for trip back to NYAS.

OBJECTIVES

1. The understand the general geologic relationships of Long Island and the occurrence of ground water in various geologic units.

2. To be duly impressed by the evidence for the rapid westward growth of the west end of Fire Island as a result of inlet migration (average rate of 1 meter per week in the interval 1834-1940).

3. To become familiar with the composition of the beach sediment (including at least three populations of particles: a. well-sorted white medium sand; b. well-sorted dark-colored, esp. dark reddish, medium sand; and c. poorly sorted coarse brown sand, gravel, and shell debris.

4. To recognize the various parts of an ocean beach, including the shore-parallel ridges of sand (are they dunes?), berm, beach face (and/or beach scarp), and the three morphodynamic zones of an ocean beach: supratidal, intertidal, and subtidal.

5. To study the relationship between deposition of new layers of sediment and sediment surfaces, including both small-scale bed forms and large-scale depositional "slopes;" and to recognize plane, parallel strata and cross strata.

6. To understand how distinctive sequences of strata are formed by shifting of depositional slopes and the significance of prograding parallel to shore and of prograding normal to shore.

7. To understand the dynamic effects of processes such as waves and tides at modern sea level and to consider the long-term history of sea-level changes, as related both to movements of the lithosphere and to world-wide (eustatic) effects, particularly with respect to climate.

8. To realize how the effects of the operation of the geologic cycle through time create a geologic record of sediments and of sedimentary bedrock.

PLAN FOR THE DAY: (To have a nice day at the beach!)

1. Reconnoiter the berm near the pavilion at Parking Field, pace its width and sketch profile.

2. Walk toward jetty and inlet; select one or more sites for digging an SST ("Sanders Scientific Trench"). An SST differs from any old trench in that one side is carefully chosen so that the relationship between the sediment surface and the vertical trench wall will be in the best light for photography after the digging has been completed. ALL SAND IS SHOVELED TO THE OPPOSITE SIDE. NO EXCEPTIONS WILL BE TOLERATED! Guards will be posted to keep curious onlookers from wandering up to look from the pristine side.

3. Visit the inlet to see the spit complex.

DRIVING DIRECTIONS:

Turn L on 5th Avenue, drive S to 34th Street, turn L and use Midtown Tunnel and Long Island Expressway. Leave LIE at exit for Northern State Pkwy and Meadowbrook Pkwy, in direction of Jones Beach. After entrance gate to Jones Beach State Park, follow Ocean Parkway E to Robert Moses Causeway. Enter Causeway S bound, cross the bridge and turn R at the traffic circle, following sign for Parking Field 2. Proceed to end of divided highway, make a U-turn, and after driving E for about 1/4 mile, turn R into first entranceway into Parking Field 2.

GEOLOGIC RELATIONSHIPS ON TRIP ROUTE (MANHATTAN, LONG ISLAND, AND MODERN OPEN-OCEAN COAST ON SOUTH SHORE OF LONG ISLAND)

In driving from Manhattan to Robert Moses State Park, we shall encounter many geologic formations that we shall generalize into four "layers," from oldest to youngest: (1) "basement" complex of ancient metamorphic rocks (ages greater than 350 million years); (2) coastal-plain strata (sediments deposited along the coast of the passive eastern margin of the North American plate, which formed when the Atlantic Ocean opened, late in the Jurassic Period, 180 million years ago and still exists today while the Atlantic Ocean continues to widen); (3) upper Pleistocene deposits (draped over the eroded edge of the elevated and tilted coastal-plain strata; their ages are not precisely known, but the tried-and-true geologic method of "guessing" gives numbers in the range of 70 thousand to 40 thousand years); and (4) the modern (=Holocene; some would say, "obscene") sediments being deposited along the margins of the Atlantic Ocean; these are no older than about 2 thousand years. Although we shall be seeing only sediments of (4) today, it will be helpful to outline the general relationships among these four "layers" and to relate them to the geologic conditions associated with the extraction of ground water on Long Island.

"Basement" Complex

The solid bedrock, which is exposed in many parts of Manhattan, underlies the tall buildings, and is encountered in the subway tunnels, ranges in age from about 350 million years to 1100 million years. Collectively, it forms a "basement" complex on which the coastal-plain and younger sediments accumulated. This complex includes many kinds of metamorphic rocks and has provided the garnets and other dark-colored "heavy" minerals (specific gravity greater than 2.80) that are locally abundant in the beach sands on Fire Island. The "basement" complex extends regionally beneath the coastal-plain cover of Long Island, underlies Long Island Sound, and is exposed at the surface the Western and Eastern Highlands of Connecticut (Figure 2). We have described the rocks of this complex in the guidebooks of several of our 1988-89 Trips on the Rocks and thus will not give them more than passing notice here.

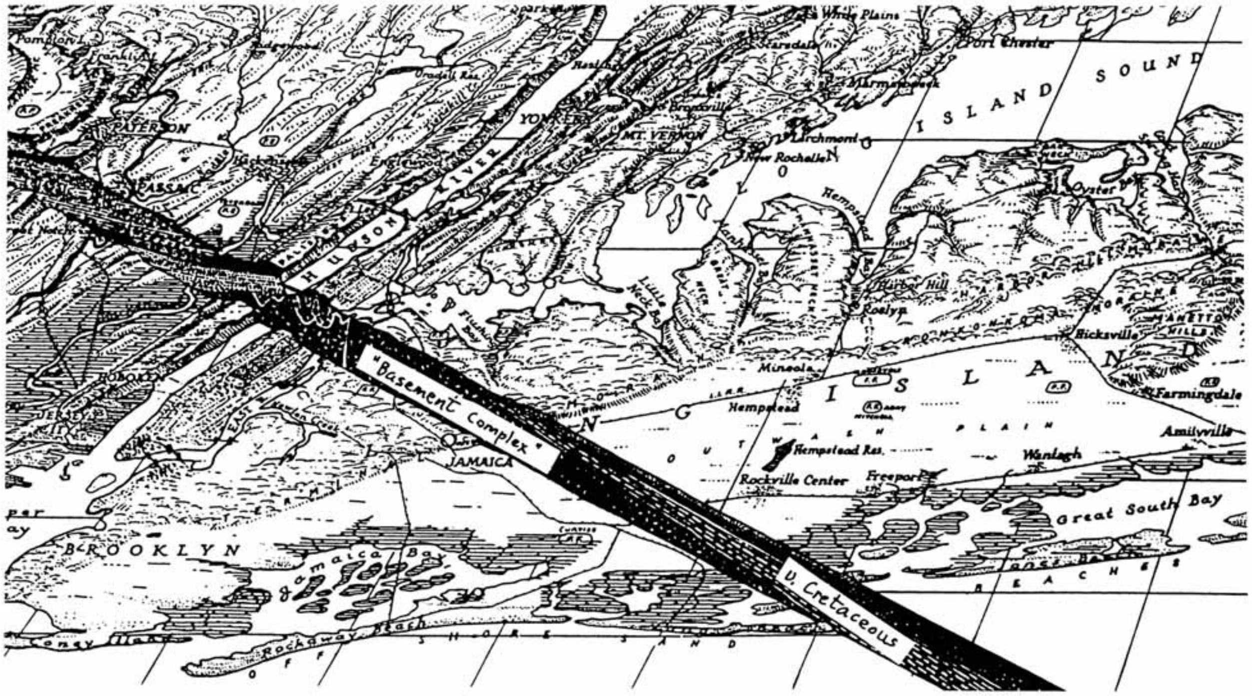
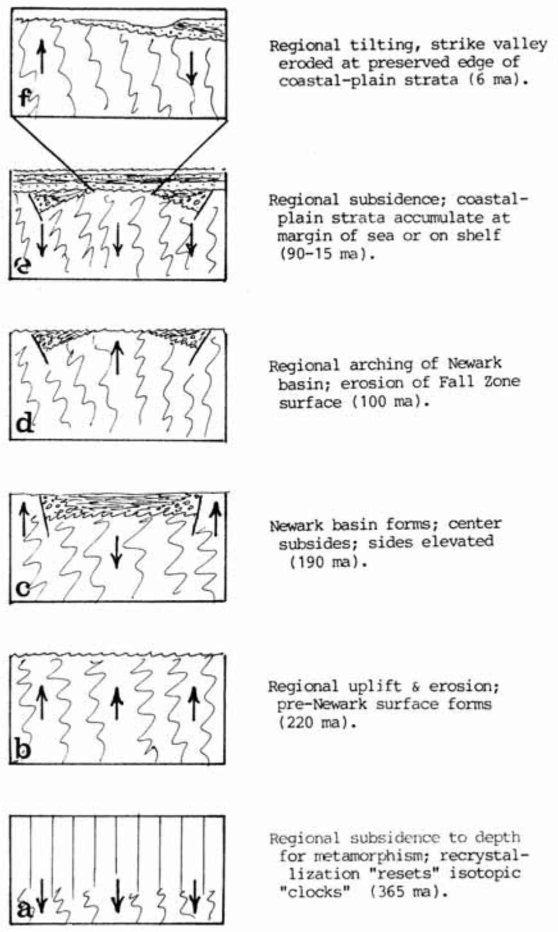


Figure 2. Physiographic block diagram with cutaway face to show geologic structure. (Modified from E. Raisz by showing U. Cretaceous, not Tertiary, beneath the south shore of Long Island.)

The kinds of rocks composing the "basement" complex form only at temperatures and pressures that prevail deep within the Earth (possibly 20 to 30 kilometers). Accordingly, the exposure of such rocks at the Earth's surface means not only that the territory in which they are found sank to great depths for long enough for the metamorphic reactions to take place, but also that it was afterward re-elevated and its former cover eroded (Figure 3). The age of 350 million years marks the last time the rocks of the complex were heated to temperatures great enough to cause their minerals to recrystallize and to drive out the gaseous radioactive-decay products so that their isotopic "clocks" were re-set to zero. The history of ups and downs of the complex (See Figure 3) involves its first re-appearance at the Earth's surface about 220 million years ago (at the beginning of the episode of subsidence of the Newark Basin); another sinking of part of it equal to the thickness of the Newark strata (possibly as much as 10 kilometers) plus closely coupled zones that were elevated to provide the coarse sediment forming the fill of the Newark Basin; and a post-Newark, pre-coastal plain elevation amounting to whatever was the amount of Newark subsidence plus another amount great enough to cause the formerly horizontal Newark strata to acquire their present-day dips. After all the post-Newark elevation and great erosion, an erosion surface having low relief (= a peneplain) formed. The surface that formed early in the Cretaceous Period is the Fall Zone surface. (See Flint, 1963, for a description of the Fall Zone surface in Connecticut.) No sooner had the Fall Zone surface formed but another period of subsidence began that enabled the coastal-plain strata to accumulate.



Regional tilting, strike valley eroded at preserved edge of coastal-plain strata (6 ma).

Regional subsidence; coastal-plain strata accumulate at margin of sea or on shelf (90-15 ma).

Regional arching of Newark basin; erosion of Fall Zone surface (100 ma).

Newark basin forms; center subsides; sides elevated (190 ma).

Regional uplift & erosion; pre-Newark surface forms (220 ma).

Regional subsidence to depth for metamorphism; recrystallization "resets" isotopic "clocks" (365 ma).

Figure 3. Stages in development of Long Island and vicinity, beginning with the subsidence and metamorphism of mid-Devonian age (a) and ending with regional southward tilting of Layer VI and erosion of inner lowland and inner cuesta of coastal plain (f; Pliocene?)

Coastal-Plain Strata; Mineralogic Maturity and the Lloyd Aquifer

After the Newark strata had been deformed and eroded, the tectonic setting of eastern North America changed profoundly. JES thinks that this change was associated with the opening of the Atlantic Ocean and the formation of a subsiding, passive continental margin, the setting which prevails today. By contrast, many geologists believe that the Newark episode coincides with the opening of the Atlantic Ocean. JES thinks that this belief has resulted from repeated assertions in articles published in geologic journals that these two events were connected and written by the "high priests" of plate tectonics whose knowledge of the Newark rocks had not progressed beyond what they learned in geologic "kindergarten." (JES subscribes to many of the points made by the author of that delightful book: "We learned it all in kindergarten;" but as for geology of the Newark strata, "kindergarten" is not good enough.)

Whatever is your geologic "religion" about the Newark and the opening of the Atlantic Ocean, no argument surrounds the conclusion that the coastal-plain strata are products of a subsiding, passive continental margin on the trailing edge of the North American plate as it moved away from the spreading center of the Atlantic Ocean, the mid-Atlantic ridge.

A mineralogic characteristic of the local coastal-plain strata is the presence of sand-size minerals such as quartz and zircon that resist chemical decomposition during weathering and a general absence of feldspars and other minerals that are easily decomposed during weathering. Such accumulations of the resistant survival products of weathering are said to be mineralogically mature. In its simplest form, mineralogic maturity or immaturity is judged on the basis of feldspar in the sand fraction. Mineralogic maturity means a lack of feldspar (where feldspar is present in the bedrock being eroded). The presence of feldspar indicates immaturity. In addition, the clay minerals of the coastal-plain strata are typified by kaolinite, a product of intense weathering that is found today mostly in the tropical zones.

The coastal-plain strata beneath Long Island consist of a lower nonmarine part and an upper, marine part. A basal sand, the Lloyd Sand, contains large supplies of potable water (=groundwater). The recharge area of this sand is Long Island itself. No long-distance subsurface route exists, as it does, for example, at Atlantic City. The deep wells at Atlantic City tap ground water from a formation that is exposed at the land surface in the New Jersey pine barrens. As shown in Figure 4, the Cretaceous strata generally stop along the south side of Long Island Sound. A few remnants are known out in the Sound (example: Stratford Shoal; see continuous seismic-reflection profiles of Tagg and Uchupi, 1967; Grim, Drake, and Heirtzler, 1970), and some Cretaceous strata may be preserved as the fillings of deep valleys (as in the West Haven valley described by JES in 1965; see also Haeni and Sanders, 1974; and Sanders, 1989 ms.; and for eastern Long Island Sound, Lewis and Needell, 1987). The geologic relationships shown by the continuous seismic-reflection profiles absolutely preclude the possibility that any of Long Island's ground water from the Lloyd aquifer comes from a distant source to the north (say, from Vermont, as JES has heard some students in his geology classes, residents of Long Island, assert). As was first pointed out by a French geologist, Jacques Avias, the fact that the ground water in the Lloyd aquifer comes from rain which falls on Long Island means that the overlying Upper Cretaceous clays are not as impermeable as many geologists suppose. Although these clays may be impermeable on the scale of laboratory specimens, on the much-larger scale prevailing in nature, they must be cut by cracks that enable the water to penetrate from the surface to the base of the Cretaceous formations.

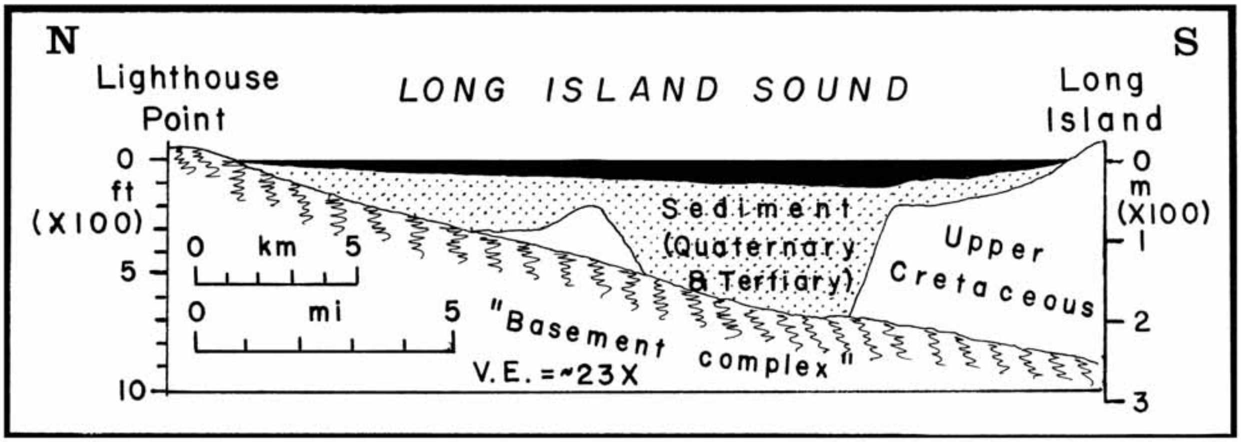


Figure 4. North-south profile-section from Connecticut, across Long Island Sound, Long Island, along longitude 72° 53' West. Water depths from NOS chart. Subbottom relationships from Grim, Drake, and Heirtzler, 1970, Figure 12, p. 661. Water of Long Island Sound shown in black.

The deep wells that supply water to Jones Beach and Robert Moses State Parks (stored in the tall towers in the traffic circles at each park) tap the Lloyd Sand. Immediately beneath the Pleistocene formations in the park wells are Upper Cretaceous marine formations. No Tertiary formations are present (as incorrectly shown on the original version of the Raisz block diagram).

The episode of coastal-plain sediment accumulation that began late in the Cretaceous Period (about 95 million years ago) continued until the Miocene Epoch (about 25 million years ago). From the record in New Jersey, we can infer that a series of fans built southeastward from the rising Appalachians. These fans pushed the shoreline southeastward and ended the episode of accumulation of marine sediments in what is now New Jersey. (However, marine sediments continued to accumulated in areas now submerged.) In the Pliocene Epoch (starting about 6 million years ago), regional uplift, possibly combined with the first of many episodes of eustatic lowering of sea level, enabled deep valleys to be eroded. One such valley, named a strike valley because it is parallel to the strike of the gently tilted coastal-plain strata, formed along the eroded updip edge of the preserved Cretaceous strata. (This feature has also been named the inner-cuesta lowland.) The depression that has been filled with sea water and forms Long Island Sound began its career as such a stream-eroded strike-valley lowland.

Upper Pleistocene Deposits: Terminal Moraines and Outwash; the "Glacial" Aquifer

Draping over the eroded edge of the Cretaceous strata occur varying thickness of Pleistocene sediments deposited close to the margin of a continental glacier. At the margins of a continental glacier, the usual pattern of sediments includes two contrasting kinds. (1) The material deposited directly by the flowing ice of the glacier is till, a heterogeneous mixture of debris ranging in size from boulders to clay. Till usually lacks internal layers (strata) and if it contains abundant clay-size particles in its matrix, is impermeable (thus is not only not an aquifer, but may drain water so slowly that low places in its surface are characterized by swamps). (2) The sediment that was deposited by water from the melting glacier is known as outwash. Much outwash is deposited by braided streams that build fans adjacent to the terminus of the glacier. The top surface of these fans is sometimes referred to as an outwash plain.

The most-prominent features of the Long Island landscape are the terminal-moraine ridges that extend nearly the entire length of the island (Figure 5). Each is associated with an adjacent lowland that is underlain by outwash. Notice that in the two profile-sections, the symbol used for the moraine differs from that of the outwash. The implication is that the moraine ridges consist of till, in contrast to the meltwater-deposited outwash. According to JES observations, much of the material in the moraine ridges closely resembles outwash. On Long Island, till is rare. It is present at the extreme western and eastern ends of the island, but is hard to find in between.

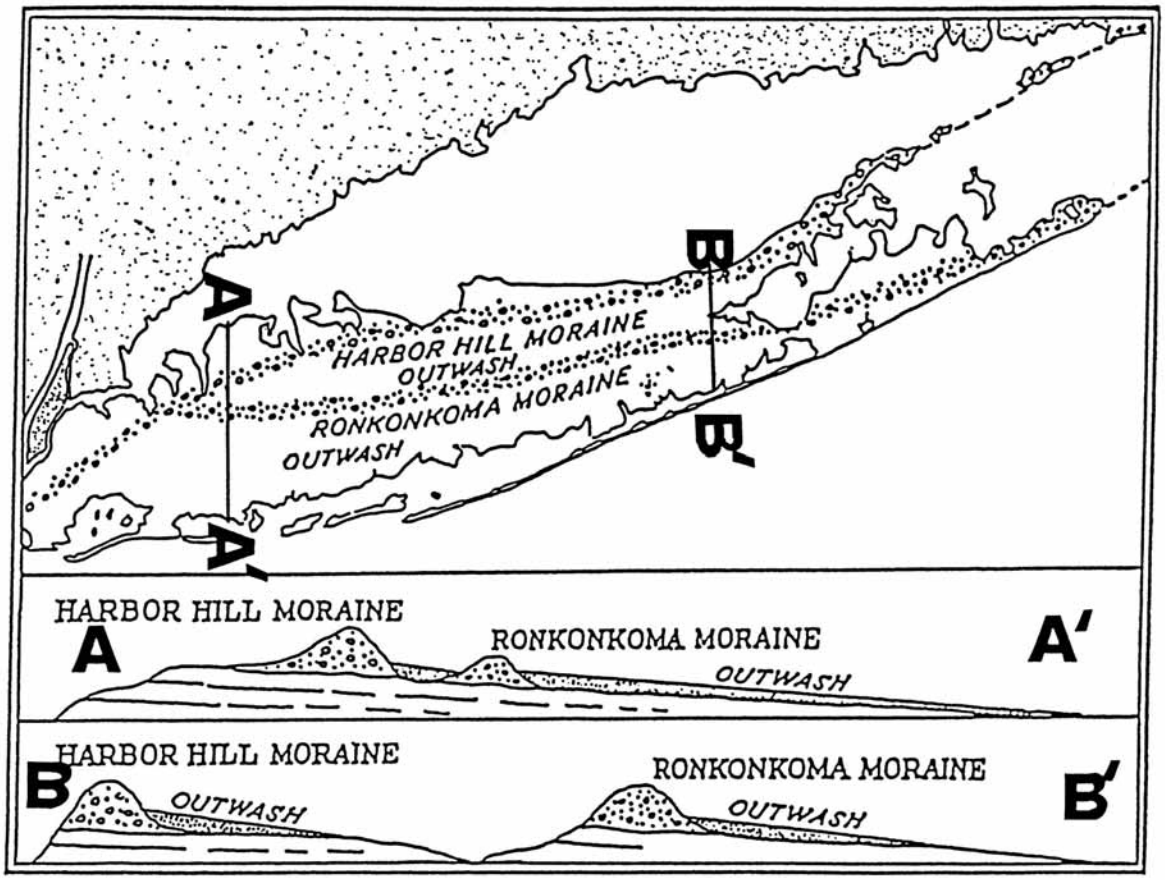


Figure 5. Map of Long Island showing two prominent moraines and associated outwash plains, with schematic N-S profile-sections along lines shown. (After A. K. Lobeck; lines of profile-sections added by J. E. Sanders, 1985.)

Another noteworthy feature of many Upper Pleistocene outwash sediments is their compositional maturity (lack of feldspar and other minerals that decompose readily during weathering). Because the chief activity of a continental glacier is to grind up whatever materials it passes over and not to decompose them, mineralogically mature outwash must mean that the advancing continental glacier was traveling over materials that generally lack feldspar, such as the Upper Cretaceous sediments. Where the continental glacier flowed directly over the pre-Cretaceous "basement" complex, its sediments are mineralogically immature.

JES thinks that both the foregoing characteristics of the Upper Pleistocene sediments underlying much of Long Island can be explained by inferring that most of the time, the terminus of the glacier was located in the lowland that is now Long Island Sound and that the ice flowed over the Lloyd Sand as shown in Figure 6. Eventually, the glacier must have stripped away all of the Lloyd Sand so that it began to grind up the abundantly feldspathic rocks of the "basement" complex and thus to deposit mineralogically immature sediments. (If this idea is correct, then the first appearance of mineralogically immature Pleistocene sediments should be a useful marker.) The two moraine ridges may have been built when the ice surged forward and pushed the adjacent outwash into linear ridges. [According to JES, these two moraine ridges were not built by the very latest Wisconsinan continental glacier (the Woodfordian), as is generally supposed, but by two older glaciers, each of which flowed regionally from NNW to SSE. The terminal moraine for the Woodfordian glacier, which flowed from the NNE to the SSW, is not present on much of Long Island, but is present along the south coast of Connecticut (Flint and Gebert, 1974, 1976)].

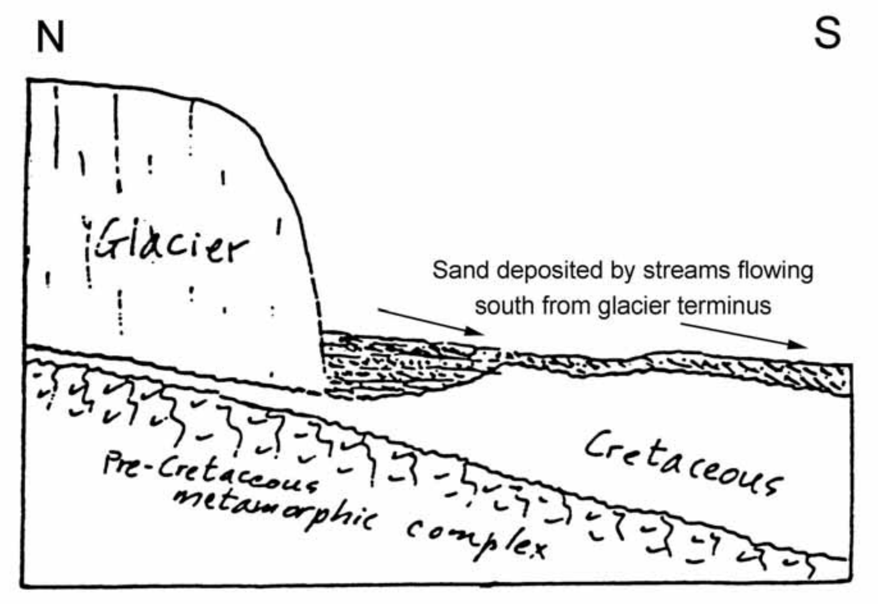


Figure 6. Restored profile-section from Connecticut to Long Island showing terminus of continental glacier standing in what is now Long Island Sound and spreading mineralogicly mature outwash sand and gravel southward to bury the Upper Cretaceous strata of Long Island. Extension of Cretaceous beneath glacier is schematic, but is based on the lack of feldspar in much of the Long Island outwash. (Drawn by J. E. Sanders in 1985 using same regional relationships shown in Figure 4, from W. deLaguna.)

That much of Long Island is underlain by outwash is confirmed by the almost-universal presence of the so-called "glacial" aquifer, the name given to the shallow blanket of sand from which most domestic wells on Long Island derive their water.

Holocene Sediments: Barrier Islands and Intertidal Salt Marshes Fringing Great South Bay

The south coast of Long Island is a place where waves and tides of the transgressing sea are reworking the Upper Pleistocene sediments (cliffs composed of till near Montauk, outwash sand and gravel in most other localities). No rivers deliver new sediment eroded from inland. The sediment present is that which happens to be available from past geologic activities.

The waves have built narrow, linear sandy islands known as barrier islands. Between this string of islands and the main part of Long Island is a "lagoon," the largest of which is Great South Bay. Over much of Great South Bay, tidal action brings in silt, which builds up mudflats that are soon colonized by salt-tolerant grasses to build intertidal salt marshes whose top surface approximates the level of mean high water. Once the marsh grasses have become established, they are able to survive further submergence at rates of up to 4 millimeters per year. They do this by trapping silt among their stalks and by growing upward. As they grow upward, they do two important things: (1) they spread landward, and hence can overlie any pre-existing material, including granitic bedrock; and (2) they build an ever-thickening layer of marsh peat beneath themselves. Initially, salt-tolerant grasses overlie intertidal mudflats and the thickness of the marsh peat equals half the mean tidal range. Thus, on a coast where the mean tidal range is 2 meters, the thickness of marsh peat is 1 meter. Marsh peat thicker than half the mean tidal range or marsh peat overlying non-tidal sediments indicates submergence (Sanders and Ellis, 1961). The intertidal salt marshes of Great South Bay are young; no older than 2 thousand years (Rampino, 1978 ms.; Rampino and Sanders, 1981b). This age coincides with that determined for the adjacent barrier islands (Kumar, 1973; Sanders and Kumar, 1975a, b; Rampino, 1978 ms.; Rampino and Sanders, 1981a, c).

The tidal oscillations cause water to enter and to leave Great South Bay through narrow inlets within which swift currents flow. At the ends of the inlets are tidal deltas, composed of sand that has been transported back and forth in the deep parts of the inlets by the tidal currents but eventually is deposited where these currents spread out as thin sheets. An ebb-tidal delta is in a lagoon; a flood-tidal delta, in the open sea.

DETAILS OF STUDIES TO BE MADE AT ROBERT MOSES STATE PARK

In the following parts of this guidebook, we summarize why we have selected Robert Moses State Park for our attention, present materials devoted to each of the objectives listed above, give you (for reference) mini-treatises on the mechanics of waves and tides, and close with an account of one of geology's most-fundamental concepts, that of the geologic cycle. This final section is intended to connect what you see today with things to be seen on other trips.

General Setting of Robert Moses State Park, Fire Island and our Reasons For Visiting It

The coastal segment that we shall study on this field trip is situated in Robert Moses State Park, Fire Island, Long Island, New York, at the western end of Fire Island (Figure 1, on cover). We have selected this part of Fire Island for many reasons. Perhaps the most compelling of these is the fact that Fire Island has long been known throughout the geological world for the rapid westward growth it has experienced. The proof of this growth is the Fire Island lighthouse, which was built in the 1830s to mark the entrance of Fire Island Inlet (Figure 7, 1834 map at top). Depending on the visibility, we may be able to see this famous lighthouse, now landlocked, by looking to the left as we cross the bridge over the inlet channel. (The lighthouse is the cement tower decorated in thick horizontal black- and white stripes; do not confuse it with the brick water towers we have seen (in the traffic circle straight ahead or in the traffic circle at Jones Beach). Judging from the relationships shown in the second panel down from the top of Figure 7 (dated 1887), all of Fire Island west of the traffic circle was open water at the beginning of this century. To JES, the remarkable thing about this demonstrably young western part of Fire Island is that it looks just like all the rest of the island. Without the lighthouse, who could tell the age of any part of Fire Island just by looking?

The rapid westward growth has resulted from wave action. Waves approaching from the SSE have dumped sand into the eastern side of the inlet channel. This seemingly endless supply of new sand being transported relentlessly westward forced the tidal currents to erode on the western side of the channel. As a result, the inlet channel has migrated westward. (During a few, brief episodes, the waves from the SW predominated over those from the SSE. These waves shifted sand eastward into the western side of the channel and this caused the inlet to erode its eastern side and thus to migrate eastward).

In 1939-40, the Corps of Engineers built the Federal Jetty at Democrat Point. The purpose in building the jetty was to try to manage the location of the inlet. When freshly built, the jetty extended 1400 feet out into the open water beyond the SW end of Fire Island. For the first 10 years of its existence, the jetty trapped sand on its eastern side. The result was to build a triangular-shaped piece of new land. The shallow water east of the jetty was filled with sand and then the waves built up a beach and capped it with several sets of shore-parallel ridges. Such ridges have been called dunes. As part of Audrey Massa's doctoral dissertation at Columbia University, she has studied the shore-parallel ridges that accumulated on this new land built in the decade 1940-1950. She has concluded that the evidence supports the interpretation that the ridges were built by larger-than-normal constructive waves and, therefore, are not correctly designated as dunes. To be sure, their sand has dried out and the surficial layer is blown by strong NW winds. But the internal sedimentary structures in these ridges and the fact that their trends change progressively so as to be always parallel to the shoreline of the time rule out an origin by the wind.

JES has found evidence in the shore-parallel sand ridges at Moriches Inlet that absolutely demonstrates an origin by water as opposed to wind. [This same conclusion had earlier been reached by W. F. Tanner and students in their studies of the Florida coast. Tanner (personal communication) refers to such ridges that have water-laid cores and a capping of wind-blown sand as "dune-decorated" ridges].

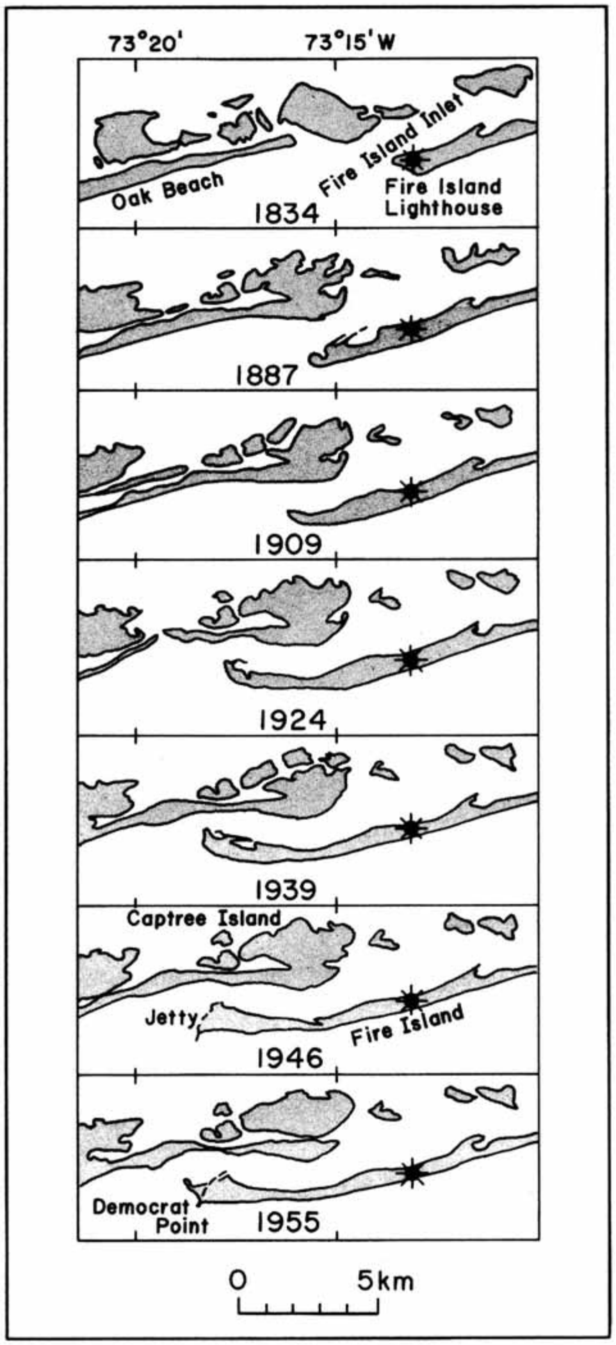


Figure 7. Series of dated maps showing westward growth of Fire Island forming new land west of the Fire Island lighthouse, which was built on the E shore of Fire Island Inlet in the 1830s, but because of the rapid migration of the inlet, now stands 8 km (5 mi) distant from the inlet. (During the interval between 1834 and 1939, the average rate was one meter per week!) (G. M. Friedman and J. E. Sanders, 1978, Principles of Sedimentology: New York, John Wiley & Sons, Inc., Figure 11-11, B, p. 316; redrafted from Naresh Kumar, 1973, Fig. 3, p. 130; also Naresh Kumar and J. E. Sanders, 1974, Fig. 3, p. 499--all of the above based on maps from U. S. Army Corps of Engineers, as published in S. Gofseyeff, 1953, and F. L. Panuzio, 1968.)

The oblique aerial view looking eastward from above the inlet on 12 October 1976 (Figure 8) shows the shore of the inlet alongside the western edge of the jetty, a condition similar to that when the jetty was newly built, but which was re-established only as a result of the 1974-76 dredging campaign (the second since the jetty was built; the first took place in the mid-1960s).

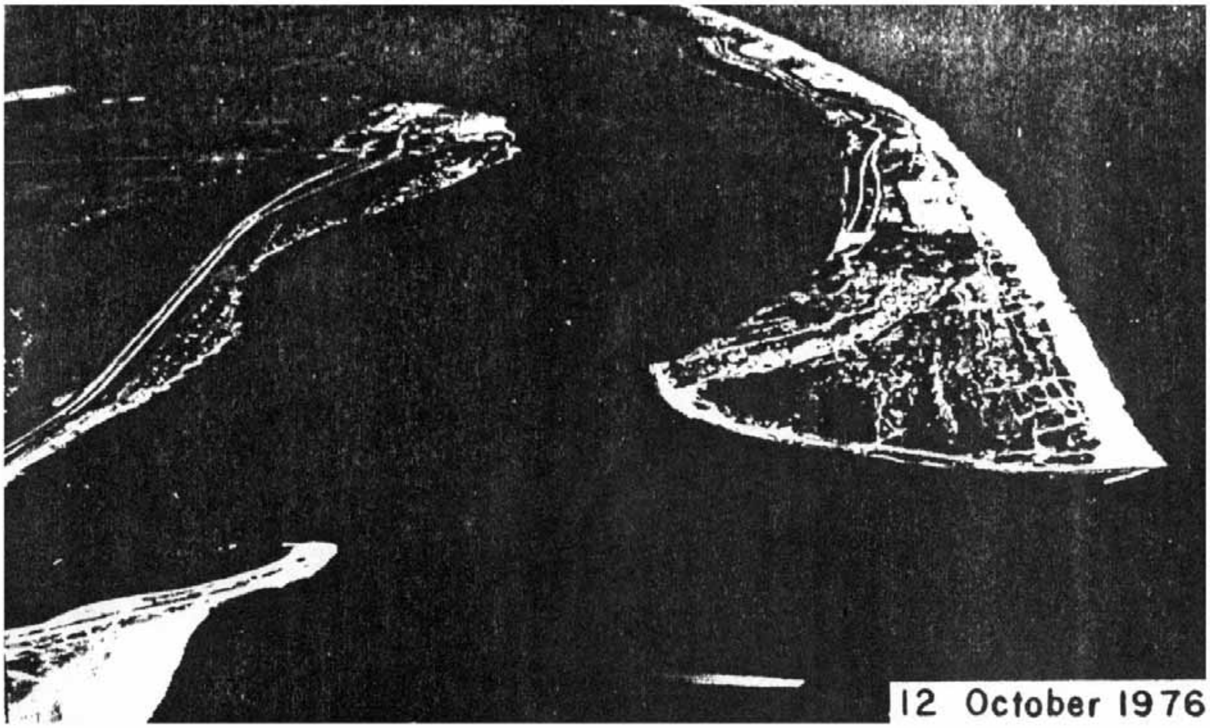


Figure 8. Oblique aerial view eastward of the SW end of Fire Island (right center) from above Fire Island Inlet. The smoothly curving east shore of the inlet is formed by the Federal Jetty. The broad white feature that curves eastward away from the N end of the jetty (at left) toward the two white rectangles (Parking Field 2 of Robert Moses State Park) is a ridge of sand that formed the 1938 shoreline. The modern beach is the broader white strip ip ip ip that extends from the S end of the jetty around to the E (at top center of photo). The triangular area in between these two white strips is land which formed by sand that accumulated E of the jetty between 1940 and 1950. (Bruce Caplan.)

A few samples of the available complete photographic record of the changes in sand that has accumulated at Democrat Point are shown in Figures 9 and 10. The photo of 24 September 1938 was taken before jetty construction began. That of June 1958 shows three spits that grew after the triangular body of sand had filled in on the E side of the jetty (the 1940-1950 deposits shown in Figure 8). By 2 December 1961, a sand dike had been constructed outward from the Oak Beach shore to keep the tidal currents from eroding the Oak Beach shore (to protect the newly built Ocean Parkway). The photo of 3 September 1964 shows a dredged channel being dug near the jetty. The photo of June 1968 displays the conditions that prevailed when Naresh Kumar began his study of the strata deposited in the migrating inlet channel.

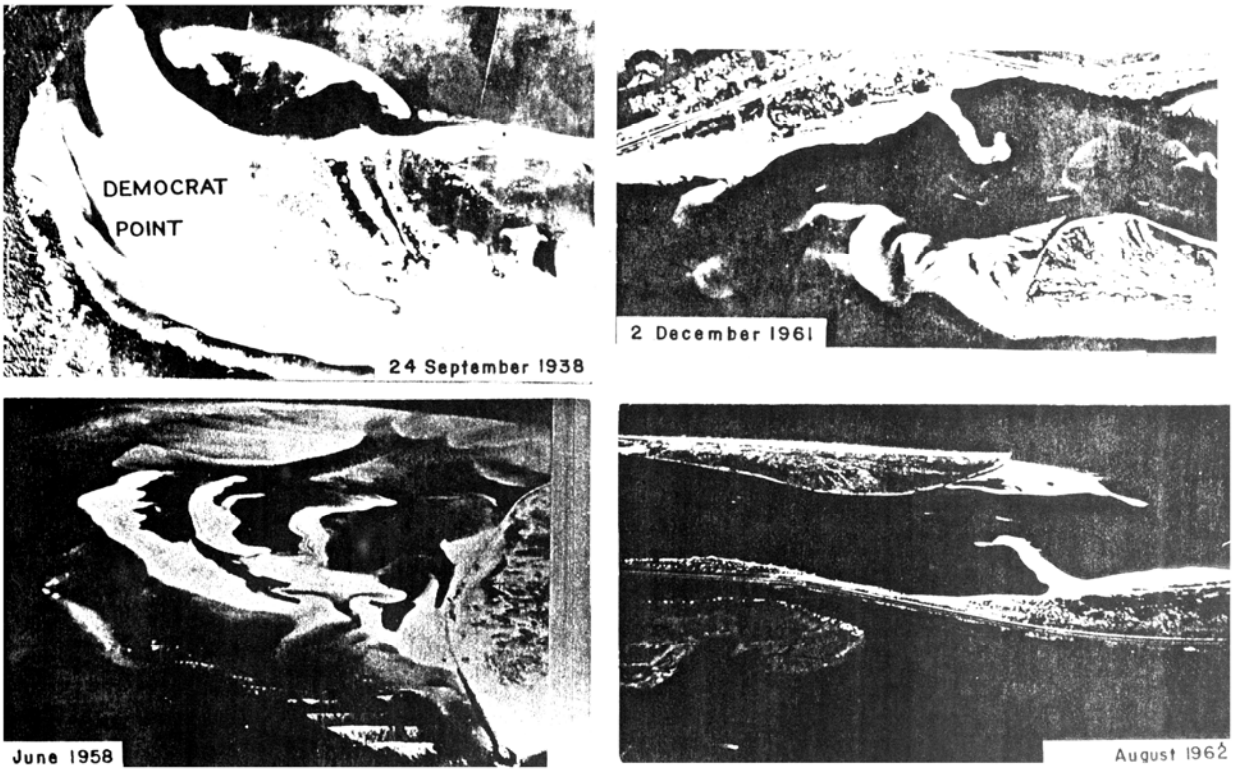


Figure 9. Selected aerial views of Democrat Point during several stages of development prior to and including spit cycle II. (Nonvegetated sand shows as white.)

A. Natural condition before Federal jetty was built. View on 24 September 1938, after the great hurricane. Notice the tendency for the spit to build toward the NW and N (at top of photo).

B. Spit cycle I (after Federal jetty had been constructed in 1940 but before the Oak Beach "sand dike"--known locally by the name of "sore thumb" had been built in 1958-59). By June 1958, three long, curved spits had built northward W of the jetty (whose S tip is shown in lower R corner). The straight segment of stones near the S end of the jetty trends N-S. Notice the large sand shoals along the top part of the photo (just N of the tips of the spits). (Fairchild Aerial Surveys; published in and photocoped from W. Bascom, 1980, Waves and beaches, rev. and updated edition, fig. 54, p. 318-319.)

C. Spit cycle II. View on 2 December 1961 shows Oak Beach sand dike at top center (white area shaped like a fishhook) before much sand had built up on its W side, as appears in later photographs. Democrat Point consisted of a triangular area of white sand including 5, possibly 6 individual spits that had coalesced, and several large current-shaped shoals farther W. Notice the narrow sand barrier extending eastward from the the curved NE end of the jetty (just below the easternmost of the small white boats in the channel). (Photo mosaic provided by U. S. Army Corps of Engineers, New York District Office.)

D. Spit cycle II; view S from commercial airliner making appproach to JFK airport. At Democrat Point, two narrow spits extend away from a solid mass of spit-deposited sand, one to the E (toward the curved part of the Federal jetty, and one to the W, toward the open water at R.) (Color-slide photo by JES, converted to black and white.)

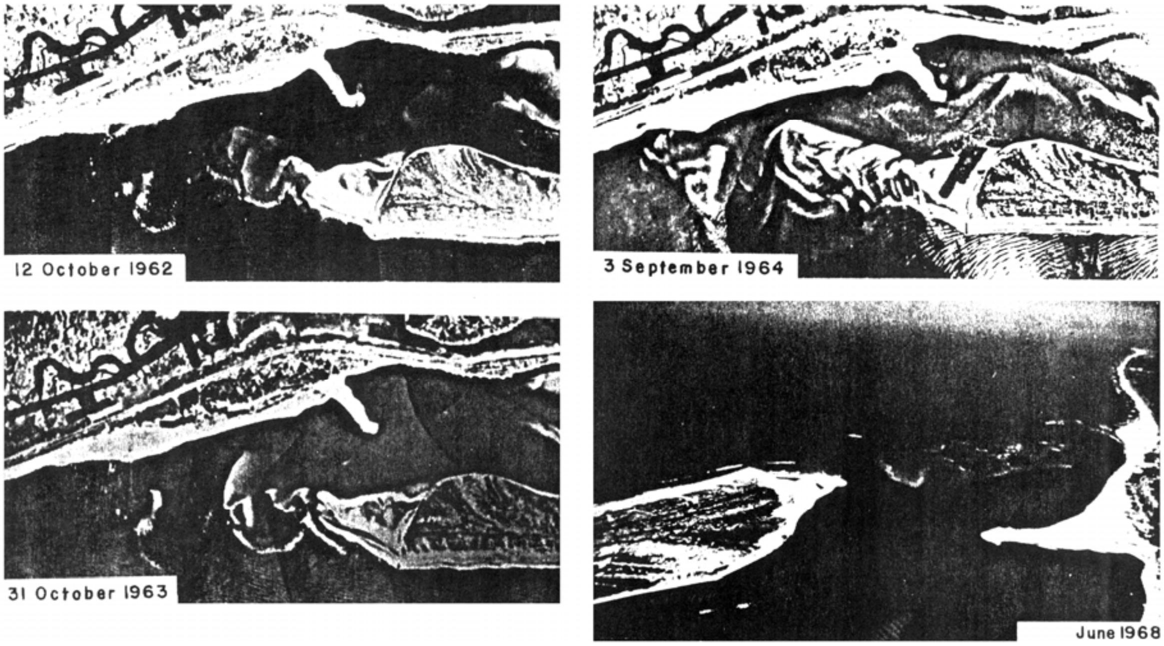


Figure 10. Fire Island Inlet, Democrat Point, and vicinity, 1962 to 1968. On 12 October 1962, Democrat Point consisted of a wide spit trending WNW from which a long, narrow recurved sand finger had grown back to the stone jetty enclosing a small lagoon (dark gray area). A second, smaller point of sand projects into the channel from the distal end of the large spit mass. Only a slight sand buildup on the W side of the Oak Beach sand dike is evident. Length of date label is about 1 mile on the picture. By 31 October 1963, the major change is the growth of a narrow, straight spit, about 0.6 mile long, extending NW from near the S tip of the jetty. The photo of 3 September 1964 shows a dredged channel near the jetty. The completion of this channel marks the end of spit cycle II. The June 1968 photo (by Ed Schreiber) looking SW into Fire Island Inlet, shows a triangular area of sand trapped W of the Oak Beach sand dike (at right), and a sand shoal W of the dredged channel, a remnant of a very large spit complex, now largely washed away by waves and currents because the dredged channel cut off its supply of sand from the E.

Figure 10. Aerial views of Fire Island Inlet, Democrat Point, and vicinity during late stages of spit cycle II and including effects of several channel-dredging efforts (rectangular dark areas).

A. On 12 October 1962, Democrat Point consisted of a solid rectangular area of sand and several linear extensions from this mass. One long recurved spit has grown from the N end of the mass back toward the Federal jetty, enclosing a small lagoon (black area). A second, smaller spit projects to the W into the channel. Notice the two, nearly identical crescent-shaped bodies of sand, concave toward the N, that lie W of Democrat Point. This barrier and the curving part of the Federal jetty truncate a series of linear sand bodies lying between the jetty and the open ocean to the S. These are wave-built features that curved to the N before the jetty was built in 1940, subsequently, as sand built up on the E side of the jetty, their trends became aligned more nearly E-W. After 1950, sand began to pass over the jetty and to build spit complexes W of it. The Oak Beach sand dike (top center), now looking more like a hockey-goalie's stick than a fishhook, still has not started to accumulate sand on its W side. Scale given by length of date label = 1 mile.

B. Slightly more than a year later (31 October 1963), and possibly after at least one channel had been dredged through the spit complex (linear W side enclosed within the large crescesnt-shaped sand body lying just W of Democrat Point?), one, possibly two narrow linear spits extend toward the NW from the tip of the Federal jetty.

C. On 3 September 1964 the spit complex has built so far to the WSW from the Federal Jetty that its tip has nearly reached the Oak Beach shore. One aborted channel-dredging attempt is visible just above the letters e and r of "September" on the date label. A second channel, nearly

completed, is in progress just W of the Federal jetty. Soon after this channel had been cut through, waves and currents removed the now-starved bodies of sand lying W of the new channel. The completion of this dredged channel marks the end of spit cycle II. At bottom R, notice the pattern of waves refracting as they approach the shore near the S tip of the Federal jetty. Waves approaching shore from this direction are the "engine" that drives the sand relentlessly westward along the S shore of Long Island. (Photos A, B, and C from vertical mosaic provided by U. S. Army Corps of Engineers, N. Y. District Office.)
D. Oblique view westward at entrance to Fire Island Inlet with Democrat Point at L and Oak Beach sand dike at R. Notice that most of the sand bodies lying W of the dredged channel have disappeared and that a triangular area of sand has built up W (toward top of view) of the Oak Beach sand dike. (Photographed by Ed Schreiber as 35-mm slide from small airplane; converted to black-and-white.)

As any channel shifts laterally by eroding on one side and accumulating sediment on the opposite side, it deposits sediments in a fixed sequence whose thickness equals the depth of the active channel. Another reason for visiting Robert Moses State Park is that studies of the inlet by Naresh Kumar led to the recognition of the distinctive sequence of inlet-filling sediments (Figure 11).

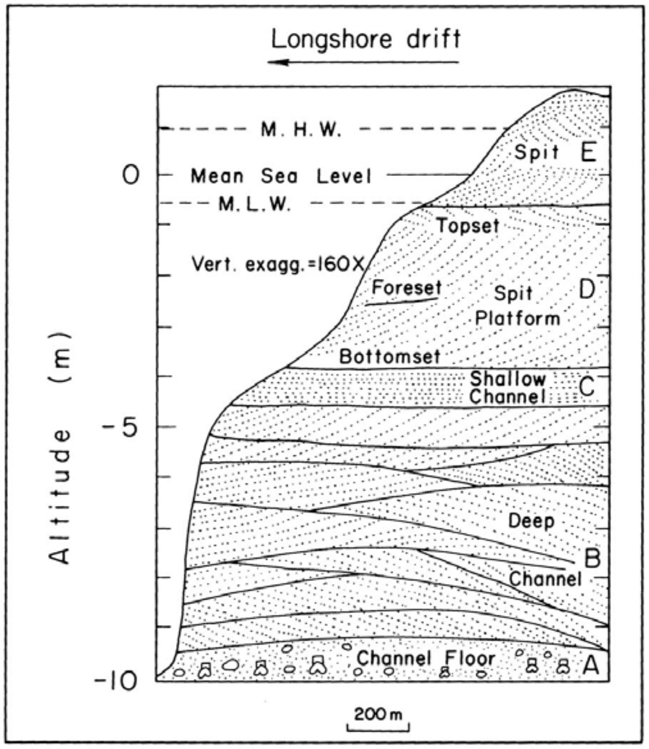


Figure 11. Schematic profile and section through east bank of Fire Island Inlet at Democrat Point spit, showing names and thickness of strata composing the succession deposited by the lateral migration of an inlet 10 m deep. The directions of dip of the cross strata in the sketch (notably in the deep channel, topsets of the spit platform, and spit) are not related to the plane of this sketch. They have been drawn to show their distinctive aspects, not their true dip directions. (G. M. Friedman and J. E. Sanders, 1978, Principles of Sedimentology, Figure 11-13, p. 317; based on Naresh Kumar and J. E. Sanders, 1974, Fig. 6, p. 506.)

The inlet-migration project was the only focus of the studies carried out late in the 1960s and early in the 1970s. JES was of the opinion that virtually everything that needed to be known about beaches and spits was already known from research carried out elsewhere. This view began to change in July 1970, when a higher-than-normal tide eroded a channel across the spit at Democrat Point that had appeared west of the jetty after a storm in mid-October 1969 (Kumar and Sanders, 1971). Early in October 1970, another new spit appeared west of the jetty, and this prompted JES and students to inaugurate a series of photo flights over Democrat Point to record the history of the spits (Figures 12-19). The eroded channel is visible in all the views of Figure 12, but because of spit migration, becomes progressively shorter with time. The series of spits that grew between the mid-1960s dredging and the mid-1970s dredging will be designated as spit series III. (Spit series I is post-1950, pre-Oak Beach sand dike of 1961; series II, post-sand dike and pre-1964 dredging; and series IV, post-1976 dredging.) Spits are discussed in a following section.

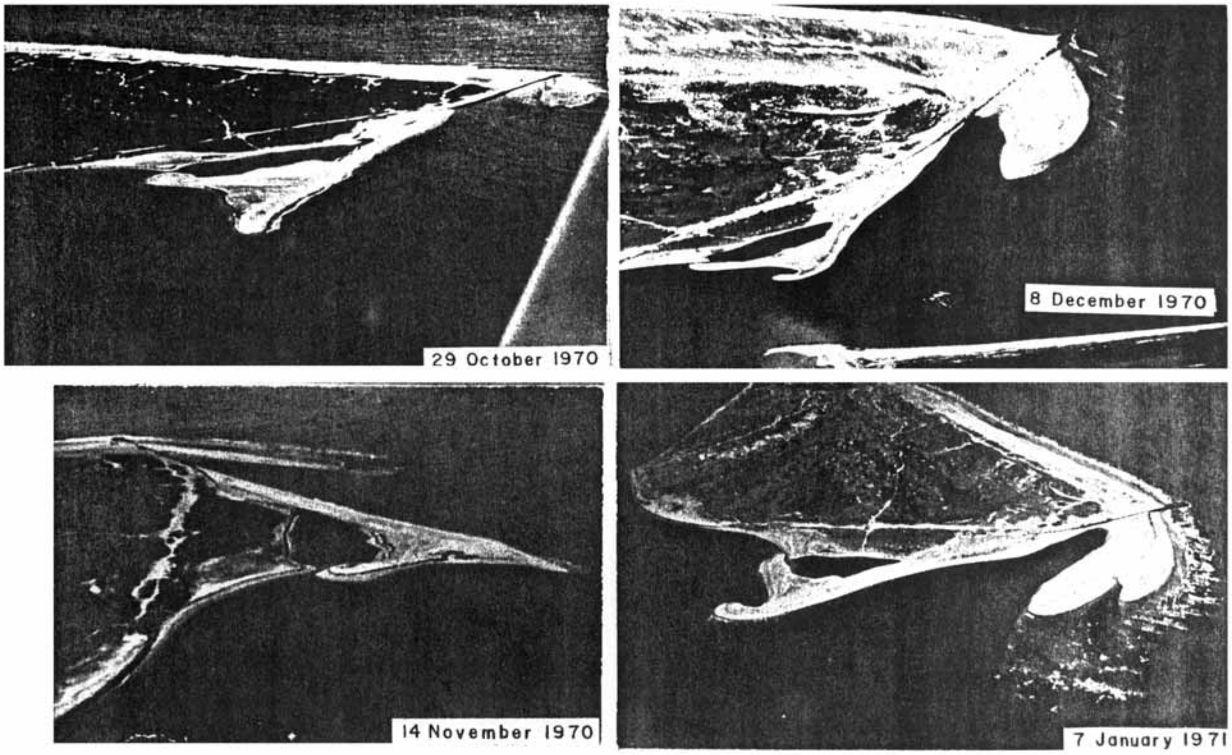


Figure 12. Oblique, low-altitude aerial photographs of spit complex west of jetty, Democrat Point, Fire Island, New York, October 1970-January 1971. View on 29 October 1970 shows straight, old spit (No. 1) at bottom with new spit (No. 2) starting at top (born on 3 October 1970). New spits here grow by rapid longshore transport at high tides when water washes sand over top of stone jetty. At normal tide levels, such washover does not take place. Sand to build the shoal near the end of the jetty (spit platform) moves almost daily under low-tide level. By 14 November 1970 spit No. 2 has lengthened. By 8 December 1970, this spit has widened and a landward curve has appeared at its tip (=hooked spit). A hook has appeared on spit No. 1. By 7 January 1971, spit No. 2 has started to swing to the N (left) and has become Y shaped by addition of new sand. Hook on spit No. 1 has lengthened.

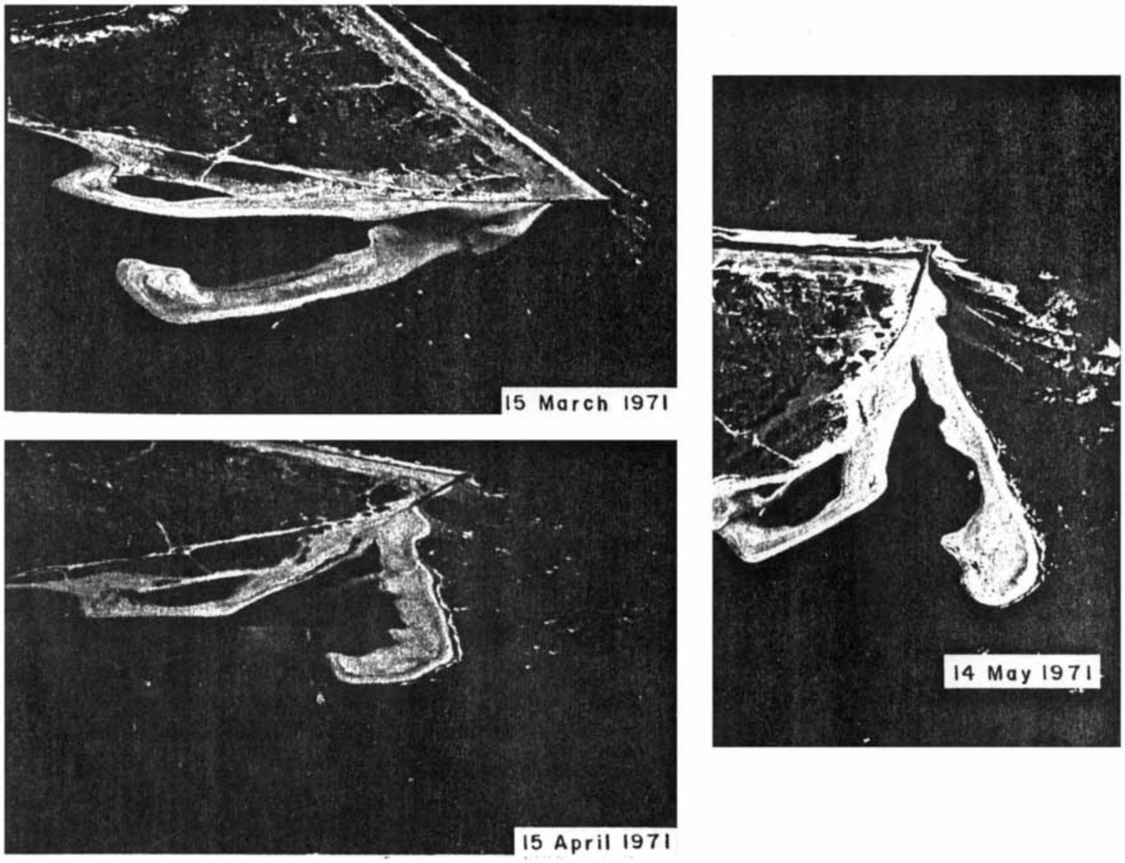


Figure 13. Early 1971. On 15 March 1971, spit No. 1 has lost its hooked tip and spit No. 2, mitten shaped on 7 January 1971, has elongated, pivoted around toward the N (at left), and has been breached by a shallow channel (dark area at right of center). In the April and May photos, spit No. 2 has continued to swing around toward the N and has elongated and become bulbous at its tip.

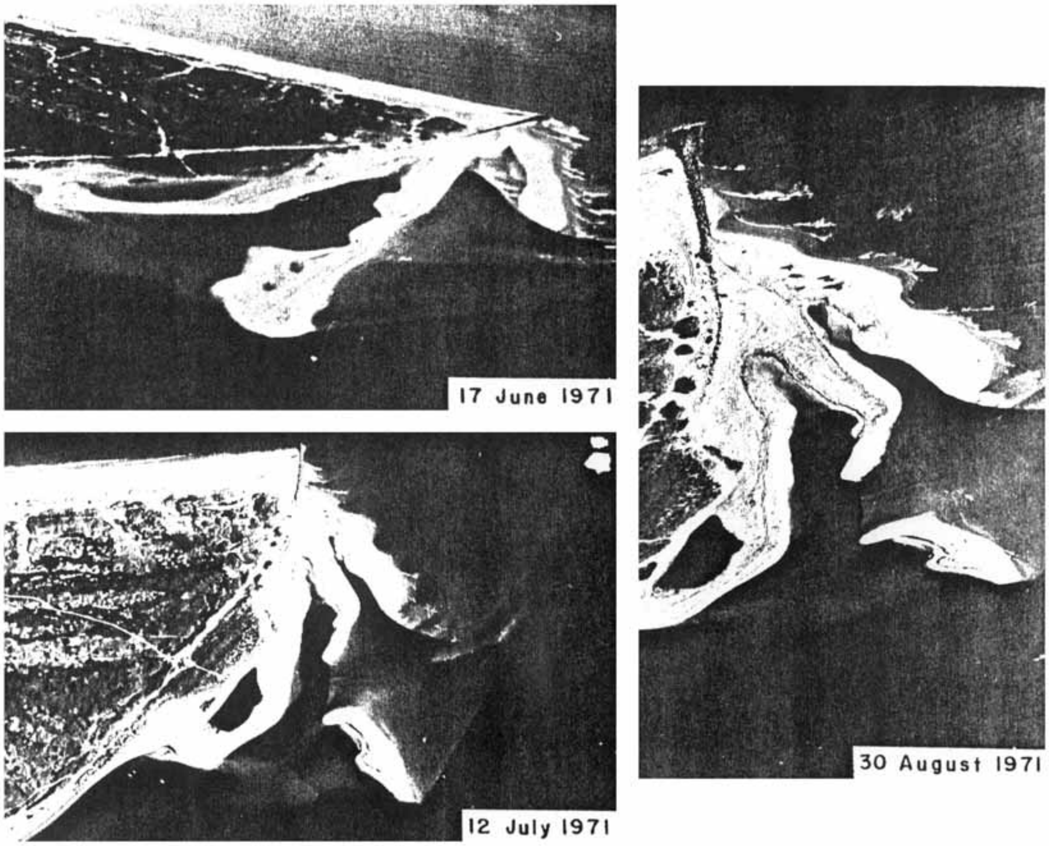


Figure 14. Summer 1971. On 17 June 1971 a new spit (No. 3) has appeared and spit No. 2 shows signs of having been breached and later healed. Subsequently, spit No. 3 has swung closer to spit No. 2, which has been breached and the segments alongside the breakthrough channel have curved around in the direction of the flood-tidal currents.

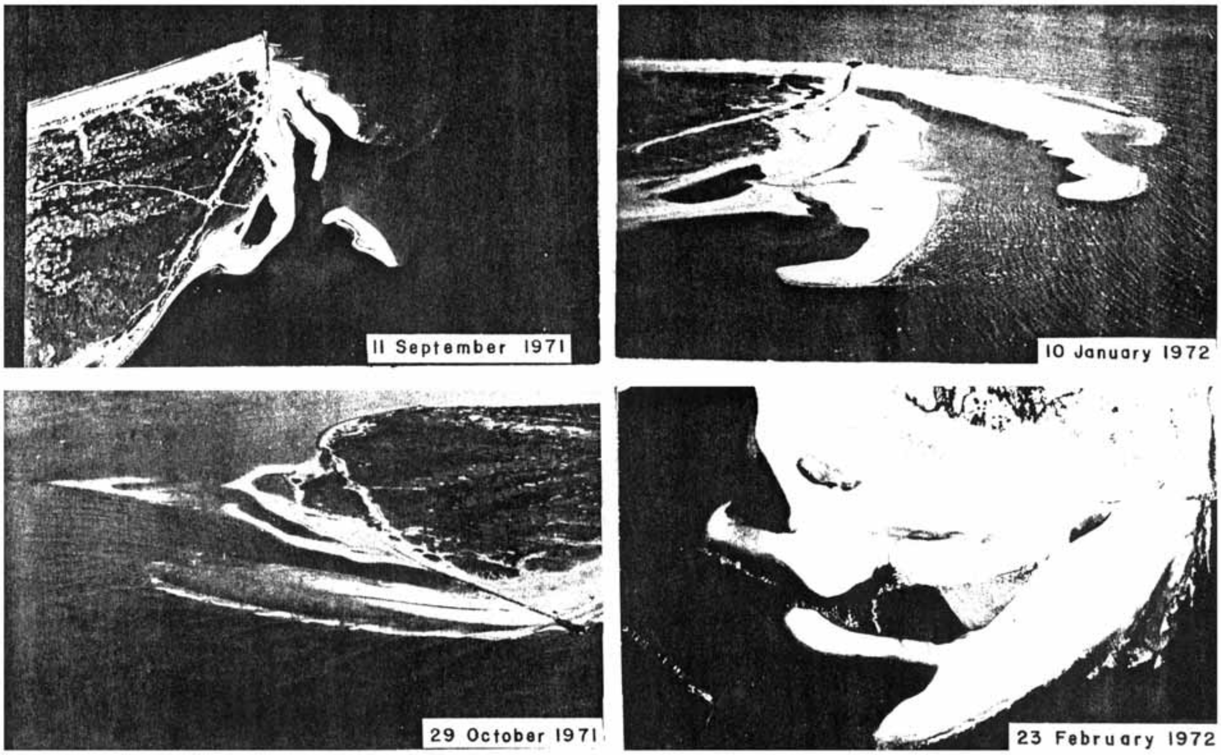


Figure 15. Late 1971-early 1972. By 29 October 1971, the bulges on the seaward shoreline of spit No. 3 have vanished and the still-segmented spit No. 2 has been straightened and lengthened. By 10 January 1972, spit No. 3 has been greatly elongated and a hook has appeared at its tip. Spit No. 2 has migrated toward spit No. 1, and the median breach has been narrowed to a straight channel from which flood-tidal currents have eroded an opening into the pond of spit No. 1. The view from vertically above on 23 February 1972 shows that spits No. 1 and No. 2 have virtually coalesced, spit No. 3 has been greatly widened, and a narrow sand "finger," pointing north, has grown from spit No. 3, A dredge is at work in the ship channel (lower L). Photo of 23 February 1972 from Grumman Ecosystems Corp., Bethpage, Long Island, N. Y.)

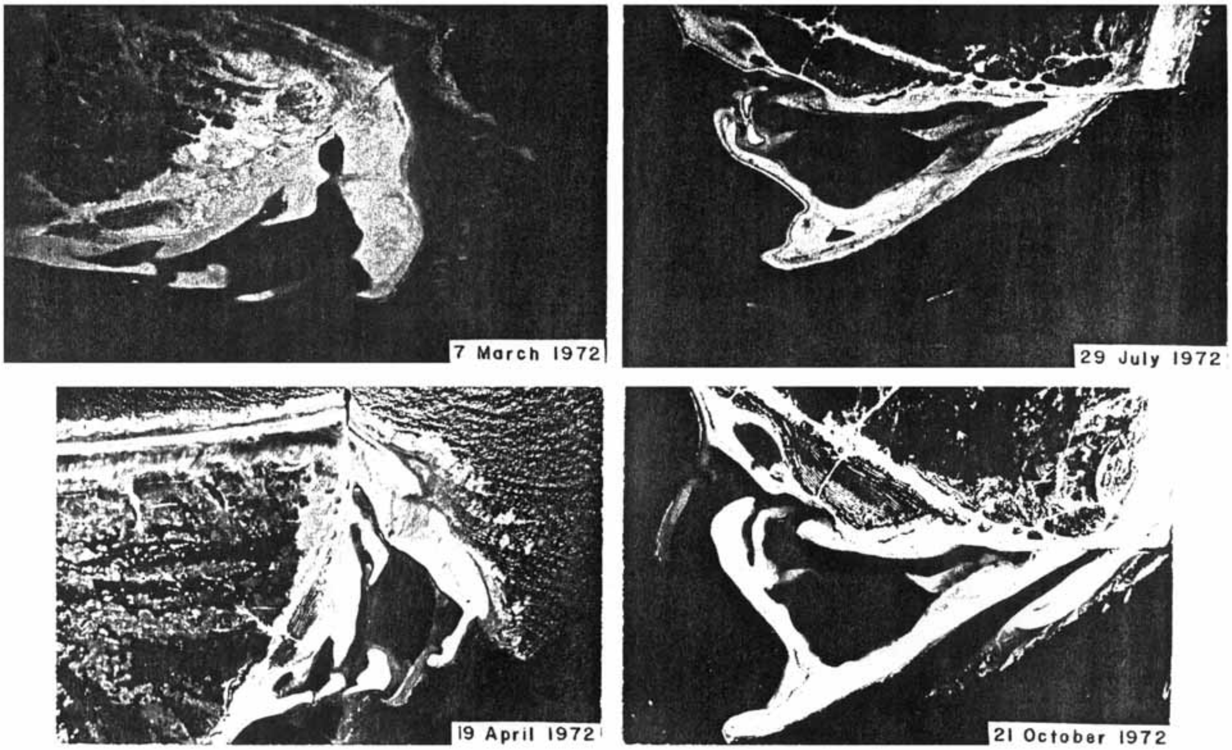


Figure 16. Spring to Fall 1972. On March 1972, spit No. 3 has widened, spit No. 2 has been reduced to two small segments, and the channel into the pond on spit No. 1 has widened. By 19 April 1972, the straight, finger-like projection from the end of spit No. 3 has elongated past the detached remnant of spit No. 2 and a recurved tip has appeared on spit No. 3. By 29 July 1972, the "finger" has grown northward nearly to the detached remnant of spit No. 2. By 21 October 1972, spit No. 3 has merged with the remnant of spit No. 2 and spit No. 4 has appeared from the usual birthplace of new spits.

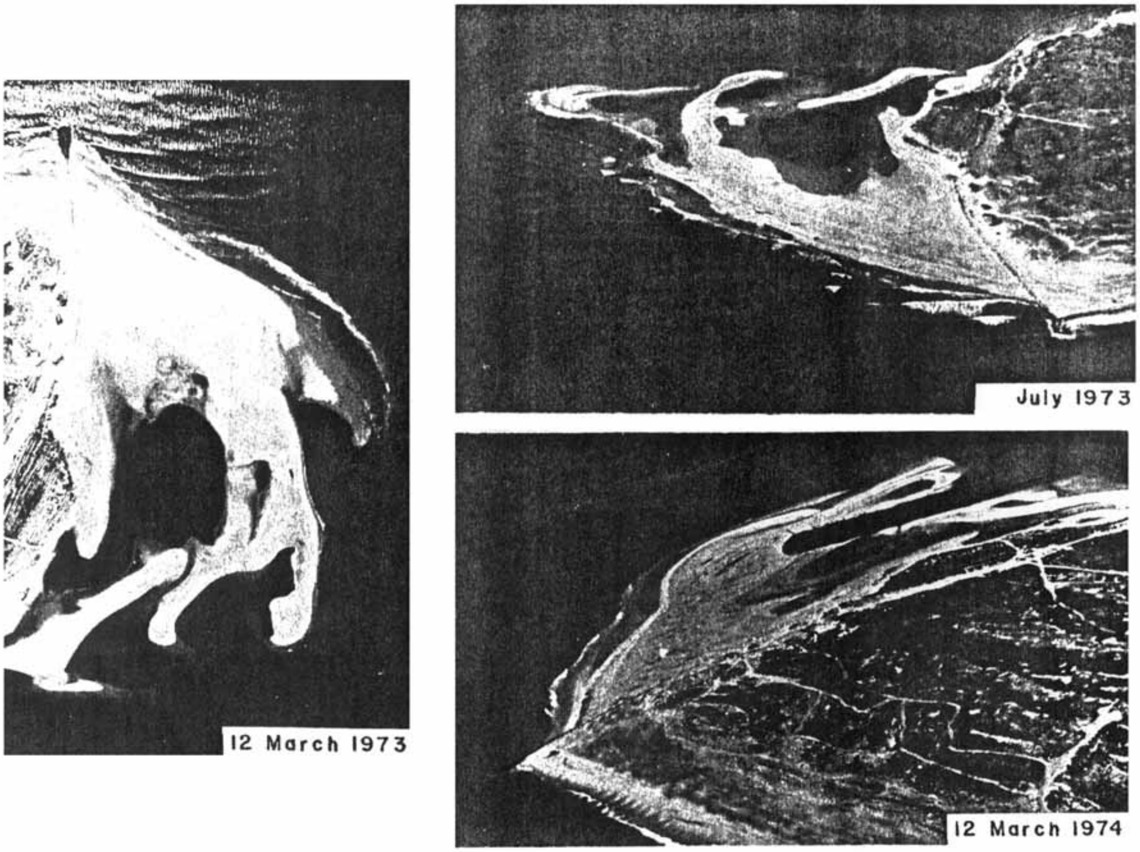


Figure 17. Early 1973 to early 1974. Nearly all spits have coalesced and the persistent pond on spit No. 1 has been breached at both ends. The distal end of coalesced spits 4 and 3 has also been breached. The view on 12 March 1974 shows a straight channel that has been cut by a dredge working from the N side.

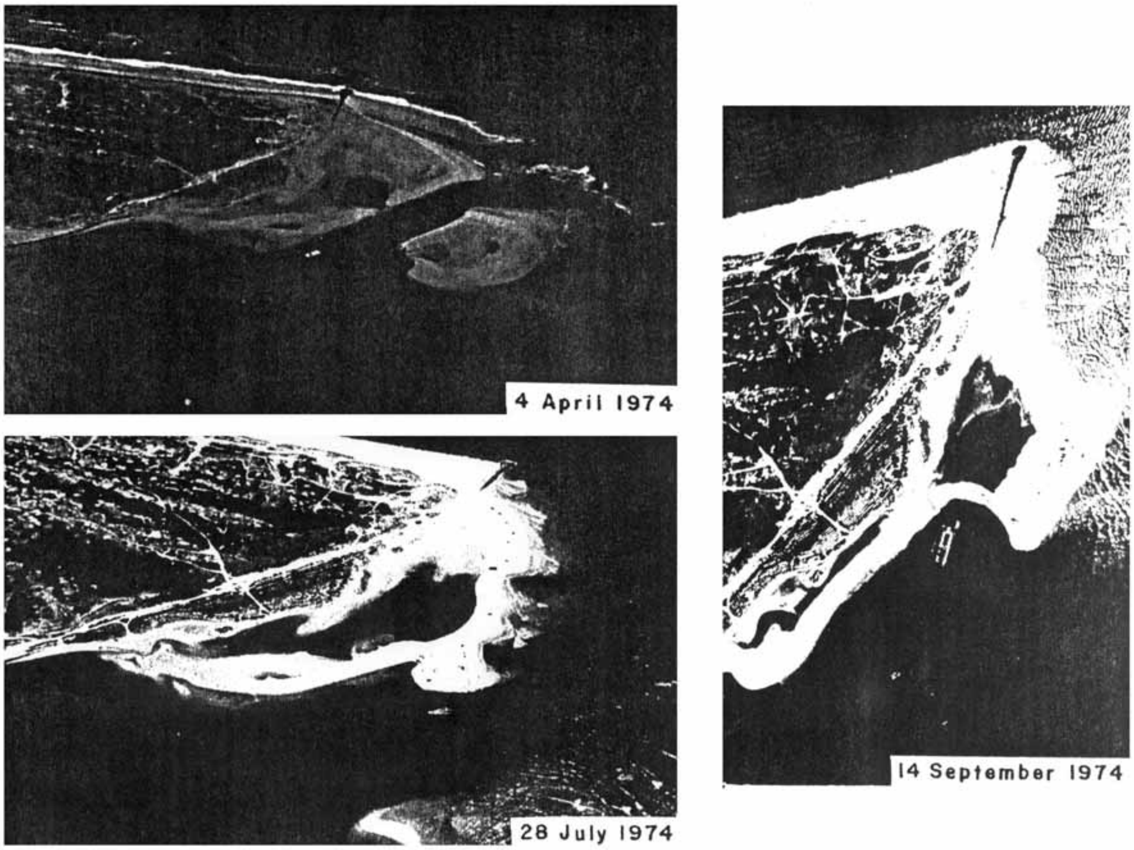


Figure 18. April - September 1974. By 4 April 1974, the dredged channel has cut completely through the sand complex of merged spits 1-4. Spit No. 5, newly formed at top, is about to force revisions on the dredging schedule. By 28 July 1974, sand from spit No. 5 has closed the formerly open S end of the dredged channel, whose northern end has been reduced to a narrow, meandering channel. By 14 September 1974, the dredge has returned to continue its activities.

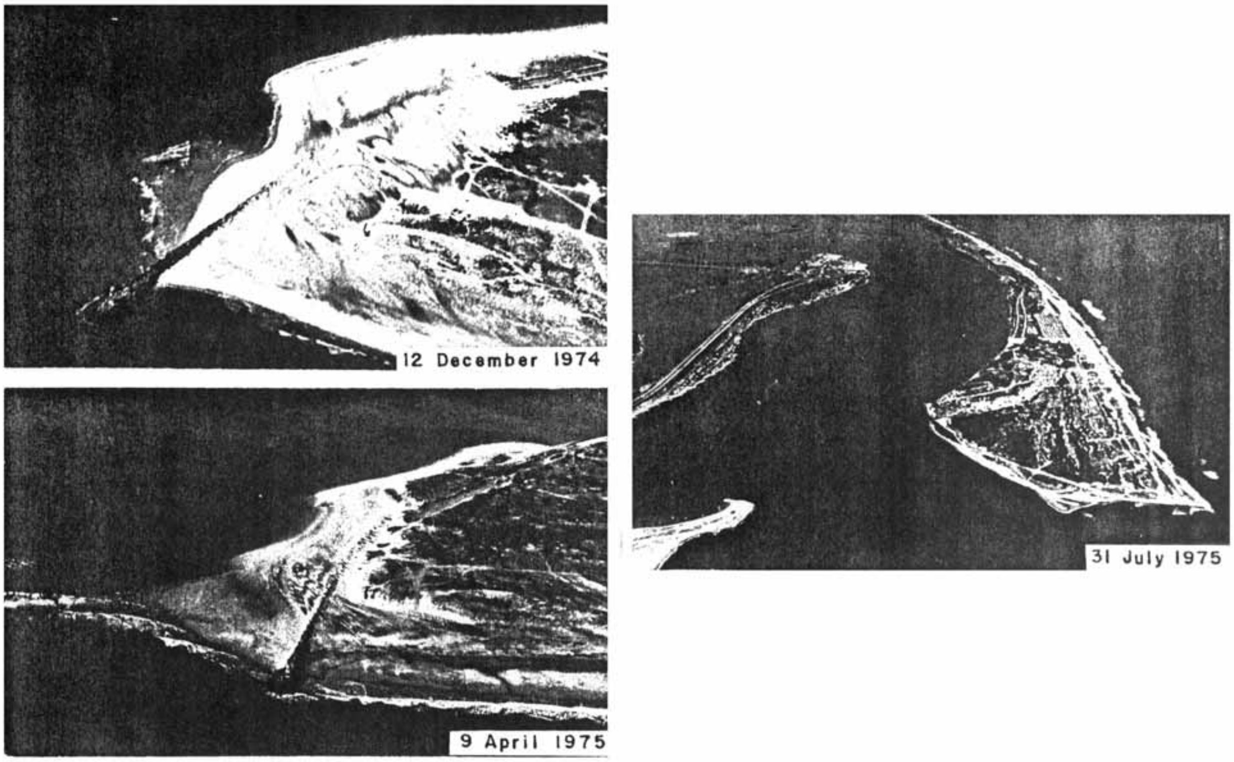


Figure 19. December 1974 through July 1975. The dredging of a deep channel parallel to the jetty has enabled all sand W of the channel to be swept away. Visible sand accumulation has practically ceased. The only exception is a slight elongation of the bulge of sand in the upper right corner of the photo dated 31 July 1975.

In connection with Naresh Kumar's studies of inlet migration and the deposition of an inlet succession, we investigated the implications of rapid inlet migration on the stratigraphic record of a marine transgression (Sanders and Kumar, 1975a, b). In this investigation, we were greatly assisted by being able to borrow and to make relief peels (using the method described by Burger, Klein, and Sanders, 1969) and from these, discovered distinctive shoreface deposits that we interpreted as storm deposits (Kumar and Sanders, 1976, 1979). After the preliminary studies of the rapid changes taking place on the spit suggested that some heretofore-ignored relationships were at work, JES and students carried out studies of the mechanism of berm destruction (by the process of grazing-swash undercutting analyzed by Imre Baumgaertner, 1975, 1977 ms.); on the stratigraphy of the barrier island and its relationship to the Holocene transgression (Rampino, 1979 ms.; Rampino and Sanders, 1980, 1981a, c); and on the behavior of spits and the relationship between spit behavior and beach behavior as controlled by tidal levels (Massa, 1987 ms.). The results of these studies through 1977 are contained in Chapter 11 and Complement A of Friedman and Sanders (1978).

These contributions by JES and students represent only a small part of the total study effort that has been devoted to Fire Island (other studies are listed in the References).

In concluding this section on why we have chosen to visit Robert Moses State Park, the reply is that a great deal is known about the place and thus it serves as an admirable "laboratory" for studying not only coastal dynamics but because of the variety of features present, as an introduction to sedimentary features likely to be found in trips to examine the bedrock.

A First Look At The Beach: Composition And Subdivisions

One of the exercises we shall undertake is to use the method of pacing to estimate the width of the sand between the base of the shore-parallel ridge and the water's edge. To do this, we first need to practice pacing and to learn how geologists fix the orientation of a dipping plane in three-dimensional space by measuring two angles: strike and dip.

Pacing

It is a very useful talent to be able to establish a 5-foot "pace." By that is meant, taking steps 2.5 feet each, two of which equal 5 feet. By means of the squares in the cement of the ramp leading down to the sand, we can practice and make necessary adjustments to perfect the 5-foot pacing technique. Two points to remember: (1) You are not the referee in a football game marching off a 15-yard penalty, one yard per step. A 5-foot pace should be a normal walking stride for most people. (2) It will be different in the sand than here on the concrete. Thus, the goals of your practices should be to establish consistency and comfort, and to set up a fixed method of counting the distance. If you always start off with your left foot, then you can count 5, 10, 15, etc., each time your right foot touches the ground. Use your fingers to keep track of the 10's up to 100 and beyond.

Strike and Dip

Strike and dip are two angles that American geologists use to fix the orientation of a dipping surface in three-dimensional space. Strike is a compass bearing. It is measured with a compass and is the angle, in the horizontal plane, between North (as determined by the compass needle; corrected to true N by reference to the local value of declination, about 12 degrees W at our location, Figure 20), and the line of intersection between the dipping plane and horizontal.

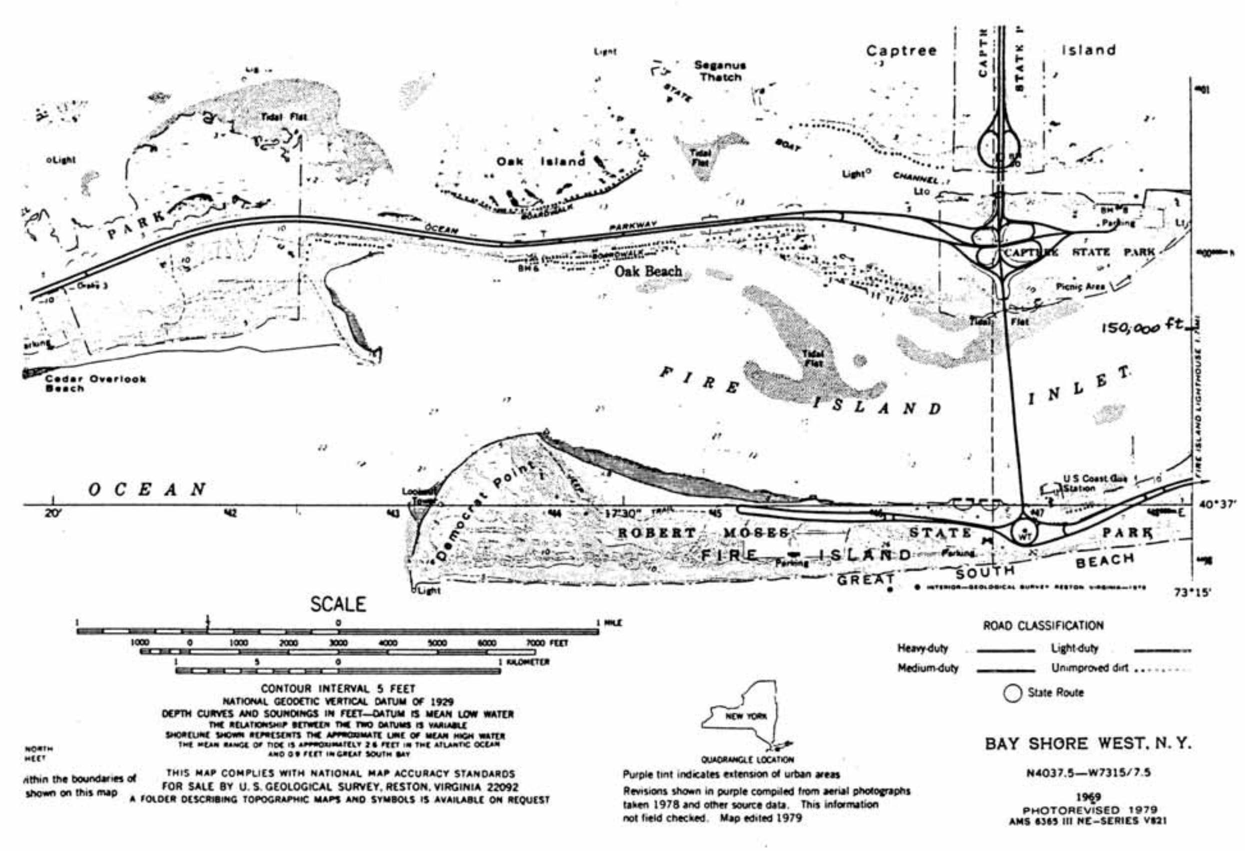


Figure 20. Map of western end of Fire Island, Long Island, New York, showing location of Robert Moses State Park and vicinity. (U. S. Geological Survey, Bay Shore West, N. Y., 7 1/2-minute topographic quadrangle map with labels shifted and size reduced.)

The most-difficult thing for a newcomer to the concepts of strike and dip to do is to visualize a horizontal line in a dipping plane. On the concrete ramp, this direction is easy to find: it is the same as the horizontal divisions in the cement. Another way to find it is to pour water on the surface and mark which way it flows. The water flows directly down the direction of inclination, which is at right angles to the horizontal line needed to measure the strike. The horizontal direction in an inclined plane is also made by the water's edge (horizontal surface) on a boat-launching ramp.

In the United States, strike is measured as an angle ranging from zero degrees (true North) to 90° E or 90° W of True N. Thus, a strike angle might be N50°E. The strike of the concrete ramp is about E-W. (The S end of the compass needle is ignored).

Dip is the angle, measured in the vertical plane at right angles to the strike direction, between the horizontal plane and the dipping surface, measured down from the horizontal (zero degrees dip is for a horizontal plane and 90°, for a vertical one). In addition to the number of degrees, a dip measurement must include a direction (to indicate toward which direction at right angles to strike the plane in question is inclined. For example, with a strike of N-S, a dip of 30°

could be to the E or to the W). The dip of the concrete ramp is about 15 degrees to the S. Note that, if the dip direction were to the N, the ramp would be inclined toward the pavilion.

One of the features for which we shall measure strike and dip is the beach face, the inclined surface that extends seaward from the crest of the berm toward the water.

A Beach Profile

Once we have satisfied ourselves about pacing and strike and dip, we shall pace off a beach profile. Before we start, let us take a look at the beach in front of us. We shall start with its morphology and then study the composition of the sand composing it.

One final geologic technique we need to use is a system for locating ourselves on a map. JES prefers to use the UTM metric grid system. (UTM means Universal Transverse Mercator; it refers to the kind of map projection used). In using the UTM grid coordinates, one specifies first the east coordinate, and then the north. (Remember this by the phrase: "Read right up;" right, for going E; up, for going N.)

JES has added the UTM grid lines to a Park Commission map of RMSP (Figure 21). The SW corner of the pavilion is located at 646.73E - 4498.13N). The water's edge south of the pavilion is at 646.73E - 4498.00N. We will use this map and the UTM coordinates to establish other locations throughout the day.

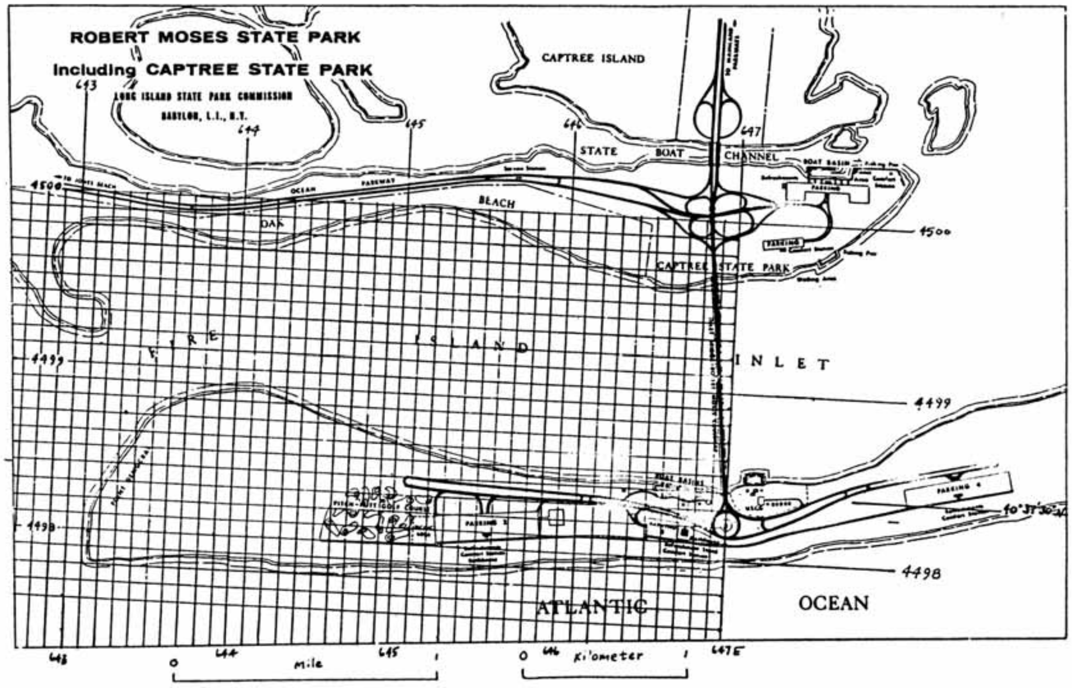


Figure 21. Map of Robert Moses State Park and vicinity. (Long Island State Park Commission map, with UTM metric grid coordinates added by JES, 1985.)

Because of the reported high waves from Hurricane Gabrielle, the beach at Robert Moses State Park (RMSP) may have experienced some significant recent changes. JES has not been here since he read press reports about problems bathers at the beach last weekend (9-10 Sept.) encountered with the large waves. Thus, the following is based on what happened previously when large waves radiating outward from a hurricane came ashore at RMSP. The JES prediction is that we shall find a new, high berm crest, with the top of the berm underlain by a layer of coarse brown sand that may be as much as 10 centimeters (4 inches) thick. Because the Moon was just past First Quarter phase, the tidal range would have been low (i. e., neap tides). Accordingly, the height of the berm crest and thickness of the berm-top layer would be governed solely by the height of the waves. Had this happened during a spring-tidal range, the upbuilding might have reached 40 centimeters. This expected high-wave berm crest may already have been isolated by the building of a newer, lower berm crest on its seaward side. JES predicts that any such new berm will be composed of uniform, nearly white medium sand.

A third population of sand that we can expect to encounter is black or deep red in color. The black is from an abundance of the iron-oxide minerals: magnetite (magnetic) or ilmenite (nonmagnetic iron-titanium oxide). The red is from garnets. The specific gravities of these dark-colored minerals are much greater than that of the light-colored minerals quartz (2.65) and feldspars (range of 2.56 to 2.76). The specific gravity of magnetite is 5.18; and that of garnet in the range of 4 (depending on the composition).

The dark-colored "heavy" minerals can be scattered throughout a population composed of light-colored "light" minerals, or the heavy minerals may have become segregated, usually as a kind of lag where the light-colored "light" minerals have been swept away. This segregation can be done by wind or water, and the heavy minerals may have been left essentially in place as a lag concentrate (as they typically are when the wind blows the light-colored minerals away or when the waves undercut the seaward side of a berm and create a berm scarp, leaving an accumulation of heavy minerals at the base of the scarp) or be transported and deposited to build up an area (as on the top of a berm).

The precise relationships among the aforementioned three populations of particles at the beach at RMSP are not well known. Other populations should perhaps be added to the list. Some questions needing answers are: (1) Where do these populations of particles come from? (2) Under what conditions are they brought ashore and added to the berm? (3) What becomes of them when they are not being brought ashore?

After we have made our profiles and had a look at the beach sediment, we shall return to the vans and drive to the far W end of the parking lot. From there, we shall leave the vans for the rest of the day and walk to the inlet.

A Walk On The Beach: Morphology And Sedimentary Strata

We shall walk past the clubhouse at the miniature golf course and head out onto the beach. The objective is to arrive at the jetty for lunch, after first seeing what shape the beach is displaying and digging one or more SST's to display the relationships between the sedimentary layers and the surface of the beach.

We shall start by pacing off another beach profile. After that, what we do will depend on what is available. The following remarks summarize what might be present and some of the factors that control how the beach behaves.

Beach Morphology; Relationship to Tidal Levels

In terms of tidal amplitudes, the coast at RMSP belongs in the Davies (1964) category of microtidal (amplitudes up to 2 m). The rising and falling water controls where the waves break and may even determine what kinds of breakers form. The tidal level also interacts with the waves to control the heights of berm crests.

It is useful to recognize several dynamic zones that are related to tidal levels. The zone between the mean low-tide level and the mean high-tide level is the intertidal zone. (Intertidal zone is close to but not an exact synonym of littoral zone, which is defined as the zone between the tides and thus could be interpreted as ranging from the highest high-tide level to the lowest low-tide level.) The region adjacent to the intertidal zone on the seaward side but that is lower than the mean low-tide level (and thus is nearly always submerged) is the subtidal zone. The region adjacent to the intertidal zone on the landward side, but which stands higher than mean high-tide level, is known as the supratidal zone. The supratidal zone is usually dry, but is flooded by tides that are higher than normal. As we shall see, these three levels: subtidal, intertidal, and supratidal, are sites of contrasting morphodynamic activities and sedimentary patterns.

Features of the Top of the Berm

The top of the berm may occupy the greatest amount of area of a beach. With reference to the morphodynamic zones just defined, the top of the berm is part of the supratidal zone. It may contain features that were made by thin sheets of water, either flowing as swift currents or ponded, or that resulted from wind action. On weekends, particularly, it is a place where people walk or drive vehicles, and thus leave behind footprints and tire tracks.

One of the first things JES looks for when he studies the top of a berm is indications that parts or all of it have been submerged recently. High-water marks include rows of driftwood and/or clumps of eelgrass. At times, JES has seen extensive bodies of water ponded on the berm top at RMSP. Water can be trapped between the crest of the berm on the sea side and the shore-parallel ridge(s) on the landward side. Not many investigators seem to have paid much attention to these supratidal ponds or spillover pools. An exception is Rosalsky (1949).

Supratidal circulation zone. The supratidal zone is subject to flow of water only when the tides are higher than normal and/or wave runup reaches higher-than-normal levels. When either or both of these conditions prevail, sheets of swash water flow up the beachface to the berm crest.

There they may deposit sheets of sediment that build it upward. Within a few hours, the crest of the beach (berm crest) may stand well above the general level of the rest of the berm. How high depends on the tidal height and sizes of the waves; it could be as much as a meter or more. The swashes that wash completely across the berm crest continue to flow landward down the back slope that leads away from the crest. If the berm-top sand is dry, as it typically is during dry weather, then many of the first-arriving sheets of spilled-over swash disappear by sinking into the dry sand. Eventually, however, the berm-top sand may become saturated. After the sand has become saturated, the water from the spillover sheets begins to accumulate; it may create spillover pools of varying sizes. These spillover pools may continue to enlarge until their ever-rising water level finds low places to serve as outlets. Such outlets may be low swales along the crestline of the berm, on the seaward side, or gaps in the crest lines of the shore-parallel ridge(s) ["dune(s)"] on the landward side. At Robert Moses State Park, some of these berm-top spillover pools have attained impressive dimensions. Their widths perpendicular to shore have reached many tens of meters; their lengths parallel to shore, a half a kilometer or so; and their maximum water depths, 2 meters. Water draining seaward from such substantial spillover pools has eroded gaps in the beach crest that were 15 meters wide and 2 meters deep. JES has even seen an example in which the skipper of a small power boat in distress guided his vessel to safety from the waves by navigating through one of these return channels and beaching his craft on the landward side of the quiet water of a spillover pool.Two days later, he returned with a low-loader trailer and hauled his boat away overland.

The floor of a spillover pool may accumulate a dark-colored layer of silt that settled out from the quiet water. Where sheet-like currents were active, ripples may form. These show flow that is parallel to the shore, where the water was moving en route to one of its return-flow gaps in the berm crest, or away from shore, where the water was flowing seaward through such a return-flow gap.

Along the landward side of the berm crest may be found small spillover-delta lobes. These are situated at the landward ends of shallow channels where the spilled-over swash coalesced in its flow past the berm crest. Such delta lobes are characterized by their steep, angle-of-repose cross strata that dip landward. They prove that the shallow channels debouched into a body of standing water.

Features made by the wind. In contrast to the sediments deposited in berm-top spillover pools are the features made on the berm top by wind action. At RMSP, most of the wind action takes place when cool, desert-dry Canadian air moves in and strong NW winds are blowing. The low humidity (~40%) rapidly dries out the sand, and the usually strong winds blow sheets of sand across the top of the berm and back into the sea. Results of this wind action include: (a) lag-concentrates of coarse debris or heavy minerals; (b) wind-generated ripples; and (c) sand "shadows."

The lag concentrates include dark-mineral lags (including very coarse sand-size garnets and other heavy minerals); "deflation armors" (a kind of coarse-particle residue of all kinds that may mantle the top of the berm; and scattered "pedestals" (capped by individual shells or shell fragments, pebbles, or clumps of eel grass; the surrounding sand, not protected by whatever caps the pedestal, was blown away). The heights of the pedestals indicate the amount of lowering of the berm top as a result of wind erosion.

Wind-generated ripples are small-scale bed forms that become active when the wind drives sheets of sand forward. The long axes of the ripples are perpendicular to the wind direction. Such ripples can be seen not only on the flat surfaces of the berm top, but on the slopes of the shore-parallel ridges (part of the "dune decoration").

"Sand shadows" are elongate bodies of light-colored sand that accumulated downwind from some obstacle, such as a driftwood log or clump of eel grass.

Sedimentary characteristics of berm-top strata. The typical sediments of the top of the berm were deposited by thin sheets of water that flowed down the gently dipping landward slope of the berm crest. Despite the berm-top irregularities, such as footprints, tire tracks, and features made by the wind, the strata underlying a berm top generally are nearly flat. In detail, they dip gently landward parallel to the berm top itself. What this implies is that these strata are deposited relatively rapidly and that the sheets of water responsible are able to erase most of the irregularities of the berm top and to substitute smooth layers. As we may find in our SST, however, a few deep tire tracks may escape this general levelling action and be preserved in sectional view. Thus, what one sees on a typical berm top is but rarely incorporated into the sedimentary record that is built upward by sheets of water in the supratidal zone.

Crest of the Berm

Berms are products of deposition by sheets of water from the broken waves. As such, berm crests are somewhat akin to the natural levees that are built alongside a river channel as the water spills out of the channel during a flood. As noted, most of the flow over the berm crest is from sea toward berm top. Exceptions are the return-flow channels, through which water from one or more spillover pools drains back to the sea. A beach that has built seaward may display several berm crests. These are younger in the seaward direction.

Features Seaward of the Berm Crest: Beachface (plane or cusped); Beach Scarps

Seaward of the berm scarp are slopes leading down to the high-tide water's edge. Two contrasting features are (a) beachface and (b) beach scarp. The beachface is the most-common slope. Beach scarps accompany episodes of berm destruction and are quickly erased.

The beachface displays two contrasting appearances. These are:

(1) a more-or-less plane surface dipping toward the sea at angles ranging from about 5 to about 8 degrees, and (2) a "corrugated" surface consisting of rounded projections toward the sea that are comparably to rocky "headlands" and intervening semicircular recessed areas comparably to "bays." Collectively, these corrugated features are named beach cusps. The

spacing from headland to headland may vary from a few tens of meters to hundreds of meters. Some cusps are symmetrical (Figure 22); others, asymmetrical.

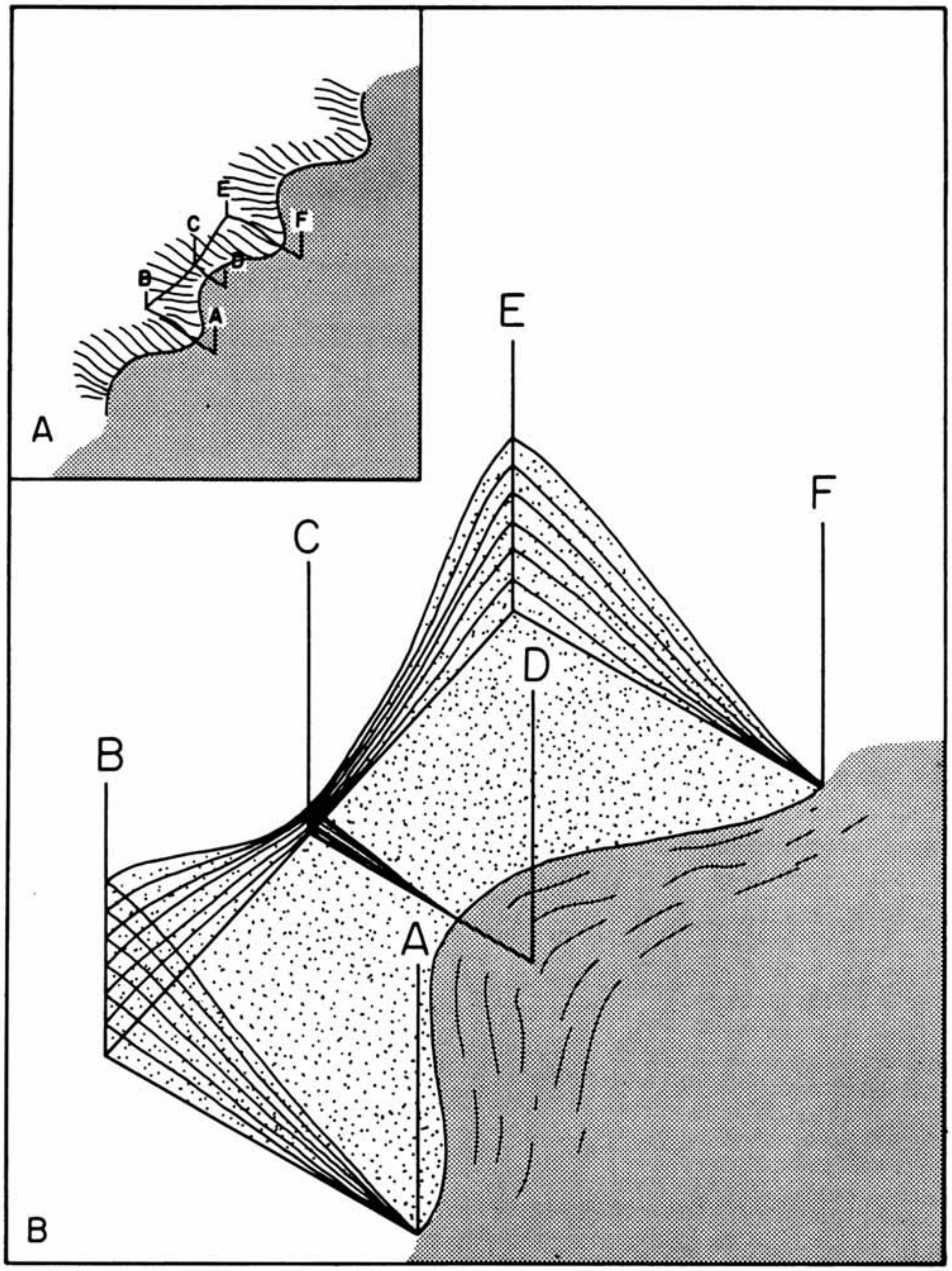


Figure 22. Beach cusps.

A. Schematic sketch showing general appearance and locations of lines of trenches dug into cusps at RMSP to show strata.

B. Enlarged view showingghow thin strata, at C, in axis of cusp bay, and containing concentrations of heavy minerals, pass laterally into thicker strata, at B and E, on cusp headlands, which are composed mostly of light-colored minerals. (From Friedman and Sanders, 1978, Fig A-28, p. 487.)

A plane beachface is probably the most typical appearance. It is the product of slightly oblique approach of the waves. Cusps, especially the symmetrical ones, are created by the interactions of several sets of waves, the chief ones being a set that approaches the beach almost head on. Presumably, a second set of waves traveling along the beach (edge waves) interferes with those coming straight in. Such interference is thought to be responsible for creating the even spacing of the cusps. However they get started, once cusps become established, they tend to be self-perpetuating. Water from swash is concentrated in the cusp bays and tends to flow seaward in streams along the axes of the bays. When these returning streams of water collide with the bores traveling landward across the surf zone, they cause the bores to divide. Thus, the directions of the arriving bores are changed; the wave forms are refracted. Part of the bore flows to the left, and part to the right, both tending to flow parallel to shore. Thus, in front of each headland, a bore approaches from the adjacent bay. The two, coming from opposite directions, cross in front of the headland, and there tend to drop their sediment. Accordingly, thicker layers of sediment are deposited than are found in the bays. A very distinctive pattern of strata results.

Cusps build seaward by adding successive relatively thick layers that are composed mostly of light-colored minerals of quartz density (2.65). Simultaneously, sediment may also be added to the bays, but at a much-slower rate than on the headlands. Successive layers are relatively thin and contain abundant dark-colored "heavy" minerals (densities exceeding 2.8; local examples are garnet, magnetite, and ilmenite). In walls of special trenches dug here at Robert Moses State Park, cusp strata have been traced continuously from bays to headlands. In one bay, a layer was one-particle-diameter thick (0.25 mm). When traced to the adjacent headland, this layer thickened to 25 cm, an increase of 100 times (Figure 22, B).

The foregoing analysis of cusps implies that under certain wave conditions, a corrugated beachface is a stable condition. On such a beachface, downbeach longshore transport has been changed into a whole series of small cells within which the transport direction reverses. Instead of a continuous flow down the beach in a single direction, as along a plane beachface or along the toe of an eroding beach scarp, on a cusped beach, a whole series of local flow cells becomes established. Water flows away from the bays and toward the headlands. And the reason it does so seems to be refraction. What JES concludes from this is that if one is intent on "managing" a beach, then one might do well to intervene in such a way so as to cause waves to refract where they are not otherwise doing so. For example, by placing a series of invisible shoals in the subtidal zone, one might be able to establish a permanent criss-crossing refraction pattern, so that no matter how the waves approached the beach, they would always be refracted so that the water would divide and thus create cusps. As a result, along the long one-way stretches of longshore the transport that characterizes the non-cusp intertidal- and supratidal zones, would be eliminated. If this could be done, it might impede erosion of the berms. (This scheme, as with many a pipe dream, seems plausible enough in the abstract, but would be very difficult to implement, because it means working in the zone of breaking waves and in the surf zone. The notion of having the waves work against themselves, however, seems far superior to projects that try to withstand the effects of the waves).

Beach scarps have long been noticed as features that are present after a berm has been eroded. Imre Baumgaertner (1975; 1977 ms.) has observed a few active scarps and has ascribed scarp formation to a process he named grazing-swash undercutting. Such scarps are products of what happens in the intertidal circulation zone. Hence, they are discussed further in the following section.

Intertidal circulation zone. The kind of circulation in the intertidal zone depends on the state of the tide. At high tide, the circulation may resemble that described for the supratidal zone. Water flowing landward from the line of breakers builds up between the innermost breaker bar and the beachface. At intervals, the confined water cuts gaps through the breaker bars within which it flows seaward as rip currents. Also at high tide, the inner edge of the intertidal circulation zone is the zone of swash and backwash on the beachface. As long as this remarkable zone of swash and backwash is operating, it serves as a kind of buffer along the landward side of the longshore current in the high-tide surf zone. This flow of water parallel to shore in the high-tide surf zone tends to create a flat bottom. At low tide, this flat surface may be exposed. If so, then most workers would probably refer to it as a "low-tide terrace." (JES thinks that this name is slightly misleading because its distinctive slope is determined by what happens at high tide).

At certain times, and for reasons that are not altogether fully understood, longshore flow of water in the high-tide surf zone becomes so intense that it displaces the zone of swash and backwash. When this happens, the beachface is undercut and becomes a vertical scarp. Sheets of water flowing more parallel to the shore than toward it undermine the base of this scarp causing the sand to collapse along vertical fractures. (This behavior of the sand is related to the pore pressure of the interstitial capillary water; the surface tension of the water acts as a "cement" to hold the sand particles together). If the undercutting mode is established on a rising tide, the entire berm can be eroded away in a few hours. If the tide rises higher than normal, the landward-retreating scarp can "eat" into any higher ridges of sand that may be present along the landward edge of the berm ("shore-parallel ridges" as a general, non-genetic term; "dunes" of most popular usage. JES concurs with Baumgaertner that such retreating berm scarps are the chief cause of erosion of the subaerial parts of beaches and adjacent sand bodies. The mechanism of scarp formation and scarp retreat seem to be related more to what happens to the water from the breaking waves than to wave action itself. If so, then litle, if any, connection may exist between "wave energy" and berm destruction. (JES once delivered a lecture at the U. S. Army Coastal Engineering Research Center in which he claimed that he was there to defend the proposition that waves do not erode beaches. Most of the audience had spent their entire professional careers dealing with how to deal with "wave energy" as the prime mover of all beach activities).

At low tide, the breakers may shift outward, exposing the sand ridge which at high tide was functioning as the innermost breaker bar. This ridge and the trough that accompanies it on its landward side (the floor of the high-tide surf zone), which become dry at low water have been named ridge and runnel (for the trough). On a ridge-and-runnel beach at low tide, it is possible to see currents of water flowing parallel to shore as the tide goes out. These currents return seaward through exposed gaps in the ridge; these are the same gaps through which the rip currents flowed at high tide. When the tide is out, the zone of swash and backwash may be transferred to the outer side of the ridge, and the floor of the runnel may become dry (Figure 23). Now, the high-tide beachface is also completely removed from wave action. Along its base, groundwater from within the berm seeps out, forming a line of miniature springs.

Figure 23. Intertidal circulation zone featuring ridge-and-runnel configuration viewed vertically at low tide, RMSP 09 April 1975 (Moon above Earth's equator; 2 days after apogee; 2 days before Full Moon). Two gaps cut the ridge. Transverse bedforms in runnel (long axes perpendicular to shore) indicate that the water flowed seaward. Small waves approaching obliquely from the SW (upper L)break before they are refracted. Other, less-obvious sets of waves are iny sets traveling from W to E, nearly perpendicular to shore, and larger swells, approaching from the S, nearly parallel to shore. Photo by B. Caplan; From Freidman and Sanders, 1978, Fig. A-31, p. 490.)

When the tide returns, the low-tide zone of swash and backwash migrates up to the crest of the now-submerging ridge, water floods into the runnel, and larger swashes may continue over the crest as wave spillovers. These sheets of water do not become backwash; they flow landward and may deposit entrained sand as tiny spillover-delta lobes in the quiet water they encounter in the runnel area. As the tide rises higher and higher, a point is reached where the zone of swash and backwash abandons the now-drowned ridge and skips across the runnel to resume its activity on the beachface. This daily shifting of the inner side of the surf zone is thought to be a small-scale model of what might happen to an entire barrier island on a larger scale during a rapid rise of sea level (futher discussion in a following section).

To summarize, the dynamic activities in the intertidal circulation zone range from those of the surf zone at high tide to the results of wave spillover and associated return currents as the tide rises.

The amounts of sand that can be shifted by the swift currents flowing in the intertidal circulation zone at high tide and along the top of the berm in the supratidal circulation zone can be tremendous. As we shall see, most of the times when spits at Democrat Point have grown rapidly have coincided with episodes of coast-parallel flow in these two zones.

Subtidal circulation zone. The chief feature of the subtidal circulation zone is the low-tide breaker zone. This area is always submerged. Its typical expression is as a trough situated just landward of the bar over which the innermost line of breakers is active; the water in this trough is deep enough to enable the breakers to reform as oscillatory waves that continue landward. Oblique approach of waves sends water into the subtidal circulation zone at an angle. As a result, the water tends to "pile up;" it adjusts by flowing parallel to shore. At intervals, this water cuts gaps through the breaker bar and returns seaward as narrow currents named rip currents.

The collective name for coast-parallel transport of sediment is longshore drift. The shore-parallel transport of sediment in the surf zone contributes significantly to the total longshore drift. Such longshore transport of sediment in the surf zone takes place independently of what may be happening in the other dynamic zones. In other words, if one uses a mathematical formula based on wave parameters to predict the amount of longshore sediment transport in the surf zone, then one has a tool that is valid only for predicting longshore sediment transport in the surf zone--period. This statement may sound ridiculous, but it has been made deliberately. Too many attempts have been made, for example, which purport to relate the longshore transport in the surf zone to erosion of the beachface. As we have just discused, such erosion takes place in the intertidal zone or in the supratidal zone; it is not related to the transport in the subtidal zone.

Depending on the range of the tides and slope of the nearshore bottom, the subtidal circulation zone may be active only at low tide. At high tide, it may be a part of the zone of shoaling waves, and as such, not a part of the beach as defined by JES. Now that we have seen something of a beach, it is appropriate to worry about the formal definition.

Definition of a Beach

Most students of beaches take it for granted that everyone knows what a beach is and no formal definition is needed. As a first approximation toward a definition of beach, one might say "a body of sand washed by waves." This statement contains two elements: (a) kind of material (i. e., sand), and (b) dynamic process (i. e., washing by waves). In the early 1930's, after the U. S. Congress had established the Beach Erosion Board as a part of the Army Corps of Engineers and had charged them with the responsibility for defending the nation's coasts against erosion, the engineers set about defining their "turf," so to speak. After all, if they were to function as the Beach Erosion Board, they had to spell out what they considered to be a beach. The definition they adopted is probably the most widely cited one, as exemplified by Wiegel's (1953) glossary of waves, tides, currents, andbeaches. Wiegel gave two definitions of beach:

(1) "Commonly, the zone (SHORE) of unconsolidated material which extends inland from the waterline to the place where there is a marked change in material or physiographic form, or

to the line of permanent vegetation (usually the effective limit of normal storm waves). The seaward limit of the beach, unless otherwise specified is the LOW WATER (sic) DATUM. A beach includes FORESHORE AND BACKSHORE." (This definition concludes with a reference to a figure showing the parts of a beach.)

(2) "Sometimes, the material which is in more or less active transit alongshore or on-and-off shore, rather than the zone involved."

This definition served a very useful purpose for the Corps of Engineers: it set the outer limit of a beach at the low-water datum, thus forestalling the necessity for these military landlubbers to get their feet wet, or to work in the water. (The water belongs to the U. S. Navy).

Totally ignored in this engineering definition of beach was any consideration of the classic work on the topographic features of lake shores written by one of the greatest American geologists of all time, G. K. Gilbert. Gilbert's treatise on shore features (1885) begins with a discussion of wave erosion and then takes up "littoral transportation." This section culminates in a discourse on sorting caused by waves; it emphasizes chiefly the separation of the fine particles from the coarse particles. Because of their large settling speeds, the coarse particles "cannot be carried beyond the zone of agitation, and remains a part of the shore." Only these coarse particles are "the subject of littoral transportation," a process he called shore drift (Gilbert, 1885, p. 86).

According to Gilbert: "The zone occupied by the shore drift in transit is the beach. Its lower margin is beneath the water, a little beyond the line where the great storm waves break. Its upper margin is usually a few feet above the level of still water" (1885, p. 87).

Another American geologist, W. O. Thompson (1937) defined a beach as a "deposit that rests on the shore;" by shore he meant the "zone over which the water line, the line of contact between land and sea, migrates" (Thompson, 1937, p. 725). Thompson's definition incorporates the concept that a beach is a deposit, but places rather vague limits on its width ("the zone across which the waterline migrates"). One can infer that Thompson's definition includes both the littoral zone (between the tide levels) and the zone washed by the waves.

Although he adopted in a general way the usage of Wiegel (1953), Ingle (1966) commented on the lack of standardization of terms for the parts of beaches. Accordingly, Ingle proposed his own subdivisions, as follows:

"The three principal dynamic zones of the beach are the swash zone, the surf zone, and the breaker zone" (Ingle, 1966, p. 11). Ingle admitted a possible fourth zone, a place of transition where the backwash collides with water from the inner part of the surf zone, which he defined as "the area between the effective seaward limit of backwash (swash zone) and the breaker zone" (p. 11).

By including the breaker zone as part of the beach, Ingle implied that the seaward limit of the beach is the seaward limit of the breaker zone. In this sense, Ingle departed from the previous usages that he otherwise generally accepted.

After sifting through dozens of definitions (details omitted here), JES concludes that most agree that the landward limit of a beach should be placed at any point where there is a significant change of material (from well-sorted, cohesionless sediment to something else), or, in the absence of such a pronounced change of material, at the upper limit of storm-wave action. On the seaward (or lakeward) side, no agreement exists. Proposals range from the low-tide datum (of the Corps of Engineers) to the depth at which waves stir the bottom sediments (which could extend to the deep-sea floor, depending on the effects of tsunami).

JES prefers to restrict beaches to the zone affected by breaking waves. This includes direct breaking; river-like currents of water circulating as a result in influxes from breaking waves (as longshore currents in the surf zone, rip currents, swash and backwash, flow of thin sheets of water that spill over the crest of the berm, currents created by the nourishment and draining of berm-top spillover pools, and through-flowing washovers that breach the shore-parallel ridges); and the shifting of the breaker zone as a result of tides. Accordingly, JES prefers the following definition of a beach as:

A body of well-sorted, coarse-grained (>0.0625 mm), continuous cohesionless sediment subject to the effects of breaking waves, and extending along the shore of a lake or the sea between the outermost line of breakers (if the appropriate sediment is continuous under the water surface; otherwise to the outer limit of the specified sediment if such a change takes place inshore of the outer line of breakers) and the landward limit of wave action on the continuous body of cohesionless sediments or to the contact of wave-washed cohesionless sediments and other materials (if such contact lies within the zone subjected to the effects of breaking waves).

As thus defined, a beach includes all the breaker bars and troughs between them; the surf zone; the rip-current channels; the zone of swash and backwash; the zone between tidal limits; the berm and associated berm-top spillover pools (of Rosalsky, 1949), plus spillover deltas deposited in these pools as well as channel deposits associated with flow of water between and out of these pools; and deposits made in breakthrough channels and other gaps in the shore-parallel ridges as well as any associated washover fans (Price, 1947).

According to this definition, a muddy shore is not a beach, nor is a rocky shore only partly covered by cohesionless sediments.

One of the most-important implications of acceptance of the definition of beach advocated by JES is a drastic expansion of ideas on what constitutes "beach sediment." The geologic literature abounds with studies of "beaches" wherein the only samples collected were carefully selected from mid-tide level on the beachface (in the zone of swash and backwash). Ignored in such studies are all the channels, the trough-cross-stratified sediments, and the other irregular features made by thin, fast-moving sheets of water at the various morphodynamic levels.

Spits: Relationships To Morphodynamic Zones of Beaches

The series of photographs contained in Figures 12 through 19 display a series of glimpses of the spits that formed during the last part of spit cycle III (defined as starting with the mid-1960's dredging and ending with the mid-1970's dredging). The aerial photos were not flown on any systematic basis other than monthly when the weather permitted. No particular attention was given to the tidal levels. By contrast, a second series, from 1982 through 1984, recording the history of spit cycle IV, was flown on days that were controlled as closely as possible by maximum tidal ranges. In addition, every effort was made to be over Democrat Point at time of low tide. These photos are parts of Audrey Massa's dissertation, which also showed the importance of the variations in tidal level in controlling spit behavior and the close connection between what was happening on the open-ocean beach and on the spit complex. As we shall see when we arrive at the jetty, a systematic pattern of spit behavior becomes clear when information is gathered at closely spaced intervals.

In Table 1, JES has assembled the astronomic information about the Moon on the days of the photo flights of both series.

The astronomic data in the three columns are lunar phase (FM = Full Moon; NM = New Moon; F/N Q = quarter phase after Full Moon and before New Moon; N/F Q = quarter phase following New Moon and preceding Full Moon); lunar distance (A = apogee, most distance between Moon and Earth in that orbit; P = perigee, least distance between Moon and Earth in that orbit); and lunar declination (N = maximum North position, highest in the sky in the Northern Hemisphere; S = maximum South position, lowest in the sky in the Northern Hemisphere; E = Moon above Earth's Equator). The significance of these factors with respect to tidal levels is explained in a following section.

Definition

A spit is a finger-like body of sand that is connected to the mainland (or to a large island) at its proximal end and grows into open water at its distal end. Before a spit can grow, several conditions must be satisfied. (1) Open water must exist at the down-drift end of a coastal segment having an abundant supply of sediment and where longshore transport in one direction predominates. (2) A submerged spit platform must be built by the longshore currents in the subtidal circulation zone. (3) Longshore transport in the intertidal and/or supratidal circulation zones must periodically exceed the capacity of waves and currents to sweep sand off the top of the spit platform.

Spits at Western End of Fire Island

The western end of Fire Island is an excellent place for studying the behavior of spits. Aerial photos taken in the 1930s before the big hurricane of 23 September 1938 (upper left panel of Figure 9, p. 17, dated 25 September 1938; and Figure 24, not dated) show the natural effects of spit building prior to the construction of the Federal Jetty in 1939-40.

Figure 24. Oblique aerial view eastward from above Fire Island Inlet showing curved spits at west end of Fire Island. Atlantic Ocean is at upper right; east-west segment of Fire Island Inlet, at left; and south shore of Jones Beach barrier, at upper left. (Photo by Fairchild Aerial Surveys, date not known, but must have been in the mid-1930s, prior to the great 1938 hurricane and also prior to construction of the Federal Jetty at Democrat Point in 1939-40; published in A. K. Lobeck, 1939, p. 334.).

As mentioned in a previous section, after the Federal Jetty had been built, the pattern of accumulation of sand at the west end of Fire Island changed temporarily. In the interval 1940 to about 1955, sand accumulated on the east side of the jetty. The trends of the visible sand ridges gradually shifted around from NW-SE, the shoreline trend on the pre-jetty spits, to E-W, the direction of the open-ocean shoreline of Fire Island (first appearance in photo dated 2 December 1961, upper right panel of Figure 9, p. 17). Thereafter, sand began to accumulate west of the jetty, an area that became the center of spit growth. By June 1958, three distinct curved spits are visible west of the jetty (Figure 9, panel at lower left). The effect of the growing spits was to force the inlet channel northward against the Oak Beach shore of the Jones Beach barrier and thus to threaten the newly constructed Ocean Parkway (See map, Figure 20, p. 30.). In order to keep the inlet channel away from the Oak Beach shore, the Corps of Engineers constructed the Oak Beach "sand dike" (the hook-shaped area of white extending into the inlet channel in the photo in the upper right panel, of Figure 9; photo dated 2 December 1961).

In 1964, the Corps of Engineers used a dredge to cut through the body of sand that had accumulated northwest of the jetty (panel at upper right, rectangular dark area close to the jetty, Figure 10). After the channel close to the jetty had been dredged, all the sand west of the channel was washed away (panel at lower right, dated June 1968, of Figure 10). After a few years, spits began to grow again west of the jetty and to build northwestward as before.

As mentioned previously, JES began to study the spits west of the jetty at Democrat Point in the summer of 1970, when Naresh Kumar was concluding his research on the sediments deposited by the westward migration of Fire Island Inlet. In July 1970, an elongate channel was eroded through the sand body west of the jetty by flood-tidal currents (elongate dark area near jetty in panel at upper left, photo dated 29 October 1970, in Figure 12). The initial depth of scour by the tidal currents was great enough so that water remained in the newly formed depression even at low tide. Subsequent northwestward migration of sand restricted the north end of this body of water, which now resembled most of the other bays that form on spit complexes by enclosure as a result of rapid sand growth (for example, the small bay to the left of the mitten-shaped body of sand in the panel at lower right, photo dated 7 January 1971, Figure 12).

On 03 October 1970, JES noticed that a new spit was starting to grow near the south end of the jetty. Accordingly, he commenced a series of photo flights over the spit, starting on 29 October 1970 and continuing at intervals of a month or more until 31 September 1975 (Figures 12 through 19). Weather and the availablity of student photo assistants (chiefly Bruce Caplan) dictated the times of these photo flights. No particular attention was paid to tidal phase nor time of low water. The chief emphasis was on flying late in the afternoon in order to take advantage of the low sun angle that created shadows that emphasized the various sets of water-surface waves.

In 1983, JES began to realize the importance of the lunar perigee-syzygy cycle. In 1988, JES compiled the astronomic data from the government tidal tables starting in 1950. The information in the tidal-prediction volumes published annually (and available in the Geosciences Library, Lamont-Doherty Geological Observatory of Columbia University) was used to prepare Table I. It shows the dates of photo flights with respect to the phases of the Moon, apogee vs. perigee, and lunar declination. This series ended in 1976, when the Corps of Engineers' dredging operations had removed all the visible sand from west of the Federal Jetty at Democrat Point (Figure 8, photo dated 12 October 1976).

In September 1982, JES became aware of the extent of the post-1976 sand build up west of the Federal Jetty and thus began a second series of photo flights. Audrey Massa and Agi Castelli (now Nadai) planned the flights and took the photographs. Sloane Six, a Barnard geology major, did the photographic conversions to black-and-white negatives and prints from the original 35-mm color transparencies (Figure 25). The Massa-Nadai series was planned to bring the photographers over the inlet at low tide and as nearly as weather and flight schedules would permit, at, or as nearly as possible, at the peaks of the spring-tidal amplitude ranges.

In the fall of 1976, a dredge had excavated a deep trench just W of the stone jetty. Accordingly, the jetty itself formed the shoreline at the SW end of Fire Island (01 and 02). By the beginning of the current phase of the study of Fire Island on 12 September 1982, all but the northern portion of the dredged trench had been filled in; a subaqueous semicircular spit platform had built westward from the jetty; and a spit curving to the NW and about 1500 feet (457 m) long has: (a) formed near the S end of the jetty; (b) migrated N at least 165 feet (50 m); and (c) been segmented into two parts (marked Spit 1 and Island 1) (03).

Between 19 September and 3 October 1982, a shoal, rooted at the S end of the jetty and trending W, has: (a) appeared; (b) grown to a length of 480 feet (146 m); and (c) rotated clockwise to trend NW. Then, in the 4 days and 8 tides of greater-than-mean range between 03 and 07 October 1982, a second spit (Spit 2) appeared and grew a phenomenal 440 feet (134 m) out on top of this shoal (04 and 05).

Between September and December 1982, Spit 1: (a) grew 940 feet (287 m) in a NW to N arc and rejoined with Island 1; (b) migrated N about 110 feet (36 m); and (c) pivoted clockwise about its root end to a N trend (03 to 07). Between 03 October 1982 and 29 January 1983 Spit 2: (a) grew to a length of 2,300 feet (701 m); (b) migrated N about 135 feet (41 m); and (c) rotated clockwise to a N-NW trend (03 to 09). The stable semicircular shape of the spit platform is shown by the pattern of breaking waves along its margin and by the dark color of the deeper water surrounding it (05 to 08).

By 31 January 1983, a third spit (Spit 3) had appeared. Like Spits 1 and 2, it appeared rooted near the S end of the jetty and initially trended W (09). This resulted from the arrival of sand from the E near the S end of the jetty. As shown by the NW-trending swash deposit crossing the jetty seen on 24 February 1983, some portion of the spit-building sand travels across the jetty in the swash zone (10). By 27 February 1983, Spit 3 had grown 675 feet. As much as 250 feet (76 m) of this growth took place in the two days and 4 higher-than-normal tides between 29 and 31 January 1983.

On 03 March 1983, a ridge-and-runnel system appeared along Spit 3's oceanside flank (11). By 24 March 1983, the ridge had merged with the main body of Spit 3, thus widening it considerably (12). During 1983, Spit 2 did not grow; by 24 March Spit 2 had become detached from its root end by abroad overwash channel. Spit 2 continued to rotate clockwise and to join up with and annex the N section of Spit 1.

During the spring of 1983, a ridge-and-runnel system developed along the strongly recurved oceanside flank of Spit 3 (13 to 16). Unlike previous ridges, this ridge was neither washed away nor did it merge with the body of Spit 3. Instead, it grew longer and by 13 May 1983, had emerged as a narrow spit branch (Branch 3B) enclosing a narrow lagoon (16). By 13 May 1983, the tip end of Spit 3 had tapered and grown out along the curved W edge of the spit platform. In the spring and summer of 1983, the root end of Spit 3 migrated N more than 600 feet (182 m), mainly by erosion of its oceanside flank, but to some degree by sand deposition on its lagoonal flank (13 to 24). Erosion resulted from retreat of beach scarps on the oceanside flank of the spit (13 and 16); deposition accompanied particularly high flood tides, when sand was washed over the crest of the spit and into the lagoon.

During the summer of 1983, the narrow and low Spit Branch 3B thickened and increased in elevation as the rest of the spit (Branch 3A) thinned and decreased in elevation. By 13 June 1983, the widths of these two branches were about the same. By 09 August 1983, the elevation of Branch 3B exceeded that of Branch 3A and the S section of Branch 3A was submerged except at low tide (17 to 24). By 27 June 1983, the root end of Spit 3 had migrated far enough N to join the S root ends of Spits 1 and 2, and to form a narrow, W-NW-trending trunk from which Spits 1, 2, and 3 branched off sharply to the N or NW in a rectilinear pattern (19).

New spits form oceanward of previously formed spits. As a result, the new spit cuts off the supply of sand to the older spits. Without new sand, and with frequent washovers during high tides, the older spits deteriorate. Because their supplies of sand had been cut off, by 09 September 1983, the central section of Spit I and the S half of Spit Branch 3A had deteriorated to become low-tide sand flats (24). During the summer of 1983, the spits did not grow much and no new spits formed. This is part of a seasonal pattern connected with the tendency of the open-ocean beaches to accrete during summer. As a result, little sand is available for longshore transport to the spits.

New spits appear and grow during the fall and winter. During these seasons, and especially during "northeasters" at any time, the open-ocean beaches tend to be eroded and the eroded sand is transported alongshore westward to the spits. Between 09 September 1983 and 07 October 1983, a new spit (Spit 4) had grown approximately 2,500 feet (762 m) (27). The "northeaster" of 28-29 March 1984, which eroded much of the open-ocean beach E of the spit complex, deposited much sand W of the jetty: (a) three low-tide branches grew out at an oblique angle to Spit 4; (b) a parabolic, NW-trending, swash deposit containing abundant heavy minerals, appeared across the jetty; and (c) a washover channel breaching Spit 4 on 19 March 1984 was healed (27 and 28). (A. Massa Ph. D. Dissertation, 1988.)

Other features of the spits are discussed in following sections devoted to strata and sequences of strata.

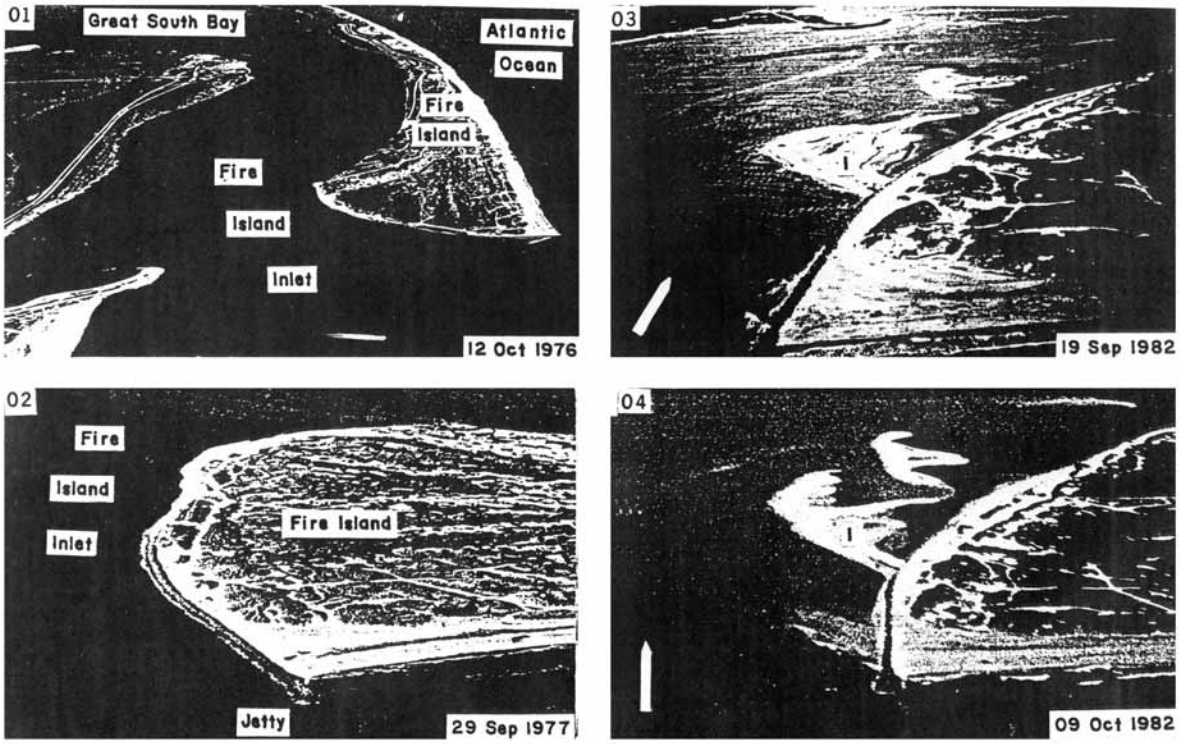


Figure 25. Development of Democrat Point from 1976 dredging to 1984 shown by a series of 29 oblique low-altitude aerial photographs (e.g. 03) taken mostly by Audrey Massa and Agi Castelli (Nadai). Panels 01 through 04.

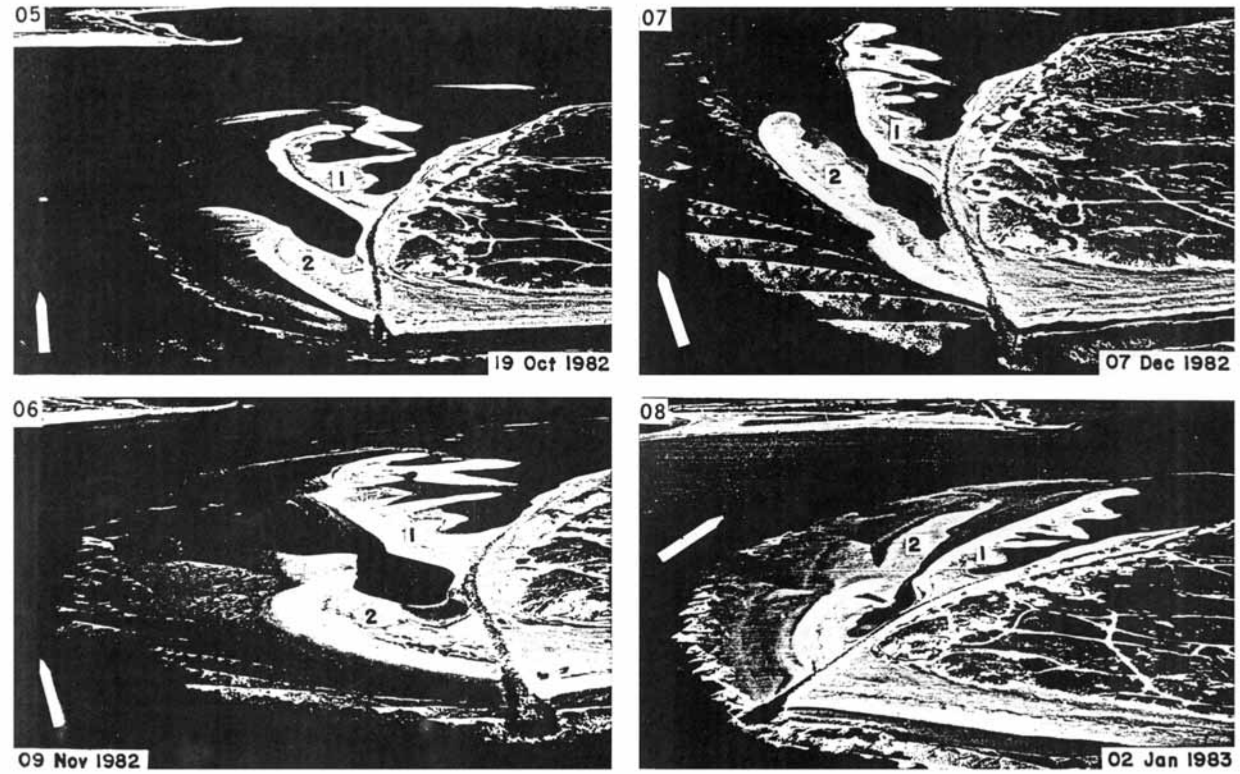


Figure 25. Panels 05 through 08.

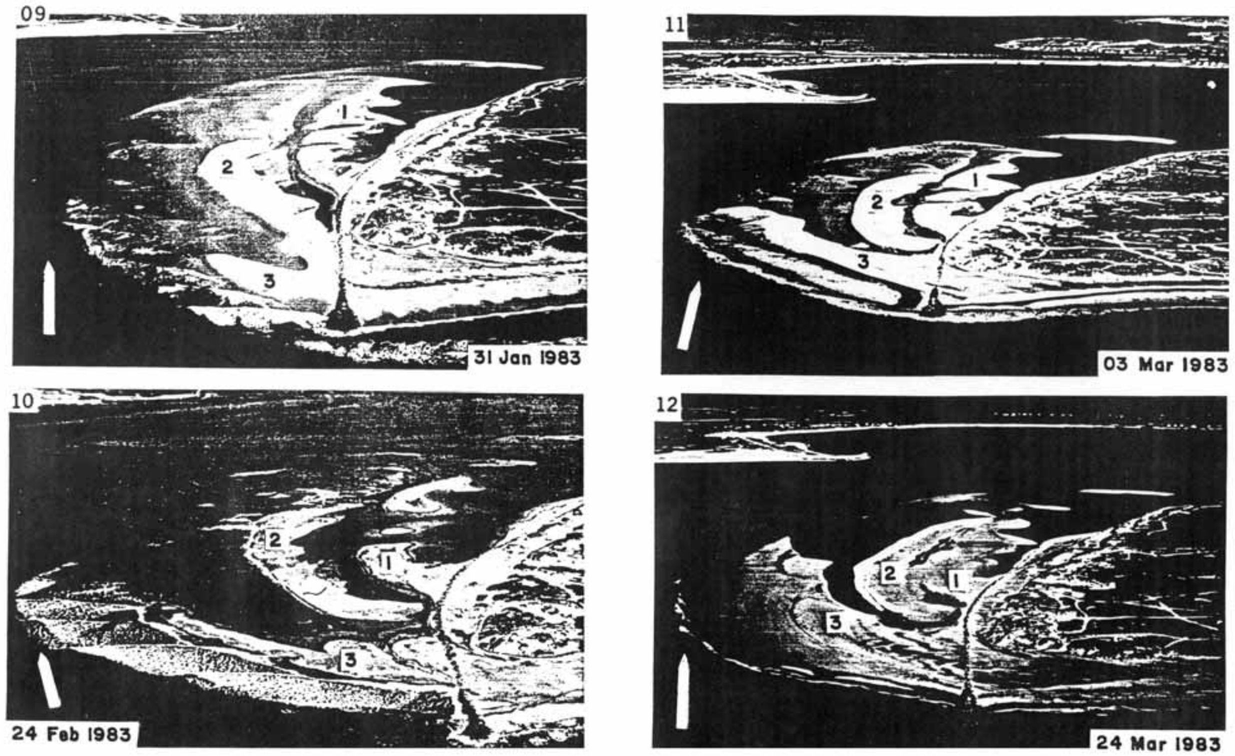


Figure 25. Panels 09 through 12.

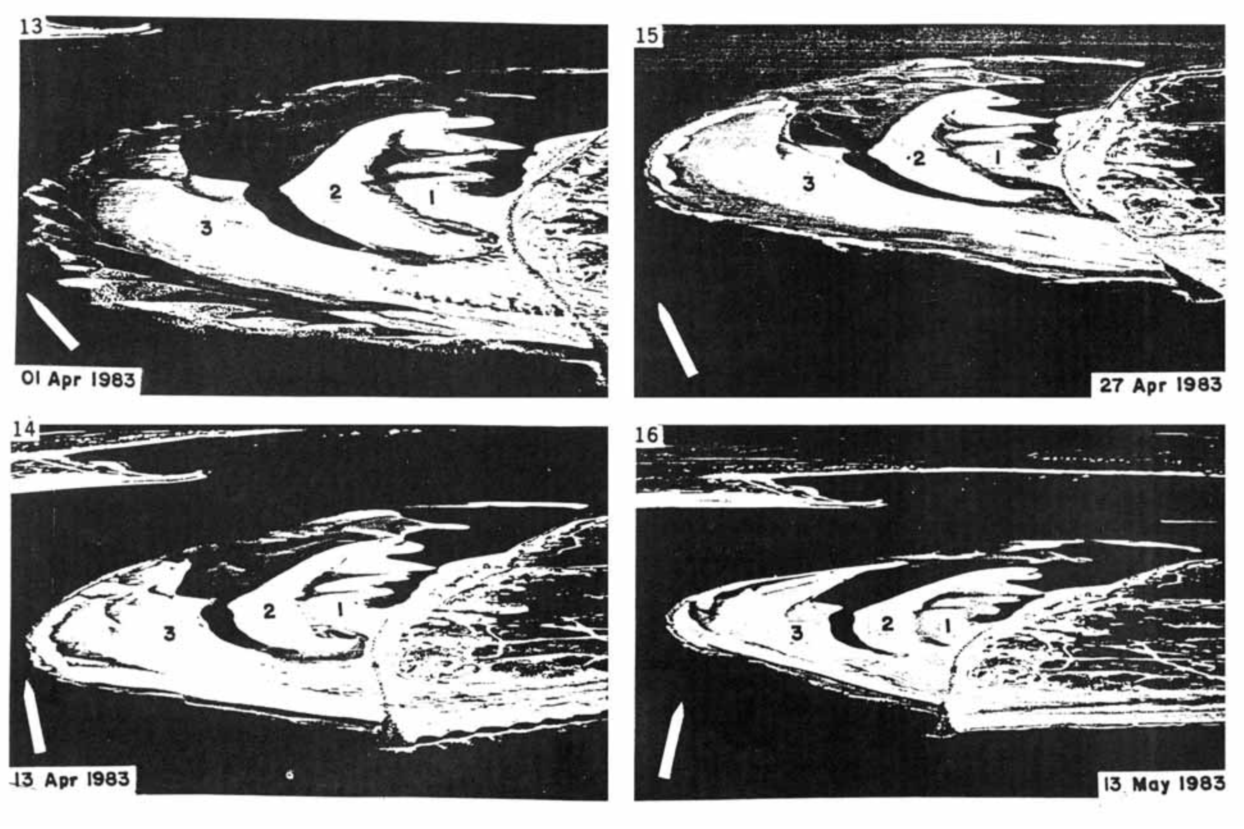


Figure 25. Panels 13 through 16.

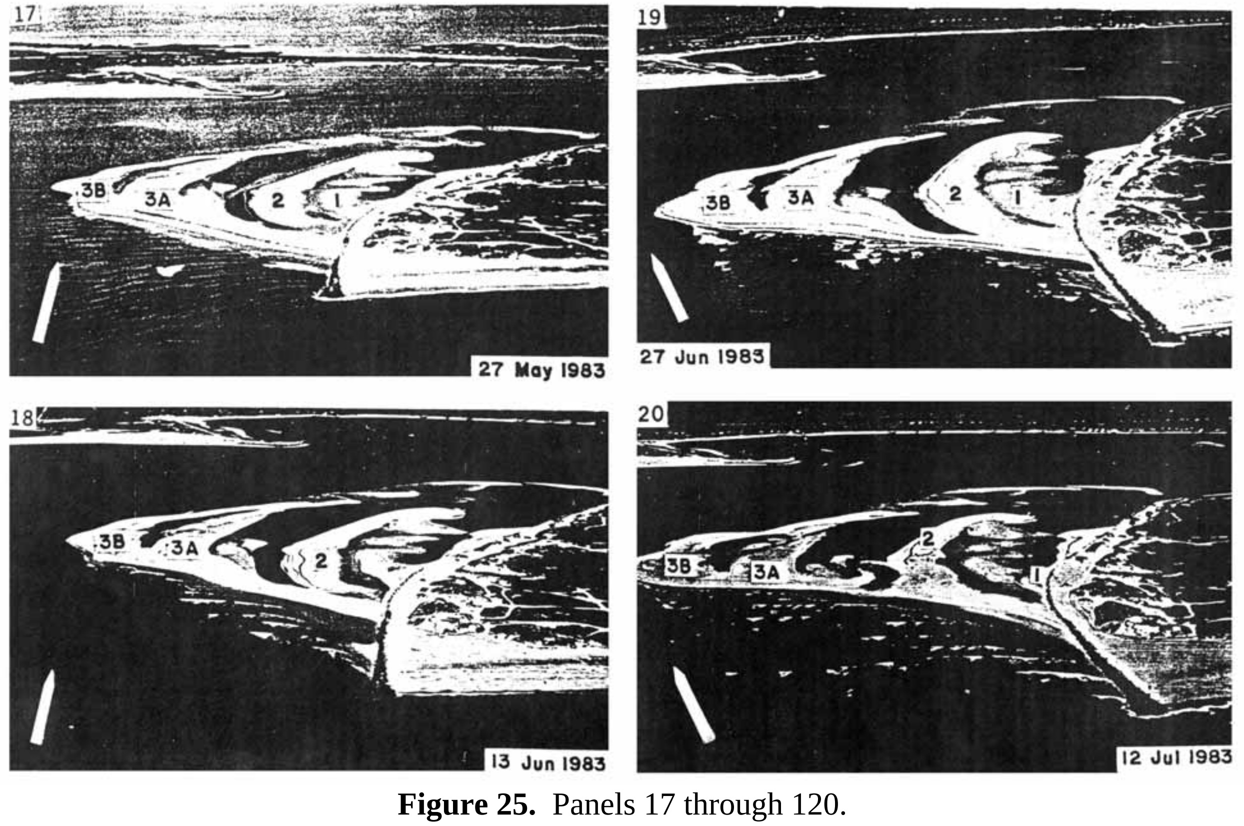


Figure 25. Panels 17 through 120.

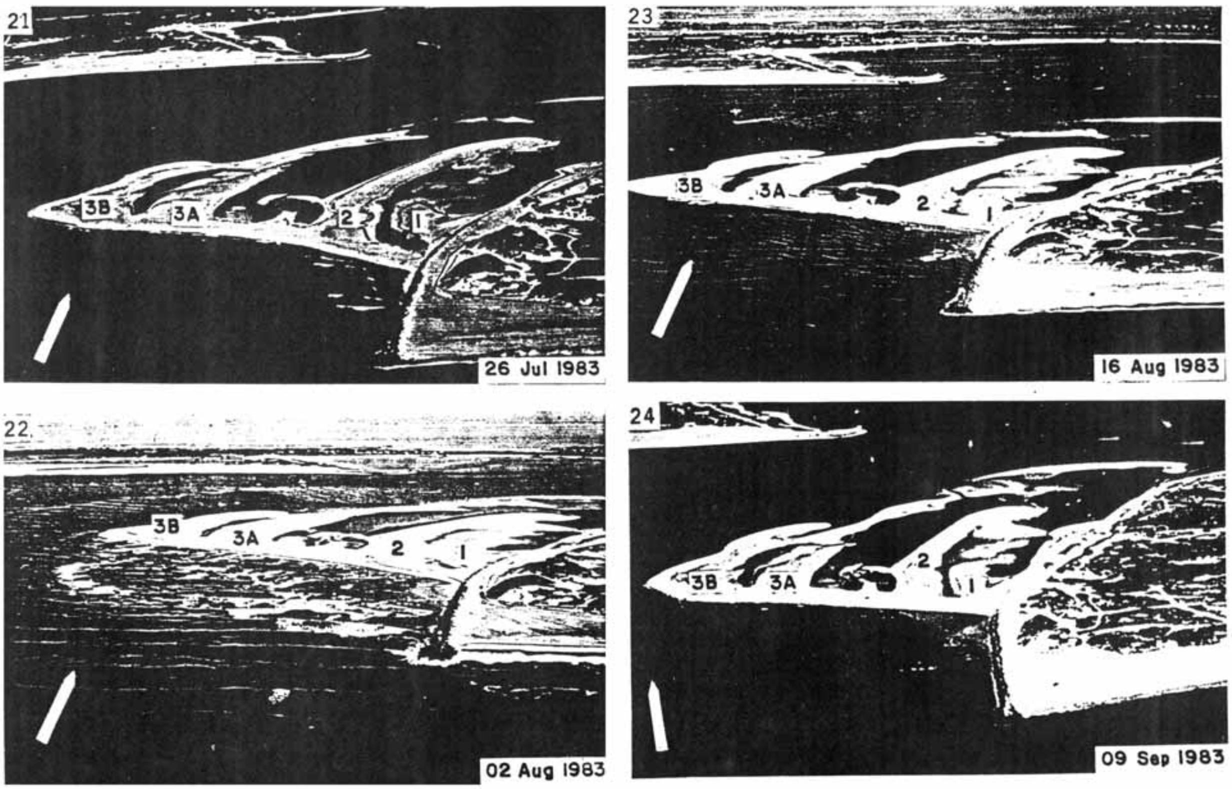


Figure 25. Panels 21 through 24.

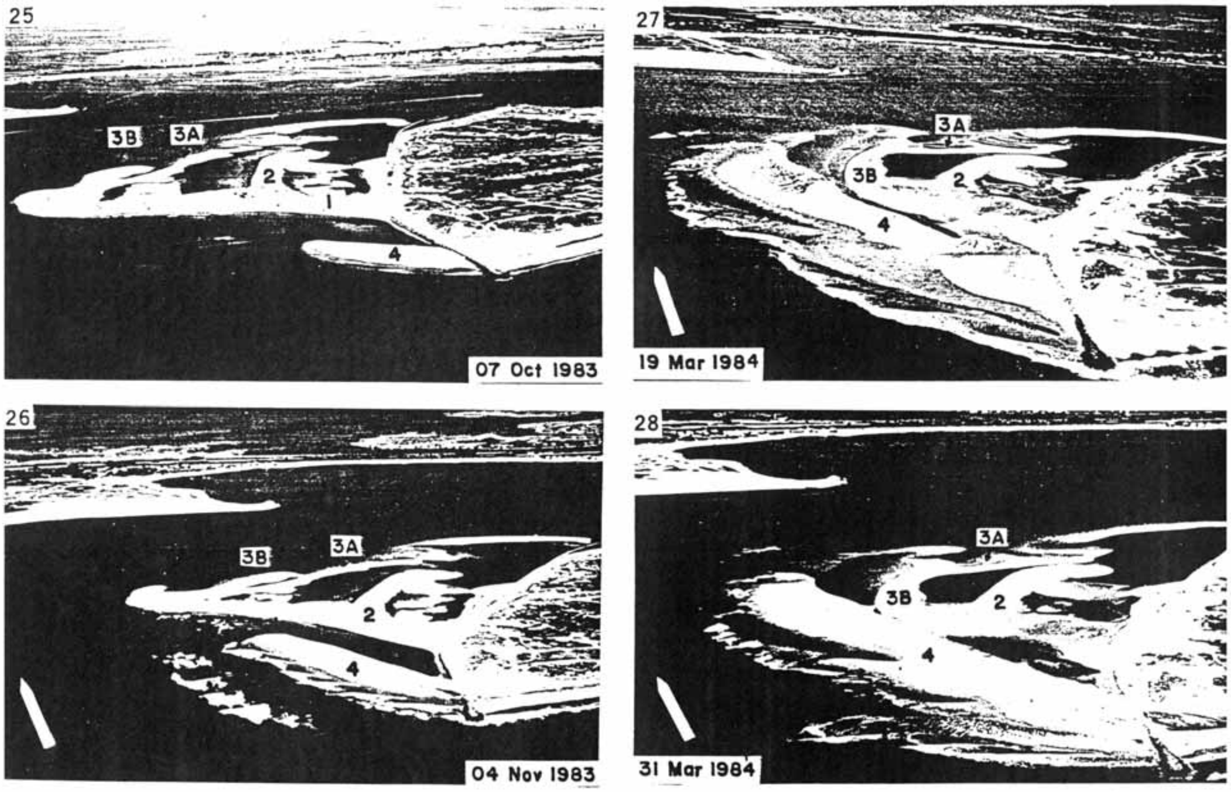


Figure 25. Panels 25 through 28.

Relationship of New Layers of Sediment to Depositional Surfaces

A problem of never-ending interest for geologists is the relationship between aspects of the environment and strata deposited. At RMSP, Fire Island, it is possible to: (1) examine directly the relationships between the surface of the beach and individual strata or groups of strata deposited by sheets of water from breaking waves and (2) find examples of fixed sequences of strata that have been deposited as a result of lateral shifting of the depositional surfaces (such as an inlet channel, a spit, or the beach and shoreface).

Surfaces of the beach and individual strata

The best examples of the relationships of individual strata to parts of the beach are the contrasts among beachface (plane or cusped), berm top, and spillover delta lobes. RMSP beach sediment generally contains dark-colored heavy minerals in abundance; these form discrete, highly visible layers that contrast decidedly with the light-colored sand in which light minerals of quartz density predominate. The key point to remember is that the new individual layers generally follow the inclination of the surface on which they are deposited. Thus, the beachface strata dip rather steeply seaward, and the berm-top strata, gently landward. The dips of cusps and on spill-over delta lobes display great directional spreads.

In order to show the relationships between strata and depositional surfaces, we shall dig a few SST's. We shall take suitable precautions to keep the sides from collapsing and to steer curious visitors from approaching the trench from the pristine side.

Beachface strata. As noted previously, the beachface may be a plane surface or may be cusped. Consider first the strata deposited on a plane beachface. Such strata dip seaward at steep angles, usually ranging between 5 and 8 degrees. (We will measure some beachface dips to see for ourselves). Because of the constant change from erosion to deposition and back again along the beachface, the beachface strata rarely attain thicknesses of more than a few centimeters. They usually form thin wedges that taper out landward and thicken toward the sea. Where a beachface is building seaward at the same time that the berm is accreting upward, then a continuous layer of sand may be deposited from the beachface, across the berm crest, and landward across the top the berm.

As mentioned in a previous section, the strata of a cusped beachface display a broadly corrugated aspect, with thicker layers of light-colored sand on the headlands, and thinner layers of dark-colored minerals in the bays (See Figure 22).

Berm-top strata. The sheet-like layers of berm-top strata dip gently landward, conforming to the landward dip of the top of the berm away from the berm crest. A remarkable feature of most of the berm-top strata JES has seen in SST's dug at RMSP is that they are uniform and planar. Only rarely is any expression preserved of the irregularities of footprints, tire tracks, and so forth, that always cover the top of the berm at the end of every weekend. As mentioned, this implies that the sheets of water which spill over the berm crest rapidly smooth out nearly all irregularities.

Berm-top strata cannot be deposited by themselves; they are always accompanied by a beachface. But, this beachface may not be preserved. Because several factors can cause the seaward side of a berm to be eroded and thus to become narrower (seaward side shifts landward), truncated berm-top strata are common. By carefully tracing the various sets of berm-top strata and beachface strata, it is possible to work out the history of erosion and deposition of sand on the berm.

On occasion, a beach scarp may be preserved. Scarps are the end products of an episode of berm erosion; no sediments layers are deposited parallel to the vertical scarps.

Strata of spillover-delta lobes. What are referred to as spillover delta lobes can be found in two places on beaches and in one place on a spit. On the beach, they are immediately landward of the crest of a ridge on a ridge-and-runnel beach, or landward of the berm crest. On a spit, they are landward of the crest of the spit berm. The strata of these lobes dip landward at the angle of repose of the sand, which is about 35 degrees. These are the classical foreset beds of a so-called Gilbert delta (named for the American geologist, G. K. Gilbert, who described and named them from his observations of the sediments deposited around the margins of ancient Lake Bonneville. The steep dips of the foreset beds prove that the lobes were built into "standing" water (no such steep dip is found on washover fans, which are spread over a newly inundated former land surface by thin sheets of water). JES thinks spillover delta lobes illustrate an important aspect associated with deltas in which such steeply dipping foresets are present: a shallow channel supplied sand to a body of water deeper than the channel. Topsets and bottomsets associated with these lobes are to be expected, but JES has never seen them in any of his many SST's.

Strata Associated with Bed Forms

Currents of water commonly fashion the sand over which they flow into a series of rhythmic relief features named bed forms. Included are such things as ripples, megaripples, sand waves, and dunes.

Strata are associated with bed forms as a result of the migration of the bed forms in response to the current. In the simplest case, the bed form migrates downcurrent by eroding sand from its upcurrent side (the gently dipping side) and depositing it on the downcurrent side. (The action resembles the deposition of foresets on a growing spillover-delta lobe.) The strata dip in the downcurrent direction and are named cross strata (or cross laminae, if they are very thin).

The only places where we are likely to see any bed forms that we can dig into and look to see if the cross strata are visible are the top of a berm where currents related to a berm-top spillover pool may have rippled the sand, or on surfaces exposed at low tide where currents flowed swiftly when water was still present. Such places include the floor of a runnel on a ridge-and-runnel beach and on the top of a spit platform.

Sequences of strata deposited by shifting depositional surfaces

Under this heading, we refer to larger-scale depositional surfaces that include several of the features discussed in the previous sections. Two examples are available at Fire Island: (1) beneath the triangular body of sand that built up on the E side of the Federal Jetty from 1940 to 1950 (See Figure 8, p. 16); and (2) beneath those parts of Fire Island through which the inlet migrated and thus deposited an inlet sequence (See Figure 11).

The principle involved is that along the various parts of a sloping sediment surface, contrasting and distinctive kinds of sediment will be deposited. The contrasts may be in particle sizes or in the kinds of primary sedimentary structures. For example, in an inlet deeper than 5 meters, the coarsest sediment, those of the channel-floor lag, will always be overlain by the deep-channel medium sands with their distinctive cross strata; and these, in turn, by the finer sands of the shallow parts of the channel. An inlet sequence is one in which the pattern is coarsest at the base, and finer upward. (Such sequences are named fining-upward sequences).

Where any sediment surface progrades, it will leave behind a distinctive sequence. On a barrier island, such prograding can take place where an inlet migrates parallel to shore (thus prograding along the shore) or where the whole seaward side of the barrier builds outward (prograding normal to the shore). Prograding of the seaward side of a barrier yields a barrier-island sequence that grades upward from shoreface sediments related to shoaling waves to various beach sediments that may be capped by wind-blown sand. The sediments of a barrier-island sequence are finer at the base and become coarser upward (=a coarsening-upward sequence).

SEA LEVEL

Two aspects of sea level are discussed here. (1) Two important processes of the modern sea at its existing level are waves (Appendix A) and tides (Appendix B). (2) Changes of sea level.

Refer to the appropriate appendices for the discussion of waves and tides. The rest of the sea-level discussion will address the subject of changes. Mere mention of the words sea level today triggers an almost reflexive association with the "greenhouse effect" and the added-on corollary expressed as "global warming." Because the features of the Long Island coast have resulted from submergence, the topic of the future situation with respect to sea level is important for most residents of the island.

To begin with, it is important to realize that the position of the water against the land is the relative resultant of the geologic situation with respect to the lithosphere and to the global ocean. Sinking land may cause submergence and rising, land, emergence; and both may take place at static world sea level. A worldwide change of sea level is named a eustatic change of sea level. It is a result of changes in quantity of water, volume of the ocean basins, or volume of the water (changes with temperature). Because continental ice sheets store so much water, their expansion or contraction is matched by changes of sea level.

According to JES, the parts of Long Island that are being submerged are doing so not because the "sky is falling," but because the land is sinking. Therefore, such submergence can be expected to continue independently of whatever may happen in terms of climate, ice volumes, and the greenhouse gases in the atmosphere.

As everyone by now has doubtless heard, several gases, including carbon dioxide and methane, are named "greenhouse" gases because they allow radiating energy in the spectral wavelengths of light from the Sun to pass, but do not allow passage of the energy in the long wavelengths (the part of the spectrum related to the heat from the incoming solar radiation that the Earth's surface re-radiates back into space). Thus, as with the glass in a greenhouse, these gases let in the incoming energy, but prevent the backreflected energy from escaping. Thus, they trap heat in the atmosphere.

As shown on the next page, clipped from the editorial page of the New York Times of 27 January 1989, the proportion of carbon dioxide in the Earth's atmosphere has increased from about 295 parts per million in 1895, to about 330 parts per million in 1985 (right-hand graph credited only to "Nature"). Alongside this graph is another, showing annual average temperatures in the US from 1895 to 1987. All kinds of discussion followed publication of this graph. According to those who believe that the surface temperature should increase in proportion to the buildup of carbon dioxide, some serious explaining was in order. Most of them seem to expect that the temperature curve should be going up along with the carbon-dioxide curve. But, clearly, it is not. Why not? JES will not bother you with the proposed explanations, none of which seems worthy of serious consideration. None that JES has seen addressed what seem to be very fundamental points. (1) Whatever the greenhouse effect is, it must be considered as something that is added to whatever the base climate is doing. This point is usually omitted, and one has to make an inference about how the "greenhouse" partisans visualize the base climate. They seem to think what is present will prevail as is into the future. But that is not necessarily so. Level ahead is only of three options. The other two are: (a) warming ahead; or (b) cooling ahead.

Consider this against the two graphs from the NY Times. Given the carbon-dioxide buildup and the principle of the greenhouse effect (and granted the point, which JES thinks should not be granted without serious challenge, of which more in a following paragraph), then how can one escape the conclusion that the level temperature curve is the algebraic result of a base-climate cooling to which the greenhouse increment has been added to give a level result? Did anyone see that point made in the discussions?

JES thinks that the evidence from the newly assembled data about the orbit of the Sun around the center of mass of the solar system is that the future base climate is headed downward into a Little Ice Age. If the greenhouse gases do not aggravate this trend, then any warming they provide might be very welcome.

Granted that the greenhouse gases are accumulating in the atmosphere and that their effect is to trap heat, then what? JES thinks it is much too naive to believe that a simple relationship exists between more trapped heat in the atmosphere and "global warming." Sir George Simpson, a distinguished British meteorologist, developed the idea that increased solar heat would trigger an ice age. This counter-intuitive result involves what JES calls "Simpson's paradox." The paradox is that the initial effect of adding heat is to intensify the circulation of the atmosphere. This causes more evaporation in the tropics, and a greater export of heat away from the tropics. The heat must be exported; geologic evidence of the persistence of reef corals proves that the tropics do not warm up (coral temperature sensitivity works at both ends of the scale, but we generally think only of the low end; their range is about 20 to 32 degrees Celsius--R. W. Fairbridge, personal communication to JES). The result of this intensified circulation, according to Simpson, is more clouds, general cooling, and arrival of moisture-bearing winds into the cold polar deserts, the birthplaces of the continental ice sheets. In order to make glaciers, these cold, polar deserts do not need to get any colder. All they need is precipitation.

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The Greenhouse Effect Is for Real

A team of Government scientists report no sign of a warming trend in the average temperatures in the United States over the last century. Does that mean the greenhouse effect, the feared heating of the earth's atmosphere by burning coal and oil, is just another false alarm? The answer, unfortunately, is an emphatic no.

Gases like carbon dioxide, spewed out in the burning of coal, wood and oil, let in the sun's light but trap the resulting heat as it tries to return to space. That's a matter of simple physics.

Also undisputed is that the amount of carbon dioxide in the atmosphere has been steadily building up since the beginning of the Industrial Revolution. Unless there is something to counteract the growing volumes of carbon dioxide, the earth's atmosphere will eventually start to heat up.

There is no certainty that it has done so. But that doesn't mean the theory is wrong. The expected amount of warming is very small compared with the natural variability in the earth's temperature. Thus any signal of a warming trend would be hard to spot.

Last summer's dramatic drought helped focus attention on the greenhouse theory because drought in mid-latitudes is one of the warming effects predicted by computer simulations. Even then, many climatologists were rightly concerned not to cry wolf by declaring too early that the warming had begun. Most of them believe, however, that the greenhouse effect is to be taken seriously.

Climatologists will argue for many years whether the greenhouse warming has started. But there's every reason to take action immediately, and not wait until that debate is concluded.

Once warming begins, its momentum will continue — even if gas emissions could be stopped immediately — for the three decades or so that it takes to heat the oceans. At that point the planet will again be in equilibrium, but at a much higher temperature than that of the initial warming signal.

It's far too early to recommend that countries stop burning coal. But there are several other steps that would help postpone the greenhouse effect, all well worth taking in their own right:

☐ Phase out chlorofluorocarbons, the industrial gases used as refrigerants and solvents. They chew up the protective ozone layer in the stratosphere and also exert a strong greenhouse effect.

☐ Conserve energy by taxing gasoline and requiring Detroit to double the fuel efficiency of its cars.

☐ Preserve tropical forests instead of letting them be burned by landless farmers. The wholesale burning of forests in Brazil contributed a tenth of the carbon dioxide injected into the world's atmosphere last year.

☐ Press the development of smokeless forms of energy generation, like solar power and a new generation of safer, cheaper nuclear power plants.

The earth's climate is far from being understood. Natural counteractions to the warming, like increased cloud cover, might come to the rescue by damping down any greenhouse effect. But why bet on it? The greenhouse warming may not arrive for several decades, or it may already have started and outrun the capacity of natural systems to adapt. Either way, the precautionary measures already at hand are cheap insurance against risks of such magnitude.

There's no warming in the weather.
Annual average temperatures in the continental U.S.

Source: National Oceanic and Atmospheric Administration

But the cause for concern is still building.
Proportion of CO_2 in the atmosphere, in parts per million.

Source: Nature

JES thinks that the intensified circulation of the atmosphere is the correct expectation of the buildup of the greenhouse gases. Such an intensified circulation seems to be borne out by: (1) the reports of higher waves in the North Atlantic (from British weather ships), and (2) the locust plagues in North Africa (which appear when rainfall increases in otherwise-dry areas).

JES conclusion: We have been ignoring the fundamental motive force of the Earth's climate: the Sun. Only belatedly are solar physicists beginning to admit that the so-called "solar constant" is not constant. After blowing a chance to measure solar radiation by having the US astronauts place an appropriate instrument on the surface of the Moon in 1968, gadgets are now being flown on satellites that show variations. What human beings are doing to the atmosphere should not be ignored. But to ballyhoo the "sky-is-falling" line (thereby making common cause with Henny Penny) without a much-more-profound understanding of the atmosphere than now exists is to JES a very nonscientific way to proceed. (It may be good "grantsmanship" politics for securing public funds for research, but it runs the risk of being shown to be well off the mark and thus in the long run, a discredit to the scientific establishment).

THE GEOLOGIC CYCLE AND THE GEOLOGIC RECORD

Modern geology began about 200 years ago, when an unusually observant Scotsman, James Hutton, delivered two lectures to the Royal Society of Edinburgh, the first on 07 March 1785 and the second, on 04 April 1785. The title of his lectures was: "Concerning the Systems of the Earth, its Duration and Stability." In 1788, the paper was published in volume 1 of the Transactions of the Society under the title of: "Investigation of the Laws observable in the Composition, Dissolution and Restoration of Land upon the Globe." In 1795, Hutton published a two-volume book entitled "Theory of the Earth with Proofs and Illustrations." Chapter one was the paper from the Transactions. Hutton finished, but never published, the manuscript for a third volume. He died on 26 March 1797 (White, 1956, p. v-xv).

In Hutton's time, geologic science had progressed to the point where it was generally agreed that beneath a surface layer of loose soils or "dirt," one encounters solid bedrock and that much of this bedrock consists of layers (named strata) that form parallel series, among which the thicknesses of some remain the same through long distances. In many places, the strata are horizontal, the same position in which they were formed initially, but in mountain chains, the strata are inclined at various angles, including vertical. Hutton's great contribution was the realization that the strata consist of "materials furnished from the ruins of former continents." In other words, the "system of universal decay and degradation" that he saw taking place all around him today was providing sediment that would be deposited in the sea, would be converted to strata, and later be elevated to form new land, only to be eroded and the debris carried into another sea, and so on, back and forth, up and down, and so on into the future. But equally important, this cycle of activities had been going on in the past. And, by tracing groups of strata and applying the concept that the lower strata are older than those covering them, Hutton was able to work his way backward in the geologic record. His most-startling conclusion was that the oldest rocks he could find in his searches within the geologic record consist of strata that resembled all the other strata. In other words, he was not able to find any rocks that had been built up under circumstances differing appreciably from those prevailing today. Accordingly, Hutton was confident that his generalization about the geologic cycle provided the key link in connecting the past, the present, and the future.

John Playfair, Professor of Mathematics at the University of Edinburgh, and a friend and pupil of Hutton's, published a memorial biography of Hutton in the Transactions of the Royal Society of Edinburgh in 1805. According to Playfair:

> "It might have been expected, when a work of so much originality as this Theory of the Earth, was given to the world, a theory which professed to be the result of such an ample and accurate induction, and which opened up so many views, interesting not to mineralogy alone, but to philosophy in general, that it would have produced a sudden and visible effect, and that men of science would have been every where eager to decide concerning its real value. Yet the truth is, that it drew their attention very slowly, so that several years elapsed before any one shewed himself publicly concerned about it, either as an enemy or a friend.
>
> "Several causes probably contributed to produce this indifference. The world was tired out with unsuccessful attempts to form geological theories, by men often but ill informed of the phenomena which they proposed to explain, and who proceeded also on the supposition that they could give an account of the origin of things, or the first establishment of that system which is now the order of nature...
>
> "Truth, however, forces me to add, that other reasons certainly contributed not a little to prevent Dr. Hutton's theory from making a due impression on the world. It was proposed too briefly, and with too little detail of facts, for a system which involved so much that was new, and opposite to the opinions generally received. The descriptions which it contains of the phenomena of geology, suppose in the reader too great a knowledge of the things described, The reasoning is sometimes embarrassed by the care taken to render it strictly logical; and the transitions, from the author's peculiar notions of arrangement, are often unexpected and abrupt. These defects run more or less through all Dr. Hutton's writings, and produce a degree of obscurity astonishing to those who knew him, and who heard him every day converse with no less clearness and precision, than animation and force. From whatever causes the want of

> perspicuity in his writings proceeded, perplexity of thought was not among the number; and the confusion of his ideas can neither be urged as an apology for himself, nor as a consolation to his readers."

To this list JES thinks should be added the turbulent state of affairs in western Europe, particularly in France, during the decade starting in 1789. Hutton had studied in Paris and was well acquainted with French-language publications by both French and Swiss investigators (for example, Dolomieu, Buffon, LaPlace, LaGrange, and Saussure; and he read J. G. Lehman's 1756 book in its translation into French dated 1759). According to Donald B. MacIntyre (Heezen Memorial Lecture to New York Academy of Sciences, Section on Geological Sciences, in October 1988), during a decade of peace between France and England (1783-1793), Hutton's close friend and "scout," John Clerk, was available full time as an illustrator and collaborator with Hutton. In 1793, England and France were at war again, a condition that prevailed more or less continuously until 1815, when Wellington defeated Napoleon at the battle of Waterloo. During these wars, Clerk served with distinction in the Royal Navy. Despite the turmoil, however, French publications such as the Jour. de Physique having dates in the 1790s are cited in the footnotes of Playfair's book (1802).

Two circumstances contributed to the eventual spread of Hutton's ideas. (1) Playfair book (1802) entitled: "Illustrations of the Huttonian Theory of the Earth" became more widely known than Hutton's original books. Moreover, Playfair's clear, elegant prose provided an easier access to Hutton's ideas than could be gained from Hutton's books. (2) Charles Lyell's textbook of geology (1830) was built on the Huttonian framework. Lyell's book founded modern geology.

The following samples of Hutton's ideas are taken from the 1956 facsimile edition of Playfair's book.

> Par. 92. "The series of changes which fossil bodies are destined to undergo, does not cease with their elevation above the level of the sea; it assumes, however, a new direction, and from the moment that they are raised up to the surface, is constantly exerted in reducing them again under the dominion of the ocean. The solidity is now destroyed which was acquired in the bowels of the earth; and as the bottom of the sea is the great laboratory, where loose materials are mineralized and formed into stone, the atmosphere is the region where stones are decomposed, and again resolved into earth."

> Par. 96. "But it would far exceed the limits of this sketch, to pursue the causes of mineral decomposition through all their forms. It is sufficient to remark, that the consequence of so many minute, but indefatigable agents, all working together, and having gravity in their favour, is a system of universal decay and degradation,

> which may be traced over the whole surface of the land, from the mountain top to the sea shore. That we may perceive the full evidence of this truth, one of the most important in the natural history of the globe, we will begin our survey from the latter of these stations, and retire gradually toward the former."
>
> Par. 97. "If the coast is bold and rocky, it speaks a language easy to be interpreted. Its broken and abrupt contour, the deep gulphs (sic) and salient promontories by which it is indented, and the proportion which these irregularities bear to the force of the waves, combined with the inequality of hardness in the rocks, prove that the present line of the shore has been determined by the action of the sea. The naked and precipitous cliffs which overhang the deep, the rocks hollowed, perforated, as they are farther advanced in the sea, and at last insulated, lead to the same conclusion, and mark very clearly so many different stages of decay. It is true, we do not see the successive steps of this progress exemplified in the states of the same individual rock, but we see them clearly in different individuals; and the conviction thus produced, when the phenomena are sufficiently multiplied and varied, is as irresistible, as if we saw the changes actually effected in the moment of observation.
>
> "On such shores, the fragments of rock once detached, become instruments of further destruction, and make the powerful artillery with which the ocean assails the bulwarks of the land: they are impelled against the rocks, from which they break off other fragments, and the whole are thus ground against one another; whatever be their hardness, they are reduced to gravel, the smooth surface and round figure of which, are the most certain proofs of a detritus which nothing can resist."

Two gems of Playfair's language are "the system of universal decay and degradation, which may be traced over the whole surface of the land" and "the fragments of rock once detached, become instruments of further destruction, and make a part of the powerful artillery with which the ocean assails the bulwarks of the land."

Another point deserving emphasis in the above discussion is the use of a collection of localities to illustrate the succession of changes that a given locality will experience ("...we do not see the successive steps of this progress exemplified in the states of the same individual rock, but we see them clearly in different individuals; and the conviction thus produced, when the phenomena are sufficiently multiplied and varied, is as irresistable, as if we saw the changes actually effected in the moment of observation.").

The key insight refers to the effects of what we now call the hydrologic cycle:

> Par. 126. "It is impossible to look back on the system which we have thus endeavoured to illustrate, without being struck with the novelty and beauty of the views which it sets before us. The very plan and scope of it distinguish it from all other theories of the earth, and point it out as a work of great and original invention. The sole object of such theories has hitherto been, to explain the manner in which the present laws of the mineral kingdom were first established, or began to - exist, without treating of the manner in which they now proceed, and by which their continuance is provided for. The authors of these same theories have accordingly gone back to a state of things altogether unlike the present, and have confined their reasonings, or fictions, to a crisis which never has existed but once, and which never can return. Dr Hutton, on the other hand, has guided his investigation by the philosophical maxim, Causam naturalem et affiduam quaerimus, non raram et fortuitam (Seneca--JES, from frontispiece). His theory, accordingly presents us with a system of wise and provident economy, where the same instruments are continually employed, and where the decay and renovation of fossils being carried on at the same time in the different regions allotted to them, preserve in the earth the conditions essential for the support of animal and vegetable life. We have been long accustomed to admire that beautiful contrivance in nature, by which the water of the ocean, drawn up in vapour by the atmosphere, imparts, in its descent, fertility to the earth, and becomes the great cause of vegetation and of life; but now we find, that this vapour not only fertilizes, but creates the soil; prepares it from the solid rock, and after employing it in the great operations of the surface, carries it back into the regions where all its mineral characters are renewed. Thus, the circulation of moisture through the air, is a prime mover, not only in the annual succession of the seasons, but in the great geological cycle, by which the waste and

> reproduction of entire continents is circumscribed.
>
> Perhaps a more striking view than this, of the wisdom that presides over nature, was never presented by any philosophical system, nor a greater addition ever made to our knowledge of final causes. It is an addition which gives constancy to the rest, by proving, that equal foresight is exerted in providing for the whole and for the parts, and that no less care is taken to maintain the constitution of the earth, than to preserve the tribes of animals and vegetables which dwell on its surface. In a word, it is the peculiar excellence of this theory, that it ascribes to the phenomena of geology an order with which we are best acquainted; that it produces seas and continents, not by accident, but by the operation of regular and uniform causes; that it makes the decay of one part subservient to the restoration of another, and gives stability to the whole, not by perpetuating individuals, but by reproducing them in succession."

In this passage, Playfair uses "the great geological cycle," a phrase that more than any other distinguishes the Huttonian viewpoint.

Playfair wrote of Hutton's idea of the long-continued operation of the geologic cycle as follows:

> (p.118) Par 117. "We are not, however, to imagine, that there is no where any means of repairing this waste; for, on comparing the conclusion at which we are now arrived, viz. that the present continents are all going to decay, and their materials descending into the ocean, with the proposition first laid down, that these same continents are composed of materials which must have been collected from the decay of former rocks, it is impossible not to recognize two corresponding steps of the same progress; of a progress, by which mineral substances are subjected to the same series of changes, and alternately wasted away and renovated. In the same manner, as the present mineral substances derive their origin from substances similar to themselves; so, from the land now going to decay, the sand and gravel forming on the sea-shore (sic), or in the beds of rivers; from the shells and corals which in such enormous quantities are every day accumulated in the bosom of the sea; from the drift

wood, and the multitude of vegetable and animal remains continually deposited in the ocean: from all these we cannot doubt, that strata are now forming in those regions, to which nature seems to have confined the powers of mineral reproduction; form which, after being consolidated, they are again destined to emerge, and to exhibit a series of changes similar to the past (Note XIX.).

Par. 118. "How often these vicissitudes of decay and renovation have been repeated, is not for us to determine: they constitute a series, of which, as the author of this theory has remarked, we neither see the beginning nor the end; a circumstance that accords well with what is known concerning other parts of the economy of the world. In the continuation of the different species of animals and vegetables that inhabit the earth, we discern neither a beginning nor an end; and, in the planetary motions, where geometry has carried the eye so far both into the future and the past, we discover no mark, either of the commencement or the termination of the present order. It is unreasonable, indeed, to suppose that such marks should any where exist.

The Author of nature has not given laws to the universe, which, like the institutions of men, carry in themselves the elements of their own destruction. He has not permitted, in his works, any symptom of infancy or of old age, or any sign by which we may estimate either their future or their past duration. He may put an end, as he no doubt gave a beginning, to the present system, at some determinate period; but we may safely conclude, that this great catastrophe will not be brought about any any of the laws now existing, and that it is not indicated by any thing which we perceive."

Par. 119. To assert, therefore, that, in the economy of the world, we see no mark, either of a beginning or an end, is very different from affirming, that the world had no beginning, and will have no end. The first is a conclusion justified by common sense, as well as sound philosophy; while the second is a presumptuous and unwarrantable assertion, for which no reason from experience or analogy can ever be assigned. Dr Hutton might, therefore, justly complain of the uncandid criticism, which, by substituting the one of these

> assertions for the other, endeavoured to load his theory with the reproach of atheism and impeity. Mr. KIRWAN, in bringing forward this harsh and ill founded censure, was neither animated by the spirit, nor guided by the maxims of true philosophy. By the spirit of philosophy, he must have been induced to reflect, that such poisoned weapons as he was preparing to use, are hardly ever allowable in scientific contest, as having a less direct tendency to overthrow the system, than to hurt the person of the adversary, and to wound, perhaps incurably, his mind, his reputation, or his peace.
>
> (p. 121) By the maxims of philosophy, he must have been reminded, that, in no part of the history of nature, has any mark been discovered, either of the beginning or the end of the present order; and that the geologist sadly mistakes, both the object of his science and the limits of his understanding, who thinks it his business to explain the means employed by INFINITE WISDOM for establishing the laws, which now govern the world."
>
> Par. 120. "But to return to the natural history of the earth: Though there be in it no data, from which the commencement of the present order can be ascertained, there are many by which the existence of that order may be traced back to an antiquity extremely remote. The beds of primitive schistus, for instance, contain sand, gravel, and other materials, collected, as already shewn, from the dissolution of mineral bodies; which bodies, therefore, must have existed long before the oldest part of the present land was formed. Again, in this gravel we sometimes find pieces of sandstone, and of other compound rocks, by which we are of course carried back a step farther, so as to reach
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> (p.123) a system of things, from which the present is the third in succession; and this may be considered as the most ancient epocha (sic), of which any memorial exists in the records of the fossil kingdom.'

Conspicuously absent in Hutton's scheme was any mention about a creation of the world, such as is spelled out in the Old Testament, for example. As a result of this notable omission, Hutton's ideas were attacked as being blasphemous. And what was even more upsetting, it was clear that the operation of the geologic cycle, as Hutton visualized it, involved vastly greater amounts of time than the 4000 to 6000 years that a few clerical scholars had calculated for the age of the Earth since its momentous initial week of "creation" (and which nearly all clergymen had accepted as being the "gospel truth").

Playfair dealt with this problem as follows:

Par. 125. "On what is now said is grounded another objection to Dr Hutton's theory, namely, that the high antiquity ascribed by it to the earth is inconsistent with that system of chronology which rests on the authority of the Sacred Writings. This objection would no doubt be of weight, if the antiquity in question were not restricted merely to the globe of the earth, but were also extended to the human race. That the origin of mankind does not go back beyond six or seven thousand years, is a position so involved in the narrative of the Mosaic books, that any thing inconsistent with it, would no doubt stand in opposition to the testimony of those ancient records. On this subject, however, geology is silent; and the history of arts and sciences, when traced as high as any authentic monuments extend, refers

(p. 126) the beginnings of civilization to a date not very different from that just mentioned, and infinitely within the limits of the most recent of the epochas, marked by the physical revolutions of the globe.

"On the other hand, the authority of the Sacred Books seems to be but little interested in what regards the mere antiquity of the earth itself; nor does it appear that their language is to be understood literally concerning the age of that body, any more than concerning its figure or its motion. The theory of Dr Hutton stands here precisely on the same footing with the system of COPERNICUS; for there is no reason to suppose, that it was the purpose of revelation to furnish a standard of geological, any more than of astronomical science. It is admitted, on all hands, that the Scriptures are not intended to resolve physical questions, or to explain matters in no way related to the morality of human actions; and if, in consequence of this principle, a considerable latitude of interpretation were not allowed, we should continue at this moment to believe, that the earth is flat; that the sun moves round the earth; and that the circumference of a circle is no more than three times its diameter.

"It is reasonable, therefore, that we should extend to the geologist the same liberty of speculation, which the astronomer and mathematician are already in possession of; and this may be done, by supposing that the chronology of

> Moses relates only to the human race. This liberty is not more necessary to Dr Hutton than to other theorists. No ingenuity has been able to reconcile the natural history of the globe with the opinion of its recent origin; and accordingly the cosmologies of Kirwan and De Luc, though contrived with more mineralogical skill, are not less forced and unsatisfactory than those of Burnet and Whiston."

Finally, we include the ultimate tribute paid to Hutton by Playfair:

> 134. "If indeed this theory of the earth is as well founded as we suppose it to be, the lapse of time must necessarily remove all objections to it, and the progress of science will only develope its evidence more fully. As it stands at present, though true, it must be still imperfect; and it cannot be doubted, that the great principles of it, though established on an immoveable basis, must yet undergo many modifications, requiring to be limited, in one place, or to be extended, in another. A work of such variety and extent cannot be carried to perfection by the efforts of an individual. Ages may be required to fill up the bold outline which Dr Hutton has traced with so masterly a hand; to detach the parts more completely from the general mass; to adjust the size and position of the subordinate members; and to give to the whole piece the exact proportion and true colouring of nature.
>
> "This, however, in length of time, may be expected from the advancement of science, and from the mutual assistance which parts of knowledge, seemingly the most remote, often afford to one another. Not only may the observations of the mineralogist, in tracts yet unexplored, complete the enumeration of geological facts; and the experiments of the chemist, on substances not yet subjected to his analysis, afford a more intimate acquaintance with the nature of fossils, and a measure of the power of those chemical agents to which this theory ascribes such vast effects: but also, from other sciences, less directly connected with the natural history
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> (p. 140) of the earth, much information may be received. The accurate geographical maps and surveys which are now making; the soundings; the observations of currents;

> the barometrical measurements, may all combine to ascertain the reality, and to fix the quantity of those changes which terrestrial bodies continually undergo. Every new improvement in science affords the means of delineating more accurately the face of nature as it now exists, and of transmitting, to future ages, an account, which may be compared with the face of nature as it shall then exist. If, therefore, the science of the present times is destined to survive the physical revolutions of the globe, the HUTTONIAN THEORY may be confirmed by historical record; and the author of it will be remembered among the illustrious few, whose systems have been verified by the observations of succeeding ages, supported by facts unknown to themselves, and established by the decisions of a tribunal, slow, but infallible, in distinguishing between truth and falsehood."

One of the first to understood fully the philosophical implications of Hutton's ideas and not to cringe from them was Sir Charles Lyell. In the first edition of his monumental textbook, "Principles of Geology," Lyell wrote:

> "...The declaration was the more startling when coupled with the doctrine, that all past changes in the globe had been brought about by the slow agency of existing causes. The imagination was first fatigued and overpowered by endeavouring to conceive the immensity of time required for the annihilation of whole continents by so insensible a process. Yet when the thoughts had wandered through these interminable periods, no resting place was assigned in the remotest distance. The oldest rocks were represented to be of a derivative nature, the last of an antecedent series, that that perhaps one of the many pre-existing worlds. Such views of the immensity of past time, like those unfolded by the Newtonian philosophy in regard to space, were too vast to awaken ideas of sublimity unmixed with a painful sense of our incapacity to conceive a plan of such infinite extent." (Sir Charles Lyell, 1830, Principles of geology, v. 1: London, John Murray, p. 63.)

The modern view is that in its formative stages, the primitive Earth did, indeed, pass through an initial stage during which conditions differed significantly from those that became established after the atmosphere and hydrosphere made their appearances, and thus the geologic cycle as visualized by Hutton could operate. Indeed, much geologic interest was attached to exploration of the Moon and the inner planets, whose surfaces have not been subjected to anything like the geologic cycle, and thus preserve a record of what the early Earth may have looked like. Nevertheless, after all these years and much exploration, no one has yet found a rock which would disprove Hutton's basic proposition that the oldest rocks had been formed by the operation of a geologic cycle driven by what we now refer to as the hydrologic cycle (Sun-powered circulation of moisture through the atmosphere whereby rain and snow that falls upon the surface of the Earth circulates--some going immediately back directly into the atmosphere, some flowing over the surface as streams or being temporarily locked up in snowfields and/or glaciers, and some seeping underground, and eventually reaching the sea, from there to be evaporated into the atmosphere only to fall as rain or snow, and around and around and around again). It is a remarkable tribute to James Hutton that despite all the progress made in exploring the world, building a geologic time scale, calibrating that time scale in years by the analysis of the decay of radioactive isotopes, and by even the exploration of the solar system, including sending men to the Moon, his conclusions about the relationships between what is happening at the surface of the Earth today and the geologic record has not been changed significantly. It is also a remarkable tribute to the efficiency of the geologic cycle in reworking the Earth's surface materials that no traces of rocks older than the start of the geologic cycle have ever been found.

Only the concepts of plate tectonics, which began in the mid-1960s and which resulted from the truly remarkable achievements in exploration of the oceans and in refined analyses of the geophysical data about the interior of the Earth and of the Earth's magnetic field, have established fundamentally new propositions about the Earth's behavior that rank alongside Hutton's ideas of the geologic cycle as cornerstones of the science of geology.

Where a seacoast consists of sediments, it is possible to see clearly the connection between the deposition of new layers of sediment and strata-forming processes and thus to understand how many parts of the geologic record have been built. Along the south shore of Long Island, notably at the western end of the Fire Island barrier island in Robert Moses State Park, the interaction of waves and tides are so dynamic that the results do not belong to the category that Lyell referred to as "the slow agency of existing causes." Far from it; what goes on along this stretch of Long Island's south coast must be considered as the "fast agency of existing causes." Although we have been examining what is happening today, bear in mind that the present is only a short interval in the time continuum that extends from the past into the future.

TABLES

Table 01 - Dates of photo flights over Democrat Point, Fire Island, Long Island, New York, compared with astronomic data controlling tidal variations (from U. S. Government annual volumes tabulating predicted tidal heights for east-coast localities). Included are the 1970s flights recording spit cycle III and the 1982-1984 flights showing spit cycle IV.

Date of photo	**Astronomic data relating to Moon (dates)**		
Flight	**Phase**	**Apogee v. Perigee**	**Lunar declination**
Spit cycle III:			
29 Oct 1970	NM 30	A 24	E 26
14 Nov 1970	FM 13	P 09	N 15
08 Dec 1970	FM 12	P 05	E 06
07 Jan 1971	FM 11	P 31 Dec 70	N 09
15 Mar 1971	FM 12	A 12	E 12
15 Apr 1971	FM 10	A 08 P 23	S 15
14 May 1971	FM 10	A 05 P 21	S 13
17 Jun 1971	F/N Q 16	P 17	E 15
12 Jul 1971	F/N Q 15	P 12	E 13
30 Aug 1971	N/F Q 29	A 24	S 30
11 Sep 1971	F/N Q 11	A 21 P 06	N 12
29 Oct 1971	N/F Q 27	P 02 Nov 71	E 30
10 Jan 1972	F/N Q 08	A 09	S 13
23 Feb 1972	N/F Q 21	P 17	N 23
07 Mar 1972	F/N Q 08	A 04	S 08
19 Apr 1972	F/N Q 20	P 14	N 17
29 Jul 1972	FM 26	P 03 Aug 72	E 29
21 Oct 1972	FM 22	P 23	E 19
13 Mar 1973	N/F Q 11	P 10	N 11
Jul 1973	NM 29	P 28	N 26
12 Mar 1974	F/N Q 15	A 18	S 15
04 Apr 1974	FM 06	P 02	E 04
28 Jul 1974	N/F Q 26	A 03 Aug 74	S 29
14 Sep 1974	FM 16	P 14	E 15
12 Dec 1974	NM 13	A 19	S 13
09 Apr 1975	NM 11	A 07	E 09
31 Jul 1975	F/N Q 31	A 27	E 27
29 Sep 1975	F/N Q 28	P 04 Oct 75	N 27
11 Aug 1976	FM 09	A 16	E 12
12 Oct 1976	NM 08	A 10	N 13
29 Sep 1977	FM 27	A 03 Oct 77	E 26

Table 01 (Cont'd)

Spit cycle IV:

Date of photo	Astronomic data relating to Moon (dates)		
Flight	**Phase**	**Apogee v. Perigee**	**Lunar declination**
19 Sep 1982	FM 17	A 25 P 13	E 18
09 Oct 1982	F/N Q 09	P 09	N 09
19 Oct 1982	NM 17	A 23	E 16
09 Nov 1982	F/N Q 08	P 04	N 05 E 12
07 Dec 1982	F/N Q 07	P 02	E 09
02 Jan 1983	N/F Q 06	P 01(?)	E 05
31 Jan 1983	FM 28	P 28	N 27
24 Feb 1983	NM 27	P 25	N 23
03 Mar 1983	FM 27 Feb 83	A 09	E 01
24 Mar 1983	FM 28	P 25	N 22
01 Apr 1983	FM 28 Mar 83	A 06	S 05
13 Apr 1983	NM 13	P 21	E 12
27 Apr 1983	FM 27	P 21	E 25
13 May 1983	NM 12	P 16	N 16
27 May 1983	FM 26	A 01 Jun 83	S 29
13 Jun 1983	NM 11	P 13	N 12
27 Jun 1983	FM 25	A 28	S 26
12 Jul 1983	NM 10	P 11	N 10
26 Jul 1983	FM 24	A 26	S 23
02 Aug 1983	F/N Q 02	P 08	N 06
16 Aug 1983	N/F Q 15	A 22 P 08	E 12
09 Sep 1983	FM 07	P 06	E 08
07 Oct 1983	NM 06	P 04	E 06
04 Nov 1983	NM 04	P 01	E 02
19 Mar 1984	FM 17	P 16	E 18
31 Mar 1984	FM 01 Apr 84	A 29	E 01 Apr 84

APPENDIX A: WAVES: ORIGIN, CHARACTERISTICS, SHOALING, BREAKING, AND EFFECTS ON SEDIMENTS

Many kinds of waves cross the sea surface. They are caused by boat wakes, by winds blowing locally, by winds from distant storms, and by displacments of the sea floor. We shall skip over boat wakes, concentrate on wind-generated waves, and mention briefly in passing the kinds of waves generated by displacements of the sea floor. As we shall see, a close relationship exists between the kinds of waves and their sizes. The most-useful expession of wave sizes is the wave period, which is the time it takes for one wavelength to pass a given point. The periods of waves we shall discuss range from seconds to minutes.

Where wind stresses are applied directly to the water surface, they generate irregular, steep, choppy waves known as sea waves. The periods of sea waves range from fractions of a second for tiny ripples to about 10 seconds for large waves in an intense storm. The crest lines of sea waves do not persist laterally; a characteristic giving rise to their choppy aspect. Considering a large storm having a diameter of say 600 kilometers crossing an open ocean, one finds that the winds (which blow counterclockwise around a low-pressure storm in the Northern Hemisphere) generate waves that can be propagated in all directions away from the center of the storm (Figure 9). After they have traveled a few tens of kilometers away from the storm, the waves, which are now no longer subject to wind stresses, begin to reorganize and to form themselves into longer, lower, more-regular waves known as swell waves (or simply as the swell or swells). The periods of swells range from about 6 seconds up to 15 seconds. The periods of a few very large swells may reach 22 seconds or so. Off Fire Island, the periods of swells usually falls between 6 and 8 seconds. The ratio of wave height to wavelength (H/L) is used to express wave steepness. A ratio of 0.025 is used as the boundary between steep waves (usually sea waves) and low waves (swells; Figure 10).

One of the first observations to make about nearshore waves is the relationship between swells and sea waves. Notice their periods and directions of travel. Periods can be determined by counting the number of waves that break in 1 minute (60 sec). The period in seconds is the number of breaking waves counted divided into 60. Thus, if you counted 10 breaking waves in a minute, their periods are 60/10 = 6 sec.

If waves are crossing water that is deeper than twice their wavelengths, they are said to be deep-water waves. The speeds of deep-water waves are determined by their wavelengths. The longer-period waves travel faster than do shorter-period waves.

Water-surface waves that are generated by displacements of the sea floor are so long and low that in the open sea, it is not possible to notice them. Their wavelengths measure in hundreds of kilometers and their heights, in a few meters. Their periods are about 15 minutes or so. The technical term for such waves is tsunami (Japanese for "harbor waves" and spelled the same in both singular and plural, as in the English word "sheep." Despite this bit of Japanese grammar, one finds widespread usage in the English-language technical literature of the erroneous version "tsunamis," which may be taken to mean that editors of journals are not sticklers for correct usage). Because of their great wavelengths, tsunami are a special kind of waves known as very-shallow-water waves everywhere, even in the deepest parts of the oceans.

Very-shallow-water waves are defined as water-surface waves in which the depth is 1/20 or less of the wavelength. (Using y for depth and L for wavelength, this is expressed as y/L = 0.05). A fundamental principle of very-shallow-water waves is that their speeds are controlled only by the depth of water. (The mathematical statement of this relationship is the speed equals the square root of the product of the Earth's gravitational acceleration times the depth of water.) Knowing the speeds of tsunami, it is possible to use this relationship to compute the depth of water over which they have traveled. On this basis, the first estimates of the depth of the Pacific Ocean were made. The great destructiveness of tsunami results from their piling up to great heights as they approach certain coasts, Hawaii, for example.

Approach of Waves to the Shore

As waves approach shore, they first react with the bottom and, eventually, break. The depth at which waves first begin to interact with the bottom is half their wavelength, or y/L = 0.5. Some investigators have applied the name wave base to this depth (Figure A-3). At a depth of about 1/8 the wavelength (y/L = 0.125), the effects of the bottom become noticeable in that the waves begin to slow down and their profiles, to change. Crests become shorter and steeper, and troughs wider and flatter. The circular paths of the water "particles" typical of deep-water waves give way to elliptical paths, with the long axes of the ellipses parallel with the bottom (Figure A-4). The waves are now known as shallow-water waves. The speeds of shallow-water waves are determined by a function that includes both the wavelengths and the water depth.

At depths of y/L of 0.05, shallow-water waves become very-shallow water waves. (See discussion of tsunami.) A brief examination of the relationships of very-shallow-water waves will show their importance in explaining how waves behave near shore. Not all waves approaching shore become very-shallow-water waves; among those that do so, they do not experience this transformation at the same depth; as mentioned, it depends on their wavelengths, hence also on their periods. However, once a wave has become a very-shallow-water wave, its speed is fixed by the depth, and the wave slows down markedly as depth decreases. For example, at the limiting depth of 1/20 of wavelength (=L/20), the speed of a wave decreases to about 60 per cent of its former speed. By the time the wave encounters water about 2 meters deep, its speed may have been reduced to about one quarter of its speed in deep water.

In the opinion of JES, the fundamental importance of this change of many shoaling waves from shallow-water waves to very shallow-water waves has been generally overlooked. In some analyses, the nearshore waves are treated as if they were solitary waves. This may be justified on the basis of mathematical convenience, but it in no way coincides with reality.

JES thinks that this remarkable change to very-shallow-water waves explains some waves, notably swells arriving on the California coast undergo such obvious nearshore wave refraction (defined as the change of direction of waves as a result of decreasing depth or of an encounter with a current traveling against the waves). Table A-1 shows some examples.

Table A-1. Relationships of wave periods, depths, and speeds

Period of waves (sec)	Speed of deep-water waves (m/sec)	Depth of water at wave base (m) (L/2)	Depth where waves become very-shallow-water waves (m) (L/20)	Speed of v-s-w waves at depth of conversion (m/sec)
08	12	50	5.0	07
05	09	20	2.0	05
04	6.6	12	1.2	04
03	3.4	07	0.7	3.1

In the zone of shoaling transformations, the shoaling waves impart an oscillatory motion to the bottom, which may give rise to wave-generated ripple marks (Figure A-5). Two noteworthy geologic characteristics of such ripple marks are their transverse profiles and the directions of the trends of their crest lines.

The transverse profiles of wave-generated ripple marks differ according to location on the bottom. In the outer zone of shoaling waves, ripple profiles are symmetrical; their crests are pointed and their troughs are rounded and concave up. In the inner zone of shoaling waves, ripple profiles are asymmetrical; their crests are rounded and their steeper sides are toward shore (Figure A-6). This configuration results from the changes in relative strengths of the back-and-forth oscillations of the bottom water as shoaling proceeds. In the outer part of the zone of shoaling waves, the oscillatory motion of the bottom water under water-wave crests equals that under water-wave troughs. In the inner part of the zone of shoaling waves, the shore-ward surge beneath the wave crests exceeds that of the offshore surge beneath the wave troughs. (Compare Figures A-4, A and A-4, C).

The second characteristic of geologic value is that the trends of the crests of wave-generated ripple marks are perpendicular to the direction of travel of the shoaling water waves. Where the shoaling waves are traveling straight in toward shore or if they arrive obliquely but have been significantly refracted, their crests parallel the shore. Correspondingly, the trends of ripple marks made by such shoaling waves are parallel to shore (Figure A-7, B, Loc. 4 on 26 Aug).

Waves break because the crests, steepened by reactions with the bottom during the shoaling transformations, exceed the limiting crestal-peak angle of 120 degrees. This can be expressed as a steepness ratio of deep-water wave height, H, divided by deep-water wavelength, L, as $H/L = 0.143$ (See Figure 10, B). Another relationship between deep-water wave height, H, and breaking depth is that breaking results at a depth of 1.28 H. If one recalls the limiting depth ($y/L = 0.05$) for conversion to very-shallow-water waves, then it is possible to use these relationships to calculate a limiting value of wave steepness (defined as H/L) for waves that will break before they become very-shallow-water waves.

We begin by setting the limiting breaker depth equal to the limiting depth for very-shallow-water waves:

Breaker depth = 1.28 H = 0.05 L (limiting depth for very shallow-water waves)

Clearing and solving for H/L:

H/L = 0.05/1.28, which is = 0.039

This means that waves steeper than 0.039 will break before they can be converted into very-shallow-water waves. This means, further, that steep, short-period waves may break before they experience the rapid refraction related to the zone of very-shallow-water waves. Accordingly, such steep waves can approach the breaker zone from any angle. This relationship explains the observations of ripple axes trending at oblique angles to shore, as in Figure A-6, B, Loc. 3 on 20 Aug.

Off Long Island, the swells doubtless are refracted as they cross the wide, shallow continental shelf. Relationships comparable to those that have been shown for the Virginia shelf (Goldsmith, 1976) can be expected on the Long Island shelf. Correspondingly, sectors of Long Island beaches undergoing chronic erosion may be responding to convergence of wave energy as a result of refraction during their travel over the Long Island shelf.

Zone of shoaling waves; shoreface. The seaward side of a barrier (or open coast) extending from the outer edge of a beach to a distinct change in slope is the shoreface (See Figure A-3). The shoreface is underlain by sediments affected chiefly by shoaling waves. Under typical conditions, the shoaling waves establish a nearly symmetrical back-and-forth action within the lower flow regime. But, conditions on a shoreface range widely between two end-member extremes. At one end of this range is zero wave action. At the other end is intense bottom-water shearing within the upper flow regime. During fair weather, the shoaling waves erode the shoreface and transport sand to the beaches. During storms, the sediment dispersed into the water column may be transported offshore.

In fair weather, when the water surface is being crossed by only small sea waves and small swells, sediments underlying the outer part of the shoreface are not shifted by wave action. At such times, the chief processes affecting the bottom sediments result from the activities of bottom-dwelling organisms. All organisms that live on the bottom of the sea are collectively designated as the benthos (=benthonic or benthic organisms). Depending on their life styles, benthonic invertebrate animals are subdivided into the epifauna, invertebrates that live upon the sea bottom, and the infauna, invertebrates that live in burrows or in other shelters within the bottom materials. The moving epifaunal organisms leave tracks and trails on the sediment/water interface. The infauna (and a few kinds of epifauna that probe or dig into the bottom in their efforts to feet upon the infauna) make various kinds of holes, burrows, and tunnels within the sediment and in so doing, may create numerous mounds and semicircular depressions on the bottom. Their activities result in burrow-mottled sediment.

The bottom lying just seaward of the shoreface is rippled by the effects of shoaling waves of moderate storms and is jostled by the shoaling waves from severe storms. Otherise, unless it is subject to strong tidal currents or wind-driven currents, it is quiet. During storms, the sediments underlying the entire shoreface are agitated, perhaps violently. No one really knows what happens on the shoreface during a storm. However, several pieces of indirect evidence contain important clues. These include reports from captains of sailing vessels; from one extraordinary accumulation of large clams on New Jersey beaches; from cores of shoreface sediments from off Long lsland, New York; and from distinctive curved strata deposited in mounds or hummocks.

Several published reports relate stories told by sea captains of finding sand on deck after storm waves had broken over the bows of their ships, which had been caught in storms near the shore where the charts showed water depths of 20 m and the bottom to be composed of sand. If these reports are true, they imply that the storm waves dispersed substantial quantities of sand from the bottom and perhaps even placed large amounts of sand into suspension. The feasibility of these stories of sand on the decks of ships during storms can be judged by comparing them with the following true-life adventure story of some New Jersey clams.

A remarkable accumulation on the beach at Ocean City, New Jersey of countless thousands of still-living pelecypods (Mercenaria mercenaria) took place on 27 and 28 February 1961. Such organisms normally live in burrows in the sediments underlying the outer part of the shoreface. How could they possibly have been taken from their burrows and tossed on shore? Ordinarily, clams do not care for this sort of adventure. Quite the contrary; in order to remain as part of the infauna, burrowing clams are capable of deepening their burrows very rapidly.

Thus, if the bottom starts to be lowered, the normal thing is for the clams immediately to dig in deeper. However, during the winter, the temperature of the bottom water off New Jersey drops into the range of 1° to 4° C. This is not cold enough to kill the infauna, but it is cold enough to chill them to the point where they cannot react very quickly. Thus, if large shoaling waves apply shearing stresses to the bottom sediments while cold bottom water has immobilized the infauna, the waves may lower the level of the bottom and the animals are helpless to do anything about it. Result: the burrowing organisms are washed out of their burrows and become playthings for the waves.

If the foregoing explanation is correct, then on the days concerned, the waves off the New Jersey coast must have lowered the sandy bottom by at least 30cm (depth of normal Mercenaria burrow). We can infer, therefore, that the shearing stresses applied to the bottom by the shoaling waves dispersed the bottom sediment and released countless thousands of clams from their burrows. Only the chilled clams were deposited on the heach. The result was a gigantic accumulation of "clams-in-the wholeshell." On exposure to the atmosphere, the clams died and the beach soon became one vast stinking mess. What became of the sand? We do not know for sure, but can guess that as the large shoaling waves died down, most of the dispersed and/or suspended sand probably was deposited back on the shoreface once again. The sand definitely was not deposited on the beach along with the clams.

We do not know of any further information about this New Jersey episode, but we do know that long cores of modern shoreface sediments off Long Island, New York, consist of thick (up to 2m) sediment couplets. The basal parts of these couplets contain structureless gravel, up to several tens of centimeters thick and containing well-rounded pebbles of rock fragments up to 4 cm in diameter, and a few large broken shells. This coarse basal zone is overlain by slightly micaceous, very well-laminated fine sands up to 2m thick. No skeletal remains of any kind have been found in these well-laminated shoreface sands.

We infer that these sediment couplets resulted from the effects of large shoaling waves, possibly storm waves. During the most-intense wave action, all the sand now forming the laminated part of these specimens was dispersed within the water (possibly kept in suspension), leaving the gravel as a widespread lag pavement on the shoreface. All large organisms and/or skeletal debris of large clams, for example, seem to have been separated from the dispersed (and/or suspended) terrigenous sediment. (Possibly the large skeletal materials were deposited on the beach, as were the New Jersey clams mentioned above). At certain times on the beach at Fire Island, large disarticulated shells are present, but no live clams. Conclusion: waves dispersed the bottom sand, the living clams burrowed in deeper, but the skeletons of dead individuals could not do so, and thus were exhumed and tossed ashore. Other skeletal debris may have been broken into pieces too small to identify. As the intensity of the wave action diminished, the dispersed (and/or suspended) sand was redeposited on the bottom. The plane-parallel laminae imply that while the sand was being deposited, the stable bed configuration was a plane surface. This suggests conditions analogous to those in the transition from the lower flow regime to the upper flow regime of alluvial channels.

If shoaling waves could disperse and/or suspend enough sand to deposit 2 m of laminated sand after a storm, then the water column could very well have contained sand all the way to the surface. Using 30 percent porosity and the density of quartz, a prism of bottom sediment 10 cm on a side and 2 m long contains a volume of 20 liters within which are 37,100 grams of quartz, or 1855 grams per liter. If this same amount of sediment were uniformly dispersed through a water column 10 cm square and 20 m deep (volume = 200 l) the concentration would be 9.275 g/l. Perhaps after all, those old "sea dogs" gave accurate reports when they said that storm waves left sand on the decks of their ships.

If only deep-water waves are present, then burrowing organisms would recolonize the inactive bottom. In either case, the top 30 cm or so of the shoreface sediments would be reworked. Ripple marks and wave-ripple laminae appear in the sediments influenced by small shoaling waves; burrow mottles riddle the sediments not subject to wave action.

On the modern barrier off Long lsland, the distinctive modern examples of shoreface sediments just described are confined to depths ranging from 5 to 21 m. We regard these sediments as being extremely diagnostic and of potentially great value in reconstructing ancient marine environments where the shelf seaward of the shoreface of is underlain by sand.

In other localities, a sandy shoreface gives way seaward to silt or clay. In the absence of large waves, the depth of the sand-silt transition may be a reflection of the time-averaged wave base. If this sand-silt boundary moves back and forth, the result may be the interbedding of layers of sand with layers of silt. The mechanism by which shoreface sand moves outward over silt is not known. This is only one of the many areas of ignorance about the sediments of modern shorefaces. Doubtless, many surprising things will be learned as research on this topic progresses.

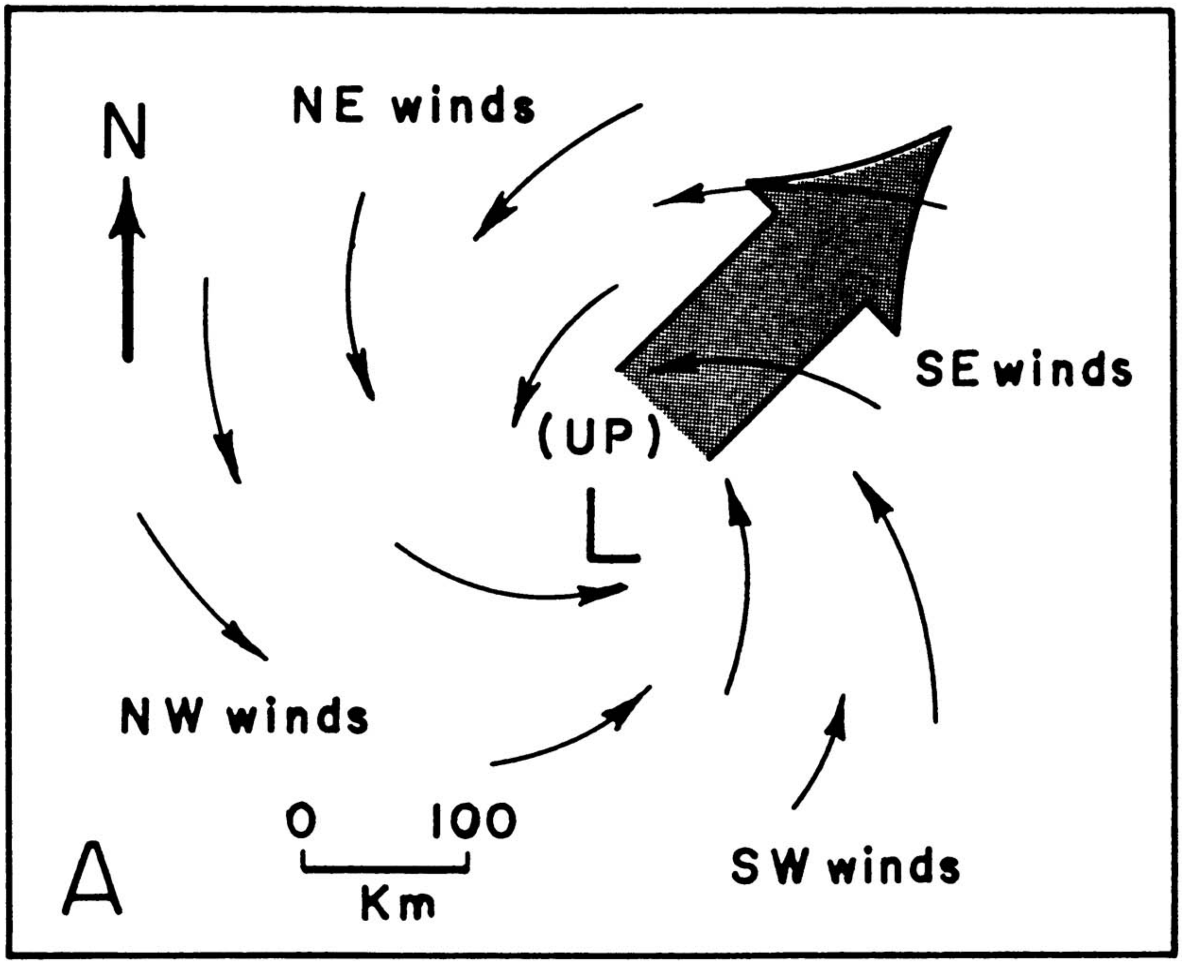

Figure A-1. Schematic view, from above, of spiral low-pressure cell of a storm crossing an ocean in the Northern Hemisphere. Storm center is moving NE (large arrow; small arrows show winds at the Earth's surface. In SE quadrant, the forward speed of the storm adds to the speed of the SW circumferential winds. Here, surface winds reach maximum values. In NW quadrant, the forward speed of the storm is opposite to and thus subtracts from the circumferential NE winds. Here, surface circumferential winds reach their minimum values. (G. M. Friedman and J. E. Sanders, 1978, Principles of Sedimentology: New York, John Wiley & Sons, Inc., Figure A-2, A, p. 465.)

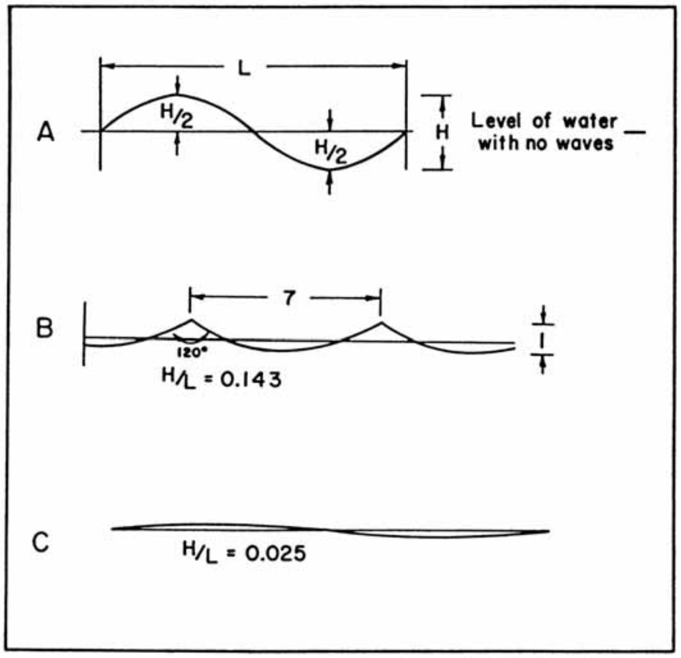

Figure A-2. Profiles of waves sketched in a vertical plane parallel to their direction of travel.
A. Idealized, symmetrical wave; the same as the graph of a sine function. Much vertical exaggeration.
B. Symmetrical waves having critical limiting steepness. Waves break before they become any steeper than 1/7 (H/L = 0.143).
C. Symmetrical wave showing dimensions of waves used as the
boundary between steep and low; no vertical exaggeration. (From Friedman and Sanders, 1978, Fig. A-1, p. 465.)

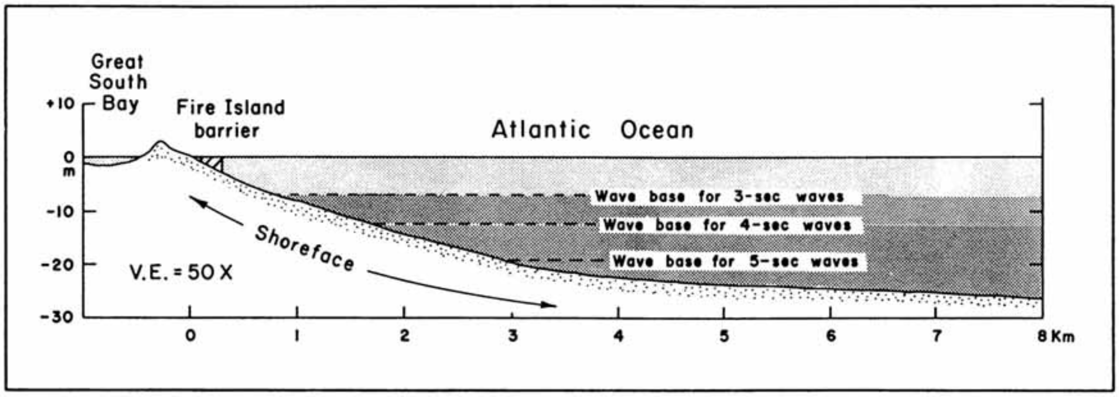

Figure A-3. Profile at right angles to shore off Fire Island barrier island, Long Island, New York, showing depths to wave base for several sizes of waves (based on periods). Diagonal lines near the shoreline mark the zone where swells having 6-sec periods be- come very-shallow-water waves. Because of the wide, shallow shelf, most swells are refracted so that they approach the shore straight on in most localities. Thus, aerial photographs do not show pronounced refraction of the swells near shore, as on the Pacific coast. (From Friedman and Sanders, 1978, Fig. A-15, p. 474.)

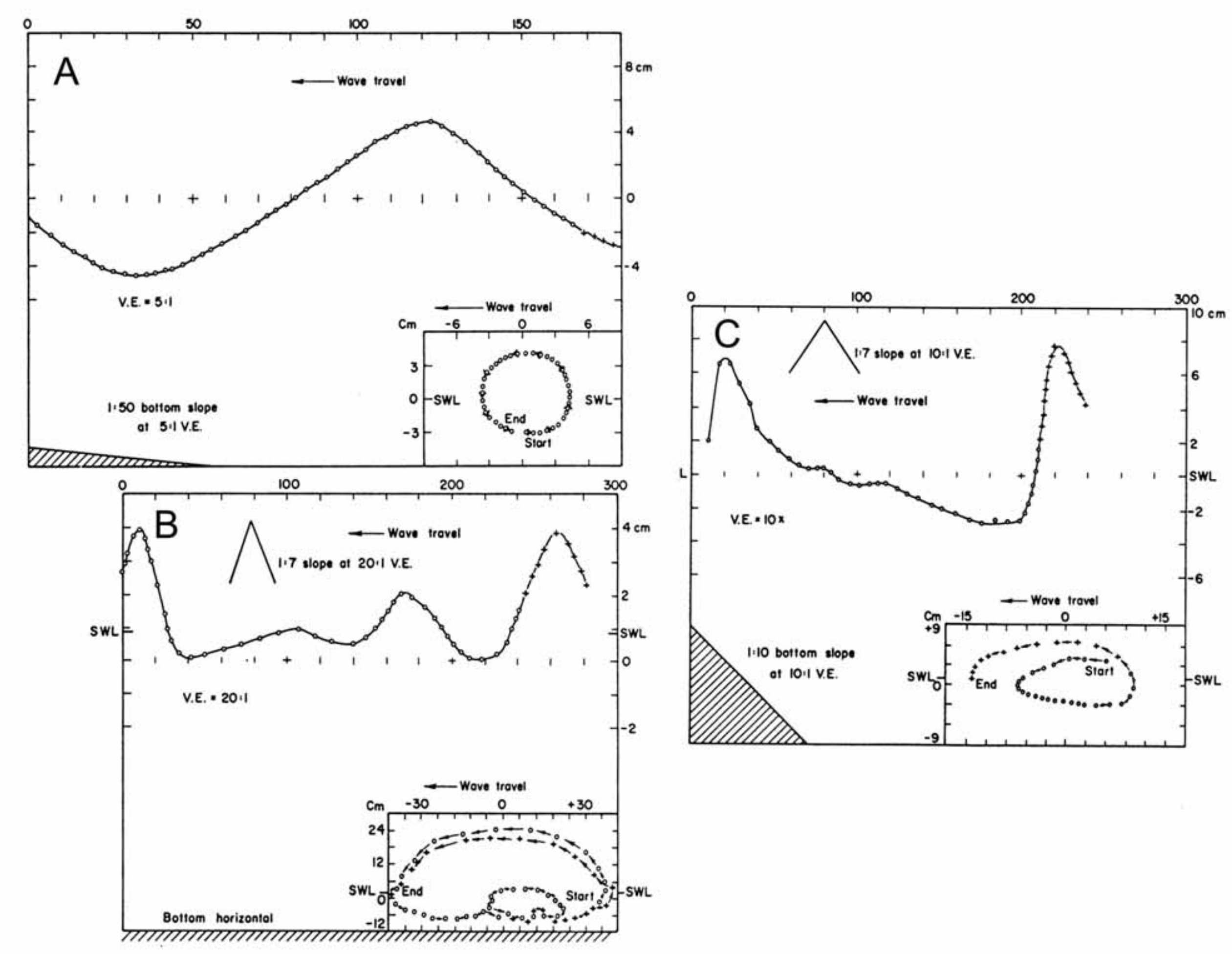

Figure A-4. Shoaling transformations shown by single-frame pro- jection of movie film taken of neutrally buoyant particles through glass side of a large wave tank (dimensions 0.3 x 1 x 20 m).

A. Shoaling waves (H=9 cm; L=158 cm; period=1.06 sec; water 36 cm deep with bottom sloping 1:50; H/L=0.057; y/L=0.228) that are still nearly symmetrical and with water-particle orbits circular (lower right).

B. Much-transformed waves close to breaking limit (H=3.8 cm; L=254 cm; period=2.67 sec; water 8.9 cm deep; bottom horizontal; H/L=0.015; y/L=0.035. Secondary wave in the flattened trough has generated a smaller elliptical path at the base oe oe oe of the main ellipse.

C. Steep waves just prior to breaking (H of breakers, 11.3 cm; H/L of waves outside breaker zone=0.0206; period of breaking waves 1.51 sec; depth of water at breakers=9.14 cm; bottom slope=1:10. Orbits are elliptical; mass transport is in direction of wave travel. (From Friedman and Sanders, 1978, Fig. A-11, p. 470-471.)

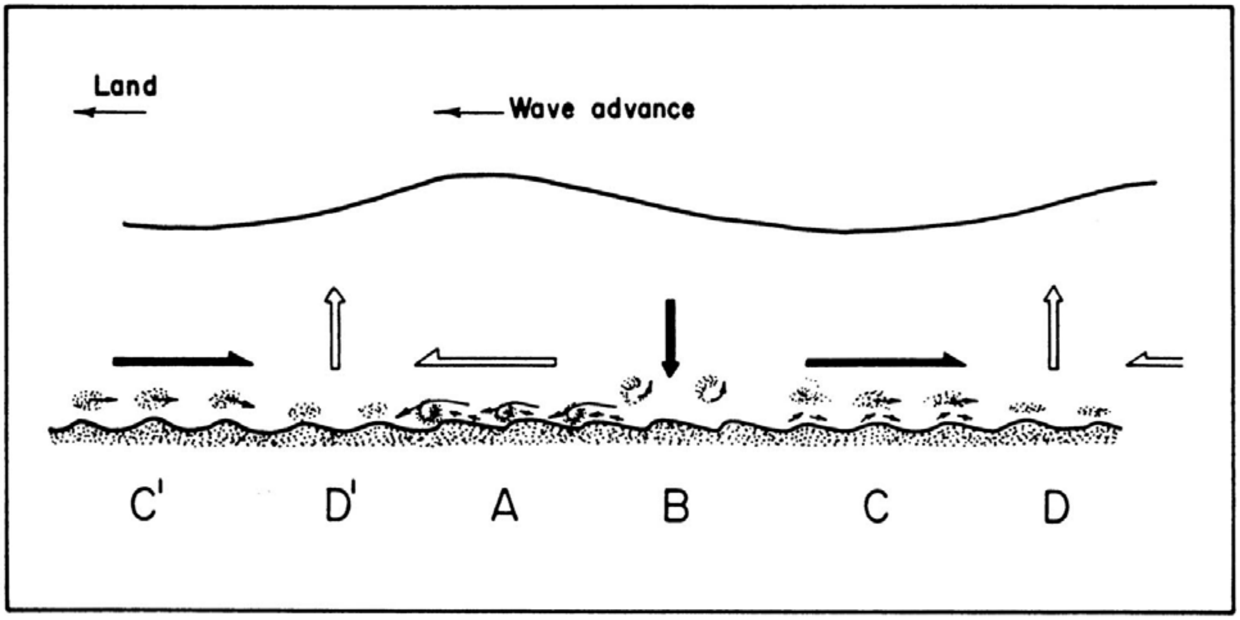

Figure A-5. Schematic profile in vertical plane parallel to direction of travel of shallow-water waves showing relationships responsible for wave-generated ripple marks in bottom sand; sizes of bottom ripple marks not related to size of water-surface waves.

Under wave crest, at A, wave-induced bottom-water oscillation surges landward (open arrow with one barb), thus imparting shearing stresses from water to bottom, which creates asymmetrical ripple marks having steeper sides landward. The tiny eddies on the downshear sides of the sand ripples tend to rise through the water, to enlarge, and to dissipate.

After the water-wave crest has passed, at B, the water surges vertically downward (large vertical black arrow), carrying sediment back toward the bottom.

Beneath wave troughs, at C and C', bottom-water oscillates in a direction opposite to wave advance (large horizontal black arrows with one barb), imparting shearing stress to the bottom sediment that is directed away from shore and creating sediment- laden eddies on both sides of sediment ripples, whose profiles now become symmetrical or nearly symmetrical.

After a water-wave trough has passed, as at D and D', the bottom water surges vertically upward, lifting sediment-laden water, and thus tending to facilitate sediment transport by the landward surge accompanying the passage of the next wave crest. This is just the opposite of what happens beneath a water-wave trough, where a vertical downward surge of water precedes the seaward surge, a situation tending to inhibit sediment transport. (From Friedman and Sanders, 1978, Fig A-16, p. 476.)

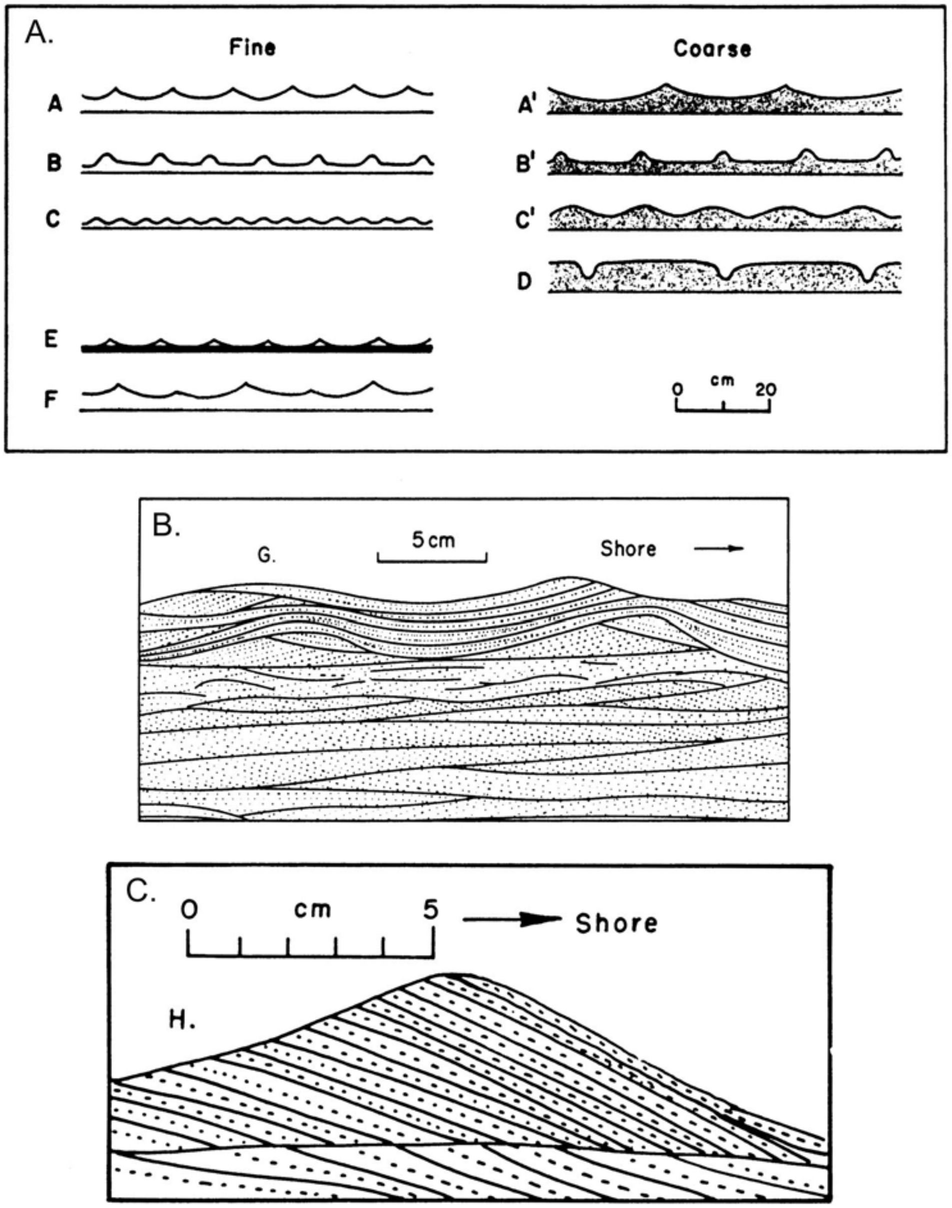

Figure A-6. Varieties of wave-generated ripple marks shown by transverse profiles in vertical planes at right angles to ripple trends.
A. Symmetrical ripples that are smaller in fine sand than in coarse sand.
B and C. Sketches of internal laminae shown by relief peels made from box cores collected off the German coast of the Baltic Sea.
B, slightly asymmetric ripples in which most cross laminae dip landward, but a few dip seaward.
C, asymmetric ripple in which all cross laminae dip toward shore. (From Friedman and Sanders, 1978, Fig. A-17, p. 477; B and C from R. S. Newton, 1968.)

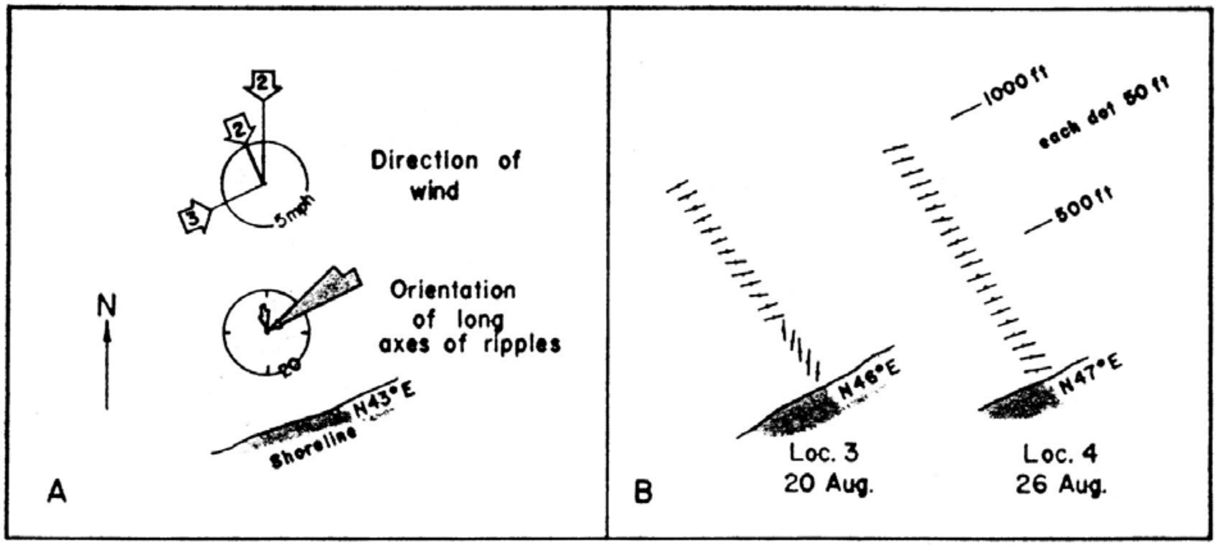

Figure A-7. Trends of wave-generated ripple marks in nearshore sand, SW Lake Michigan, Berrien Co., Michigan, observed by R. A. Davis, Jr., in August 1963, compared with directions of winds and trend of shoreline.

A. Summary of all observations. Lines in upper rose diagram show wind speeds (lengths proportion to miles per hour; circle gives reference length for 5 mph) and wind directions. Numerals inside open arrows give number of days the wind blew from that direction. Lower rose diagram summarizes long axes of all wave-generated ripple marks measured (plotted in 5-degree sectors). Lengths of pie-shaped sectors are proportional to total number of ripple axes measured within each 5-degree class. Circle gives reference length for 20 readings.

B. Maps of ripple orientations at two closely spaced stations on different days. Observation points (dots) were spaced 50 feet apart on line perpendicular to shore. At Loc. 3 on 20 Aug 1963, inner ripples trend oblique to shore but are practically perpendicular to wind from the WSW; the trends of the outer ripple set are nearly parallel to shore. At Loc. 4 on 26 Aug 1963, the trends of all ripples nearly parallel the shore and are perpendicular to waves from the NNW. (From Friedman and Sanders, 1978, Fig 9-16, p. 251.)

APPENDIX B: TIDES

Nearly anyone who has visited the seashore is aware of the daily changes of water level known as the tides. Moreover, this awareness may extend to the notion that tidal action is somehow connected to the Moon and/or the Sun. But, beyond that, a certain vagueness is likely to prevail. In order to keep all participants in this trip on the same level, the following paragraphs review the principles of the tides, with emphasis on the factors that create cyclic variability.

The first principle which one needs to understand in analyzing the ocean tides is one of the fundamental precepts of celestial mechanics, namely that in any pair (or more) of orbiting bodies, the focus of the elliptical orbits is not the center of any of the orbiting bodies (not even that of one body which may be very much larger than the others), but rather is the common center of mass (=barycenter) of all the bodies.

Orbit of the Earth and the Moon Around the Earth-Moon Barycenter

As for the Earth and the Moon, their common center of mass, or barycenter, lies within the Earth in a zone that ranges in depth from the surface between 1436.5 km at lunar apogee and 2047.5 km at lunar perigee (the mean value is 1707 km; Figure B-1).

To a first approximation, tidal rise and fall of the sea can be visualized as resulting from the interaction of a rapidly rotating oblate spheroid, the solid Earth, and a slower-moving prolate spheroid of the Earth's oceans that results from and moves around with the orbiting Earth-Moon pair. This concept forms what is known as the equilibrium theory of tides (Figure B-2). Another way of describing the prolate spheroid is to visualize the ocean as consisting of two "bulges," one on the side of the Earth that is toward the Moon, and the other, on the side of the Earth that is opposite the Moon. These two "bulges" result from the ocean water's combined interactions between the Moon's gravitational attraction, which varies cyclically as the longitude of lunar perihelian shifts, and the centrifgal force of the Earth-Moon pair's orbit around the Earth-Moon barycenter (not to be confused with the centrifgual force associated with the Earth's daily rotation on its polar axis, which results in the oblate shape of the solid Earth).

The three chief variables that can be noticed easily on a monthly time scale are phase, Earth-Moon separation distance, and declination. The phases of the Moon result from the ever-changing alignments of the Sun, the Earth, and the Moon. Twice during each orbit, the Moon experiences what are known as syzygy phases; that is, times when the centers of the Sun, the Earth, and the Moon lie along a straight line. At the syzygy of New Moon, the Moon lies between the Earth and the Sun. At the syzygy of Full Moon, the Earth lies between the Sun and the Moon (Fig. B-3).

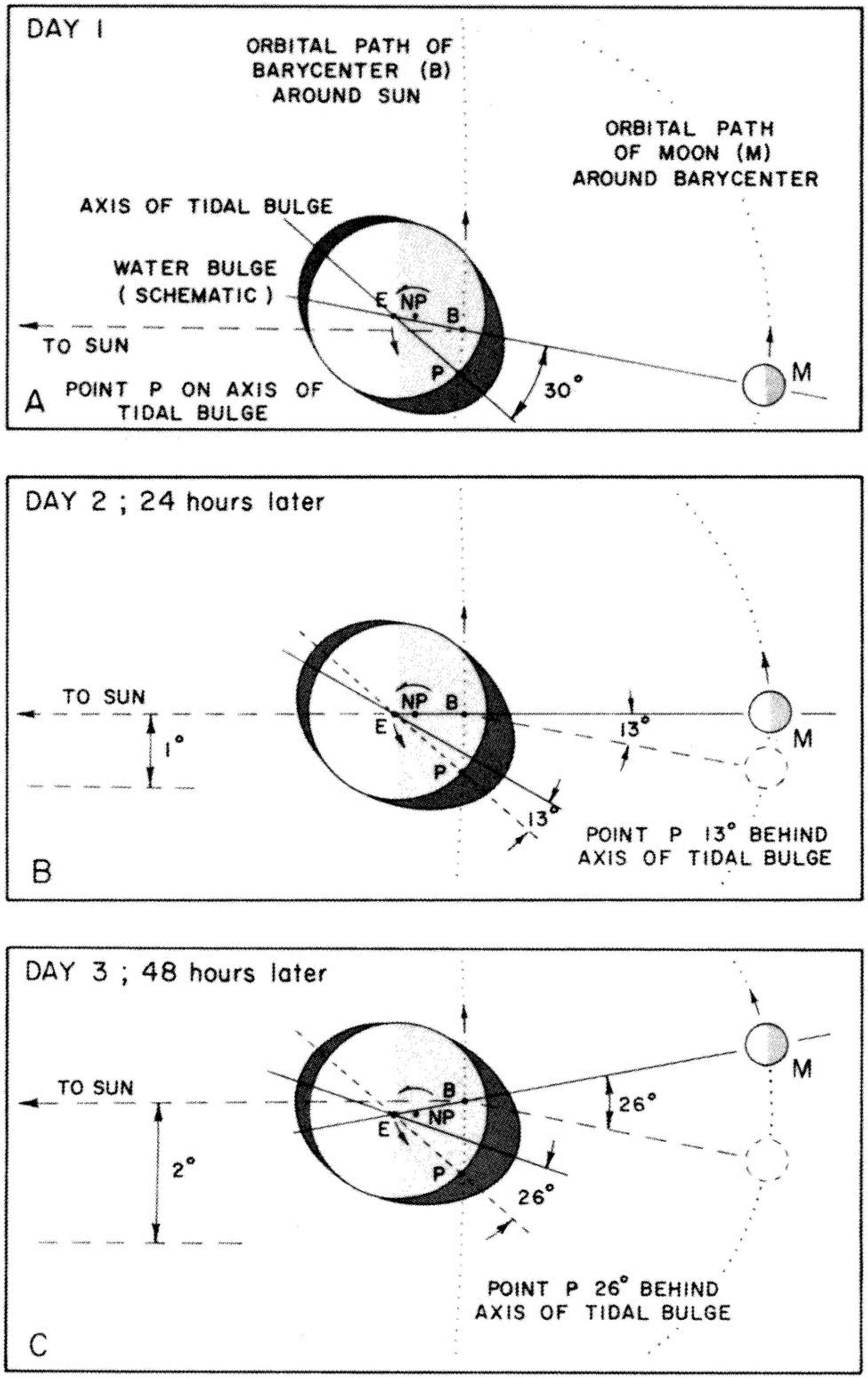
DAY 1
ORBITAL PATH OF BARYCENTER (B) AROUND SUN
ORBITAL PATH OF MOON (M) AROUND BARYCENTER
AXIS OF TIDAL BULGE
WATER BULGE (SCHEMATIC)
E
NP
B
TO SUN
P
30°
M
A
POINT P ON AXIS OF TIDAL BULGE
DAY 2 ; 24 hours later
TO SUN
NP
B
E
1°
13°
M
P
13°
POINT P 13° BEHIND AXIS OF TIDAL BULGE
B
DAY 3 ; 48 hours later
M
TO SUN
B
NP
E
26°
2°
P
26°
POINT P 26° BEHIND AXIS OF TIDAL BULGE
C

Figure B-1

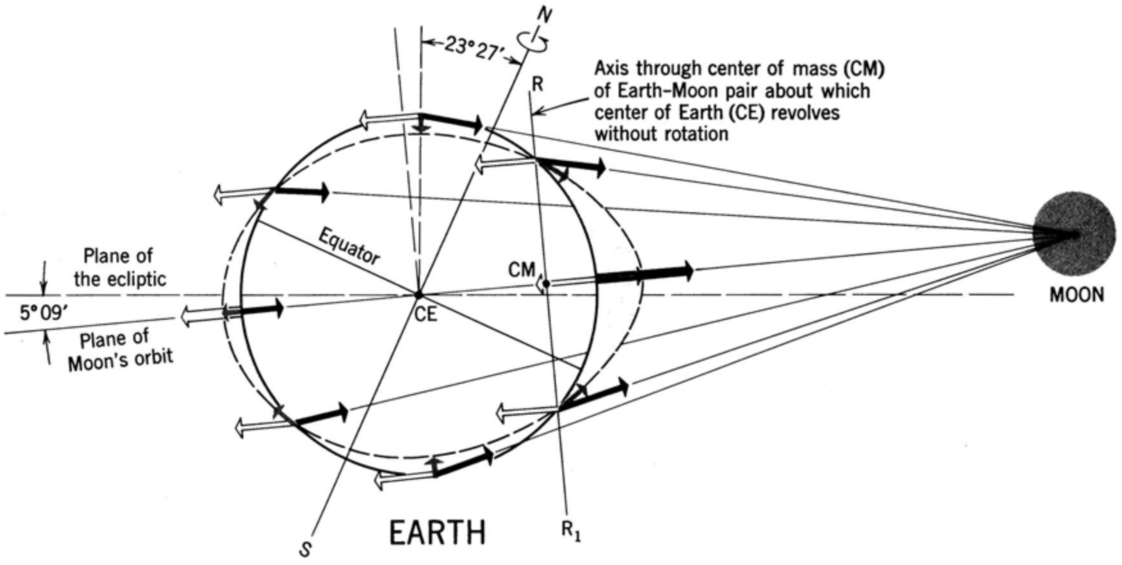

Figure B-2

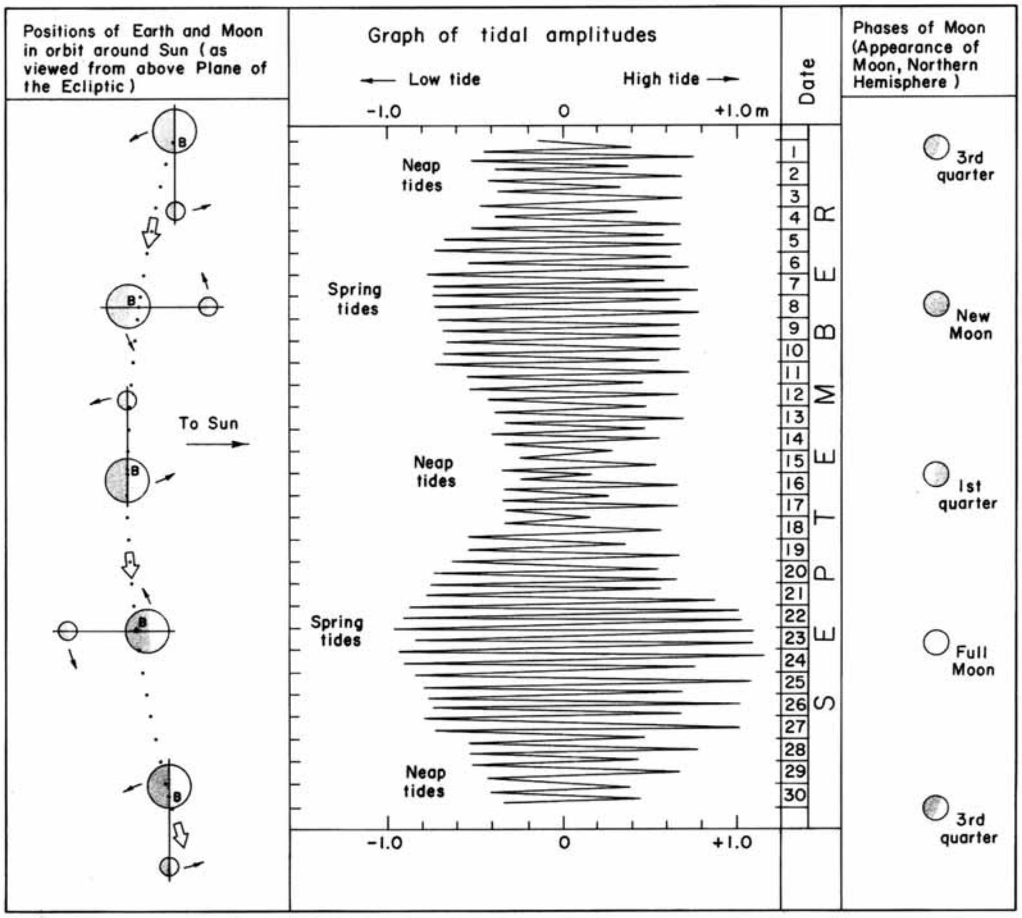

Figure B-3

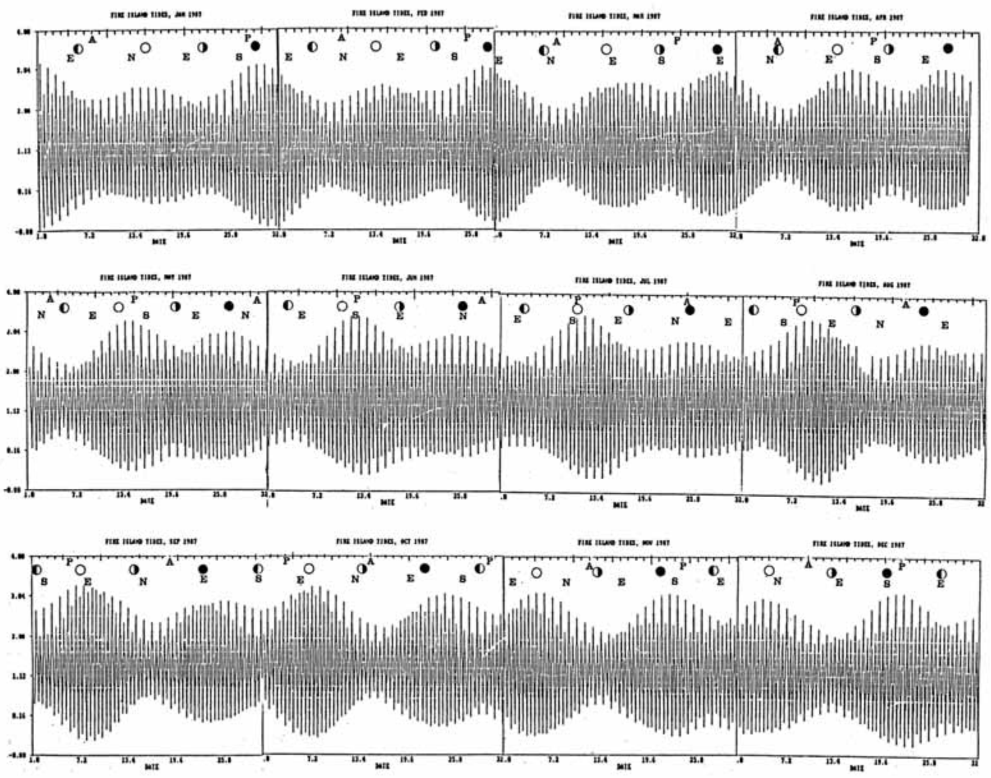

Figure B-4

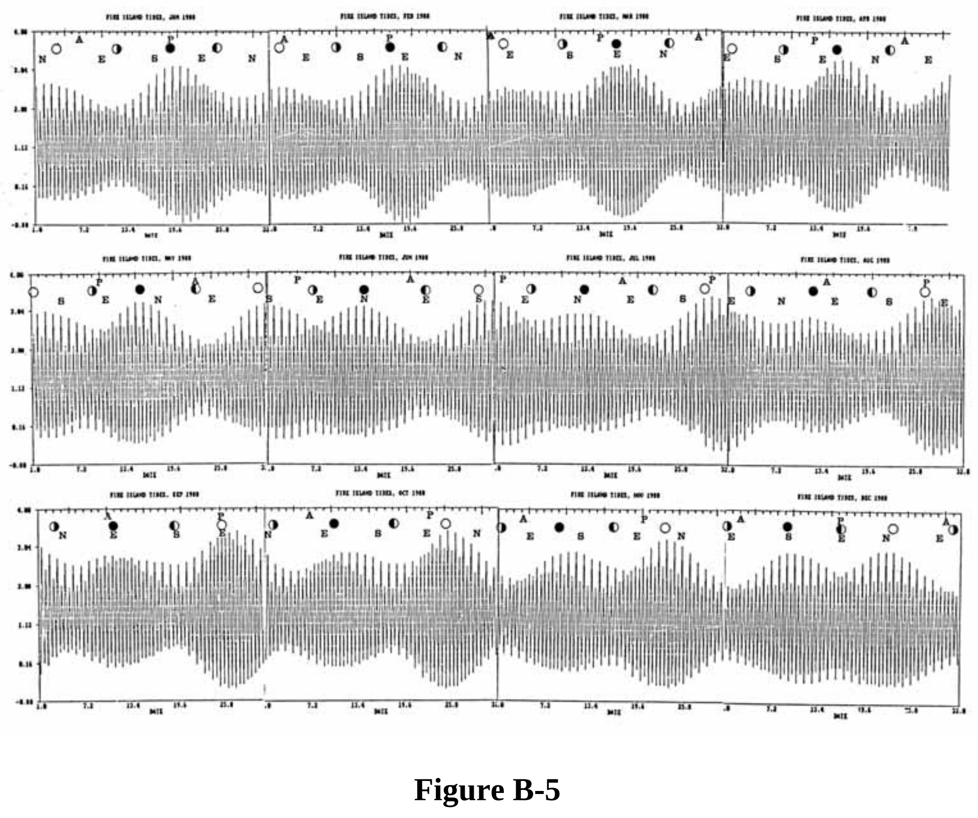

Figure B-5

Tidal Cycles

From the foregoing, it can be seen that tidal cycles are numerous and are the result of many interacting factors. Figures B-4 and B-5 are graphs of predicted tidal levels for Fire Island Inlet for 1987 and 1988. These graphs have been drawn on an IBM PC having a Hercules graphics board added and using a spreadsheet made with a Lotus 1-2-3 program. The spreadsheet program accepts as inputs the dates, times, and predicted heights for Sandy Hook, New Jersey, as given in the National Ocean Survey (NOS) yearly tidal tables. The program then converts to the times and heights at Fire Island Inlet. After the computer-drawn graphs have been prepared, JES added in by hand drafting the features along the tops of each monthly graph: reference marks for each day and the astronomic data (also from the NOS tide-table publication), which includes apogee (A), perigee (P), phases of the Moon, and declination of the Moon (N = farthest north; E = above the Earth's Equator; and S = farthest south).

The two yearly graphs clearly show how the amplitude bulges shift back and forth between peaks at New Moon-perigee and Full-Moon perigee. Late in December 1986, New Moon and perigee coincided just a few days before perihelion. During the first three months of 1987, the amplitude peak coinciding with the New Moon phases decreased, whereas that coinciding with the Full Moon phases increased. By April, they were equal. Thereafter the amplitude peaks of the Full Moon phases became the larger ones, reaching a maximum in early July, and thus completing half of a perigee-syzygy cycle. During the rest of the year, the Full Moon amplitude peaks decreased, whereas the New Moon peaks increased. Equality was reached in November 1987, after which time the New Moon peaks exceeded the Full Moon peaks. The New Moon maxima of January and February 1988 completed a full cycle. Amplitude equality was reached in late May-early June 1988, and the Full Moon amplitude maximum will appear in late September. The importance of the perigee-syzygy cycles in coastal activities has been emphasized by Fergus J. Wood (1976) in his monograph entitled: "The strategic role of perigean spring tides in nautical history and North American coastal flooding, 1635-1976." Subsequently, he published a revised version with Elsevier, but as one familiar with such things might guess, the volume published by the US GPO costs about 1/5 of what Elsevier charges.

Also apparent from the yearly tidal graphs is the effect of the lunar declination. Notice how the diurnal inequality nearly or completely disappears when the Moon is above the Earth's Equator.

We have selected the date of this field trip by the predicted tidal heights, notably to be present near the culmination of what is known as a perigee-syzygy cycle. In September 1988, perigee and Full Moon coincide on the 25th; the year's highest predicted PM tide falls on the evening of Wednesday, Sept. 28. (In 1989, Full Moon on the Equator is 15 Sep.; perigee is on 16 Sept.). Times of higher-than-normal astronomic tides represent what might be termed "windows of vulnerability" for coastal areas. During intense coastal storms, the higher-than-normal wind-generated waves typically are accompanied by storm surges. Potential for severe damages varies according to the relationships between times of maximum waves and/or storm surge and times of maximum astronomic tides. For example, the last hurricane to graze the New York metropolitan area made landfall a few hours after high tide. As a result, coastal flooding was not serious. By contrast, in March 1962, at a time when New Moon and perigee coincided (on the 6th) and the Moon was over the Earth's Equator (on the 8th), a severe coastal storm raged for several days. This storm was one of the most destructive in modern time along a segment of the Atlantic coast reaching from Long Island to North Carolina. High wind-generated waves and storm surge persisted through 5 consecutive high tides that were not only higher than normal because of the perigee-syzygy coincidence but also of equal height because of the Moon's equatorial position.

Study of the strata deposited when sand builds up beaches or spits suggests that most activity takes place during a few days when successive tidal high-water levels increase as the amplitude maxima of a perigee-syzygy coincidence are approaching. Local studies of the relationship between strata deposited during upward accretion and lunar cycles have not yet reached the point where one can relate a given layer to a particular tidal-cycle setting.

REFERENCES CITED

Allen, J. R., and Psuty, N. P., 1987, Morphodynamics of a single-barred beach with a rip channel, Fire Island, New York: Coastal Sediments '87: American Society of Civil Engineers, p. 1964-1975.

Andrews, K. S., Dacunha, N. M., and Hogben, N., 1983, Wave climate synthesis: Faltham, England, National Maritime Institute, NMI Report No. R 149, 143 p.

Andrews, W. E., 1938ms., Restoration and protection of Fire Island: Babylon, New York, Long Island State Park Commission.

Arcilla, A. S., Vidaor, A., and Monso, J. L., 1987, Influence of breaker type on surf zone (sic) dynamics, p. 909-922 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Taipei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Arthur, R. S., 1946, Refraction of water waves by islands and shoals with circular bottom-contours (sic): American Geophysical Union, Transactions, v. 27, p. 168-177.

Arthur, R. S., 1951, The effect of islands on surface waves: La Jolla, California, Scripps Institute of Oceanography, Bulletin, v. 6, p. 1-26.

Bagnold, R. A., 1963, Beach (sic) and nearshore processes. Part I. Mechanics of marine sedimentation, p. 507-528 in Hill, M. N., gen. ed., The sea--ideas and observations on progress in the study of the seas: New York and London, Wiley-Interscience, v. 3, The Earth beneath the sea, 963 p.

Bakker, W. T., and van Kersteren, W. G. M., 1987, The dynamics of oscillating sheetflow, p. 940-954 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Bascom, W. J., 1954a, Characteristics of natural beaches, p. 163-180 in Johnson, J. W., ed., Conference on Coastal Engineering, 4th, Proceedings: Berkeley, California, Council on Wave Research, 398 p.

Bascom, W. J., 1954b, The control of stream outlets by wave refraction: Journal of Geology, v. 62, p. 600-605.

Bascom, W. J., 1964, Waves and beaches; the dynamics of the ocean surface: Garden City, New York, Doubleday and Company, 267 p.

Bates, C. C., 1949, Utilization of wave forecasting in the invasions of Normandy, Burma and Japan: New York Academy of Sciences, Annals, v. 51, p. 545-569.

Baumgaertner, Imre van, 1975, A major beach erosional (sic) cycle at Robert Moses State Park, Fire Island, during the storm of 1-2 December 1974: the confirmation of "grazing-swash undercutting" as a major beach erosional (sic) mechanism, p. 259-278 in Wolff, M. P., ed., New York State Geological Association, Annual Meeting, 47th, Hofstra University, Hempstead, New York, 31 Oct.-02 Nov. 1975, Guidebook: Department of Geology, Hofstra University, Hempstead, New York, 327 p.

Baumgaertner, Imre van, 1977 ms., Some new processes of beach dynamics, Robert Moses State Park, Fire Island, New York: New York, New York, Columbia University, Department of Geological Sciences, Ph. D. dissertation, 456 p.

Bennett, H. H., 1939, A permanent loss for New England: soil erosion resulting from the hurricane: Geographical Review, v. 29, p. 196-204.

Bobb, W. H., and Boland, R. A., Jr., 1969, Channel improvement, Fire Island Inlet, New York: Vicksburg, Mississippi, U. S. Army, Engineering Experiment Station, Technical Report H-69-16, 205 p.

Bokuniewicz, H. J., 1981a, The seasonal beach at East Hampton, New York: Shore and Beach, v. 49, no. 3, p. 28-33.

Bokuniewicz, H. J., 1981b, Monitoring seasonal beach responses: an educational and public service (sic) program: Journal of Geological Education, v. 29, p. 121-127.

Bokuniewicz, H. J., 1985 ms., The condition of the beach at the Fire Island Pines, NY, 1984-1985: Stony Brook, NY, State University of New York, Marine Sciences Research Center, Report to the Fire Island National Seashore Advisory Board, 36 p. + App.

Bokuniewicz, H. J., 1986 ms., The condition of the beach at the Fire Island Pines, NY, 1986-l986: Stony Brook, NY, State University of New York, Marine Sciences Research Center, Report to the Fire Island National Seashore Advisory Board, 23 p. + App.

Bokuniewicz, H. J., 1987, The condition of the beach at the Fire Island Pines, New York, 1986-1987: Stony Brook, NY, State University of New York, Marine Sciences Research Center, Report to the Fire Island National Seashore Advisory Board, 33 p. + App.

Bokuniewicz, H. J., and Schubel, J. R., 1987, The vicissitudes of Long Island beaches, New York: Shore and Beach, v. 55, p. 71-75.

Bokuniewicz, H. J., and Tangren, Sara, 1985, Volume requirements for the subaerial beach at East Hampton, New York: Shore and Beach, v. 53, no. 1, p. 16-18.

Bokuniewicz, H. J., Zimmerman, M., Keyes, M., and McCabe, B., 1980, Seasonal beach responses at East Hampton, N.Y.: Stony Brook, N.Y., State University of New York, Marine Sciences Research Center, Special Report No. 38, 35 p.

Bowen, A. J., 1980, Simple models of nearshore sedimentation; beach profiles and longshore bars, p. 1-11 in McCann, S. B., ed., The coastline of Canada: Canada Geological Survey, pr. 80-10.

Brenninkmeyer, B. M., 1976, Sand fountains in the surf zone, p. 69-91 in Davis, R. A., Jr., and Ethington, R. L., eds., Beach (sic) and nearshore sedimentation: Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists, Special Publication No. 24, 187 p.

Bretschneider, C. L., 1954, Field investigation of wave energy (sic) loss in shallow water (sic) ocean waves: U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum, No. 46, 21 p.

Bretschneider, C. L., and Reid, R. O., 1954, Modification of wave height due to bottom friction, percolation and refraction: U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum, No. 45, 36 p.

Brink-Kjaer, O., 1984, Depth-current refraction of wave spectra: Symposium on description and modelling of directional seas: Technical University of Denmark, Paper No. C7.

Brock, P. J. C., 1989, Stratigraphy of the northeastern Manhattan Prong, Peach Lake quadrangle, New York-Connecticut, p. 1-27 in Weiss, Dennis, ed., New York State Geological Association Annual Meeting, 61st, Field trip guidebook: Middletown, NY, Orange County Community College, Department of Science and Engineering, 302 p.

Brock, P. J. C., 1993 ms., Geology of parts of the Peach Lake and Brewster quadrangle, southeastern New York and adjacent Connecticut, and basement blocks of the north-central Appalachians: New York, NY, City University of New York Graduate Faculty in Earth and Environmental Sciences, Ph. D. Dissertation, 494 p., 6 plates.

Brooks, C. F., 1939, Hurricanes into New England: meteorology of the storm of September 21, 1938: Geographical Review, v. 29, p. 119-127.

Brown, E. I., 1939, Beach erosion (sic) studies: American Society of Civil Engineers, Proceedings, v. 65, p. 69-91.

Burger, J. A., Klein, G. deV., and Sanders, J. E., 1969, A field technique for making epoxy relief peels in sandy sediments saturated with saltwater: Journal of Sedimentary Petrology, v. 39, no. 1, p. 338-341.

Burrows, Richard; and Salih, B. A., 1987, Statistical modeling of long-term wave climate, p. 42-56 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Butler, H. L., and Prater, M. D., 1983, Fire Island to Montauk Point storm surge (sic) study: Somebody's (?) Interim Report.

Buttner, P. J. R., 1987, The barrier system of the south shore of Long Island, New York, U. S. A.--response to the expected rise of sea level: Northeastern Environmental Science, v. 6, no. 1, p. 1-22.

Carlisle, D., and Wallace, W. A., 1978, Sand and gravel in the greater New York metropolitan area: what kind and how much?: Albany, New York, New York Sea Grant Institute, NYSSGP-RS-78-13, 67 p.

Chao, Y. Y., and Pierson, W. J., 1972, Experimental studies of the refraction of uniform wave trains and transient wave groups near a straight caustic: Journal of Geophysical Research, v. 77, p. 4545-4554.

Christoffersen, J. B., 1982, Current refraction of dissipative water waves: Technical University of Denmark, Institute of Hydrodynamics and Hydraulic Engineering, Series Paper 30.

Coffey, F. C., and Nielsen, P., 1987, The influence of waves on current profiles, p. 82-96 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Colony, R. J., 1932, Source of the sands on the south shore of Long Island and the coast of New Jersey: Journal of Sedimentary Petrology, v. 2, p. 150-159.

Corson, W. D., and Tracy, B. A., 1985, Atlantic coast hindcast, phase II wave information: additional extremal estimates: Vicksburg, MS., U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Wave Information Study Report No. 15, 15 p. + App.

Courtney, K., Dehais, J., and Wallace, W. A., 1979, The demand for construction minerals in the greater New York metropolitan area: Albany, NY, New York Sea Grant Institute, NYSG-RS-79-10, 37 p.

Crosby, W. O., 1908, Outline of the geology of Long Island: Science, new series, v. 28, p. 836.

Crosby, W. O., 1910ms., Report on the geological relations (sic) of the ground water of Long Island: New York City, Board of Water Supply, Open-File Report, 64 p.

Czerniak, M. T., 1976, Engineering concepts and environmental assessment for the stabilization and bypassing of Moriches Inlet, New York: New York, NY, Report for the U. S. Army Corps of Engineers, New York District, 102 p. + App.

Czerniak, M. T., l977 ms., Inlet interaction and stability theory (sic) verification: Pasadena, CA., Tetra Tech, Inc., 20 p.

Dally, W. R., and Dean, R. G., 1987, Transformation of random breaking waves on surf beat, p. 109-123 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Davies, J. L., 1964, A morphogenetic approach to world shorelines: Zeitschrift fur Geomorphologie, v. 8 (Sonderheft), p. 127-142.

Davies, J. L., 1977, Geographical variation in coastal development: New York, Longman, Inc., 204 p.

Davis, R. A., Jr., 1965, Underwater study of ripples, southeastern Lake Michigan: Journal of Sedimentary Petrology, v. 36, p. 857-866.

Davis, R. A., Jr., and Fox, W. T., 1972, Coastal processes and nearshore bars: Journal of Sedimentary Petrology, v. 42, p. 401-412.

Davis, R. A., Jr., Fox, W. T., Hayes, M. O., and Boothroyd, J. C., 1972, Comparison of ridge and runnel (sic) systems in marine (sic) and non-marine environments: Journal of Sedimentary Petrology, v. 42, p. 413-421.

Dean, R. G., 1981 ms., Shoreline changes and causes, East Hampton beach, New York: Report to East Hampton Beach Preservation Society, 27 p.

Dehais, J.; and Wallace, W. A., N.D., The economic viability of offshore mining of mineral aggregate in the greater New York metropolitan area: Albany, NY, New York Sea Grant Institute, 23 p.

Deigaard, R. and Fredsoe, J., 1987, Offshore sand waves, p. 1047-1061 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

deLaguna, W., and Brashears, M. L., Jr., 1948, The configuration of the rock floor in western Long Island, New York: New York State Department of Conservation, Water Power and Control Commission, Bulletin GW 13, 32 p.

deLaguna, W., 1963, Geology of Brookhaven National Laboratory and vicinity, Suffolk County, New York: U. S. Geological Survey, Bulletin 1156-A, p. A1-A35.

DeWall, A. E., 1979, Beach changes at Westhampton Beach, New York, 1962-1973: Fort Belvoir, Virginia, U. S. Corps of Engineers, Coastal Engineering Research Center, Miscellaneous Report 79-5, 129 p.

Dietz, R. S., and Fairbridge, R. W., 1968, Wave base, p. 1224-1228 in Fairbridge, R. W., ed., Encyclopedia of geomorphology: Encyclopedia of the Earth Sciences, v. 3: New York, Reinhold Publishing Corporation, 1295 p.

Doering, J. C., and Bowen, A. J., 1987, Shoaling surface gravity waves: a bispectral analysis, p. 150-162 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Donn, W. L., 1949, Studies of waves and swell in the western North Atlantic: American Geophysical Union, Transactions, v. 30, p. 705-718.

Donn, W. L., 1958, An empirical basis for forecasting storm tides: American Meteorological Society, Bulletin, v. 39, no. 12, p. 640-647.

Donn, W. L., Farrand, W. R., and Ewing, M., 1962, Pleistocene ice volumes and sea-level lowering: Journal of Geology, v. 70, no. 2, p. 206-214.

Donner, J. J., 1964, Pleistocene geology of eastern Long Island, New York: American Journal of Science, v. 262, p. 355-376.

Ellis, C. W., 1962, Marine sedimentary environments in the vicinity of the Norwalk Islands, Connecticut: Connecticut Geological and Natural History Survey, Bulletin 94, 89 p.

Evans, O. F., 1940, Low and ball of the eastern shore of Lake Michigan: Journal of Sedimentary Petrology, v. 10, p. 476-511.

Everts, C. H., 1973, Beach profile (sic) changes on western Long Island, p. 279-301 in Coates, D. R., ed., Coastal geomorphology: Geomorphology symposium, 3rd, Binghamton, New York, 28-30 September 1972, Proceedings: Binghamton, New York, State University of New York, Publications in Geomorphology, 404 p.

Fairbridge, R. W., and Newman, W. S., 1968, Postglacial crustal sub-sidence of the New York area: Annals of Geomorphology, N. S., v. 12, p. 296-317.

Faust, G. T., 1963, Physical properties and mineralogy of selected samples of the sediments from the vicinity of the Brookhaven National Laboratory, Long Island, New York: United States Geological Survey Bulletin 1156-B, p. B1-B34.

Figueiredo, A. G., Jr., Sanders, J. E., and Swift, D. J. P., 1982, Storm-graded layers in inner continental shelves: examples from southern Brazil and the Atlantic coast of the central United States: Sedimentary Geology, v. 31, no. 1, p. 171-190.

Fleming, C. A., Pinchin, B. M., and Nairn, R. B., 1987 Evaluation of models of nearshore processes, p. 1116-1131 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Fleming, W. L. S., 1935, Glacial geology of central Long Island: American Journal of Science, 5th series, v. 30, p. 216-238.

Flint, R. F., 1963a, Altitude, lithology, and the Fall Zone in Connecticut: Journal of Geology, v. 71, no. 6, p. 683-697.

Flint, R. F., and Gebert, J. A., 1974, End moraines on and off the Connecticut shore (abs.): Geological Society of America, Abstracts with Programs, v. 6, no. 7, p. 738-739.

Flint, R. F., and Gebert, J. A., 1976, Latest Laurentide ice sheet: new evidence from southern New England: Geological Society of America Bulletin, v. 87, p. 182-188.

Foord, E. E., Parrott, W. R., and Ritter, D. F., 1970, Definition of possible stratigraphic units in north central (sic) Long Island New York, based on detailed examination of selected well cores: Journal of Sedimentary Petrology, v. 40, no. 1, p. 194-204.

Fox, W. T., and Davis, R. A., Jr., 1973, Simulation model for storm cycles and beach erosion on Lake Michigan: Geological Society of America Bulletin, v. 84, p. 1769-1790.

Fox, W. T., and Davis, R. A., Jr., 1976, Weather patterns and coastal processes, p. 1-23 in Davis, R. A., Jr., and Ethington, R. L., eds., Beach (sic) and nearshore sedimentation: Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists, Special Publication No. 24, 187 p.

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

Fuller, M. L., 1914, The geology of Long Island, New York: United States Geological Survey Professional Paper 82, 231 p.

Gadd, P. E., Lavelle, J. W., and Swift, D. J. P., 1978, Estimates of sand transport on the New York shelf using near-bottom current meter (sic) observations: Journal of Sedimentary Petrology, v. 48, no. 1, p. 239-252.

Gager, C. S., 1932, The story of our boulders: Brooklyn Botanical Gardens, Records, v. 21, no. 8, p. 165-207.

Galvin, Cyril, 1985, Review of general design (sic) memorandum for project works at Fire Island Inlet: New York, NY, U. S. Army Corps of Engineers, New York District, Final Report, 198 p. + App.

Galvin, Cyril; Rooney, C. J., and Nersesian, G. K., 1987, Federal jetty and sand dike at the entrance to Fire Island Inlet, New York, p. 1150-1165 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, Taipei, Taiwan, 9-14 November 1986, Proceedings: New York, New York, American Society of Civil Engineers, 3 volumes: v. 1, p. 1-922; v. 2, p. 925-1842, v. 3, p. 1843-2796.

Gilbert, G. K., 1885, The topographic features of lake shores, p. 69-123 in United States Geological Survey, Annual Report, 5th (1883-1884), 469 p.

Gofseyeff, S., 1953, A case history of Fire Island Inlet, New York, p. 272-305 in Johnson, J. W., ed., Conference on Coastal Engineering, 3rd, Cambridge, Massachusetts, Proceedings: Berkeley, California, Council on Wave Research, The Engineering Foundation.

Goldsmith, V., 1972 ms., Coastal processes of a barrier island (sic) complex and adjacent ocean floor: Monomoy Island-Nauset Spit, Cape Cod, Massachusetts: Amherst, Massachusetts, University of Massachusetts, Department of Geology, Ph. D. Dissertation, 469 p.

Goldsmith, V., 1976, Wave climate (sic) models for the continental shelf: critical links between shelf hydraulics and shoreline processes, p. 24-47 in Davis, R. A., Jr., and Ethington, R. L., eds., Beach (sic) and nearshore sedimentation: Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists, Special Publication No. 24, 187 p.

Goldsmith, V., and Colonell, J., 1970, Effects of nonuniform wave energy in the littoral zone, p. 767-785 in Conference on Coastal Engineering, 12th, Proceedings: New York, N. Y., American Society of Civil Engineers.

Goldsmith, V., and Colonell, J., 1974, Results of ocean wave- continental shelf interaction, p. 586-600 in Conference on Coastal Engineering, 14th, Proceedings: New York, N. Y., American Society of Civil Engineers.

Goldsmith, V., Morris, W. D., Byrne, R. J., and Whitlock, C. H., 1974, Wave climate (sic) model of the mid-Atlantic shelf and shoreline (Virginian Sea): model development, shelf geomorph- ology, and preliminary results: Gloucester Point, Virginia, Virginia Institute of Marine Sciences, Special Report, Applied Marine Science and Ocean Engineering, No. 38, 146 p.

Gordon, R. L., 1982, Coastal ocean (sic) current response to storm winds: Journal of Geophysical Research, v. 87, no. C3, p. 1939-19 .

Grant, W. B., and Madsen, O. X., 1979, Combined wave and current interaction with a rough bottom: Journal of Geophysical Research, v. 84, no. C4, p. 1797-1808.

Grim, M. S., Drake, C. L., and Heirtzler, J. R., 1970, Sub-bottom study of Long Island Sound: Geological Society of America, Bulletin, v. 81, no. 3, p. 649-665.

Groen, P., and Weenink, M. P. H., 1950, Two diagrams for finding breaker characteristics along a straight coast: American Geophysical Union, Transactions, v. 31, p. 398-400.

Gross, M. G., 1972, Oceanography. A view of the Earth: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 581 p. (Chap. 9, Waves, p. 240-265; Chap. 10, Tides and tidal currents, p. 268- 293; Chap. 12, The coastal ocean, p. 328-389; and Chap. 13, Shorelines and shoreline processes, p. 358-389.)

Haeni, F. D., and Sanders, J. E., 1974, Contour map of the bedrock surface, New Haven-Woodmont quadrangles, Conn.: United States Geological Survey, Map MF 557A.

Halpern, N. L., 1980, Revetments at East Hampton: Report to the East Hampton Beach Preservation Society, 12 p.

Hands, E., 1982, Predicting adjustments in shore and offshore sand profiles on the Great Lakes: Fort Belvoir, VA, U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Coastal Engineering Technical Aid No. 81-4, 18 p.

Hanley, T., and Graff, M. M., 1976, Rock trails in Central Park: New York, The Greensward Foundation, Inc., 94 p.

Harris, D. L., 1963, Characteristics of the hurricane storm surge: Washington, D. C., U. S. Department of Commerce, Weather Bureau, Technical Paper No. 48, 15 p.

Harris, D. L., 1972, Characteristics of wave records in the coastal zone, p. 1-51 in Meyer, R. E., ed., Waves on beaches and resulting sediment transport: New York, N. Y., Academic Press.

Harrison, W., 1969, Empirical equations for foreshore changes over a tidal cycle: Marine Geology, v. 7, p. 529-551.

Harrison, W., and Wilson, W. S., 1964, Development of a method for numerical calculation of wave refraction: U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Technical Memorandum No. 6, 64 p.

Hattori, M., 1987, Experimental study on the validity range of various wave theories, p. 232-246 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Hayes, M. O., and Boothroyd, J. C., 1969, Storms as modifying agents in the coastal environment: Society of Economic Paleontologists and Mineralogists, Eastern Section, Annual Field-Trip Guidebook: Amherst, Massachusetts, University of Massachusetts, Department of Geology. (Reprinted in 1987: Society of Economic Paleontolo-gists and Mineralogists, Reprint Series No. 12, p. 25-39.)

Hicks, S. D., 1972, Vertical crustal movements from sea level (sic) measurements along the east coast of the United States: Journal of Geophysical Research, v. 77, no. 30, p. 5930-5934.

Hicks, S. D., 1981, Long-period sea level (sic) variations for the United States through 1978: Shore and Beach, v. 49, no. 2, p. 26-29.

Hicks, S. D., and Crosby, J. E., 1974, Trends and variability of yearly mean sea level 1893-1972: Rockville, Maryland, National Oceanic and Atmospheric Administration, NOAA Technical Memo- randum NOS 13

Hollman, R., and Thatcher, M. L., 1979, Flow augmentation needs (sic) study Great South Bay salinity: Report to Suffolk County, NY, 94 p.

Holthuijsen, L. H.; and Booij, N., 1987, A grid model for shallow water (sic) waves, p. 261-270 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Horod, P. A., and Holman, R. A., 1985, Beach foreshore (sic) response to long-period waves, p. 1968-1982 in Edge, B. L., ed., Conference on Coastal Engineering, 19th, Houston, Texas, 03-07 September 1984, Proceedings: New York, American Society of Civil Engineers, 3 vols., v. 1, p. 1-1102; v. 2, p. 1103-2180; v. 3, p. 2181-3282.

Horrer, P. L., 1950, Southerm hemisphere swell and waves from a tropical storm at Long Beach, California: U. S. Army, Corps of Engineers, Beach Erosion Board, Bulletin, v. 4, no. 3, 18 p.

Howard, A. D., l939, Hurricane modification of offshore bar of Long Island, New York: Geographical Review, v. 29, p. 400-415.

Ingle, J. C., Jr., 1966, The movement of beach sand; an analysis using fluorescent grains. Amsterdam-London-New York, Elsevier Publishing Company, 221 p. (Developments in sedimentology, v. 5)

Inman, D. L., 1963, Ocean waves and associated currents, Chapter 3, p. 49-81 in Shepard, F. P., Submarine geology (2nd ed.): New York-Evanston-London, Harper and Row, 557 p.

Inman, D. L., and Bagnold, R. A., 1963, Beach and nearshore processes. Part II. Littoral processes, p. 529-553 in Hill, M. N., gen. ed., The Sea--ideas and observations on progress in the study of the seas: New York and London: Wiley-Interscience, v. 3, The Earth beneath the sea, 963 p.

Izumija, T., and Isabe, M., 1987, Breaking criterion for non-uniformly sloping beach, p. 318-327 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Jensen, R. E., 1983, Atlantic coast hindcast, shallow-water, significant wave (sic) information: Vicksburg, MS, U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Wave Information Study Report 9, 19 p. + App.

Johnson, D. W., 1919, Shoreline processes and shoreline development: New York, John Wiley and Sons, Inc., 584 p.

Johnson, D. W., and Winter, E., 1927, Sea-level surfaces and the problem of coastal subsidence: American Philosophical Society, Proceedings, v. 66, p. 465-496.

Johnson, J. W., 1950, Relationships between wind and waves, Abbott's Lagoon, California: American Geophysical Union, Transactions, v. 31, p. 386-392.

Johnson, J. W., O'Brien, M. P., and Isaacs, J. D., 1948, Graphical construction of wave refraction (sic) diagrams: U. S. Navy, Hydrographic Office, Publication 605, 45 p.

Joneja, D. C., 1981, Sedimentary dynamics of Fire Island, New York: Amherst, MA, University of Massachusetts, Master's Thesis, 92 p.

Kassner, J., and Black, J. A., 1982, Efforts to stabilize a coastal inlet: a case study of Moriches Inlet, New York: Shore and Beach, v. 50, no. 2, p. 21-29.

Kassner, J., and Black, J. A., 1983, Fire Island Inlet, New York, Management of a complex inlet: Shore and Beach, v. 51, no. 1, p. 3-8.

Kemp, P. H., and Simons, R. R., 1982, The interaction between waves and a turbulent current: waves propagating with the current: Journal of Fluid Mechanics, v. 116, p. 227-250.

Kemp, P. H., and Simons, R. R., 1983, The interaction between waves and a turbulent current: waves propagating against the current: Journal of Fluid Mechanics, v. 130, p. 73-89.

Kenyon, K. E., 1971, Wave refraction in ocean currents: Deep-Sea Research, v. 18.

Kerckaert, P., Grobben, A., and DeCandt, P., 1987, Measurements from a fast-moving air-cushion platform, p. 342-353 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Keulegan, G. H., 1945, Depths of offshore bars: U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum, No. 8.

Keulegan, G. H., and Harrison, J., 1970, Tsunamic refraction diagrams by digital computer: American Society of Civil Engineers, Transactions, Waterways, Harbors and Coastal Engineering Division, Journal, v. 96, p. 219-233.

Khandekar, M. L., and Eid, B. M., 1987, Wind specification for spectral ocean-wave models, p. 354-365 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Komar, P. D., 1975, Summary of longshore drift (sic) computations: American Society of Civil Engineers, Civil Engineering in the Oceans III, 09-12 June, Newark, Delaware, Proceedings.

Komar, P. D., 1976, Evaluation of wave-generated longshore current (sic) velocities and sand transport (sic) rates on beaches, p. 48-53 in Davis, R. A., Jr., and Ethington, R. L., eds., Beach (sic) and nearshore sedimentation: Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists, Special Publication No. 24, 187 p.

Krumbein, W. C., 1944a, Shore processes and beach characteristics: U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum, No. 3

Krumbein, W. C., 1944b, Shore currents and sand movement on a model beach: U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum, No. 7.

Krumbein, W. C., 1950, Geological aspects of beach engineering, p. 195-223 in Paige, Sidney, Chm., Applications of geology to Engineering practice: Geological Society of America, Engineering geology (Berkey) volume, 327 p.

Krumbein, W. C., and Griffith, J. S., 1938, Beach environment in Little Sister Bay, Wisconsin: Geological Society of America, Bulletin, v. 49, p. 629-652.

Kumar, N., 1973, Modern (sic) and ancient barrier sediments: new interpretation based on stratal sequence in inlet-filling sands and on recognition of nearshore storm deposits: New York Academy of Sciences, Annals, v. 220, art. 5, p. 245-340.

Kumar, N., 1973, Modern (sic) and ancient barrier sediments: new interpretation based on stratal sequence in inlet-filling sands and on recognition of nearshore storm deposits: New York Academy of Sciences, Annals, v. 220, art. 5, p. 245-340.

Kumar, N., and Sanders, J. E., 1978, Storm deposits, p. 767-770 in Fairbridge R. W., and Bourgeois, Joanne, eds., Encyclopedia of sedimentology (Vol. VI, The Encyclopedia of Earth Sciences: Stroudsburg, Pennsylvania, Dowden, Hutchinson and Ross, Inc. 90l p.

Kumar, N., and Sanders, J. E., 1974, Inlet sequence: a vertical succession of sedimentary structures and textures created by the lateral migration of tidal inlets: Sedimentology, v. 21, p. 491-532.

Kumar, N., and Sanders, J. E., 1975, Inlet sequence formed by the migration of Fire Island Inlet, Long Island, New York, p. 75-83 in Ginsburg, R. N., ed., Tidal deposits. A casebook of recent examples and fossil counterparts: New York-Heidelberg-Berlin, Springer-Verlag, 428 p.

Kumar, N., and Sanders, J. E., 1976, Characteristics of shoreface storm deposits: modern and ancient examples: Journal of Sedimentary Petrology, v. 76, no. 1, p. 145-162.

Lavelle, J. W., Gadd, P. E., Han, G. C., Mayer, D. A., Stubblefield, W. L., Swift, D. J. P., Charness, R. L., Brashear, H. R., Case, F. N., Haff, K. W., and Kunselman, 1976, Preliminary results of coincident current meter (sic) and sediment transport (sic) observations for wintertime conditions of the Long Island inner shelf: Geophysical Research Letters, v. 3, no. 2, p. 97-100.

Lavelle, J. W., Swift, D. J. P., Gadd, P. E., Stubblefield, W. L., Case, F. N., Brashear, H. R., and Haff, K. W., 1978, Fair weather (sic) and storm sand transport on the Long Island, New York, inner shelf: Sedimentology, v. 25, p. 823-842.

Leatherman, S. P., 1987, Time frames for barrier island (sic) migration: Shore and Beach, v. 55, nos. 3/4, p. 82-86.

Leatherman, S. P., and Allen, J. R. 1985, Geomorphic analysis Fire Island Inlet to Montauk Point Long Island, New York: U. S. Army, Corps of Engineers, New York District, Final Report, 298 p. + App.

Lewis, R. S., and Needell, S. W., 1987, Maps showing stratigraphic framework and Quaternary geologic history of eastern Long Island Sound: United States Geological Survey, Miscellaneous Field Studies, Map MF-1939-A, Pamphlet.

Liebling, R. S., 1973, Clay minerals of the weathered bedrock underlying coastal New York: Geological Society of America Bulletin, v. 84, p. 1813-1816.

Liebling, R. S., and Scherp, H. S., 1975, Stratigraphic importance of chlorite in the Cretaceous Raritan Formation underlying coastal New York: Geological Society of America Bulletin, v. 86, no. 7, p. 928-928.

Liu, P. C., 1987, Estimating long-term wave statistics from long-term wind statistics, p. 512-521 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Lobeck, A. K., 1939, Geomorphology. An introduction to the study of landscapes: New York and London, McGraw-Hill Book Company, Inc., 731 p.

Longuet-Higgins, M. S., 1972, Recent progress in the study of longshore currents, p. 203-248 in Meyer, R. E., ed., Waves on beaches: New York, Academic Press.

Longuet-Higgins, M. S., 1980, On the longshore currents generated by obliquely incident sea waves: Journal of Geophysical Research, v. 75, p. 6778-6801.

Longuet-Higgins, M. S., 1982, On the skewness of sea-surface slopes: Journal of Physical Oceanography, v. 12, p. 1283-1291.

Longuet-Higgins, M. S., 1984, Statistical properties of wave groups in a random sea state: Royal Society of London, Philosophical Transactions, v. 312 A, p. 219-250.

Longuet-Higgins, M. S., and Parkin, D. W., 1962, Sea waves and beach cusps: Geographical Journal, v. 128, p. 194-201.

Longwell, C. R., Flint, R. F., and Sanders, J. E., 1969, Physical geology: New York-London-Sydney, John Wiley and Sons, Inc., 685 p.

Lyell, Sir Charles, 1830, Principles of geology, v. 1: London, John Murray,

Manoha, B., Bemeir, J., and Graff, M., 1987, An efficient statistical method of estimation of extreme maritime events using two sets of related information, p. 550-564 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Mason, C., Sallenger, A. H., Jr., Holman, R. A., and Birkemeier, W. A., 1985, Duck82--a coastal storm (sic) process experiment, p. 1913-1928 in Edge, B. L., ed., Conference on Coastal Engineering, 19th, Houston, Texas, 03-07 September 1984, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols. v. 1, p. 1-1102; v. 2, p. 1103-2180; v. 3, p. 2181-3282.

Mason, M. W., 1950, Geology in shore-control problems, p. 276-290 in Trask, P. D., ed., Applied sedimentation: New York, John Wiley and Sons, Inc.

Mathiesen, M., 1984, Current-depth refraction of directional wave spectra, in Symposium on description and modelling of directional seas: Technical University of Denmark, Paper No. C7.

McCormick, C. L., 1972, Probable causes of shoreline recession and advance on the south shore of eastern Long Island, p. 61-71 in Coates, D., ed., Coastal geomorphology: Geomorphology Symposium, 3rd, Binghamton, New York, 28-30 September 1972, Proceedings: Binghamton, New York, State University of New York, Publications in Geomorphology, 404 p.

Meistrell, F. J., 1972, The spit-platform concept: Laboratory observation of spit development, p. 225-283 in Schwartz, M. L., ed., Spits and Bars: Stroudsberg, Pennsylvania, Dowden, Hutchinson, and Ross, Mills, H. C., and Wells, P. D., 1974, Ice-shove deformation and glacial stratigraphy of Port Washington, Long Island, New York: Geological Society of America Bulletin, v. 85, no. 2, p. 357-364.

Mizuguchi, M., 1985, Swash on a natural beach, p. 678-694 in Edge, B. L., ed., Conference on Coastal Engineering, 19th, Houston, Texas, 03-07 September 1984, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols. v. 1, p. 1-1102; v. 2, p. 1103-2180; v. 3, p. 2181-3282.

Morton, R. W., Bohlen, W. F., and Aubrey, P. G., 1986, Beach changes at Jones Beach, Long Island, New York, 1962-1974: U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Miscellaneous Paper CERC-86-1, 95 p.

Munk, W. H., 1949, Surf beats: American Geophysical Union, Transactions, v. 30, p. 849-854.

Munk, W. H., and Arthur, R. S., 1951, Wave intensity along a refracted ray: U. S. National Bureau of Standards, Circular 521, p. 95-108.

Munk, W. H., and Traylor, M. A., 1947, Refraction of ocean waves: a process linking underwater topography to beach erosion: Journal of Geology, v. 55, p. 1-26.

Newton, R. S., 1968, The internal structure of wave-formed ripple marks in the nearshore zone: Sedimentology, v. 11, p. 275-292.

Niederoda, A. W., and Swift, D. J. P., 1981, Maintenance of the shoreface by wave orbital (sic) currents and mean flow: observations from the Long Island coast: Geophysical Research Letters, v. 8, p. 337-340.

Niederoda, A. W., Swift, D. J. P., Hopkins, T. S., and Ma, C., 1984, Shoreface morphodynamics on wave-dominated coasts, p. 331-354 in Greenwood, B., and Davis, R. A., Jr., eds., Hydro- dynamics and sedimentation in wave-dominated coastal environments: Marine Geology, v. 60 (special issue), 473 p.

Nielsen, P., 1985, On the structure of oscillatory boundary waves: Coastal Engineering, v. 9, no. 3, p. 261-276.

Nielsen, P., 1987, Local approximations: a new way of dealing with irregular waves, p. 633-646 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Nordstrom, K. F., and McCluskey, J. M., 1985, The effects of houses and sand fences on the eolian sediment (sic) budget at Fire Island, New York: Journal of Coastal Researc, v. 1, no. 1, p. 39-46.

Nuemann, G., and James, R. W., 1957, North Atlantic coast waves hindcast by the wave spectrum (sic) method: U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum, No. 57, 23 p.

O'Brien, M. P., 1947, Wave refraction at Long Beach and Santa Barbara, California: Berkeley, California, University of California, Fluid Mechanics Laboratory, Technical Report HE-116- 246, 14 p.

O'Brien, M. P., 1979 ms., Supplementary notes of coastal processes on the shoreline of the Village of East Hampton, Long Island: 8 p.

O'Brien, M. P., and Dean, R. G., 1978 ms., Coastal processes and structures on the shoreline of the Village of East Hampton, Long Island: Report to East Hampton Beach Preservation Society, 20 p.

O'Brien, M. P., and Mason, M. A., 1942, A summary of the theory of oscillatory waves: U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Report, No. 2, 43 p.

Ocean Seismic Survey, Inc., 1983, Development of borrow areas, south shore of Long Island, New York: New York, NY, Report to the U. S. Army, Corps of Engineers, New York District, 3 volumes.

Offshore, Inc., 1975, Offshore borrow investigation and evaluation and side scan (sic) survey, reach 2, Fire Island Inlet to Montauk Point: New York, NY, U. S. Army Corps of Engineers New York District: 20 p. + tables and plates.

Olson, J. S., 1958, Lake Michigan dune development: 3. Lake level beach and dune oscillation: Journal of Geology, v. 66, p. 473-483.

Panuzio, F. L., 1968, The Atlantic coast of Long Island, p. 1222- 1241 in Johnson, J. W., ed., Conference on Coastal Engineering, 11th, London, September 1968, Proceedings: New York, New York, American Society of Civil Engineers, 2 volumes, v. 1, p. 1-742; v. 2, p. 745-1585.

Patton, R. S., 1931, Moriches Inlet: a problem in beach evolution: Geographical Review, v. 21, p. 627-632.

Penland, S., and Suter, R. J., 1985, Low-profile barrier island (sic) overwash and breaching in the Gulf of Mexico, p. 2339-2345 in Edge, B. L., ed., Conference on Coastal Engineering, 19th, Houston, Texas, 03-07 September 1984, Proceedings: New York, American Society of Civil Engineers, 3 vols., v. 1, p. 1-1102; v. 2, p. 1103-2180; v. 3, p. 2181-3282.

Perlmutter, N. M., and Todd, R., 1965, Correlation and foraminifera of the Monmouth Group (Upper Cretaceous), Long Island, New York: United States Geological Survey Professional Paper 483-I, 24 p.

Pierce, J. W., 1970, Tidal inlets and washover fans: Journal of Geology, v. 78, p. 230-234.

Pierson, W. J., Jr., 1972, The loss of two British trawlers--a study in wave refraction: Journal of Navigation, v. 25, p. 291-304.

Pierson, W. J., Jr.; Newmann, Gerhard; and James, R. W., 1955, Observing and forecasting ocean waves: Washington, D. C., U. S. Navy Hydrographic Office, Publication 603, 284 p.

Playfair, J., 1802, Illustrations of the Huttonian theory of the Earth: (1956 reprint edition, Urbana, Illinois, University of Illinois Press), 528 p.

Pore, N. A., and Barrientos, C. S., 1976, Storm surge: Albany, New York, New York Sea Grant Institute, Marine EcoSystems Analysis [MESA] Program: MESA New York Bight Atlas Monograph 6, 44 p.

Potter, R. D., 1939, The New England hurricane: Science, 20 Jan. Suppl. p. 10

PRC Harris, 1983, Beach erosion (sic) control and hurricane protection, Fire Island to Montauk Point, task 3--dune and beach design: New York, NY, U. S. Army Corps of Engineers, New York District, Interim Report.

PRC Harris, 1984, Beach erosion (sic) control and hurricane protection, Fire Island to Montauk Point, task 4--removal of groins: New York, NY, U. S. Army Corps of Engineers, New York District, Final Report.

PRC Harris, 1985, Beach erosion (sic) control and hurricane protection, Fire Island to Montauk Point, task 5--gate design: New York, NY, U. S. Army Corps of Engineers, New York District, Final Report.

PRC Harris, 1986, Beach erosion (sic) control and hurricane protection, Fire Island to Montauk Point, task 6--inlet bypassing: New York, NY, U. S. Army Corps of Engineers, New York District, Final Report.

Price, W. A., 1947, Equilibrium of form and forces in tidal basins of coast of Texas and Louisiana: American Association of Petroleum Geologists, Bulletin, v. 31, no. 9, p. 1784-1800.

Psuty, N. P., Allen, J. R., and Starcher, R., 1988, Spatial analysis of dune crest (sic) mobility, Fire Island National Seashore, New York, p. 115-120 in Psuty, N. P. ed., Dune/beach interaction: Journal of Coastal Research, Special Issue No. 3.

Psuty, N. P., and Allen, J. R., 1986, Analysis of dune crestline (sic) changes, Fire Island, New York, p. 1169-1183 in Gardiner, V., ed., International geomorphology, 1986, Part I: New York, John Wiley and Sons, Inc.

Putnam, J. A., and Johnson, J. W., 1949, The dissipation of wave energy by bottom friction: American Geophysical Union, Transactions, v. 30, p. 69-74

Rampino, M. R., 1978 ms., Quaternary history of south-central Long Island, New York: New York, New York, Columbia University, Department of Geological Sciences, Ph. D. Dissertation, 742 p.

Rampino, M. R., 1978 ms., Quaternary history of south-central Long Island, New York: New York, New York, Columbia University, Department of Geological Sciences, Ph. D. Dissertation, 742 p.

Rampino, M. R., and Sanders, J. E., 1980, Holocene transgression in south-central Long Island, New York: Journal of Sedimentary Petrology, v. 50, no. 3, p. 1063-1080.

Rampino, M. R., and Sanders, J. E., 1981a, Evolution of the barrier islands of southern Long Island, New York: Sedimentology, v. 28, no. 1, p. 37-47.

Rampino, M. R., and Sanders, J. E., 1981b, Episodic growth of Holocene tidal marshes in the northeastern United States: a possible indicator of eustatic sea-level fluctuations: Geology, v. 9, no. 2, p. 63-67.

Rampino, M. R., and Sanders, J. E., 1981c, Upper Quaternary stratigraphy of southern Long Island, New York: Northeastern Geology, v. 3, no. 2, p. 116-128.

Redfield, A. C., 1958, The influence of the continental shelf on the tides of the Atlantic coast of the United States: Journal of Marine Research, v. 17, p. 432-438.

Redfield, A. C., and Miller, A. R., 1956, Water levels accompanying Atlantic coast hurricanes: American Meteorological Society (Boston), Meteorological Monographs, v. 2, no. 10, p. 1-23.

Research Planning Institute, Inc., 1981, Sediment budget, phase 1--Moriches Inlet, Fire Island Inlet to Montauk Point reformulation study: New York, NY, U. S. Army Corps of Engineers, New York District, Interim Report, 82 p. + App.

Research Planning Institute, Inc., 1983, Sediment budget (sic) analysis, Fire Island Inlet to Montauk Point, Long Island, New York, reformulation study: New York, NY, U. S. Army Corps of Engineers, New York District, Interim Report, 82 p + App.

Research Planning Institute, Inc., 1985, Sediment budget (sic) summary, Fire Island Inlet to Montauk Point reformulation study: New York, NY, U. S. Army Corps of Engineers, New York District, Final Report, 85 p. + App.

Rich, C. A., 1975 ms., Effects of storms and construction activities on beach accretion (sic) and recession (sic) rates from Moriches Inlet to Amagansett, Long Island: Flushing, NY, Queens College, City University of New York, Department of Earth and Environmental Sciences, Master's Thesis, 95 p.

Richmond, B. M., and Sallenger, A. H., Jr., 1985, Cross-shore transport of bimodal sands, p. 1997-2008 in Edge, B. L., ed., Conference on Coastal Engineering, 19th, Houston, Texas, 03-07 September 1984, Proceedings: New York, American Society of Civil Engineers, 3 vols., v. 1, p. 1-1102; v. 2, p. 1103-2180; v. 3, p. 2181-3282.

Roberts, E. B., 1957, Tsunamis (sic), the strangest waves on the sea: U. S. Naval Institute, Proceedings, v. 83, p. 1201-1207.

Roberts, J. A., and Kauper, E. K., 1964, The effects of wind and precipitation on the modification of south beach, Crescent City, California: Altadena, California, Atmospheric Research Group, 32 p.

Rosalsky, M. B., 1949, A study of minor beach features at Fire Island, Long Island, New York: New York Academy of Sciences, Transactions, series 2, v. 12, p. 9-16.

Rosalsky, M. B., 1950, Characteristics of beach drifting: Shore and Beach, v. 18, p. 6-8.

Rosalsky, M. B., 1964, Swash and backwash action at the beach scarp: Rocks and Minerals, v. 39, p. 5-14.

Ruzyla, K., 1973, Effects of erosion on barrier island (sic) morphology--Fire Island, New York, p. 219-237 in Coates, D. R., ed., Coastal geomorphology: Geomorphology symposium, 3rd, Binghamton, New York, 28-30 September 1972, Proceedings: Binghamton, New York, State University of New York, Publications in Geomorphology, 404 p.

Sanders, J. E., 1965, Sediment-filled deep valleys underlying New Haven Harbor, Connecticut, revealed by continuous seismic profiling using sparker and pneumatic sources (abs.): American Geophysical Union, Transactions, v. 46, no. 1, p. 105.

Sanders, J. E., 1978, Beaches and spits: new observations on longshore sand transport at three dynamic levels--subtidal, inter-tidal, and supratidal (abstract): Geological Society of America, Abstracts with Programs, v. 10, no. 1, p. 84 (only).

Sanders, J. E., 1980, Dynamic implications of post-storm recovery of eroded berms: shoreface sediment passes landward through breaker bar(s) (abs.): Geological Society of America, Abstracts with Programs, v. 12, no. 1, p. 80 (only).

Sanders, J. E., 1989 ms. Sediment-filled deep V-whaped, bedrock-walled valleys underlying New Haven harbor, Connecticut, revealed by continuous seismic-reflection profiling using sparker- and compressed-air sound sources: 76 p.

Sanders, J. E., and Ellis, C. R., 1961a, Geological and economic aspects of beach erosion along the Connecticut coast: Connecticut Geological and Natural History Survey, Report of Investigations, No. 1, l4 p.

Sanders, J. E., and Ellis, C. R., 1961b, Geological aspects of Connecticut's coastal marshes: The Connecticut Arboretum Bulletin, no. 12, p. 16-20.

Sanders, J. E., and Kumar, N., 1971, Washover erosion: important process in creating bays of digitate spit, Democrat Point, L. I., New York (abstract): Geological Society of American, Abstracts with Programs, v. 3, no. 1, p. 53-54.

Sanders, J. E., and Kumar, N., 1975a, Shoreface retreat versus in-place "drowning" of barriers during submergence: new data from shelf off Fire Island, New York: Geological Society of America Bulletin, v. 86, no. 1, p. 65-76.

Sanders, J. E., and Kumar, N., 1975b, Holocene shoestring sand on inner continental shelf off Long Island, New York: American Association of Petroleum Geologists Bulletin, v. 59, no. 6, p. 997-1009 (reprinted with corrections, no. 9, p. 1549-1561).

Saville, T., Jr., 1950, Model study of sand transport along an infinitely long, straight beach: American Geophysical Union, Transactions, v. 31, p. 555-565.

Saville, T., Jr., 1954, North Atlantic coast wave statistics hindcast by Bretschneider--revised Sverdrup-Munk method: U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum, No. 55, 18 p.

Saville, T., Jr., 1961, Sand transfer, beach control, and inlet improvements, Fire Island inlet to Jones Beach, New York, p. 785-807 in Johnson, J. W., ed., Conference on Coastal Engineering, 7th, The Hague, Netherlands, August 1960, Pro- ceedings: Berkeley, California, Council on Wave Research, The Engineering Foundation, 2 volumes, v. 1, p. 1-484; v. 2, p. 485-1001.

Scheffner, N. W., 1987, Biperiodic waves in shallow water, p. 724-736 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Schideler, G. L., and McGrath, D. G., 1974, Submarine strain-gage instrumentation for monitoring diurnal beach sediment (sic) mi- gration: Journal of Sedimentary Petrology, v. 44, p. 1305-1309.

Schlee, J., 1975, Sand and gravel: Albany, NY, New York Sea Grant Institute, Marine EcoSystems Analysis [MESA] Program, MESA New York Bight Atlas Monograph 21, 26 p.

Schmetlz, E. J., Sorensen, R. M., McCarthy, M. J., and Nersesian, G. K., 1982, Beach/inlet interaction at Moriches Inlet, p. 1062- 1077 in ed, Conference on Coastal Engineering, 18th, Proceedings: New York, NY, American Society of Civil Engineers,

Schubel, J. R. Zarillo, G. A., and Bokuniewicz, H. J., 1983, Erosion of Long Island's south shore: A preliminary identification and assessment of alternative rersponses to the problem: Stony Brook, NY, State University of New York, Marine Sciences Research Center, Special Report No. 50, 23 p.

Scott, J. T., and Csanady, G. T., 1976, Nearshore currents off Long Island: Journal of Geophysical Research, v. 81, p. 5403-5407.

Scripps Institute of Oceanography, 1944, Wind, waves, and swell; principles of forecasting: U. S. Navy, Hydrographic Office, Miscellaneous Publications, No. 11, 275 p.

Selwyn, S., 1980, Erosional beaches analyzed through the use of an interactive computer simulation (sic) model (abs.): Geological Society of America, Abstracts With Programs, v. 12, no. 1, p. 82.

Sheng, Y. P., and Chiu, S. S., 1987, Tropical cyclone generated (sic) currents, p. 737-751 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Shepard, F. P., 1950, Longshore current (sic) observations in southern California: U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum, No. 13.

Shepard, F. P., and Grant, U. S., IV, 1947, Wave erosion along the southern California coast: Geological Society of America, Bulletin, v. 58, p. 919-926.

Shepard, F. P., and Inman, D. L., 1950, Nearshore water circulation related to bottom topography and wave refraction: American Geophysical Union, Transactions, v. 31, p. 196-212.

Shepard, F. P., and Wanless, H. R., 1971, Our changing coastlines: New York, McGraw-Hill Book Company, 579 p.

Sherman, D. J., and Nordstrom, K. F., 1987, Beach scarps: Zeitschrift fur Geomorphologie, v. 29, no. 2, p. 139-152.

Shipp, R. C., 1980 ms., Morphology and sedimentology of a single- barred nearshore system, eastern Long Island, New York: Columbia, SC, University of South Carolina, Master's Thesis, 169 p.

Shipp, R. C., 1984, Bedforms and depositional sedimentary structures of a barred nearshore system, eastern Long Island, New York, p. 235-259 in Greenwood, Brian; and Davis, R. A., Jr., eds., Hydrodynamics and sedimentation in wave-dominated coastal environments: Marine Geology, v. 60 (special issue), 473 p.

Silvester, R., 1985, Fluctuations in littoral drift, p. 1291-1305 in Edge, B. L., ed., Conference on Coastal Engineering, 19th, Houston, Texas, 03-07 September 1984, Proceedings: New York, American Society of Civil Engineers, 3 vols., v. 1, p. 1-1102; v. 2, p. 1103-2180; v. 3, p. 2181-3282.

Simpson, Sir G. C., 1957, Further studies in world climate: Royal Meteorological Society, Quarterly Journal, v. 83, no. 3, p. 459-480.

Sirkin, L. A., and Mills, H. C., 1975, Wisconsinan glacial stratigraphy and structure of northwestern Long Island, Trip. B-5, p. 299-327 in Wolff, M. P., ed., Guildebook to Field Excursions: New York State Geological Association, Annual Meeting, 47th, Hofstra University, Hempstead, New York, October 1975: Hempstead, New York, Hofstra University, Department of Geology.

Smith, R. L., 1972, A description of current, wind, and sea level (sic) variations during coastal upwellings off the Oregon coast, July-August, 1972: Journal of Geophysical Research, v. 79, p. 435-443.

Sobey, R. J., and Liang, H., 1987, Complex envelope identification of wave groups, p. 752-766 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Sonu, C. J., and Russell, R. J., 1966, Topographic changes in the surf zone (sic) profile, p. 502-524 in Johnson, J. W., ed., Conference on Coastal Engineering, 10th, Tokyo, Japan, September 1966, Proceedings: New York, American Society of Civil Engineers, 790 p.

Steele, K., and Johnson, Jr., A., 1977, Data buoy (sic) wave measurements, p. 301-316 in Earle, M. D., and Malahoff, A., eds., Ocean wave (sic) climate: New York, Plenum Press.

Su, M., 1987, Extreme wave groups in storm seas near coastal water, p. 767-779 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

Suter, R., de Laguna, W., and Perlmutter, N. M., 1949, Mapping of geologic formations and aquifers of Long Island, New York: New York State Department of Conservation, Water Power and Control Commission, Bulletin GW-18, 212 p.

Sverdrup, H. U., 1947, Period increase of ocean swell: American Geophysical Union, Transactions, v. 28, p. 407-417.

Sverdrup, H. U., and Munk, W. H., 1946a, Empirical and theoretical relations (sic) between (sic) wind, sea, and swell: American Geophysical Union, Transactions, v. 27, p. 823-827.

Sverdrup, H. U., and Munk, W. H., 1946b, Theoretical and empirical relations (sic) in forecasting breakers and surf: American Geophysical Union, Transactions, v. 27, p. 828-836.

Swanson, R. L., 1976, Tides: Albany, New York, New York Sea Grant Institute, Marine EcoSystems Analysis [MESA] Program, MESA New York Bight Atlas Monograph 4, 34 p.

Swart, D. H., 1976, Coastal sediment (sic) transport: computation of longshore transport: Delft, The Netherlands, Delft Hydraulics Laboratory, Report PL968.

Swarzenski, W. V., 1959, Ground-water supplies in Pleistocene and Cretaceous deposits of northwestern Nassau County, New York: New York Academy of Sciences, Annals, v. 80, art. 4, p. 1077-1091.

Swift, D. J. P., 1973, Delaware Shelf Valley: estuary retreat path, not drowned river valley: Geological Society of America, Bulletin, v. 84, p. 2743-2748.

Swift, D. J. P., and Freeland, G. L., 1978, Current lineations and sand waves on the inner shelf, Middle Atlantic Bight of North America: Journal of Sedimentary Petrology, v. 48, no. 4, p. 1257-1266.

Swift, D. J. P., Niederoda, A. W., Vincent, C. E. and Hopkins, T. S., 1985, Barrier island (sic) evolution, Middle Atlantic shelf, U. S. A., Part I: shoreface dynamics, p. 331-361 in Oertel, G. F., and Leatherman, S. P., eds., Barrier islands: Marine Geology, v. 63.

Swift, D. J. P., Sanford, R. B., Dill, C. E., Jr., and Avignone, N. F., 1971, Textural differentiation of the shore face (sic) during erosional retreat of an unconsolidated coast, Cape Henry to Cape Hatteras, western north Atlantaic shelf: Sedimentology, v. 16, p. 221-250.

Swift, D. J. P.; Kofoed, J. W.; Saulsbury, F. P.; and Sears, Phillip, 1972, Holocene evolution of the shelf surface, central and southern Atlantic shelf of North America, p. 499-574 in Swift, D. J. P., Duane, D. B., and Pilkey, O. H., eds., Shelf sediment transport: Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, Inc.

Tagg, A. R., and Uchupi, E., 1967, Subsurface morphology of Long Island Sound, Block Island Sound, Rhode Island Sound, and Buzzards Bay: United States Geological Survey, Professional Paper 575-C, p. C92-C96.

Taney, N. E., 1961a, Geomorphology of the south shore of Long Island, New York: Washington, D. C., U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum 128, 51 p.

Taney, N. E., 1961b, Littoral materials of the south shore of Long Island, New York: Washington, D. C., U. S. Army, Corps of Engineers, Beach Erosion Board, Technical Memorandum 129, 59 p.

Tanski, J. J., 1982 ms., Fire Island beach observation program, interim report: Stony Point, NY, State University of New York, Marine Sciences Research Center, 25 p.

Tanski, J. J., 1983 ms., Monthly beach changes at Ocean Beach, Fire Island New York, as measured by students of Bay Shore High School: Stony Brook, NY, State University of New York, Marine Sciences Research Center, 70 p.

Tanski, J. J., and Bokuniewicz, H. J., 1988, Westhampton Beach: Options for the future: Stony Brook, NY, New York Sea Grant Institute, Special Report No. 102, 28 p.

Thompson, D. G., Wells, F. G., and Blank, H. B., 1937, Recent geologic studies on Long Island with respect to ground-water supplies: Economic Geology, v. 32, p. 451-470.

Thompson, E. F., 1977, Wave climate at selected locations along U. S. coasts: Fort Belvoir, Virginia, U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Technical Report 77-1, 364 p.

Thompson, E. F., and Harris, D. L., 1972, A wave climatology for U. S. coastal waters: Annual Offshore Technology Conference, Fourth, Preprints, v. II, p. II-675 to II-688.

Thompson, W. O., 1937, Original structures of beaches, bars, and dunes: Geological Society of America Bulletin, v. 48, p. 723- 752.

Thornton, E. B., 1969, Longshore current and sediment transport: Gainesville, Florida, University of Florida, College of Engineering, Technical Report 5, 171 p.

Tsien, H. S., 1986 ms., Differential transport of sand on the south shore of Long Island: Stony Brook, NY, State University of New York, Marine Sciences Research Center, Master's Thesis, 119 p.

U. S. Army, Corps of Engineers, 1955, Beach erosion (sic) control report on cooperative study of Atlantic coast of Long Island, Fire Island Inlet, and shore westerly to Jones Inlet, New York: U. S. Congress, 84th, 2nd Session, House Document No. 411 (1957), 167 p.

U. S. Army, Corps of Engineers, Beach Erosion Board, 1933, Interim report: Washington, D. C.

U. S. Army, Corps of Engineers, Beach Erosion Board, 1939, Inspection of beaches in path of the hurricane of September 21, 1938: Shore and Beach, v. 7, p. 43-47.

U. S. Army, Corps of Engineers, New York District, 1958, Report on cooperative beach erosion (sic) control (sic) and interim hurricane study of the Atlantic coast of Long Island, New York, Fire Island Inlet to Montauk Point: U. S. Congress, 86th, 2nd Session, House Document No. 425 (1960).

U. S. Army, Corps of Engineers, New York District, 196 , Jones Inlet to Montauk Point, Long Island, New York: U. S. Congress, 90th, Session, House Document No. 191 (1967), 119 p.

U. S. Army, Corps of Engineers, New York District, 1963a, Review report on beach erosion (sic) control cooperative study of Atlantic coast of Long Island, New York, Fire Island Inlet and the shore westerly to Jones Inlet: U. S. Congress, 89th, 1st Session, House Document No. 115 (1965), 253 p.

U. S. Army, Corps of Engineers, New York District, 1977, Final environmental impact statement for Fire Island Inlet to Montauk Point, New York--Beach erosion (sic) control and hurricane protection project, volumes I and II, 375 p.

U. S. Geological Survey, 1967, Engineering geology of the northeast corridor, Washington, D. C., to Boston, Massachusetts: United States Geological Survey, Miscellaneous Map Investigations, Map I514A, B, C.

Upson, J. E., and Spencer, C. W., 1964, Bedrock valleys of the New England coast as related to fluctuations of sea level: United States Geological Survey, Professional Paper 454-M, p. M1-M-44.

Valentin, H., 1952, Die Kusten der Erde: Petermanns Geographsiche Mitteilung, Erganzungsheft, 246 p.

Van Doorn, T., 1981, Experimental investigation of near bottom (sic) velocities in water waves with and without a current: Delft Hydraulics Laboratory, TOW Report 1423.

Veatch, A. C., Schlichter, C. A., Bowman, I., Crosby, W. O., and Horton, R. E., 1906, Underground water resources of Long Island, New York: United States Geological Survey, Professional Paper 44, 394 p. (Chapter 1, Veatch, Outline of the geology of Long Island, p. 15-52.)

Vincent, C. E., Young, R. A., and Swift, D. J. P., 1983, Sediment transport in the Long Island shoreface, North American continental shelf: role of waves and currents in shoreface maintenance: Continental Shelf Research, v. 2, p. 163-181.

Visco, C., 1977 ms., The geomorphic effects of off-road vehicles on the beach, Fire Island, New York: Binghampton, NY, State University of New York, Master's Thesis, 67 p.

Vogel, M. J., and Kana, T. W., 1985, Sedimentation patterns in a tidal inlet (sic) system Moriches Inlet, New York, p. 3017-3033 in Edge, B. L., ed., Conference on Coastal Engineering, 19th, Houston, Texas, 03-07 September 1984, Proceedings: New York, American Society of Civil Engineers, 3 vols., v. 1, p. 1-1102; v. 2, p. 1103-2180; v. 3, p. 2181-3282.

Waddell, E., 1976, Swash-groundwater-beach profile (sic) interactions, p. 115-125 in Davis, R. A., Jr., and Ethington, R. L., eds., Beach (sic) and nearshore sedimentation: Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists, Special Publication No. 24, 187 p.

Welby, C. W., Pilkey, O. H., Jr., and Machemehl, J. L., 1981 ms., Beach and shoreline trends, Incorporated Village of East Hampton: Report to the Village of East Hampton: 183 p. + App.

Wensink, H., and Schilperoot, T., 1987, Real-time wave forecasting with adaptive ARMAX models, p. 837-848 in Edge, B. L., ed., Conference on Coastal Engineering, 20th, 9-14 November 1986, Tapei, Taiwan, Proceedings: New York, N. Y., American Society of Civil Engineers, 3 vols.

White, G. H., 1956, Introduction and biographical notes, p. v-xix in Playfair's Illustrations of the Huttonian theory (1956 reprint edition, Urbana, Illinois, University of Illinois Press, 528 p.)

Wiegel, R. L., 1953, Waves, tides, currents, and beaches: glossary of terms and list of standard symbols: Berkeley, California, University of California, Council on Wave Research, The Engineering Foundation, 113 p.

Williams, A. T., and Morgan, P., 1988, Quartz grain (sic) S. E. M. textural variations of the beach/dune interface, Long Island, U. S. A., p. 37-45 in Psuty, N. P., ed., Dune/beach interaction: Journal of Coastal Research, Special Issue, No. 3.

Williams, S. J., 1976, Geomorphology, shallow subbottom structure, and sediments of the Atlantic inner continental shelf off Long Island, New York: Fort Belvoir, Virginia, U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Technical Paper No. 76-2, 123 p.

Williams, S. J., and Meisburger, E. P., 1987, Sand sources for for the transgressive barrier coast of Long Island, New York: evidence for landward transport of shelf sediments: Coastal Sediments '87: New York, NY, American Society of Civil Engineers, p. 1517-1532.

Wilson, B. W., and Torum, A., 1968, The tsunami of the Alaska earthquake, 1964: engineering evaluation: U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Technical Memorandum, No. 25, 401 p.

Wolff, M. P., 1975a, Environmental geology of Democrat Point, Fire Island, N. Y., and influences on adjacent barrier islands, p. 73-88 in Wolff, M. P., ed., New York State Geological Association, Annual Meeting, 47th, Hofstra University, Hemp- stead, New York, 31 October-02 November 1975, Guidebook: Depart- ment of Geology, Hofstra University, Hempstead, New York, 327 p.

Wolff, M. P., 1975b, Natural and man-made erosional (sic) and depositional features associated with the stabilization of migrating barrier islands, Fire Island Inlet, New York, p. 213-258 in Wolff M. P., ed., New York State Geological Association, Annual Meeting, 47th, Hofstra University, Hempstead, New York, 31 October-02 November 1975, Guidebook: Department of Geology, Hofstra University, Hempstead, New York, 327 p.

Wolff, M. P., 1982, Evidence for onshore sand transfer along the south shore of Long Island, New York and its implication against the "Bruun Rule:" Northeastern Geology, v. 4, no. 1, p. 10-16.

Wood, F. J., 1978, The strategic role of perigean spring tides in nautical history and North American coastal flooding 1635-1976: Washington, D. C., U. S. Department of Commerce, National Oceanic and Atmospheric Administration, U. S. Government Printing Office, Stock No. 003-017-00420-1, 538 p.

Wood, S. M., 1944, Erosion of our coastal frontiers: Illinois Engineer, v. 20, p. 5-34.

Wood, W. L., and Ivershar, L. L., 1985, Beach response to long period (sic) lake-level variation, p. 1571-1583 in Edge, B. L., ed., Conference on Coastal Engineering, 19th, Houston, Texas, 03-07 September 1984, Proceedings: New York, American Society of Civil Engineers, 3 vols., v. 1, p. 1-1102; v. 2, p. 1103-2180; v. 3, p. 2181-3282.

Wright, L. D., 1980, Beach cut in relation to surf zone (sic) morpho-dynamics, p. 97l8-996 in Conference on Coastal Engineering, 17th, Proceedings: New York, American Society of Civil Engineers.

Wright, L. D., Chappell, J., Thom, B. J., Bradshaw, M. P., and Cowell, P., 1970, Morphodynamics of reflective and dissipative beach and inshore systems, Southeastern Australia: Marine Geology, v. 32, p. 105-140.

Yasso, W. E., and Hartman, E. M., Jr., 1975, Beach forms and coastal processes: Albany, New York, New York Sea Grant Institute, Marine EcoSystems Analysis [MESA] Program: MESA New York Bight Atlas Monograph 11, 51 p.

Zarillo, G., A., and Zarillo, K. A., 1989, Assessment of long-term shoreline recession (sic) rates on eastern Long Island, p. in Tanner, W. F., ed., Coastal sediment mobility: Symposium on coastal sedimentology, 8th, Proceedings: Tallahassee, FL, Florida State University.

Zeigler, J. M., Hayes, C. R., and Tuttle, S. D., 1959, Beach changes during storms on outer Cape Cod, Massachusetts: Journal of Geology, v. 67, p. 318-336.

Zimmerman, M. S., and Bokuniewicz, H. J., 1986, Long-term beach response at Ocean Beach, Fire Island, New York, October 1981 through January 1986: Stony Brook, NY, State University of New York, Marine Sciences Research Center, Special Report No. 76, 43 p.

Zimmerman, M. S., and Bokuniewicz, H. J., 1987, Multi-year beach response along the south shore of Long Island, New York: Shore and Beach, v. 55, no. 4, p. 3-8.

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