B-3-AM Natural and Man-made Erosional and Depositional Features Associated with the Stabilization of Migrating Barrier Islands, Fire Island Inlet, N. Y. - Manfred P. (Fred) Wolff

B-3-PM A Major Beach Erosional Cycle at Robert Moses State Park, Fire Island, During Storm of December, 1974 - the confirmation of "grazing" swash undercutting as a major beach erosional mechanism - Imre v. Baumgaertner

Cumulative Miles	Miles	
0.0	0.0	Leave Hofstra Campus and head east on Hempstead Turnpike toward Meadowbrook Parkway.
0.5	0.5	Cross California Avenue.
1.5	1.0	Bear right at junction with Meadowbrook Parkway (southbound) to Southern State Parkway.
9.9	8.4	Continue south on Meadowbrook to toll booth at entrance to Jones Beach State Park.
11.8	1.9	Bear left on Ocean Parkway, follow signs to Parking Fields #1, 2, 6 (Jones Beach water tower is in distance).
13.4	1.4	Pass about traffic circle, follow signs to Parking Field #6, Theatre, and Town Beaches.
14.1	0.7	Pass Field #6.
15.4	1.3	Parking Field #9 (Picture stop, if possible).
17.7	2.3	Pass Tobay Beach.
19.6	1.9	Pass Gilgo Beach - follow signs to Parking area at Gilgo.
20.2	0.6	STOP #1. Gilgo Beach.

STOP #1, Gilgo Beach

INTRODUCTION

This area has been designated as one of the western feeder beaches used to disperse sands dredged and pumped from Democrat Point and Fire Island Inlet by the Army Corps of Engineers. Located on a barrier island between Jones Beach and Fire Island Inlet (Figure 1) it has undergone numerous natural and man-made changes during the past 150 years principally related to sand migration by longshore drift and a rising sea. Numerous inlets were present some years ago, but all of them have since been closed by the construction of the Ocean Parkway and the littoral drift.

The purpose of this stop is to view the erosional and depositional features of a feeder beach. With a horizontal shoreward rate of erosion of 3 feet (1 meter)/year during the past 15 years (Everets, 1973), nearly 10 million cubic yards of sand have been artifically added to the beaches between here and Fire Island Inlet since 1959. The beach now has its nearly maximum seaward and vertical extent because of recently completed sand bypassing operations terminated in April, 1975. The oceanographic information for this area is in article A-5 of this guidebook. Additional data and reference sources for this area are in the study by Everets.

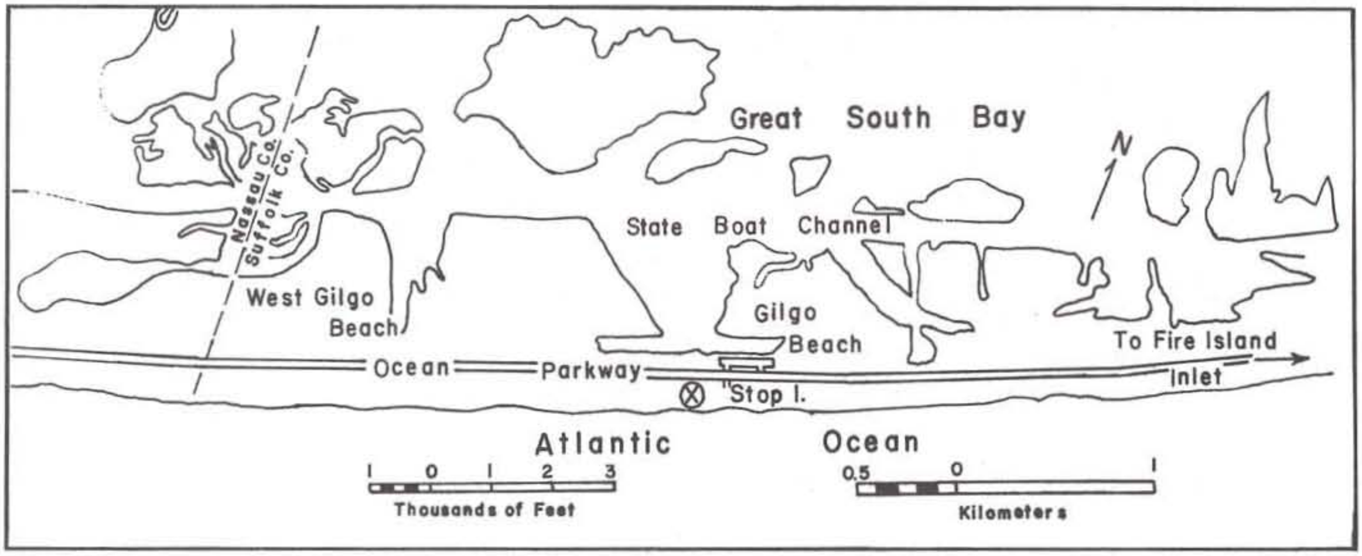


Figure 1. Location map of Stop #1 on the Jones-Captree Beach barrier island.

HISTORY OF AREA (See Figure 2)

Prior to 1851, and for some time thereafter, Gilgo Beach (then called Oak Beach) was near the site of an old inlet. Gilgo Inlet formed the western terminus of this beach while Oak Inlet occurred on the east. By 1888 Gilgo Inlet was divided by shoals into two smaller inlets while erosion along Grassy Beach had closed Oak Inlet. At that time Fire Island Inlet began to develop parallel to the coastline as lateral accretion along Democrat Point swept sands past the eastern terminus of Oak Beach (Figure 2).

By 1901 a new inlet developed near Cedar Island, but this was closed from the littoral drift by 1914. The original Gilgo Inlets were also closed as storm waves opened a second Gilgo Inlet about one-half mile east of the former location. Fire Island Inlet continued to be extended as Democrat Point continued its westward growth (Figure 2).

In 1923 Gilgo and Oak Inlets were sealed - though Cedar Island Inlet was again temporarily reopened between 1923-1930. From 1923-1939 Fire Island Inlet became more elongate but also more constricted as sands at Democrat Point began to migrate northwestward to close off the S-shaped inlet. Erosion near Oak Beach nearly reopened Oak Inlet, but dredging and the construction of a federal jetty in 1940-41 removed the "hook" of Democrat Point, straightened the S-shaped bend and widened the inlet.

By 1950, the littoral sediment had filled the basin behind the jetty, migrated past this point, and again supplied sand into the inlet. By 1959 the littoral sediment threatened to shoal Fire Island Inlet and again reopen Oak Inlet. A sand dike was constructed on Oak Beach in 1959 and revetted in 1960 (Figure 2). Periodic dredging of the sediment accreting west of the jetty has taken place since then by hopper dredging and hydraulic pumping across the inlet and onto Cedar Island and Gilgo Beaches (the present "feeder" beaches). The last major period of sand bypassing was completed in April of 1975 when nearly one million cubic yards of sediment was removed from Democrat Point and added to over 2 miles of these feeder beaches (Nersesian, 1975).

Without the shoaling and accretion of Fire Island against the offset barrier island chain to the west, only a small amount of the sand in littoral transport is accreted to these beaches. One effect has been progressive erosion along much (but not all) of the Jones Beach-Captree Beach barrier island (House Document #411, 1957; and #115, 1965), with an average rate of recession of 3 feet (1 meter)/year between Jones and Fire Island Inlets (Corps of Engineers, 1971).

Sand for nourishment of Gilgo Beach has been supplied from the tidal marshes during the early 30's (construction of Ocean Parkway and the State Boat Channel). Periodic sediment bypassing by dredging from Democrat Point (1959-1975) has added over 6 million cubic yards to these feeder beaches while another 3 million have been added from Great South Bay (Everets, 1973).

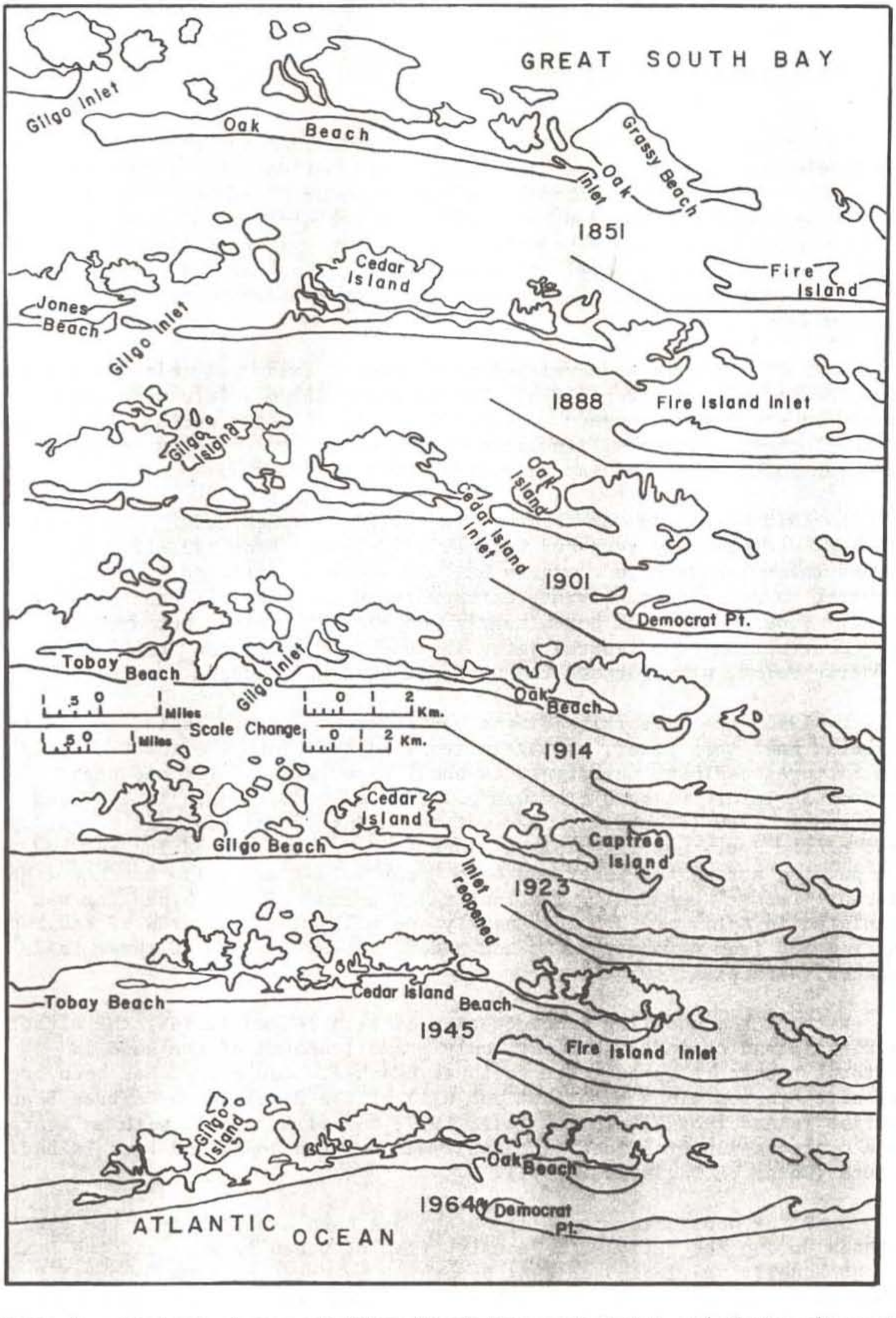


Figure 2. Historical map of Gilgo Beach-Democrat Point and their adjacent features (1851-1964). See text for explanation. (Data taken from Coast & Geodetic Survey Maps and Topographic Maps.)

It is interesting to note (Wolff, 1973) that construction and attempts at stabilization have produced wide, straight islands with no natural washovers and a few narrow but artifically deep inlets. Historical records indicate narrow, sinuous islands with wide shoals and washovers and several migrating shallow inlets - a direct contrast (U.S. Coast and Geodetic Survey Charts).

EROSIONAL AND DEPOSITIONAL FEATURES

During the spring storm of 1973, the profile of Gilgo Beach exhibited a low, gentle foreshore, and backshore with steep dune scarps from the recent erosion (Figure 3A). At low tide several patches of old marsh deposits were exposed near remnants of the old Gilgo Beach Pavillion (Figure 3B). Both of these were originally located behind a dune ridge on the barrier island.

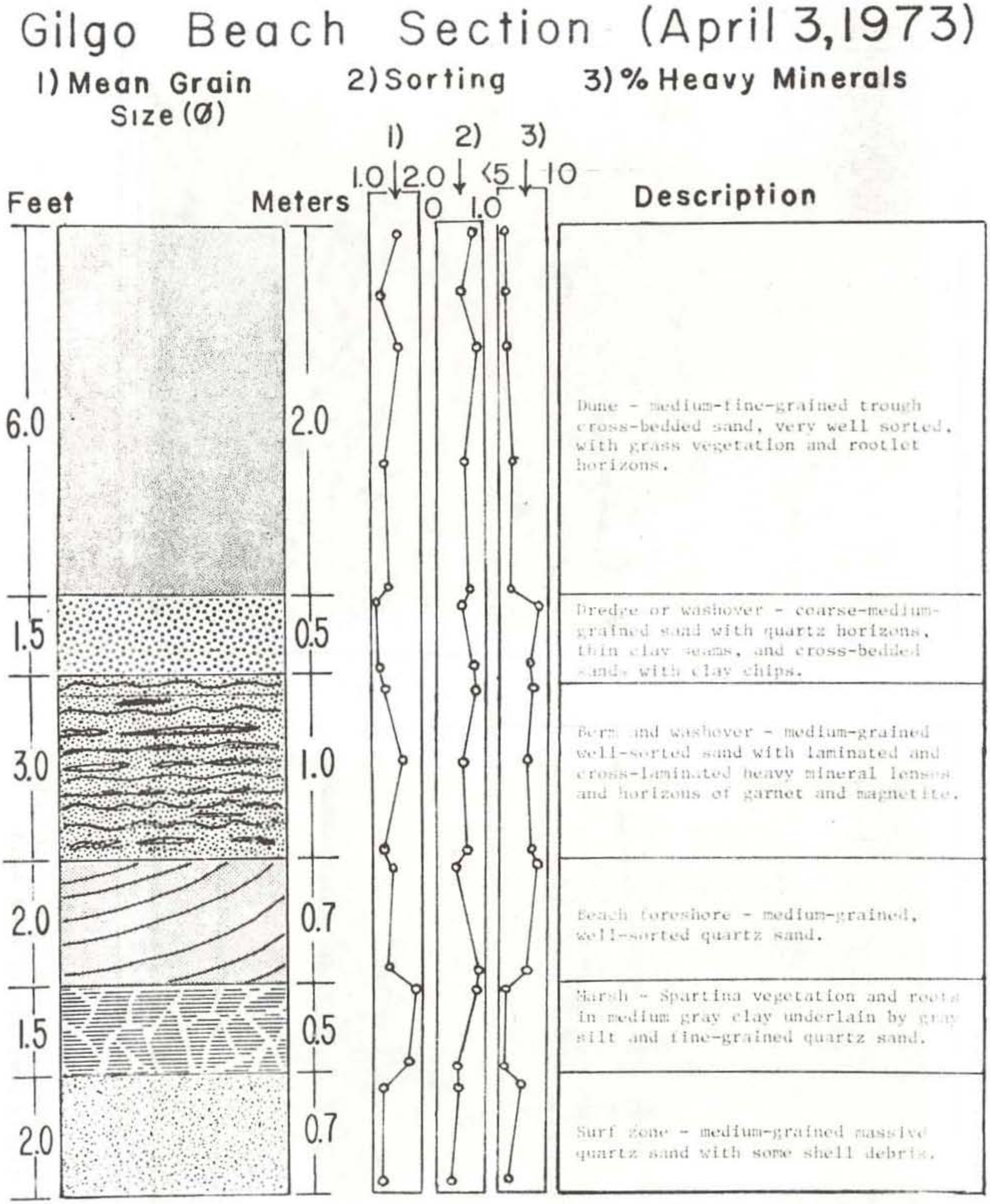
A vertical section of the Holocene beach and dune ridge deposits (Figure 4) indicates the presence of overwash and or dredged sands between the marsh layer (meadow mat) and the dune sands. The marsh deposits have been cored in several places along the Jones-Captree Beach barrier island (House Document #115, 1965).

The medium-grained, well-sorted and stratified beach and overwash sands, are overlain by sands now also containing gray-green clay horizons, clay chips, quartz pebble seams, and a lower concentration of heavy minerals. This zone may represent lenses of older back-barrier marsh deposits, as suggested for a similar section on the eastern end of Fire Island (Ruzyla, 1973), or they may represent, in addition, salt marsh dredge spoils added during construction of the Ocean Parkway and maintenance of the barrier beaches (Figures 5A and B).

The net loss of sand from Gilgo Beach has been nearly 1 million cubic yards between 1960 and 1973 (Everets, 1973) producing a horizontal shoreward erosion rate of 3 feet (1 meter) per year here, compared with a loss of 3-5 feet (1-1.7 meters)/year along the eastern edge of Fire Island (Ruzyla, 1973). The effect of the recent addition of sand from Fire Island Inlet onto Gilgo and adjacent feeder beaches is shown in Figure 6. The marsh layer is now buried beneath 3-4 feet (1-1.2 meters) of sand added during the recent beach nourishment operation.

Figure 3A. Eroded foreshore, backshore and dune deposits at Gilgo Beach exposing salt marsh layer (April, 1973).

Figure 3B. Eroded beach foreshore exposing remnant pilings of Gilgo Beach Pavillion and salt marsh layer (April, 1973).



Dune - medium-fine-grained trough cross-bedded sand, very well sorted, with grass vegetation and rootlet horizons.

Dredge or washover - coarse-medium-grained sand with quartz horizons, thin clay seams, and cross-bedded sands with clay chips.

Berm and washover - medium-grained well-sorted sand with laminated and cross-laminated heavy mineral lenses and horizons of garnet and magnetite.

Beach foreshore - medium-grained, well-sorted quartz sand.

Marsh - Spartina vegetation and roots in medium gray clay underlain by gray silt and fine-grained quartz sand.

Surf zone - medium-grained massive quartz sand with some shell debris.

Figure 4. Vertical section of exposed dune ridge at Gilgo Beach (April, 1973). Columnar graph indicates changes in : 1) size distribution of medium sand (10=0.50 mm.-20=0.25 mm.); 2) sorting (0=very well-1=moderately well; 3) concentration of H. M. (beach and dredge material 5-10%; marsh and dunes 5% or less).

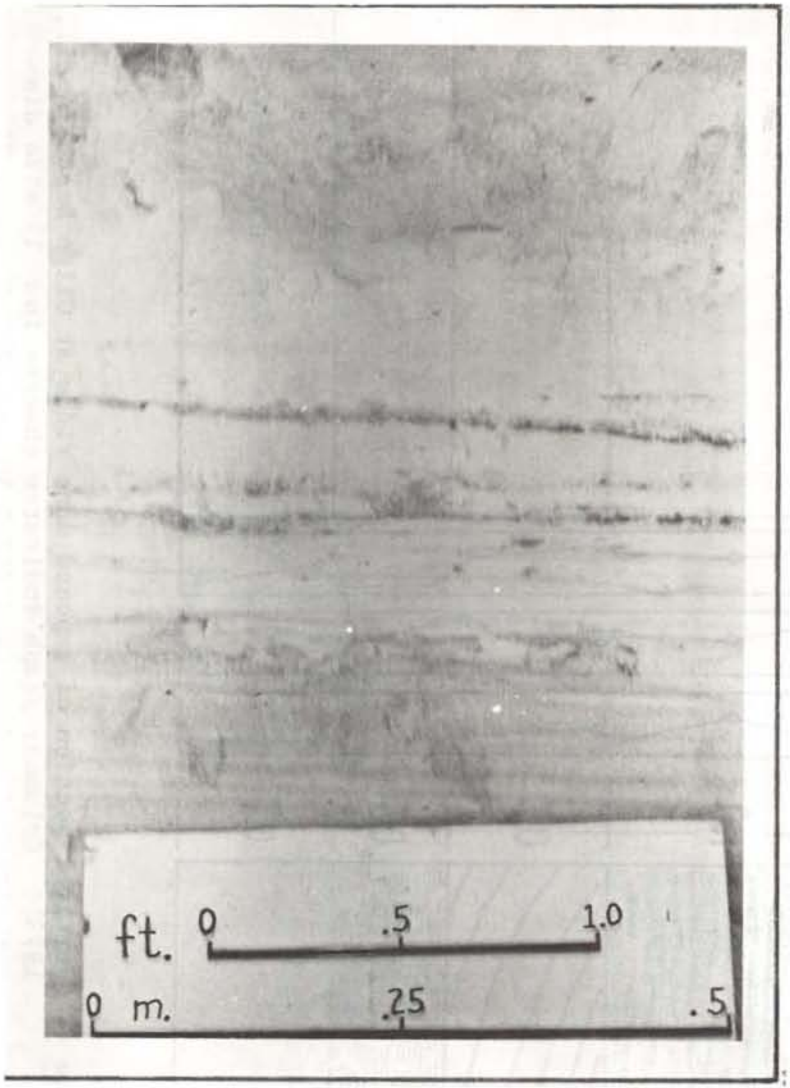


Figure 5A. Berm and overwash deposits with seams of marsh clay and disoriented clay chips; overlain by dune sands.

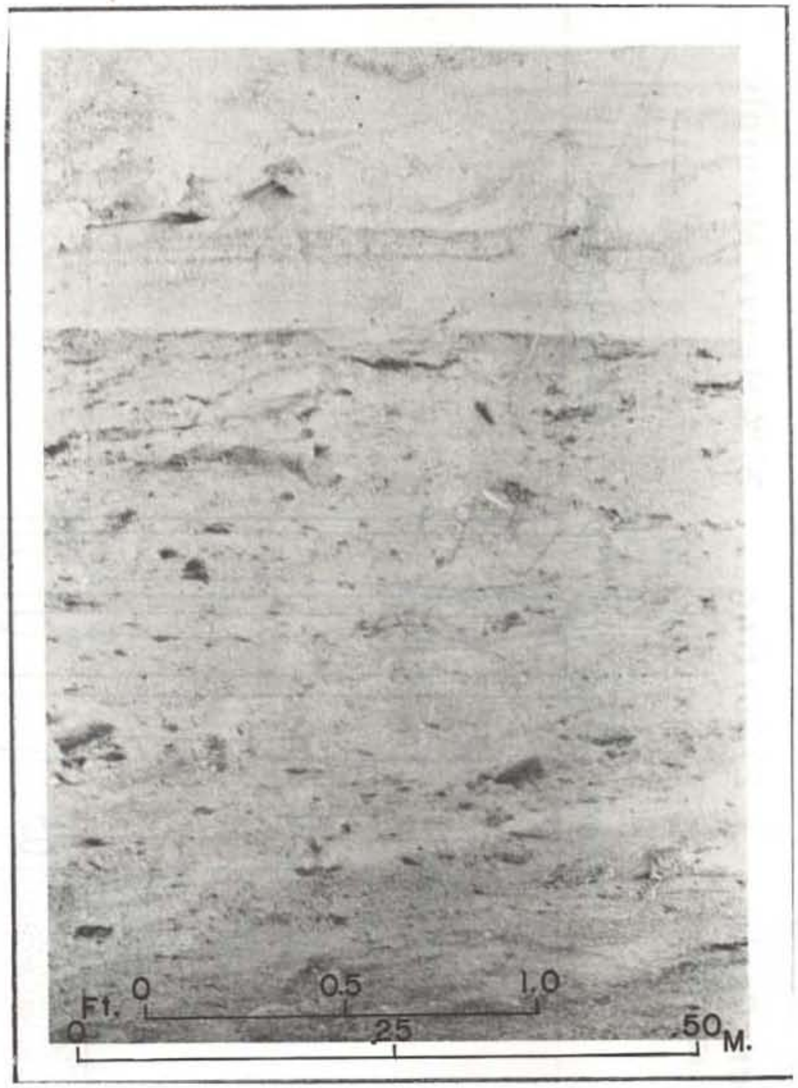


Figure 5B. Overwash and dredge (?) deposits beneath dune sands.

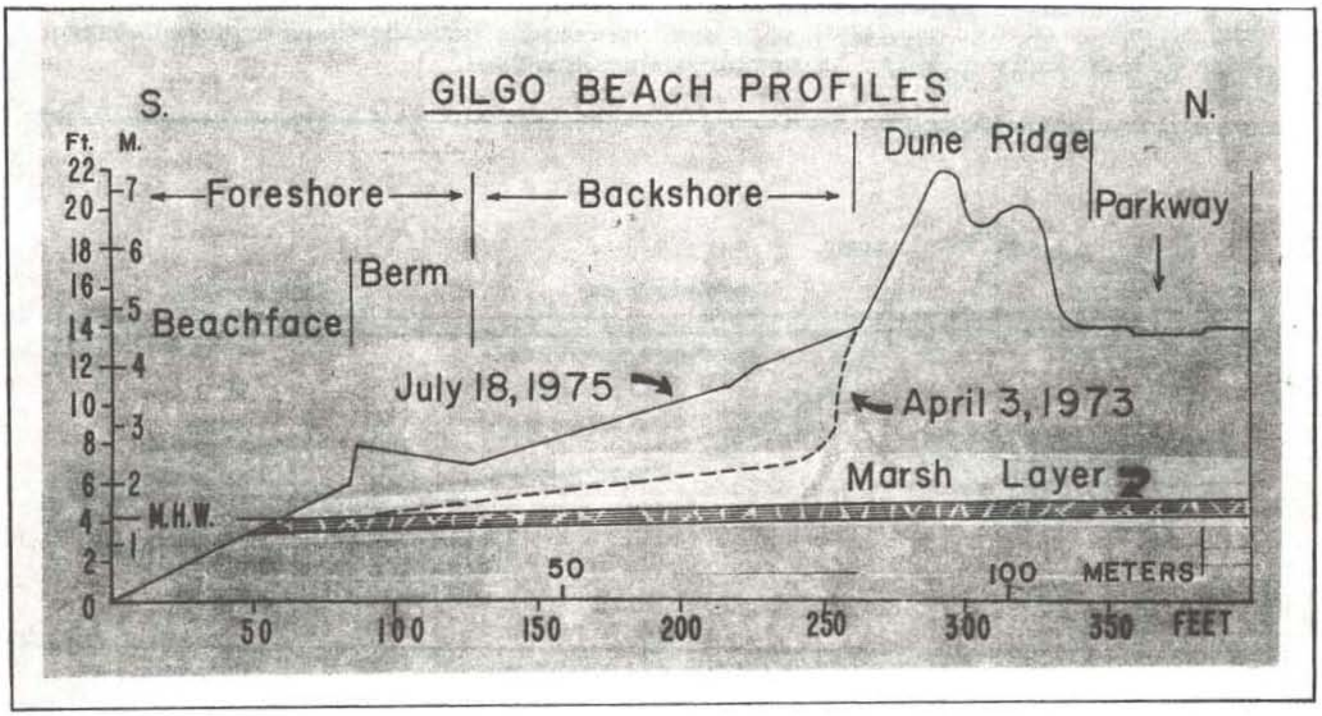


Figure 6. Gilgo Beach cross-profile indicating losses and gains of dredged beach sand and position of marsh layer.

EFFECT OF MARINE TRANSGRESSION AND REVINEMENT

Bruun (1962) provided evidence to indicate the pattern of coastal erosion associated with a rising sea level (Figure 7). Based on this pattern of sea level rise and transgression, Swift (1968) has shown that an active surf zone on a beach or barrier island will gradually expose and destroy marsh and lagoonal deposits by "ravinement." As long as there is a strong littoral drift and a large sand supply, spits will enable barrier islands to undergo lateral progradation, and marshes will be preserved beneath them (except along the surf zone) by the construction of beach, berm and washover, and dune deposits. If wave energy begins to exceed the rate of sediment supply, as occurs during a transgression, the marsh deposits are continuously exposed and eroded on the beachface, and the "ravinement" process takes place.

This has been the characteristic process on the south shore of Long Island, particularly near the eastern terminus of the barrier islands (as at Fire Island Inlet). While the average retreat of Fire Island is only 2 feet (0.7 m.)/year, the average retreat of Oak Beach (interval of 1825-1946) was 19 feet (6.2 m.)/year (Shepard & Wanless, 1971). Similar ravinement rates have been determined for Gilgo Beach (Figure 8) where over 1200 feet (400 m.) of barrier beach have been eroded in 75 years - a rate of 16 feet (5.3 m.)/ year. Without dredging, sand-bypassing, and inlet stabilization, a major storm could have reopened an inlet at Oak, Cedar Island or Gilgo Beaches as

Fire Island Inlet became shoaled and filled. Further ravinement can only be prevented by the development of a semi-permanent sand by-pass system between Fire Island Inlet and the adjacent feeder beaches.

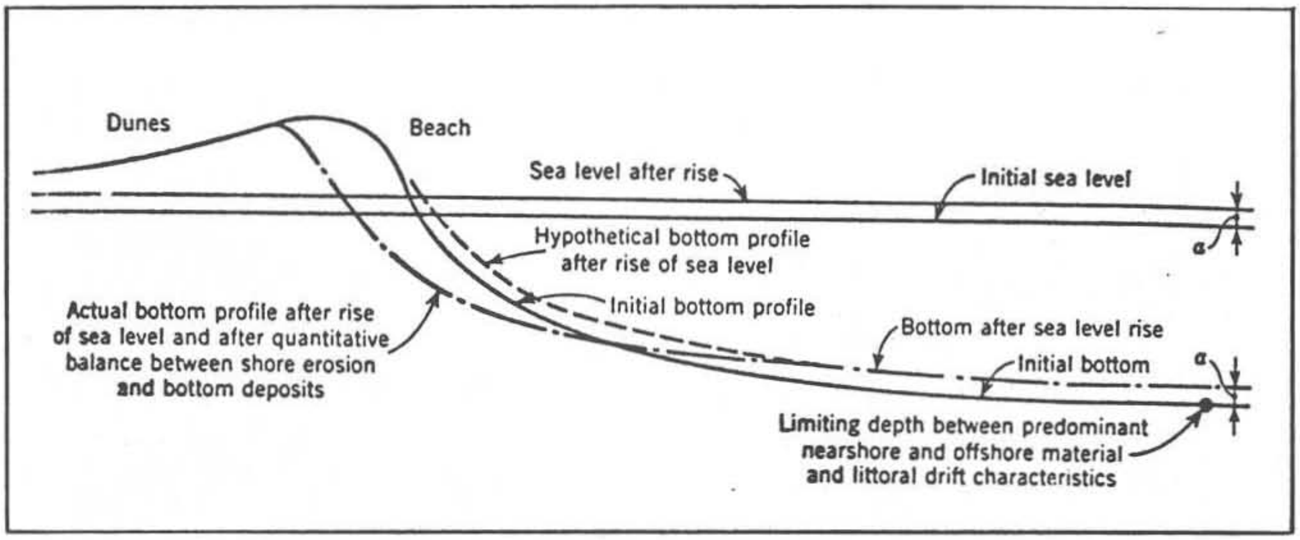


Figure 7. Hypothetical and actual offshore and beach profiles (after Bruun, 1962) indicating the influence of a rising sea on the Long Island coastline.

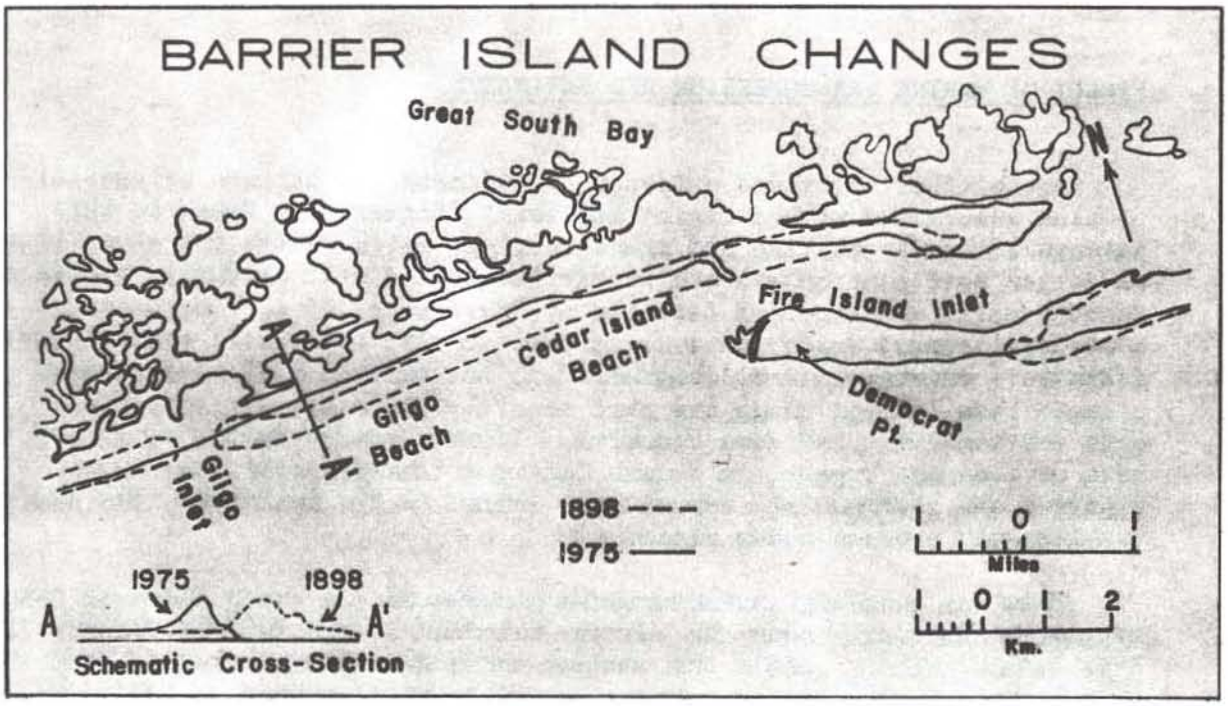


Figure 8. Overlay of 1898 and 1972 Coast and Geodetic Survey Maps at same scale to indicate effects of erosion and ravinement (see also Taney, 1961).

20.5	0.3	Leave Gilgo Beach, turn right (west) and at first crossover, head east on Ocean Parkway.
23.5	3.0	Pass Cedar Beach.
27.5	4.0	Bear right at junction with Robert Moses Causeway to the State Park and cross bridge to Fire Island.
28.7	1.2	Bear right at traffic circle (Fire Island water tower) and follow signs to Parking Field #2.
29.8	1.1	Circle about loop at end of road.
30.0	0.2	Enter Parking Lot #2, park in SW (right diagonal) corner near Pitch-Putt Golf Course and beach.

STOP #2, Democrat Point

INTRODUCTION

This area, known locally as Democrat Point, has been mapped by the U.S. Coast and Geodetic Survey since 1834, and has been recognized as a classic area of rapid, complex spit growth adjacent to a man-modified parallel inlet (Shepard and Wanless, 1971). During the period of 1834-1940 it has grown westward 4.6 miles (7.4 km.) from the Fire Island Lighthouse to the federal jetty at an average rate of 229 feet (76 m.)/year (see Figure 9).

The purpose of this stop is to view the complex spits and other sediment features, to explain their origin and migration patterns, provide some data on flow conditions and grain size parameters, and to examine the surface and subsurface sediment features.

Because of the present necessity for sediment bypassing across Fire Island Inlet to the western feeder beaches at Cedar Island and Gilgo (as noted at Stop #1) the area is dredged periodically. It is unfortunate that this trip follows after such a period - the last dredging operation ceased in April, 1975 and only remnants of the intertidal spit platform are currently preserved. However, participants are invited to return at other intervals during the next few years when some of the features described for this stop will again be more evident. A single trip to Democrat Point and Robert Moses State Park has always been more meaningful if it is followed by another excursion within a few months to note the rapid changes.

PROCEDURES AND ACKNOWLEDGEMENTS

The descriptions at this stop reflect the efforts of several on-going research projects assisted by undergraduates and supported by faculty research grants from Hofstra University. The spits and bars were plane table-mapped at low tide on a monthly basis over a two year period with 15-20 surface samples (1 cm. deep) collected from designated sub-environments during each visit. Current readings, tubular cores, and peels were collected and trenches constructed at various intervals. For past efforts, my heartfelt thanks are extended to Christine Anderson, Harold Corley, Margaret and William Johnson, Frank Sardone, and the many other students who assisted with the field and lab work. Thanks also go to Mr. Drew Kewderas who first introduced me to the area.

HISTORY OF DEMOCRAT POINT AND FIRE ISLAND INLET

Stages in the progressive growth of Democrat Point and the resultant changes in the inlet are indicated in Figure 9. The rapid westward growth of the barrier island and accretion against Oak Beach (closing off the inlet) was nearly completed by 1938. The migration of sand spits and shoals northward had constricted the inlet to a narrow, but deep gorge opposite Oak Beach which was then being eroded at 40 feet (13.6 m.)/year (House Document #411, 1957). Construction of the 5000 foot federal jetty in 1940-41 prevented this closure, entrained the sand "updrift" of the jetty, and allowed the tidal flow to transfer the remaining sand into and across the inlet (Figure 9). However, by 1950, the basin behind the jetty was filled to capacity; sands again swept around the edge of the barrier and accumulated as spits and shoals in the inlet (House Document #115, 1965). By 1959, the sediment extended one mile (1.6 km.) northwest of the jetty, constricted the inlet to 1200 feet (400 m.), and again created a deep gorge opposite Oak Beach (Figure 9). A perpendicular sand dike was then constructed at Oak Beach (known locally as the "Sore Thumb") and periodic hopper and hydraulic dredging were initiated. Several proposals regarding jetty extension, breakwaters, littoral basins and dikes have since been suggested, based on modelling studies by the Corps of Engineers (Bobb and Boland, 1969).

The history of Fire Island Inlet concerns the extension of the inlet parallel to the coast, the curvature of the inlet channel, and the constriction of the mouth of the inlet. Initially 4200 feet (1,400 m.) wide it became constricted and S-shaped as it continued to develop behind Democrat Point. Two gorges (ebb and flow channels) were commonly present, and shifted position as sands accumulated (Gofseyoff, 1953). The northern (ebb) channel was usually the main one, but after jetty construction, it became filled and formed an eastward migrating shoal now located at Oak Beach near the Robert Moses State Park Bridge. The shoal was stabilized by the revetted sand dike constructed at Oak Beach in 1959. For a more complete history of the area, the reader is referred to Gofseyoff (1953), House Document #411 (1959), Taney (1961), House Document #115 (1965), #191 (1967), and Shepard and Wanless (1971). The position of the inlet is now controlled by a single channel which migrates northward as sands accumulate in front of the federal jetty until it is dredged (Figure 10). Inlet currents are deflected by the sand dike, and erosion at Oak Beach is no longer a serious problem - the problem of a long range sand supply for the sediment bypassing system remains (Article A-5 of this guidebook).

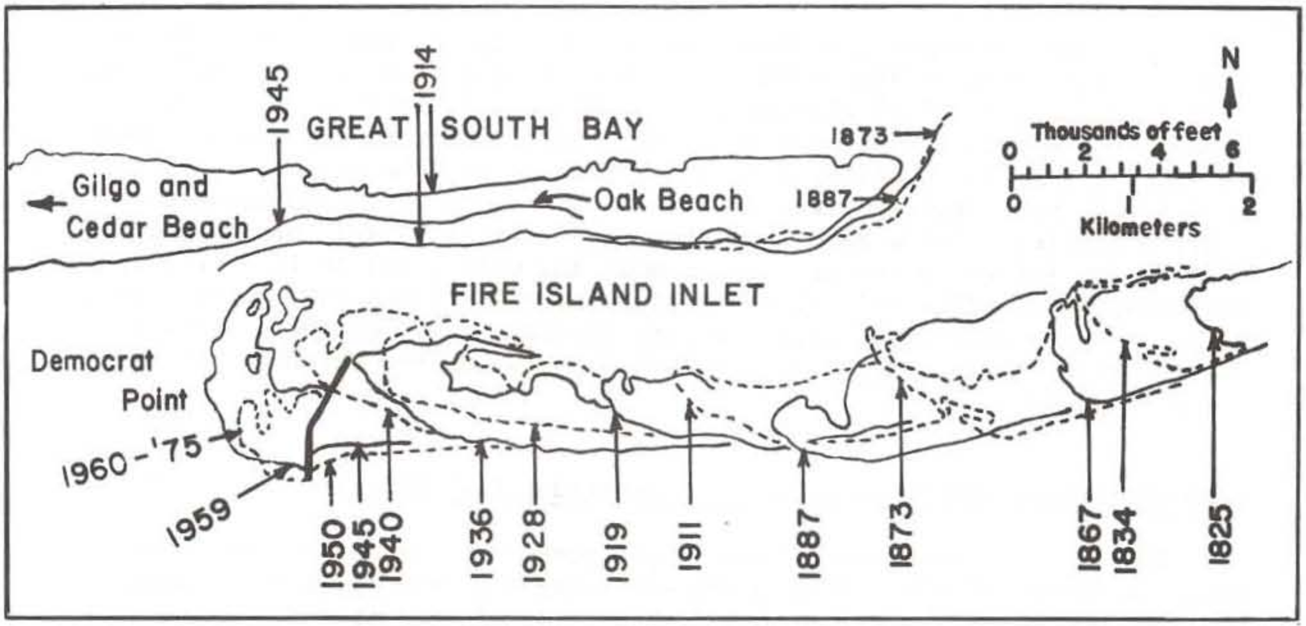


Figure 9. Historical changes in the growth of Democrat Point and erosion of Oak Beach along Fire Island Inlet.

Figure 10. Dredging and sand bypass by hydraulic pumping - looking north (February, 1972).

SPIT PLATFORM

The Intertidal Spit Platform

The features exposed at low tide on the well-developed intertidal spit platform are noted in Figure 11. The concept of a spit platform was developed by Meistrell (1966) through laboratory observations involving an erodable headland, a spit platform, and a spit. Because the present study is field oriented, involving several complex spits, the definition of the spit platform of Meistrell was modified. Instead of the area above the coastal shelf but below mean low water, the intertidal spit platform in this report refers to the area above mean low water, and includes all spits and embayments. (The spit platform of Meistrell becomes the subtidal spit platform - the intertidal spit platform remains until vegetated dunes develop across the feature - when it then becomes another extension of the barrier island).

Flow Conditions and Features of the Intertidal Spit Platform

Based on observations of wave conditions, surface morphology, and internal stratification, flow conditions vary with the tides and seasons but are dominated by flood oriented structures of the upper and lower flow regimes because of the location of the area at an inlet that parallels the coast. This unidirectional "landward" orientation of vectorial properties is a significant feature at Democrat Point. Here, the complex spits, arranged in en-echelon arrangement migrate across the lagoons and embayments of the spit platform and become welded against the leading edge of barrier island (Wolff, 1972).

Flood tidal currents, averaging 2-3 feet (0.7-1 m.)/sec. move across the edge of the platform and, coupled with wave refraction and overwash, shift the spit noses up to 100 feet (33 m.) a week. On the backside of these bars refraction moves and disperses the sands into the lagoons and embayments (Figure 11). Ebb tides do not recross or modify these features but drain into the runnels and embayments near the ocean or into the backshore lagoons and tidal creeks that drain into the inlet. Ebb currents on the lagoons and sandflats average 0 to 1 foot (0-.3 m.)/sec. with 1-2 feet (.3-.6 m.)/sec. in the tidal creeks.

Flow conditions in intertidal zones have undergone active study for the past several years (Klein, 1963, 1970; Hayes, 1969; Boothroyd and Hubbard, 1971; Davis and Fox, 1972). What is unique for Democrat Point is the volume of sand transported by the littoral drift, the extension and refraction of spits and "hooks", and the rapid lateral and vertical migration of these features across the intertidal spit platform as they become welded against the barrier island.

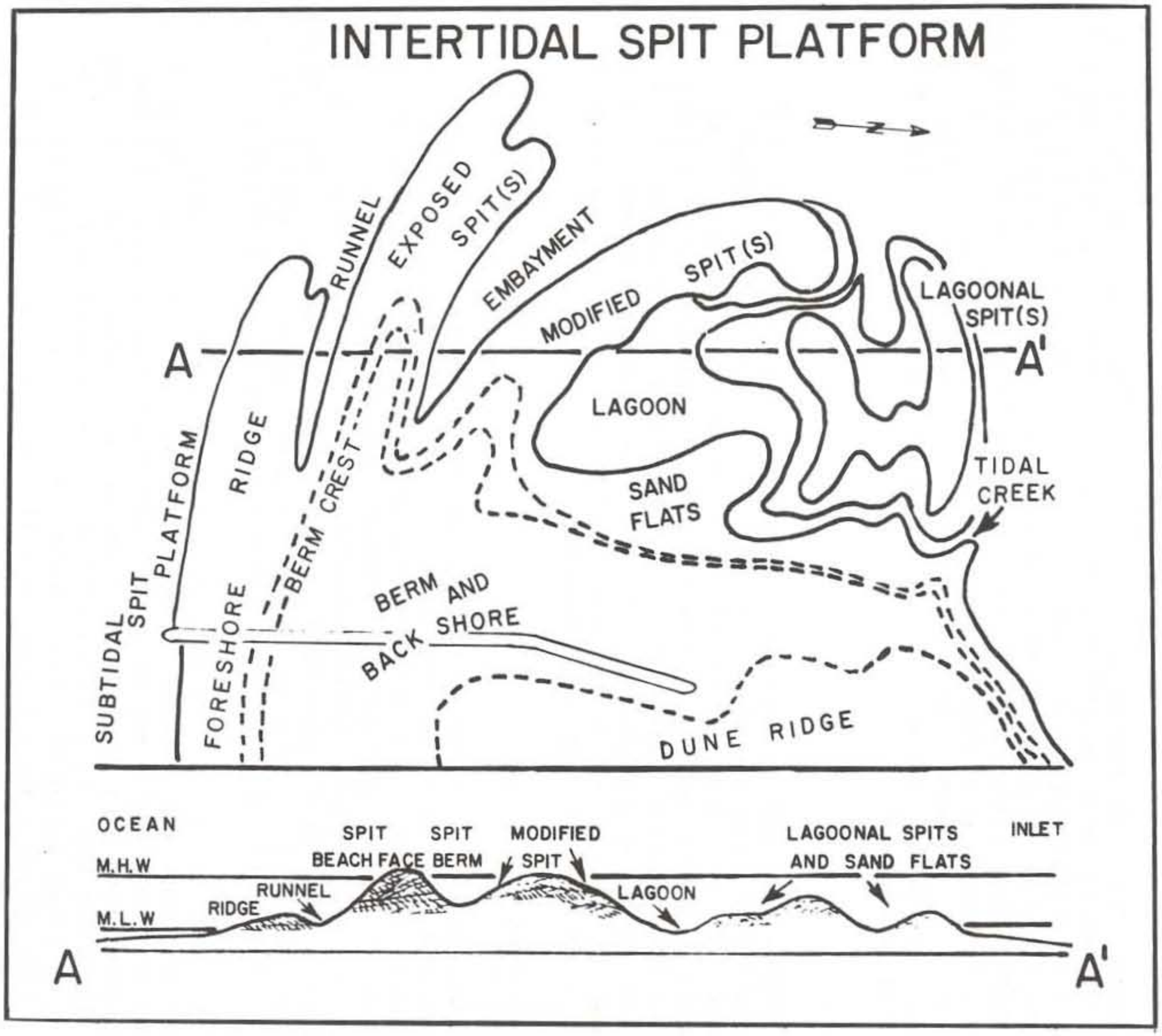


Figure 11. Features and environments associated with the intertidal spit platform.

CHARACTERISTICS OF THE INTERTIDAL SPIT PLATFORM FEATURES

The major features of spit platform, at a time of maximum development, are indicated in Figure 11. Bimonthly maps of these features are provided in the Appendix A (pp. B-3-AM 42 to B-3-AM 46).

Ridges

Ridges are dominated by upper flow regime plane-bed transport when in the swash zone. Near low tide this area becomes part of the surf zone with lower flow regime ripples and dunes. The sand is deposited on a gentle seaward slope by accretion of material from suspension as horizontal or low-angle planar crossbeds. During flood tide the sand is moved onshore by bedload transport as avalanche foreset deposits (Figure 12). The general increase in flow regime from the breaker zone shoreward reflects the increase in orbital velocity of shoaling waves with decrease in wave depth (Clifton et al., 1971).

Runnels

Runnels are narrow elongate troughs behind the ridge that extend to the beachface of the exposed spit (Figure 13). They are drained westward by currents that move down the runnel toward the inlet. Megaripples are commonly exposed at low tide. Lower flow regime sinuous linguoid-lunate ripples form when the runnel becomes constricted by ridge accretion. Progressive avalanche deposition across the ridge closes the seaward edge of the runnel, leaving a berm top pond. At low tide it may be drained by a series of braided streamlets (Figure 14).

Exposed Spit

An exposed spit extends from the edge of the jetty into the inlet. The zone is dominated by coarse-medium sand near the inlet and it is also the feature of maximum relief on the spit platform (Appendix A). Near the jetty the beachface is usually convex upward (because of the accretion of a beach ridge) and becomes more concave toward the inlet - but this depends on local sand supply and energy conditions. Seaward-dipping laminations are distinctive in the foreshore zone because of the grain segregation between swash and backwash (Clifton, 1969), but these are not always evident here.

Near the inlet the spit nose is affected by lower-upper and upper flow regime transport and different types of bedforms (depending on wave conditions) are periodically exposed. The flow conditions necessary for this development have been described by Boothroyd and Hubbard (1971). Sinuous and planed-off scour megaripples dominate, indicating the effects of low amplitude waves during the change toward ebb tide and the transition to upper flow regime transport conditions (Figure 15). Lower flow regime sinuous linguoid and lunate ripples are frequently superimposed across these structures. The dip slope of the scour is perpendicular to the foreshore, but during spit migration and refraction across the intertidal spit platform, the orientation of cross-bedding varies by nearly 90°.

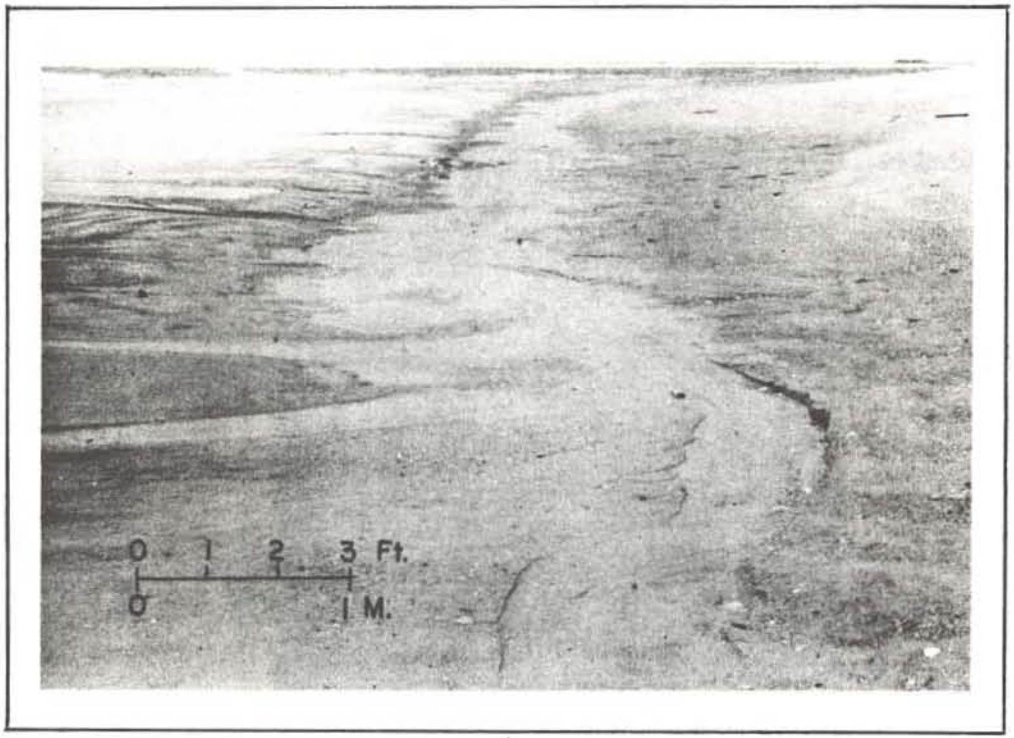


Figure 12. Ridge accretion (left) toward foreshore of exposed spit (right). View is toward west. (November, 1971.)

Figure 13. Narrow runnel between accreting ridge (right) and beach foreshore (left). View is toward east. (November, 1972.)

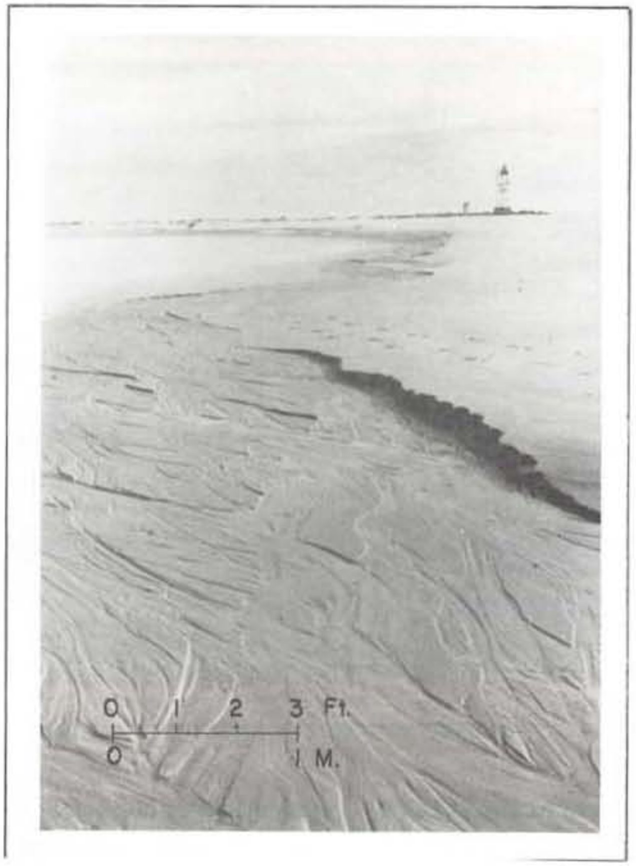


Figure 14. Tidal drainage between accreting ridge (right) and beach foreshore (left) creating a new berm, exposed spit, and beach foreshore. View is toward east. (January, 1973.)

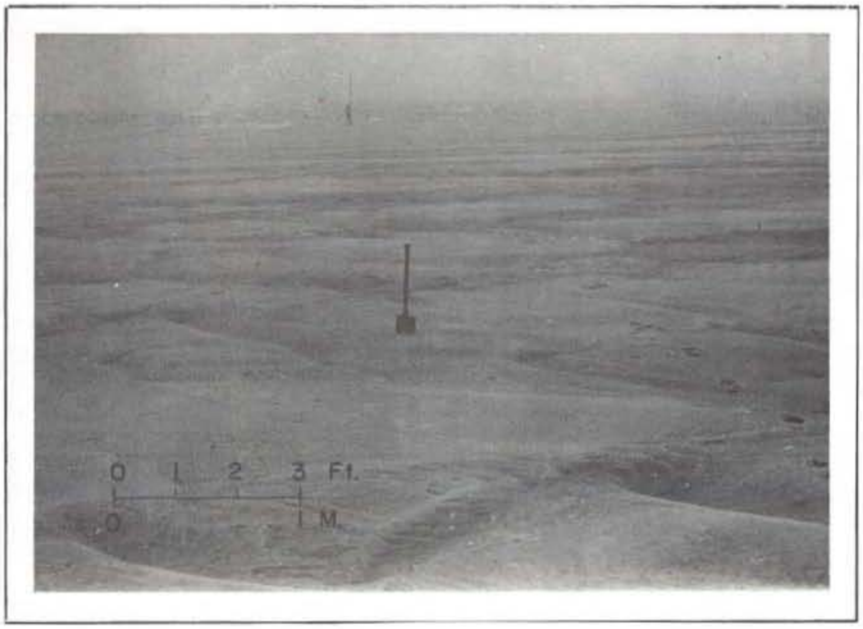


Figure 15. Sinuous and planed-off scour megaripples and superimposed linguoid ripples near the nose of the exposed spit. View is to northwest. (June, 1971.)

Figure 16. Backshore of exposed spit and washover lobes extending into lagoon. View is to east. (June, 1971.)

On the backshore of the exposed spit avalanche foresets from overwash are common. The result is a steep landward-sloping backshore. Near the nose of the spit some washover lobes form recurved spits or hooks from refraction and washover (Figure 16). Sand is also removed from the backshore by the ebb tides draining the adjacent embayments.

Embayments

The bays are larger than runnels, remain open longer, and have a more restricted circulation (Figure 17). They commonly exhibit bedforms that are dominated by straight asymmetrical ripples or sinuous linguoid-lunate ripples. Eventually, wave refraction and tides from the inlet cause the migration of the backshore of the exposed spit into the embayment and a lagoon is formed once the drainage near the inlet becomes constricted (Figure 18). Embayments are therefore not erosional features but temporary gaps between exposed or modified spits that act as sand reservoirs during storms until they are filled and become sand flats.

Modified Spit

The modified spit is similar in origin and form to the exposed spit except that wave refraction from tides and storm surges has been more extensive. The beachface is usually concave upward because of the diminished sand supply (Figure 19). Extension occurs at the expense of the beachface along the embayment, and overwash is now more extensive with

Figure 17. Early stage of bay development between exposed and modified spits. View looking west. (June, 1971.)

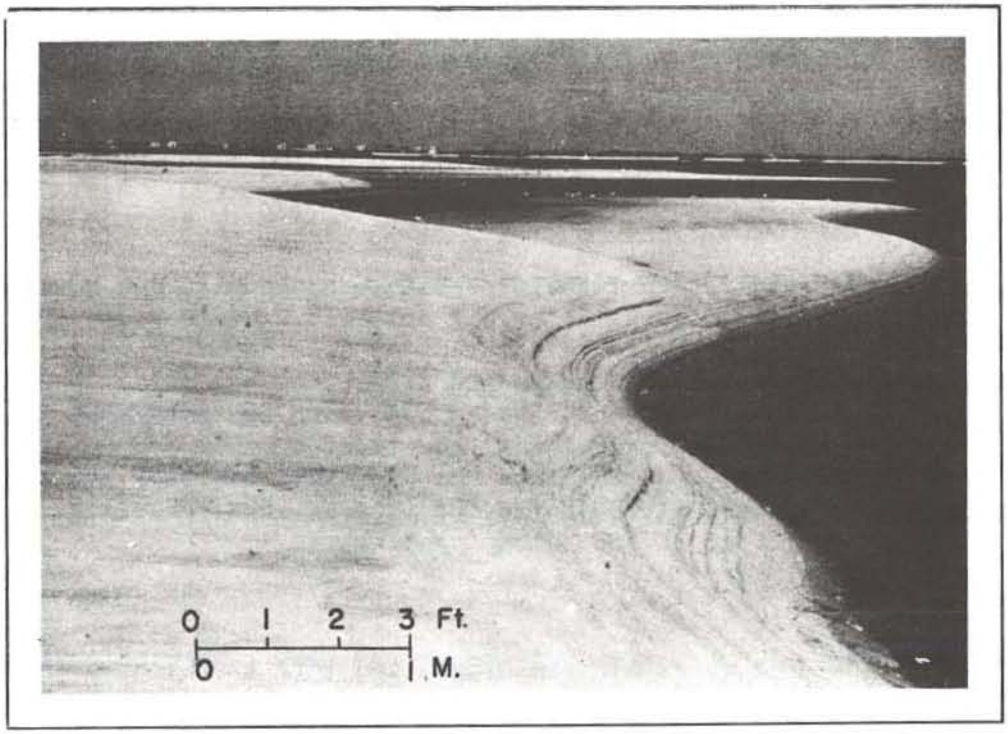


Figure 18. Late stage of bay development as overlapping washover lobes constrict embayment near inlet to form a lagoon. View is to northwest. (October, 1971.)

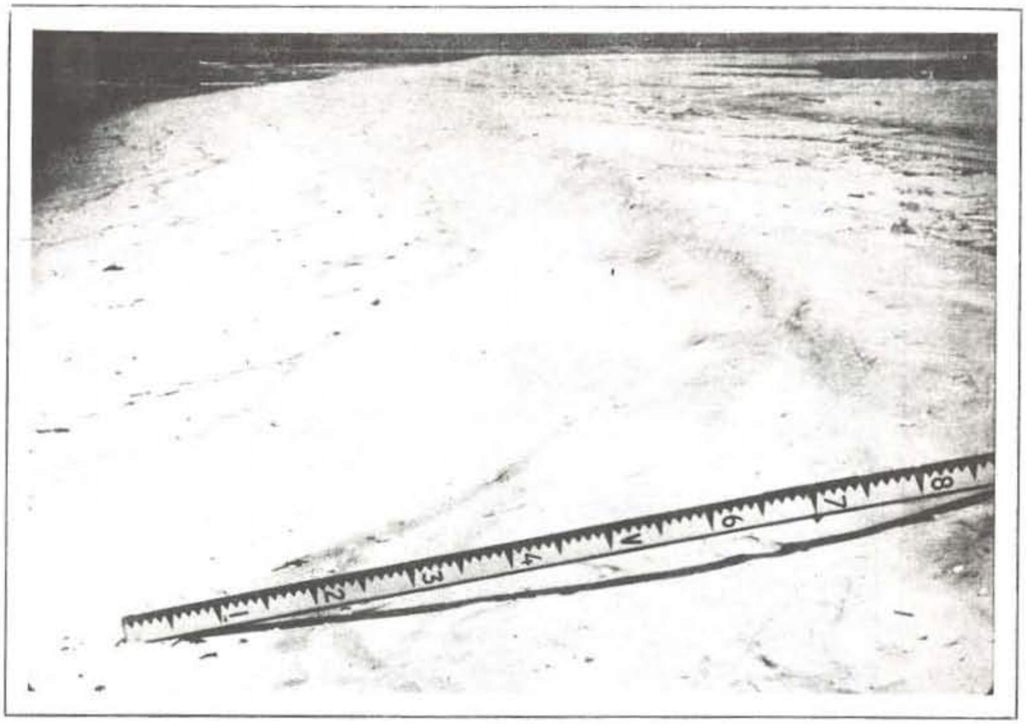


Figure 19. Concave beach foreshore and berm of modified spit - lagoon at upper right. View is to northwest. (June, 1973.)

washovers forming broad channels or sheets between spits. Erosion near the inlet provides a lag concentrate of coarse sand for the spit noses that spread toward the sandflats, forming hooks that close the embayment (Figure 20). As with the nose of the exposed spit, scour megaripples and avalanche foresets are common. The migration of lobes to the steep backshore frequently occur as a series of overlaps (Figure 21). This process of spit migration across the embayments and lagoons has been referred to as a naturally occurring landfill system (Wolff, 1972).

Lagoons

These are relatively permanent areas, that become inaccessible to the natural spit migration processes. They occupy depressions between spits and are periodically flushed by waters entering and leaving the tidal creeks. They may have steep slopes of 14-20° (near the backshore of modified or exposed spits) or gentle slopes (1-5°) near the sandflats. Lower flow regime bedforms (straight or sinuous symmetric ripples or megaripples) dominate (Figure 22). The lagoons are filled in by storm deposits when waves break over the berm crests of the spits and carry bedload material onto the sandflats. Lagoons may act as protected areas for the accumulation of some fine sand because of the shallow water, and low current velocity.

Lagoonal Spits

These form by the vertical swash-backwash of sand in the surf zone on

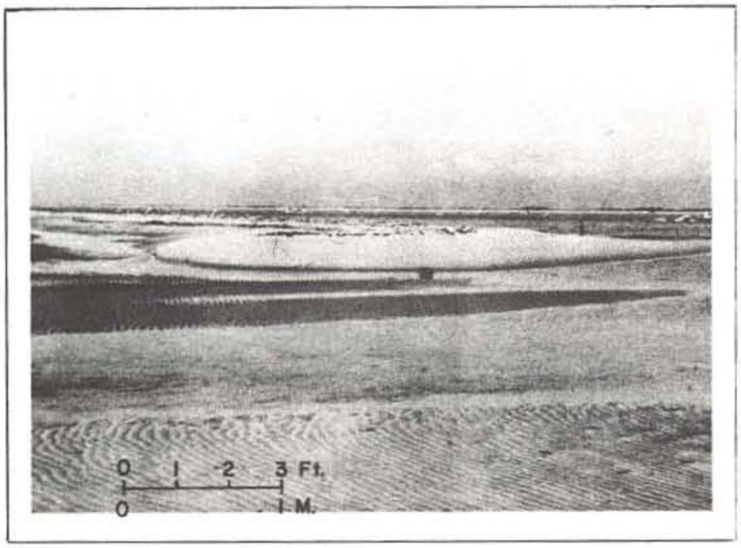


Figure 20. Recurved spit or hook at inlet edge of modified spit and embayment. View is to northwest. (September, 1972.)

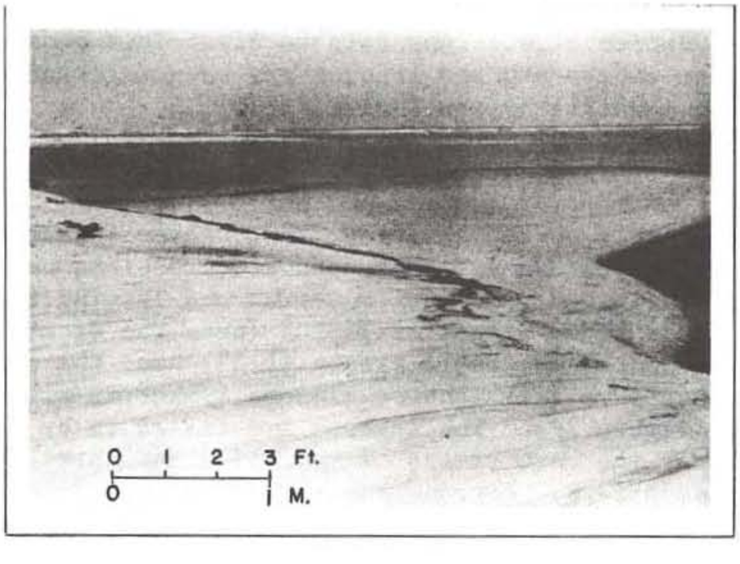


Figure 21. Overlapping washover deposits along backshore of modified spit. View is toward north. (September, 1971.)

Figure 22. Ebb-oriented linguoid-lunate ripples of lagoon near a tidal creek. View is toward west. (November, 1972.)

the sandflats near the inlet. Their morphology is controlled by the position of the tidal creeks and washover zones on the sandflats, and by refraction of sand lobes from the modified spit (Figure 23). Coarse sand is supplied by the nose of the modified spit and dispersed across the lagoonal spits and sandflats. Concave upward slopes (4-10°) are common and lower flow regime bedforms (ripples and megaripples) dominate.

Sandflats and Tidal Creeks

Lower flow regime bedforms dominate on the sandflats (straight or sinuous symmetric ripples, linguoid-lunate ripples, and ladderback ripples) and form during ebb tidal drainage into the inlet (Figure 24). The sinuous tidal creeks occur between the lagoonal spits and may also contain sinuous ripples and megaripples (Figure 25). Near the inlet they make excellent areas to observe plane beds, standing waves and antidune wave motion of the upper flow regime.

Beach Backshore and Dunes

Only the most intense northeasters or hurricanes move sand, granules, pebbles and shell debris onto the beach backshore (Figure 26). These lobes of sand gradually raise the sandflats above the level of the tides, allowing vegetation to become established. Unlike the Spartina grasses characteristic of the marshes, the high energy of the intertidal environment prevents their rooting until the backshore is removed from the tidal influence, beachgrass can take hold and dunes form (Figure 27).

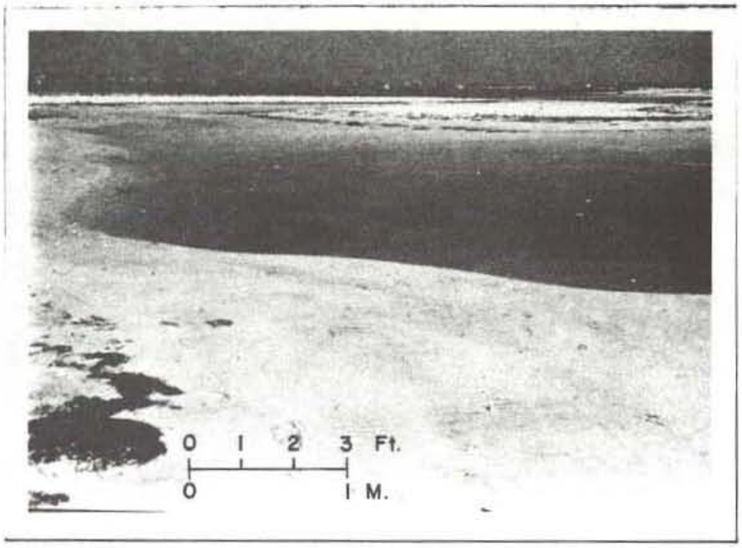


Figure 23. Development of lagoonal spits on the sand flats near the inlet. View (from modified spit) is to the north. (July, 1972.)

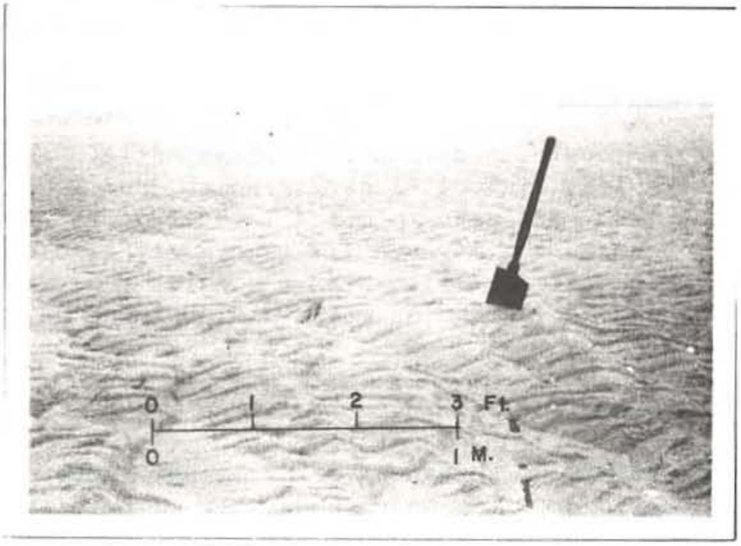


Figure 24. Superimposed ripples to form "ladderback" pattern during ebb tidal drainage on the sandflats. View is toward south. (September, 1973.)

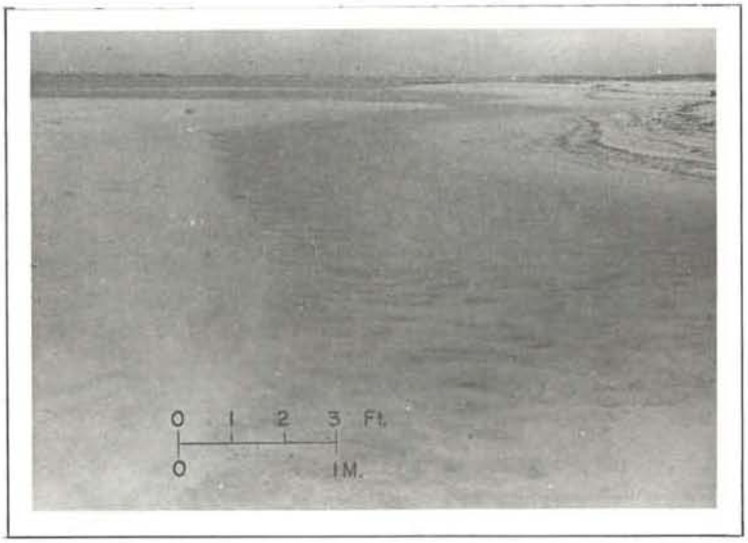


Figure 25. Tidal drainage creek between modified (left) and lagoonal spits (right). View is toward north. (May, 1973.)

Figure 26. Small washover lobes on sandflats near inlet. View is to northeast. (June, 1972.)

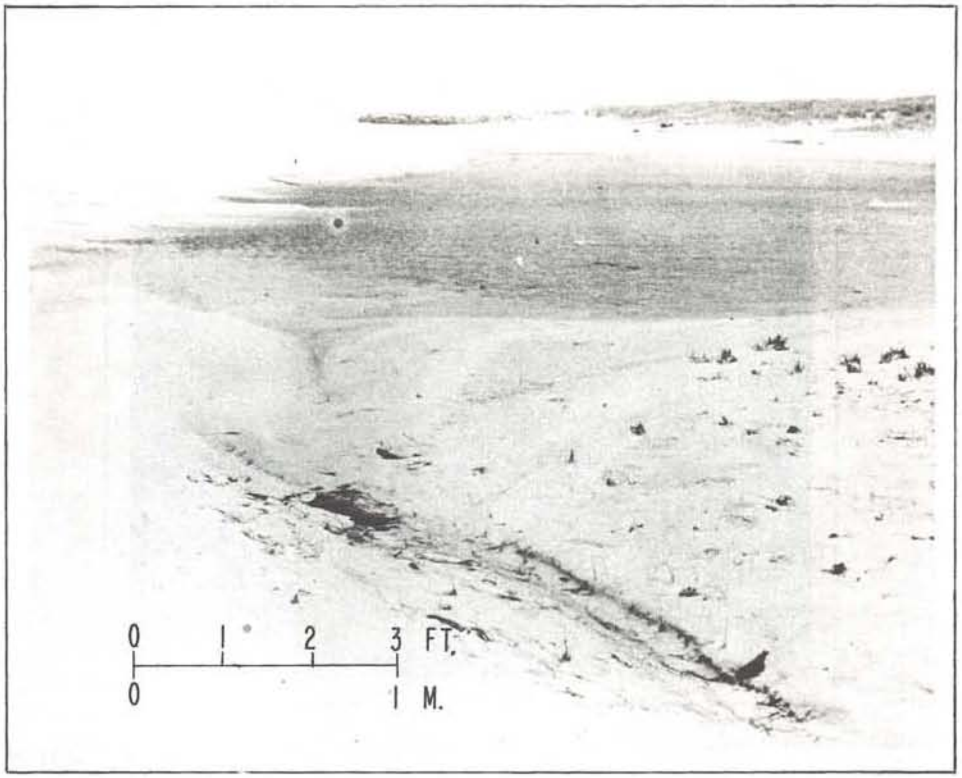


Figure 27. Development of beach grass on dunes near sandflats and beach of inlet. View is to northeast. (June, 1972).

Dunes occur as low vegetated mounds behind the beach backshore and were only beginning to encroach across the rock jetty near the northern terminus of Democrat Point before dredging occurred. Since onshore winds dominate in this environment, coarse sands and heavy minerals may form thick local lag concentrations and build up the dune ridge - especially during the winter months (Figure 28). Low, straight, small-scale ripples are the chief surface feature with the coarser sizes and heavy minerals concentrated on the crests rather than in the troughs (as with current ripples).

MIGRATION PATTERN OF SPIT PLATFORM FEATURES

The progressive development of the intertidal spit platform features and their pattern of growth, extension, and accretion against the federal jetty is shown in Figure 29 (A-D). The numbers reflect the order of spit development during this period.

Under more detailed analysis, initiation of the spits and hooks on the intertidal spit platform began in 1970 - after the dredging and sediment bypass operation of 1969. By the spring of 1971, the initial sand ridges and spits (0 and 1) have migrated across the platform to form a lagoonal spit and the first lagoon - with a small tidal creek draining northward into the inlet (Figure 30A). During this period of migration a wide but low-relief exposed spit (2) was formed at the jetty. By May, after further littoral extension and wave refraction, the low-relief of the tip, now

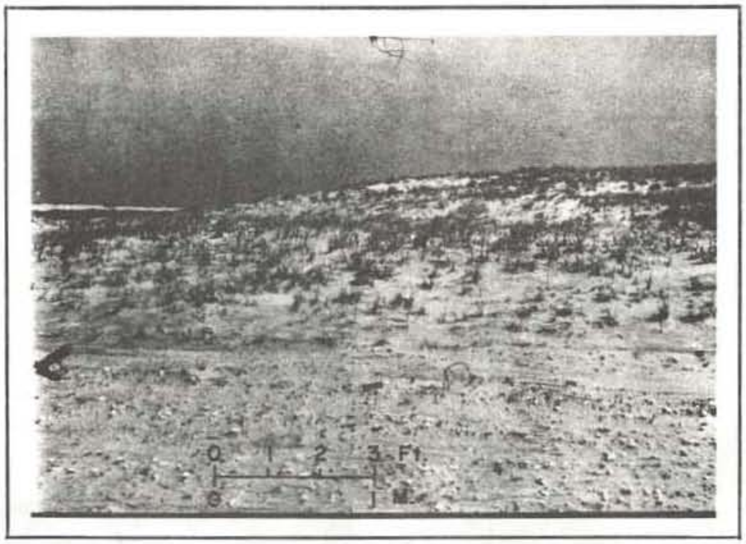


Figure 28. Lag concentrations of shell debris and coarse sand near base of dune ridge. View is toward east. (June, 1973.)

acting as a modified spit, spread into several lobes (Figure 30B). In early June, an additional ridge-runnel system developed (3), but with low relief on both spits - a late June storm truncated the ridge (now exposed spit 3) and, with the development of a tidal washover, separated the modified spit (2) into two components (Figure 30C). Late summer changes (July-September) produce a new ridge-runnel system (4), and an extension, widening, and migration of the exposed spit (3) - scalloped and hooked by wave surge from hurricane Doria. The extension and refraction of the modified spit (2B) across the subtidal spit platform also continues, producing a series of lagoons and embayments (Figure 30D).

By fall a new exposed spit (4) has developed (Figure 31A) as bar 3 becomes the modified spit and, with the loss of its littoral sand source and increasing wave activity, migrates rapidly across the subtidal spit platform onto the modified spit (2). Winter northeasters enable storm surges to break over the primary spit at the jetty, establishing a steep narrow runnel and berm-top pond (Figure 31B). While spit extension was minimal, rapid migration through inlet refraction and tidal overwash persisted and by December, shoals and lagoonal spits appear above the subtidal spit platform near the inlet. The dispersal and sand produces, at ebb tide, a series of tributary tidal creeks draining water from a washover sandflat, a constricted embayment, and a lagoon. Because of the difficulty in distinguishing modified and lagoonal spits and sandflats that have welded and overlapped during migration, numerical adjustments were made at the start

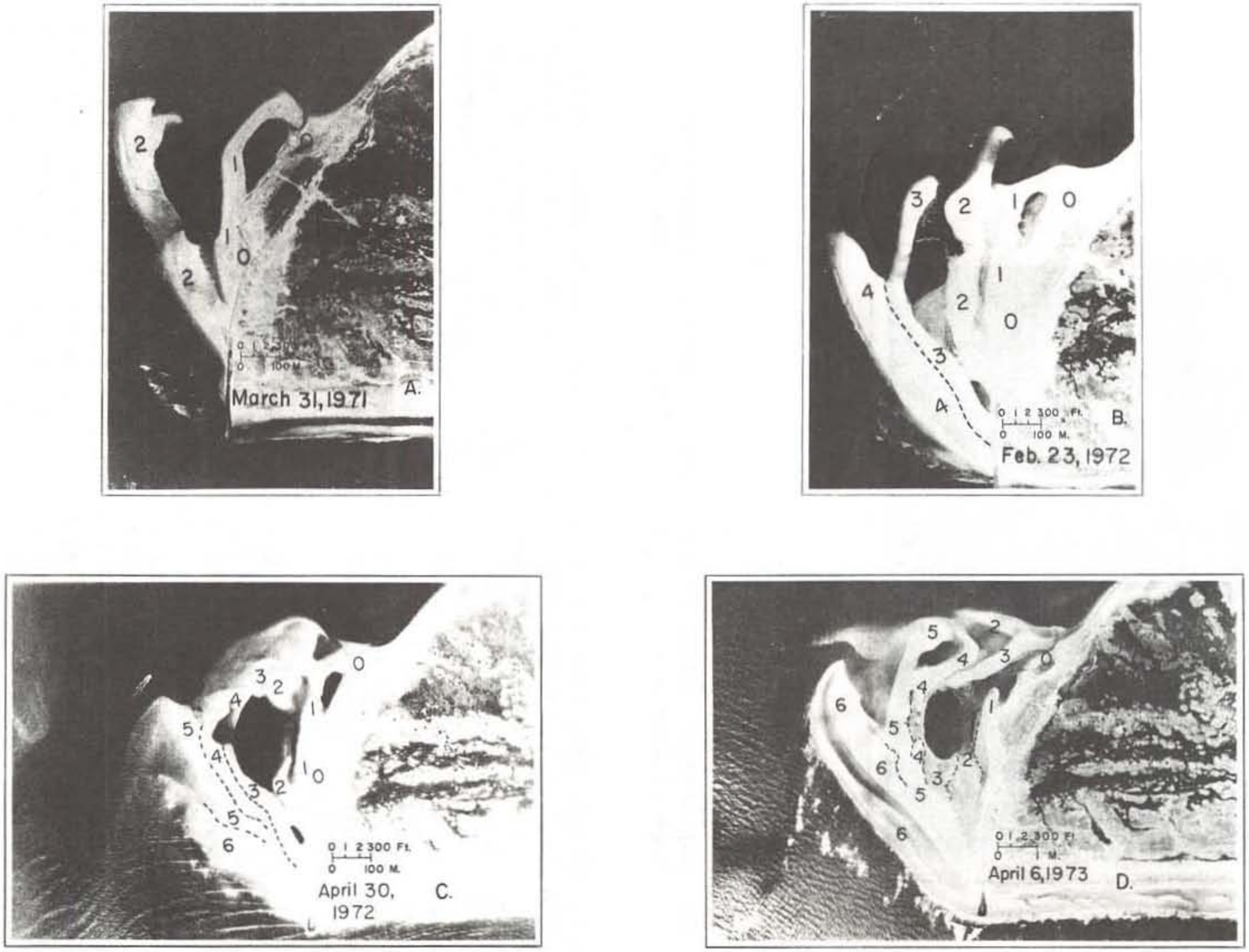


Figure 29 (A-D). Progressive development of intertidal spit platform features at Democrat Point - 1971 to 1973. Numbers reflect the order of spit development.

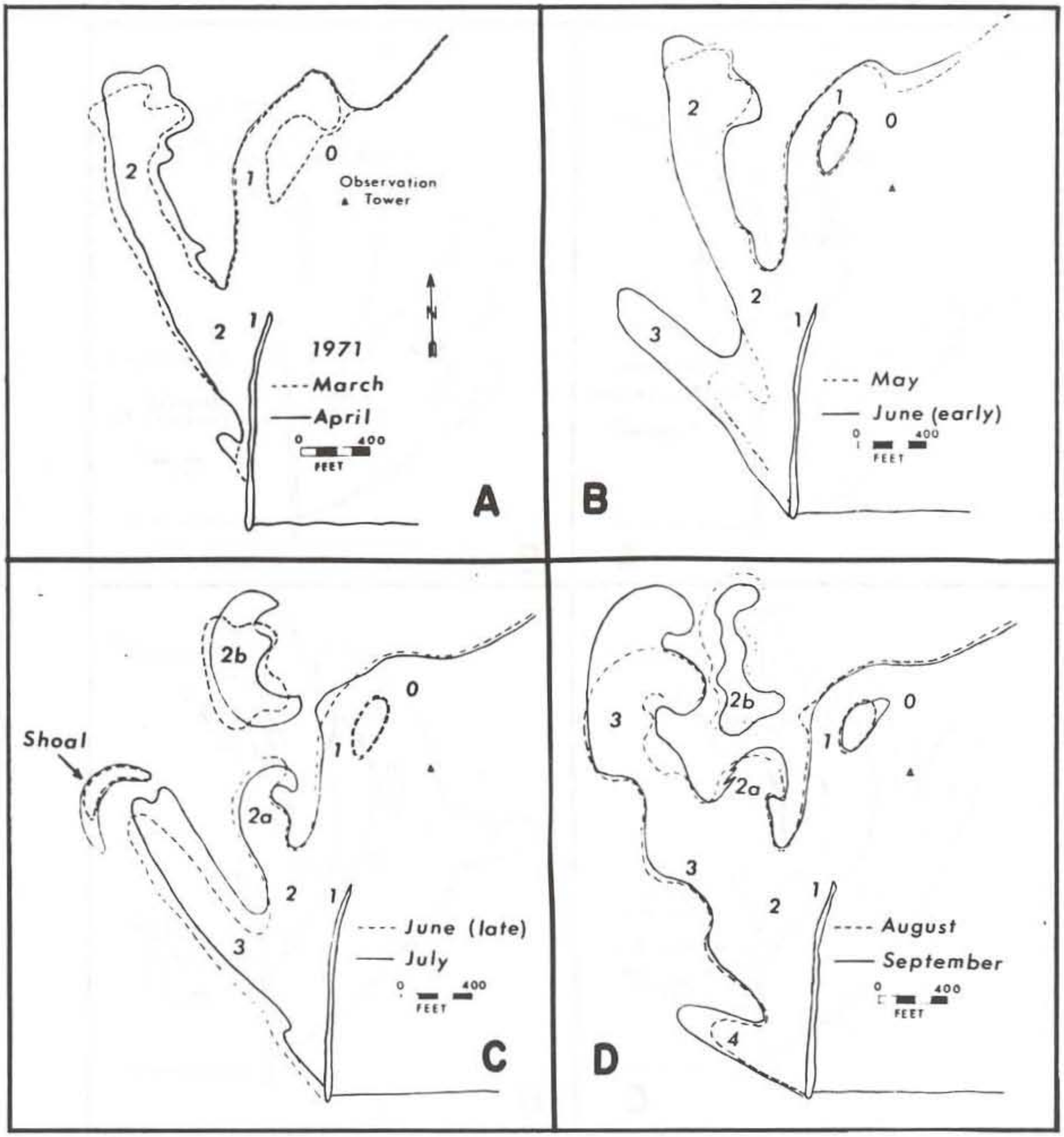


Figure 30 (A-D). Monthly pattern of spit accretion and refraction (March-September, 1971). See Text for more detailed explanation.

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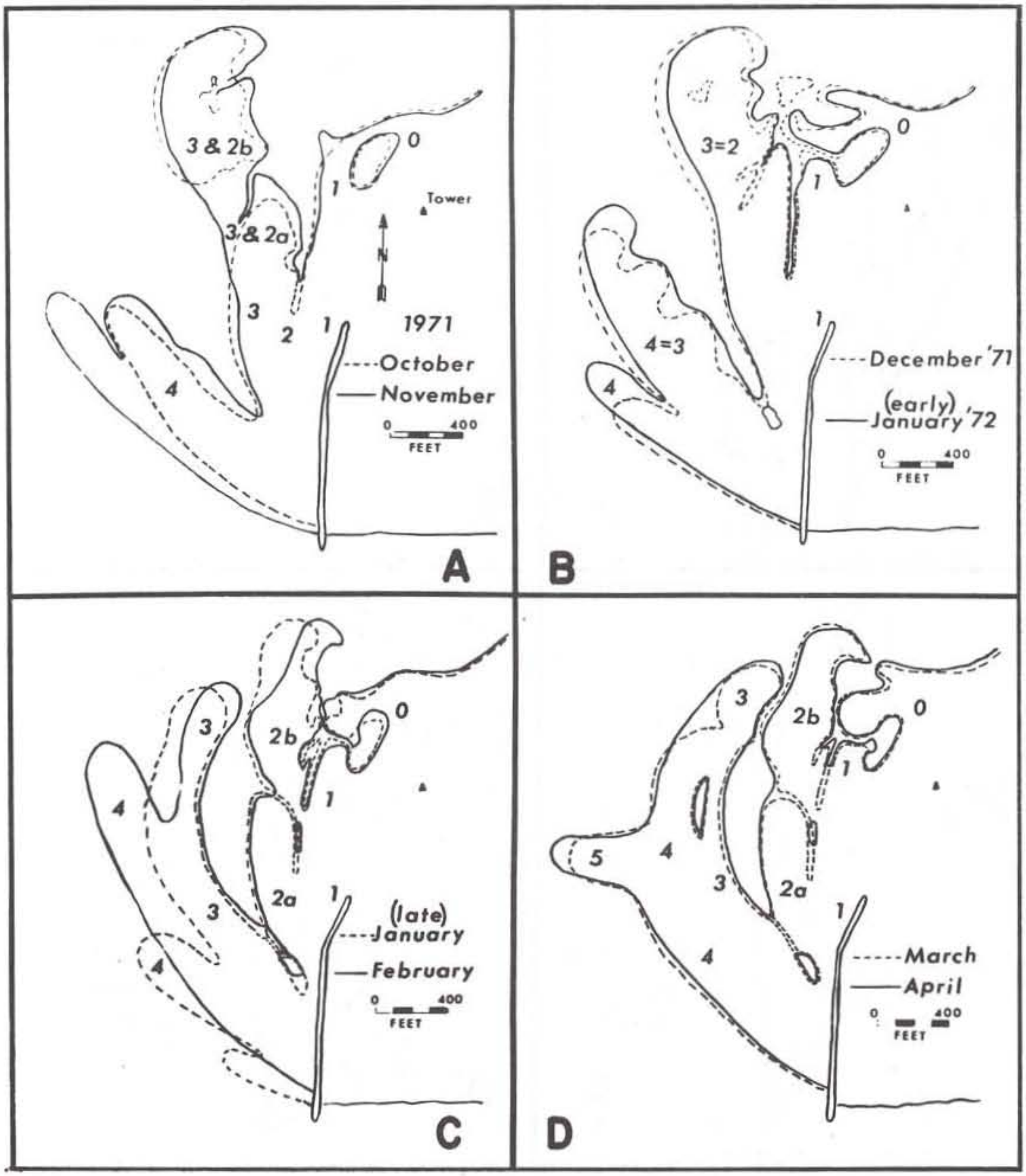

Figure 31 (A-D). Monthly pattern of spit accretion and refraction (October, 1971-April, 1972). See Text for more detailed explanation.

of each year (i.e. some spits were given a "reversing birthday", 3=2, 4=3, etc.) - see Figure 31B. Flood tides and wave refraction from storm surges now become more dominant and by late January all the intertidal spit platform features are present simultaneously (Figure 31C). The bifurcation of the exposed spit begins in February, but is delayed until March because of a short period of dredging. Extension and refraction of the exposed spit (4) and modified spit (3) continues, but the rapid shoreward migration of bar 3 constricts the embayment into a lagoon-tidal creek. By March the edge of the exposed spit (4) has been welded and overlapped against bar 3, leaving a temporary berm top pond near the dredge site (Figure 31D). The intertidal spit platform development cycle is now renewed as the subtidal spit platform, followed by a new exposed spit (5), extends into the inlet. Refraction and migration of the modified spits (4 and 3) continues while the lagoonal spits (2 and 1) and sandflats (1 and 0) develop sinuous tidal creeks that drain into the inlet.

In late spring a new series of ridges develop near the jetty and near the edge of the exposed spit (Figure 32A). The tip of the modified spit (3) forms a hook, closes one tidal channel and extends the other from bars 1 and 0. This also changes the level of the lagoon waters exposed at low tide on the intertidal spit platform and initiates the development of lagoonal spits on the sandflats as well as the edge of the inlet. The pattern of ridge accretion along the beachface of the exposed spit continues through the summer as its length and elevation gradually increase (Figure 32B). Flood tides disperse the sand by overwash across the modified spits (3 and 4), build up the sandflats, and encroach into the lagoon. Tidal overwash near the inlet causes the development of clusters of lagoonal spits (2a, 2b, 3) sub-parallel to the inlet while ebb tide drainage of creeks persists near the initial lagoonal spits (1 and 0). This pattern continues into the fall (Figure 32C) as new ridge-runnel systems form near the jetty. Winter storms again break over the crest of the primary spit, extending and deepening the embayment (Figure 32D). Refraction of this spit (5 and 6) continues while the modified spit (3) is swept onto the sandflats and between the lagoonal spits. Relief of the lagoonal spits decreases as flood tides spread the different lobes onto the sandflats.

By January, 1973 the storm surges crossing the spit platform have formed new washover lobes as hooks near edge of the exposed spit, creating a new northward extension and modified spit (5) and again reopening a former tidal creek (Figure 33A). Because of extension, accretion and overlap during lateral migration, the various spits are again renumbered with the exposed spit (5), a modified spit (4 and 3) and a composite lagoonal spit (2). By February a new ridge-runnel system has also developed (6) while the opening between spits 3 and 2 is being sealed. During the early spring inlet extension and refraction of the oceanward spits is accentuated (Figure 33B). The ridge (6) develops into a shallow embankment, the exposed spit (5) migrates toward the inlet, the modified spit (4) toward a washover sandflat, and the earlier modified spit (3) closes off the tidal creek near the lagoonal spit (2). During the summer, ocean and inlet accretion on the intertidal spit platform continues with the development of small seaward ridges on bar 6, and the extension and refraction of the exposed spit (5) into the inlet (Figure 33C). A series of washover lobes near the edge of this spit (5b) begin to seal off the embayment and create

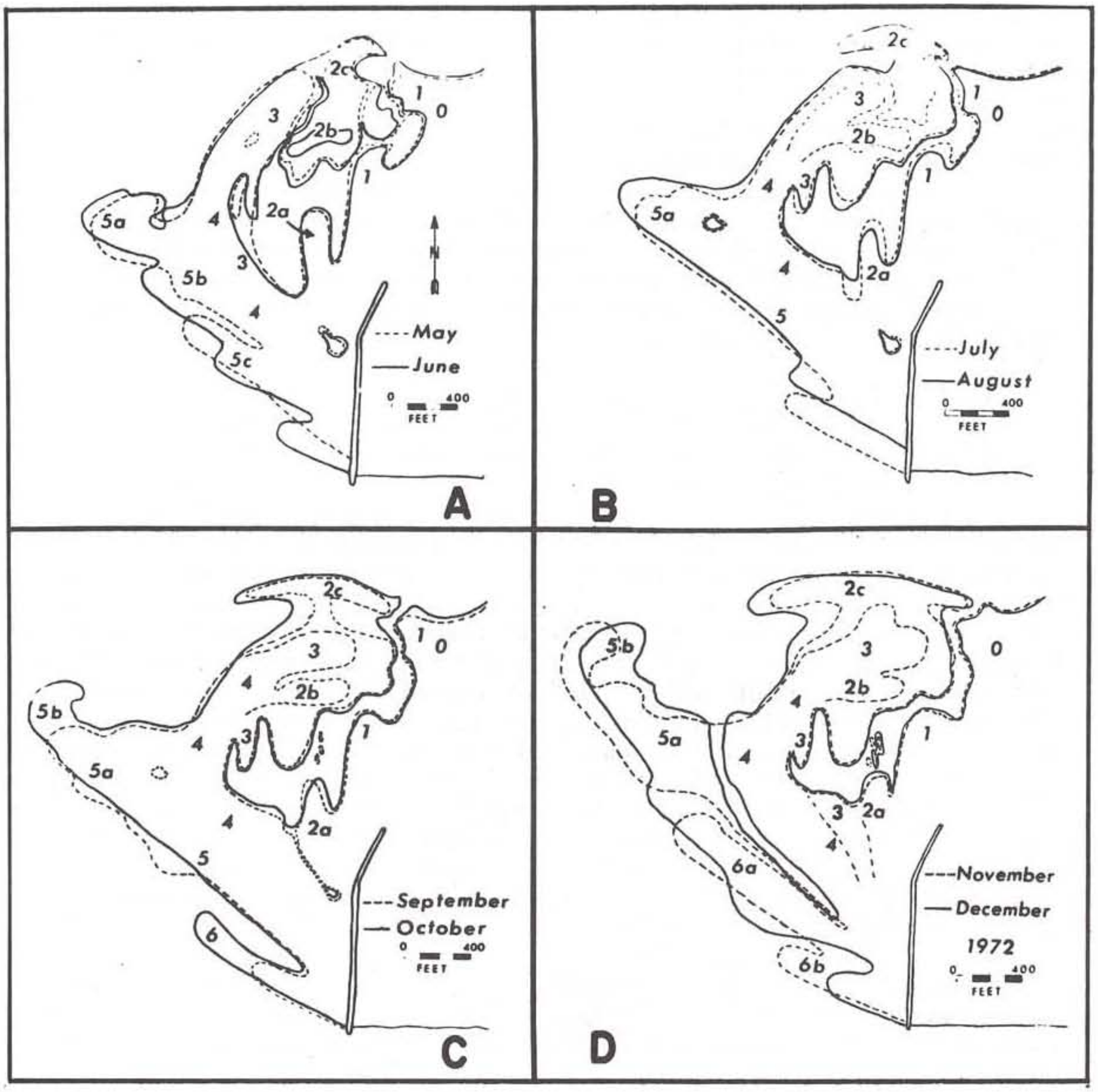

Figure 32 (A-D). Monthly pattern of spit accretion and refraction (May-December, 1972). See Text for more detailed explanation.

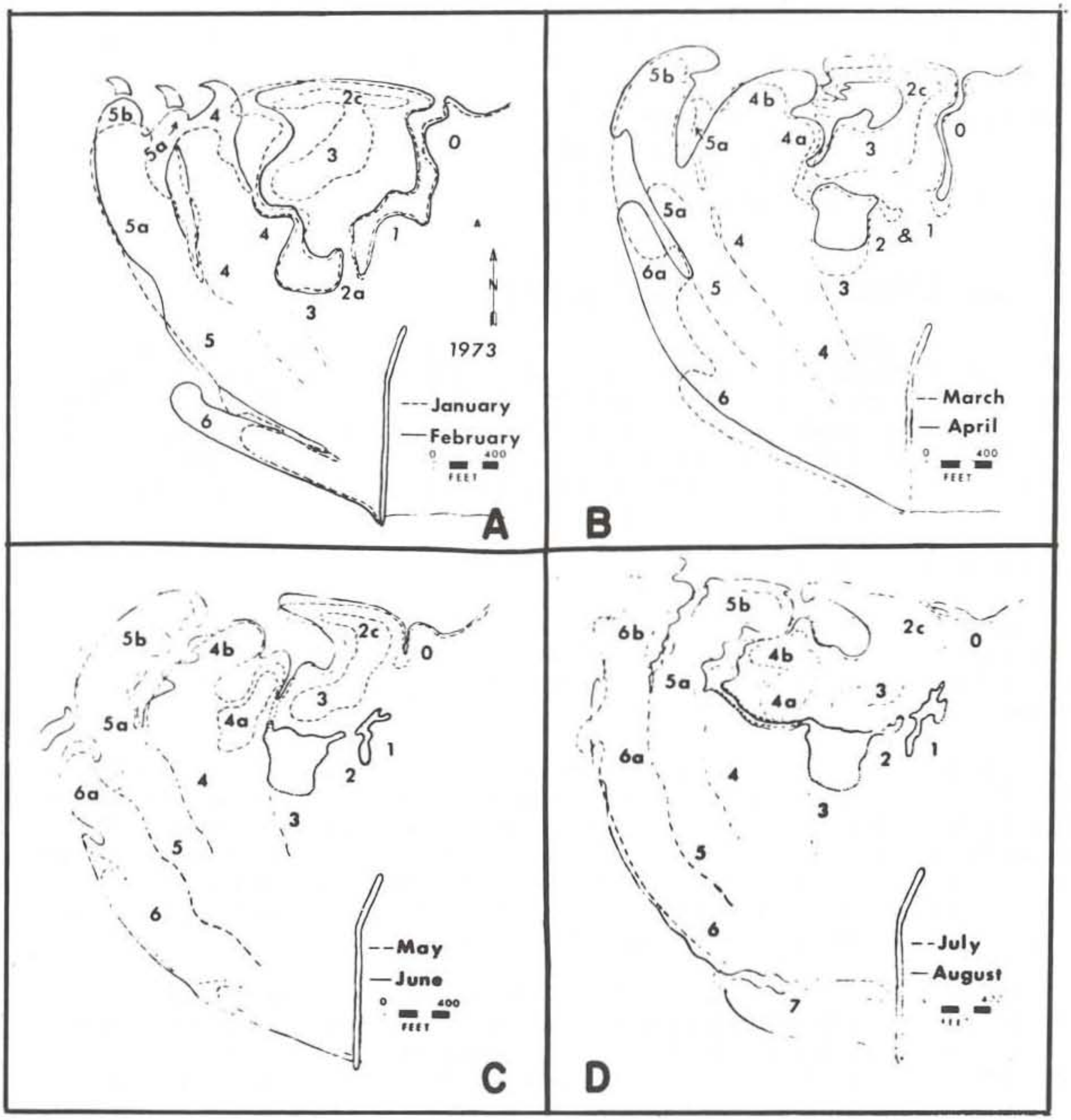

Figure 33 (A-D). Monthly pattern of spit accretion and refraction (January-August, 1973). See Text for more detailed explanation.

a new lagoon and connecting tidal creek. The creation of this new modified spit along with the previous modified spit (4a and b) enable the confining flood tides to disperse sand onto and across the lagoonal spits and sandflats. Ebb tidal drainage is gradually reoriented from the initial lagoonal spits (0 and 2) to a tidal creek between a modified spit (4a) and a lagoonal spit (3). By late summer a new ridge-runnel system develops (7) as the exposed spit (6) extends northward, and begins to be refracted toward the modified spit (5a and b) (Figure 33D). The embayment between the modified and lagoonal spits becomes constricted and opens a new tidal creek between bars 4 and 5 that extends to the interior lagoon. Thus, the pattern of accretion, extension, and migration continues.

GRAIN SIZE PARAMETERS - PRELIMINARY RESULTS

Surface samples, to a depth of 1 cm. were periodically collected from the sub-environments on the intertidal spit platform (15-25 samples/trip). These were washed, dried, and sieved (whole phi (Ø) intervals). Histograms were plotted and moment measures computed for all samples. However, until the frequency distribution curves and analysis of variance for the moment measures of the different environmental populations are complete, only preliminary results can be included.

Mean Grain Size (Figure 34)

Coarse sand (1.0-.75 mm or 0-.5Ø) - occurs in the swash zone of the ridge and near the nose of the modified spit. It is less common near the nose of the exposed spit because of the steeper slope and narrow swash interval.

Coarse-medium sand (.75-.50 mm or 0.5-1.0Ø) - characteristic along the nose of the exposed spit, along the extensions (foreshore and backshore) of the modified spits, and, near the inlet, on the sandflats and dunes. While the coarse sands represent the competency of the wave regime upon the sediment load within the traction carpet, these represent the effect of selective sorting as medium and fine sand is moved by overwash or wind into the sandflats or inlet (i.e. a lag concentrate).

Medium sand (.50-.25 mm or 1-2Ø) - characteristic of most other environments (silt-sized material was rarely obtained and if present, occurs in less than 1% of the weight fraction). Large scale monthly variations in grain size are common in environments dominated by medium sand; they are rare in the environments dominated by the coarser fractions.

Sorting

Nearly all sands are well sorted (.50-.99Ø). Lagoonal sands tend to be moderately well sorted (1.0-1.49Ø) while vegetated inlet dune sands are very well sorted (0.0-.49Ø). Through time, lagoons become collecting basins for coarse sands (from overwash) and also fine sand and silt (suspension from tidal cycles). The selective removal of some fine sand by onshore winds accounts for the sorting on the dunes.

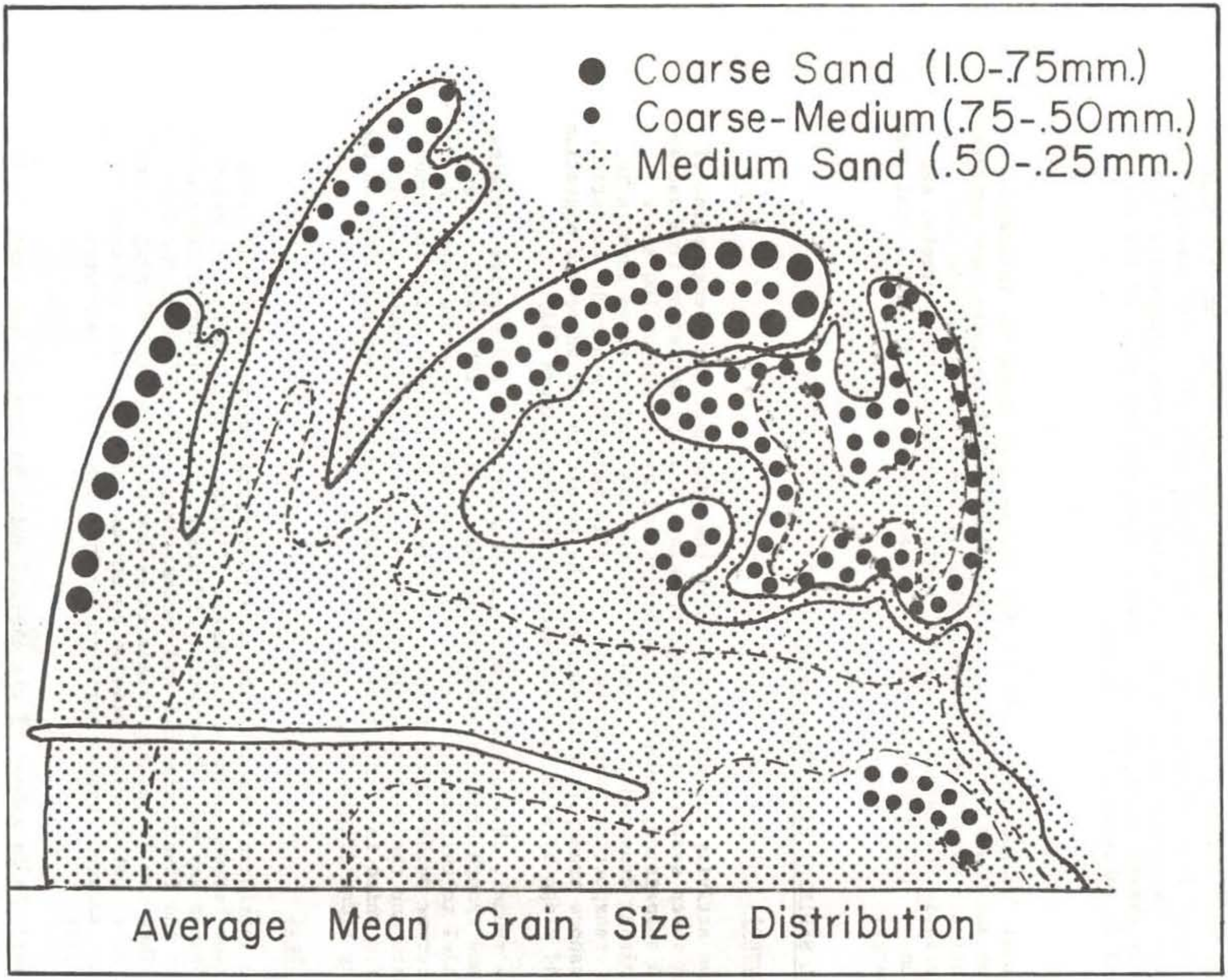

Figure 34. Variations in mean grain size for different intertidal spit platform environments averaged over a two year period.

Skewness

Nearly all sands tend to be unimodal and symmetrical (±0.99) except the positively skewed (i.e. coarser) ridge and spit noses, and the negatively skewed (i.e. finer) dunes. The former indicates a lag concentrate, the latter the result of winnowing. Variations between symmetrical and positively skewed sands are most common along the backshore of the various spits and in embayments and lagoons.

Kurtosis

Normal "peakedness" (-.99 to .99) occurs only along the foreshore extension and noses of spits and on sandflats. Most features have surface sands that are usually moderately peaked (1.0-9.9); this is even more characteristic for lagoons, lagoonal spits, sandflats, tidal creeks, and inlet dunes. This indicates the restricted variability of wave, tidal and wind energy.

INTERNAL SEDIMENT STRUCTURES (Figure 35)

Ridge-Runnel

Wave activity during ebb flow move the sand near the plunge point of breaking waves seaward onto the gentle slope and, by accretion from saltation and suspension, deposit it as horizontal plane beds or low angle (2-4°) planar crossbeds. During flood tide the sand is moved onshore in bedload transport to form steep (6-12°) slip faces by avalanche accretion. Since onshore transport predominates, the result is the shoreward migration of a sand ridge by slip face avalanche accretion (Figure 35A).

The runnel, characterized by scoured megaripples and ripples, retains planar and trough cross stratification (Davis et al., 1972) with slopes subparallel to the coastline - but these are rarely preserved here. As the ridge becomes welded against the foreshore of the exposed spit, the runnel disappears and the remaining crossbeds are covered by a seaward sloping truncation which is overlain by the landward sloping steep slip face of the accreting ridge (Figure 35A).

Exposed Spit

The foreshore zone contains seaward sloping lamination due to grain segregation between swash and backwash (Clifton, 1969). A lack of heavy mineral bands may make observation difficult, but they occur at low angles (2-8°) in the lower foreshore and become steeper (10-16°) near the berm crest. They are frequently truncated by low angle seaward sloping crossbeds (i.e. accretion after erosion by storms and tides) and may truncate low angle landward dipping horizontal laminations of a former berm (Figure 35B).

Toward the backshore of the exposed spit, horizontal and steep (8-22°) landward dipping planar crossbeds are common because of horizontal and slip face avalanche accretion by overwash (Figure 35B). The exposed spit

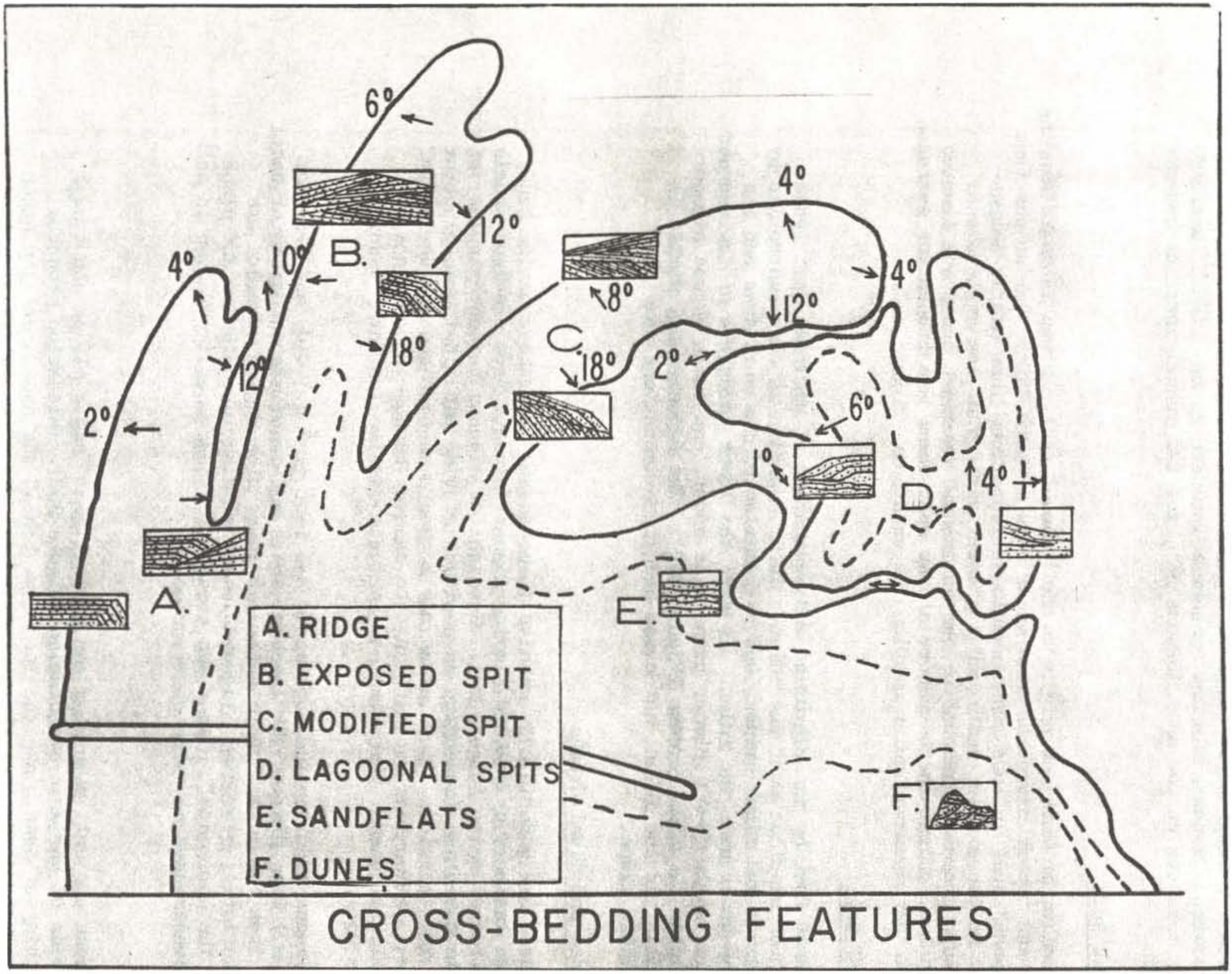

Figure 35. Foreshore and backshore cross-bedding features on the intertidal spit platform. See Text for explanation.

is therefore a large scale ridge with successive accretion of smaller spits and overwash. Seaward sloping crossbeds dominate on the ridge, landward sloping foresets on the spit (Figure 36), and the runnel contains aspects for both.

Modified Spit

Similar in form and origin to the exposed spit. Steep landward dipping planar and trough crossbeds also occur here (Figure 35C). Deviations from the exposed spit include cross-bedding orientations (now nearly perpendicular to the exposed spit) and a greater variety of low angle planar and trough crossbeds because of the horizontal overwash zones and scoured megaripples. Along the backshore of the spit there are truncation surfaces as hooks and recurved spits overlap the sandflats (Figure 35C).

Lagoonal Spit

These form by the migration and separation of modified spit lobes across the sandflat near the inlet. Their position is also controlled by the lagoons and tidal creeks, and by position of the surf zone and its breaking waves near the inlet. As with the lower foreshore of the exposed spit, low angle (2-4°) planar cross beds occur, and these become steeper (4-8°) near the tidal creeks (Figure 35D). The depositional strike is subparallel to the inlet, but cross-bedding orientations vary with topographic slope.

Sandflats and Tidal Creeks

These are underlain by massive (homogeneous) nearshore marine sands and some landward or seaward sloping planar foresets from previous shoals and refracted spits (Figure 37). Straight or sinuous current ripples, of variable direction (depending on position of tide and tidal creeks) occur across many portions. Some areas may be near washover zones. Horizontal and cross laminations are difficult to observe because of the lack of heavy mineral bands. Most trenches indicate massive (uniform) bedding (Figure 35E).

Sinuous tidal drainage channels 3-6 feet (1-2 m.) wide and 1-3 feet (0.3-1 m.) deep dissect the lagoonal spits and sandflats and transfer water to and from the inlet. Both upper and lower flow regime currents are characteristic, producing linguoid-lunate ripples, megaripples and plane beds. The horizontal, planar and trough crossbeds normally formed in such environments have not been observed here.

Dunes

These are well vegetated and exhibit small scale planar and trough cross beds of variable orientation (Figure 35F). Migration produces avalanching of sand along the lee slope behind the dune crest and steep erosional planes form on the upwind side of the dune. Rootlet horizons extend from near the base of the dune to their present surface.

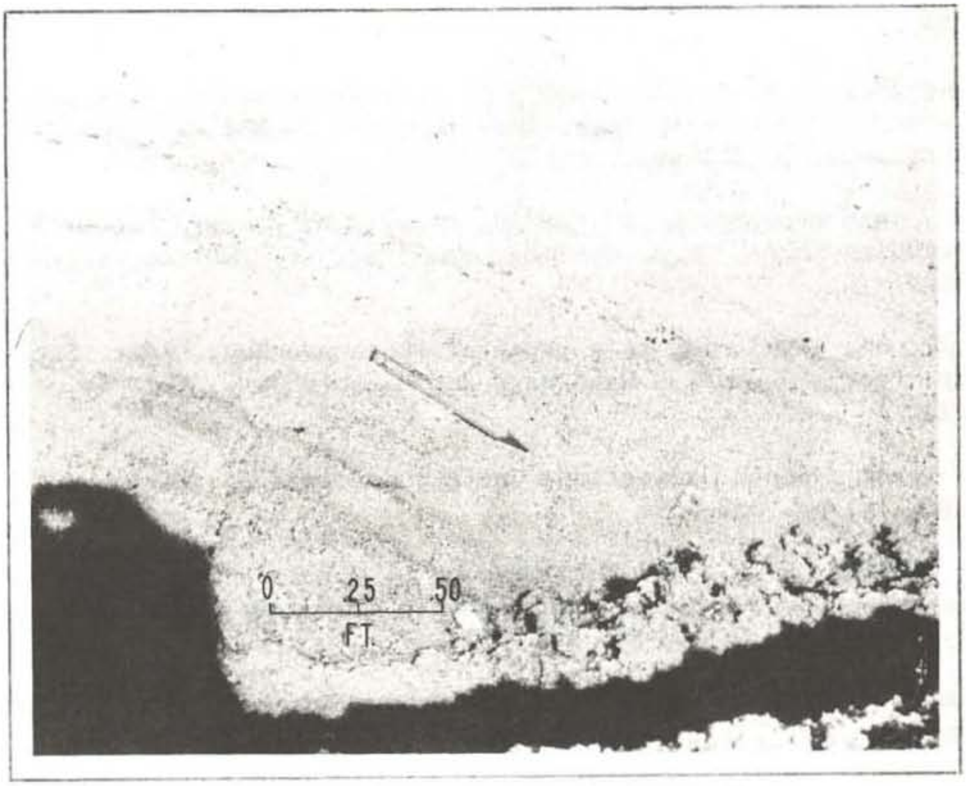

Figure 36. Steep, landward dipping planar foresets on backshore of exposed spit.

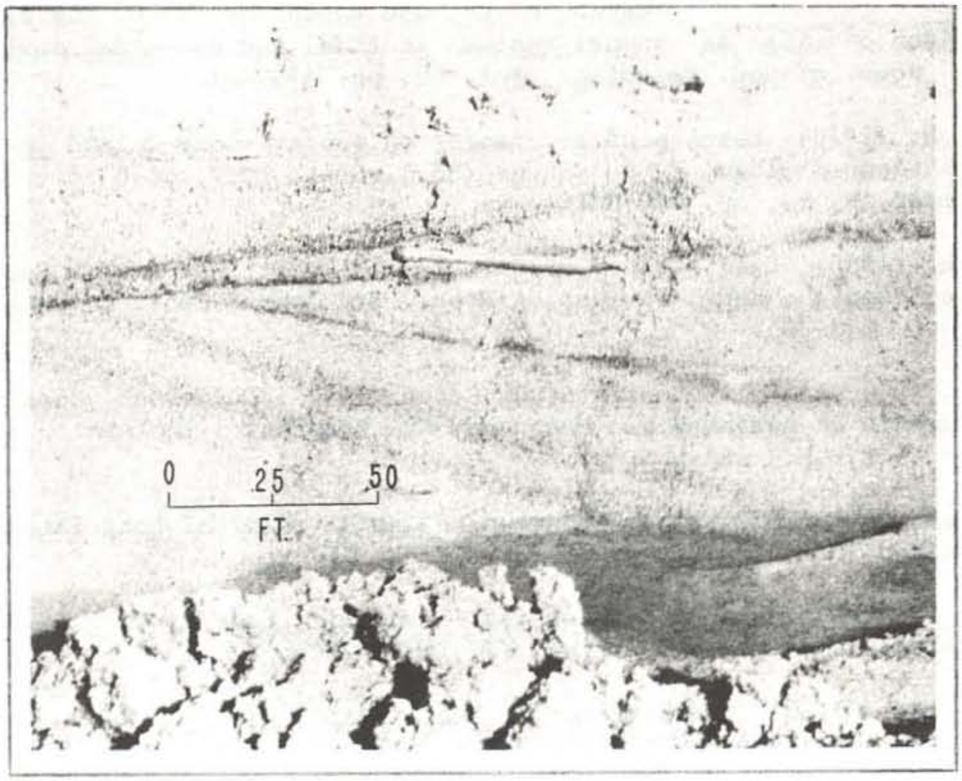

Figure 37. Gentle, landward-sloping planar foresets overlain by tidal washover deposits of the sandflats.

REFERENCES CITED

Bobb, W. H., and Boland, R. A. Jr. (1969), Channel Improvement, Fire Island Inlet, New York: U. S. Army Engr. Exp. Station, Vicksburg, Miss., Tech. Report H-69-16, 205 pp.

Boothroyd, J. C., and Hubbard, D. K. (1971), Genesis of estuarine bedforms and crossbedding (Abst.) Ann. Meeting, Geol. Soc. of America Program, pp. 509-510.

Bruun, P. (1962), Sea level rise as a cause of shore erosion: Amer. Soc. Civil Engr. Proc., Journal - Waterways and Harbors Div., Vol. 88, pp. 117-130.

Clifton, H. E. (1969), Beach lamination: nature and origin: Marine Geology, Vol. 7, pp. 553-559.

______________, Hunter, R. E., and Phillips, R. L. (1971), Depositional structures and processes in the non-barred high-energy nearshore: Jour. Sed. Petrology, V. 41, pp. 651-670.

Corps of Engineers (1971), National Shoreline Study, North Atlantic Region: U. S. Army Engr. District, Corps of Engineers, N. Y., 120 pp.

Davis, R. A. Jr., and Fox, W. T. (1972), Coastal processes and nearshore sandbars: Jour. of Sed. Petrology, Vol. 42, pp. 401-412.

________________, __________, Hayes, M. O., and Boothroyd, J. C. (1972), Comparison of ridge and runnel systems in tidal and non-tidal environments: Jour. of Sed. Petrology, Vol. 42, pp. 413-421.

Everets, C. H. (1973), Beach profile changes on western Long Island <u>in</u> Coastal Geomorphology, D. R. Coates (Ed.), State Univ. of N. Y., Binghamton, N. Y., pp. 279-301.

Gofseyeff, S. (1953), Case history of Fire Island Inlet, New York: Council of Wave Research, Engr. Foundation Proc., 3rd Annual Conf. on Coastal Engr., pp. 272-305.

Hayes, M. O., and Coastal Research Study Group (1969), Guidebook, Coastal environments of northeastern Mass. and New Hampshire, Eastern Section, S.E.P.M., 462 pp.

House Document #411 (1957), 84th Congress - Atlantic coast of Long Island, Fire Island Inlet to Jones Inlet, New York, 167 pp.

_____________ #115 (1965), 89th Congress - Atlantic coast of Long Island, Fire Island Inlet to Jones Inlet, New York, 253 pp.

Ingle, J. C. Jr. (1966), The movement of beach sand: Elsevier Pub. Co., Amsterdam, The Netherlands, 221 pp.

Klein, G. deVries (1963), Bay of Fundy intertidal zone sediments: Jour. of Sed. Petrology, Vol. 33, pp. 844-854.

_______________ (1970), Depositional and dispersal dynamics of intertidal sand bars : Jour. of Sed. Petrology, Vol. 40, pp. 1095-1127.

Kumar, N. (1973), Modern and ancient barrier sediments: new interpretations based on stratal sequences in inlet-filling sands and on recognition of nearshore storm deposits: Annals of N. Y. Acad. Sciences, V. 220, pp. 245-340.

Meistrell, F. J. (1966), The spit-platform concept: laboratory observation of spit development (M.S. thesis - Univ. of Alberta) in: Spits and Bars (M. L. Schwartz (Ed.), Dowden, Hutchinson and Ross, Inc. (1972)), pp. 224-284.

Nersesian (1975), personal communication.

Ruzyla, K. (1973), Effects of erosion on barrier island morphology - Fire Island, N. Y.: in Coastal Geomorphology, D. R. Coates (Ed.), State Univ. of N. Y., Binghamton, N. Y., pp. 219-237.

Shepard, F. P., and Wanless, H. R. (1971), Our changing coastlines, McGraw-Hill Pub. Co.,

Swift, D. J. P. (1968), Coastal erosion and transgressive stratigraphy ; Jour. of Geology, Vol. 76, pp. 444-456.

Taney, N. E. (1961), Geomorphology of the south shore of L. I., N. Y. Beach Erosion Board Tech. Memo #128, 50 pp.

Wolff, M. P. (1972), Growth and migration of digitate spits (April-Sept., 1971) at Democrat Point, Fire Island, New York: an example of a naturally occurring modified sanitary landfill system (Abst.) 7th Ann. Meeting, Northeastern section of Geol. Soc. America Program, pp. 53-54.

___________ (1973), The effects of stabilization on the natural processes of beach, dune, and inlet migration along the barrier islands of the south shore of L. I., New York (Abst.), 6th Annual L. I. Sound Conference, N. Y. Ocean Science Lab., Montauk, N. Y., p. 30.

APPENDIX A

Figures A-1 to A-4. Topographic maps of intertidal spit platform features at periodic intervals (1971-74).

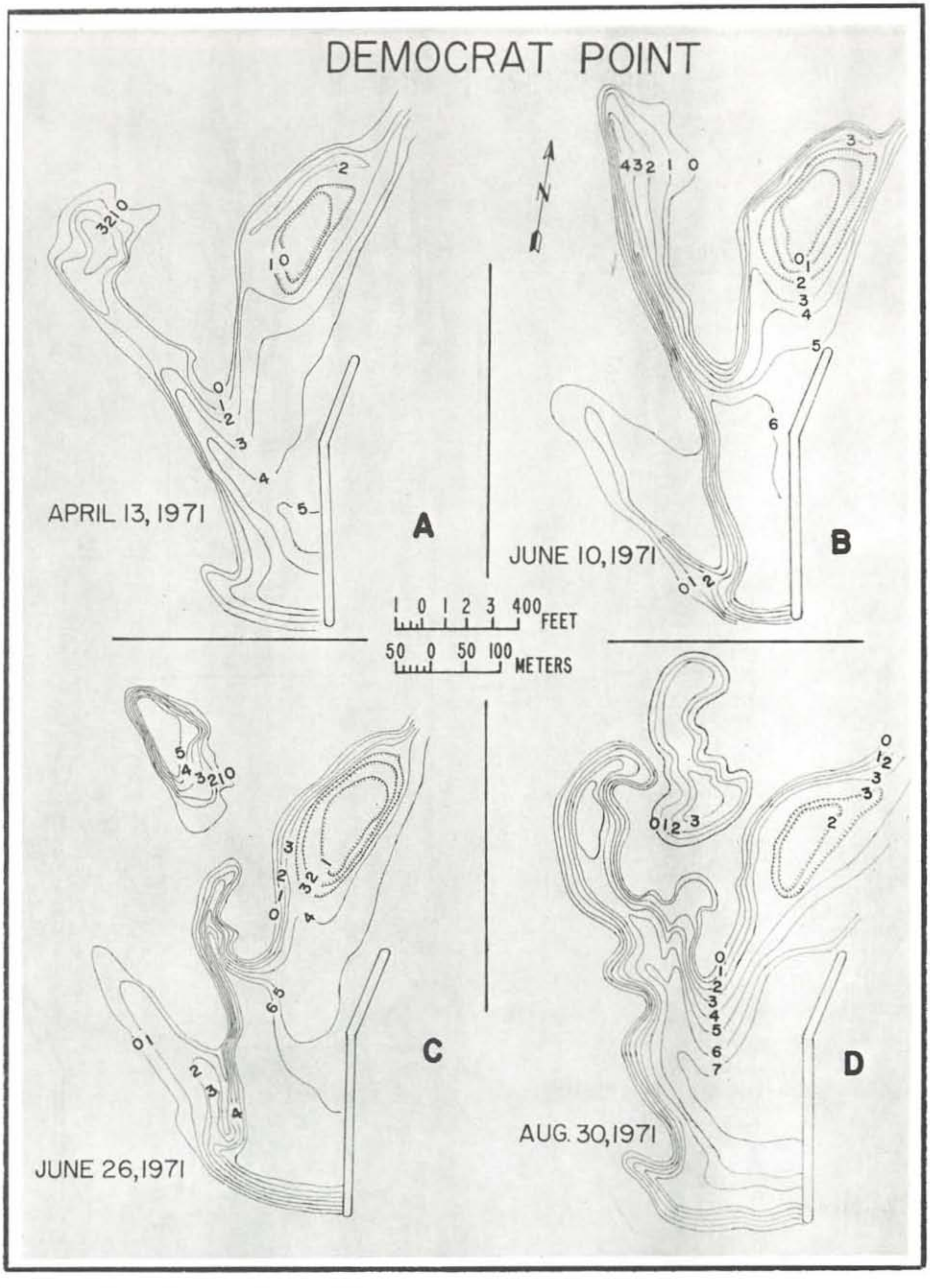
DEMOCRAT POINT
N
APRIL 13, 1971
A
JUNE 10, 1971
B
JUNE 26, 1971
C
AUG. 30, 1971
D
1 0 1 2 3 400 FEET
50 0 50 100 METERS
3210
2
10
0
1
2
3
4
5
432 1 0
3
0
1
2
3
4
5
6
0 1 2
5
4 3210
3
2
32 1
0
1
4
6 5
0 1
2
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Figure A-1.

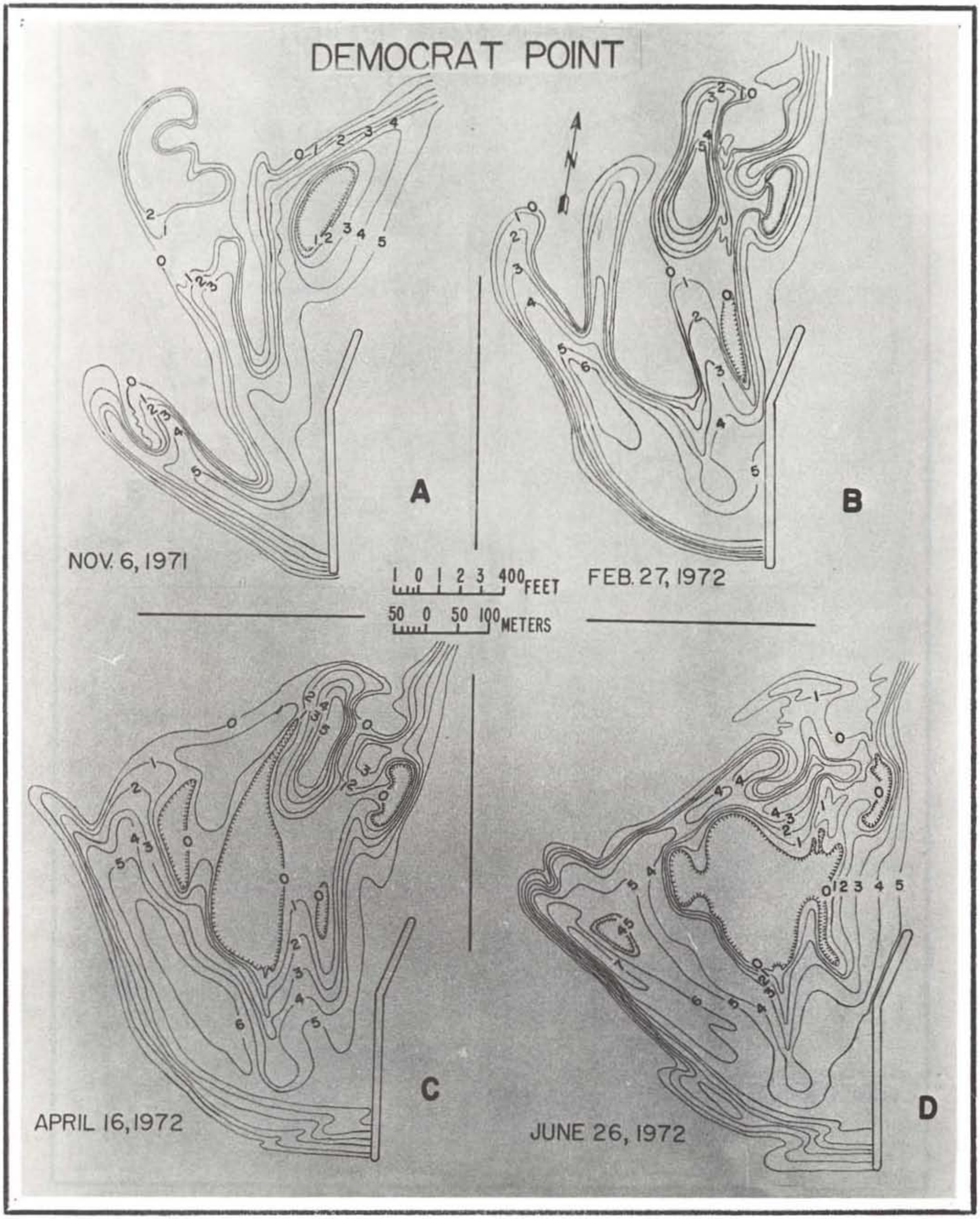
DEMOCRAT POINT
N
A
NOV. 6, 1971
B
FEB. 27, 1972
C
APRIL 16, 1972
D
JUNE 26, 1972
1 0 1 2 3 400 FEET
50 0 50 100 METERS

Figure A-2

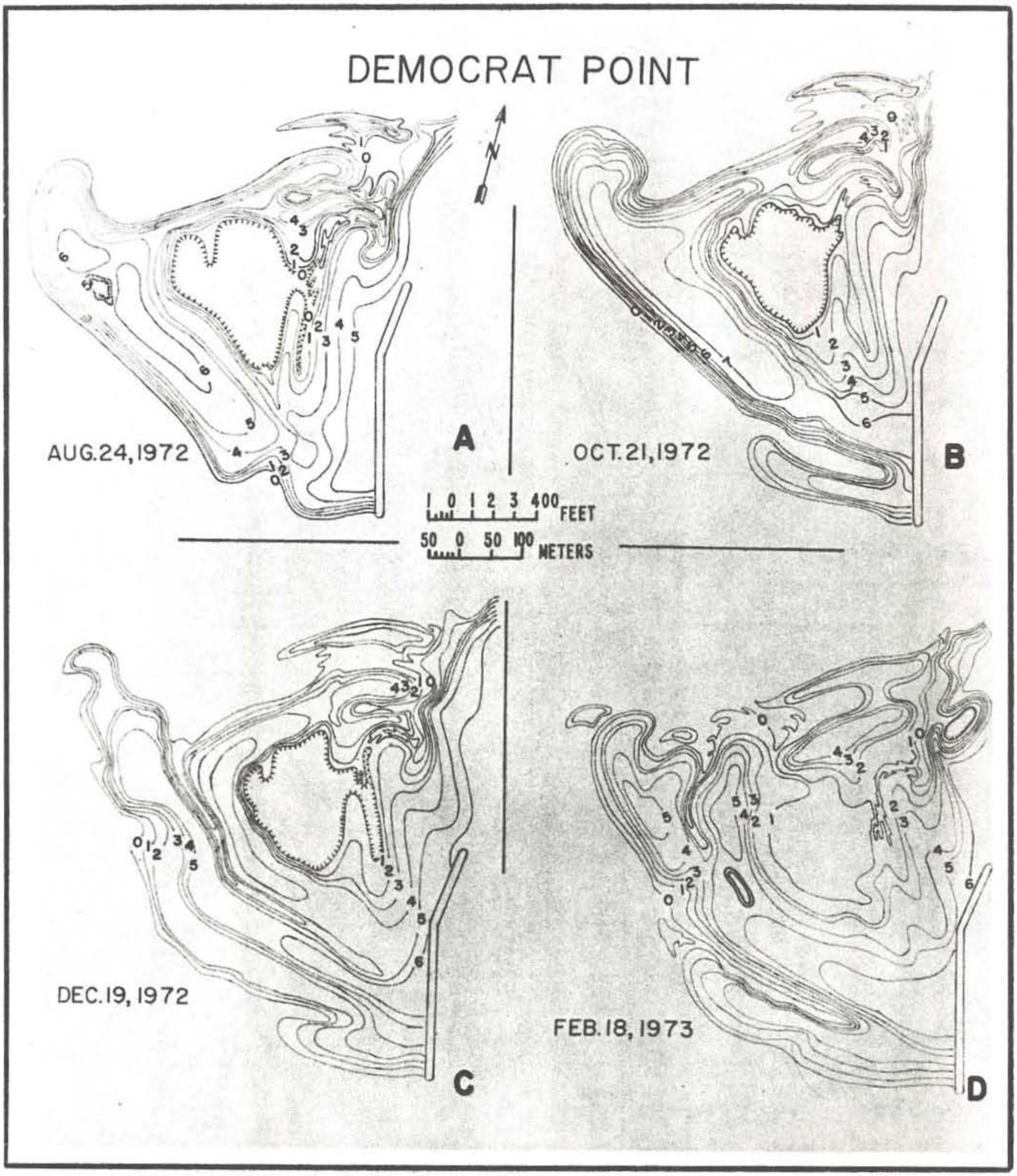
DEMOCRAT POINT
N
AUG.24,1972
A
OCT.21,1972
B
1 0 1 2 3 400 FEET
50 0 50 100 METERS
DEC.19,1972
C
FEB.18,1973
D

Figure A-3.

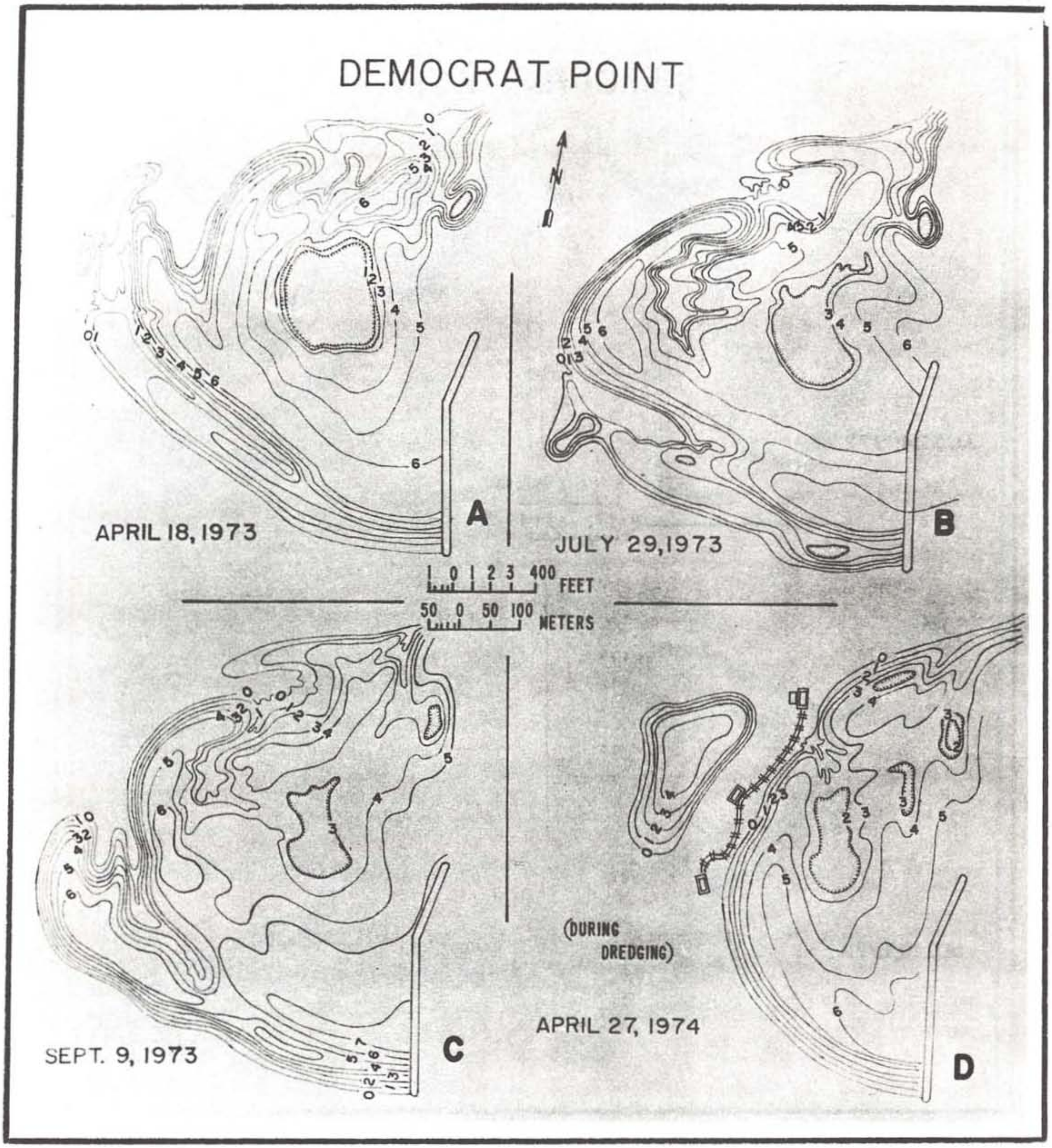
DEMOCRAT POINT
N
A
APRIL 18, 1973
B
JULY 29, 1973
0 1 2 3 400 FEET
50 0 50 100 METERS
C
SEPT. 9, 1973
D
(DURING DREDGING)
APRIL 27, 1974

Figure A-4.

A Major Beach Erosional 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 mechanism

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ROAD LOG

Return from Democrat Point to the beach near the pitch-putt golf course.

STOP 3. Beach foreshore and berm at Robert Moses State Park (Figure 1). Since the trip to Democrat Point is timed to coincide with low-tide, grazing-swash undercutting, even if operating, cannot be observed. A trench across the berm will be examined to reveal details of the very recent history of the beach.

INTRODUCTION

At the present time the beaches around the world's coastlines, in general, are undergoing erosion (Tanner and Stapor, 1972). This applies not only to beaches "stabilized" by man, but also to areas where man's influence has not as yet disturbed the natural dynamic balance of the coastal zone. Where man has interferred directly with the natural movement of littoral drift by "improving" the shoreline or where large areas of the coastal plain have been altered for the sake of human progress, beach erosion has been more pronounced.

The quasi-universal problem of beach erosion may result from or is complicated by the many parameters that determine beach and shore dynamics, but the basic cause is the shortage of sand on and around the beaches.

Our problem at the present is further burdened by the fact that the "state of the art" in beach-erosion research has not as yet progressed to such perfection. We are unable to predict the kind of processes and the magnitude of transport on or off the beach for a set of approximate energy-input parameters, and we are far from describing the expected short- or long-term geomorphic changes.

Progress has been slow mainly, because hydraulic engineers (who alone possess the large and expensive apparatus needed for controlled experiments) are less interested in discovering the underlying principles of nature than finding an approximate empirical formula of limited scope. "None of the many empirical theories have either been confirmed or rejected by critical experiments designed to test the various arbitrary assumptions made" (Bagnold, 1968, p. 45).

In this report an explanation is offered for one of the hitherto-unexplained problems in beach-erosion studies - namely the origin of berm

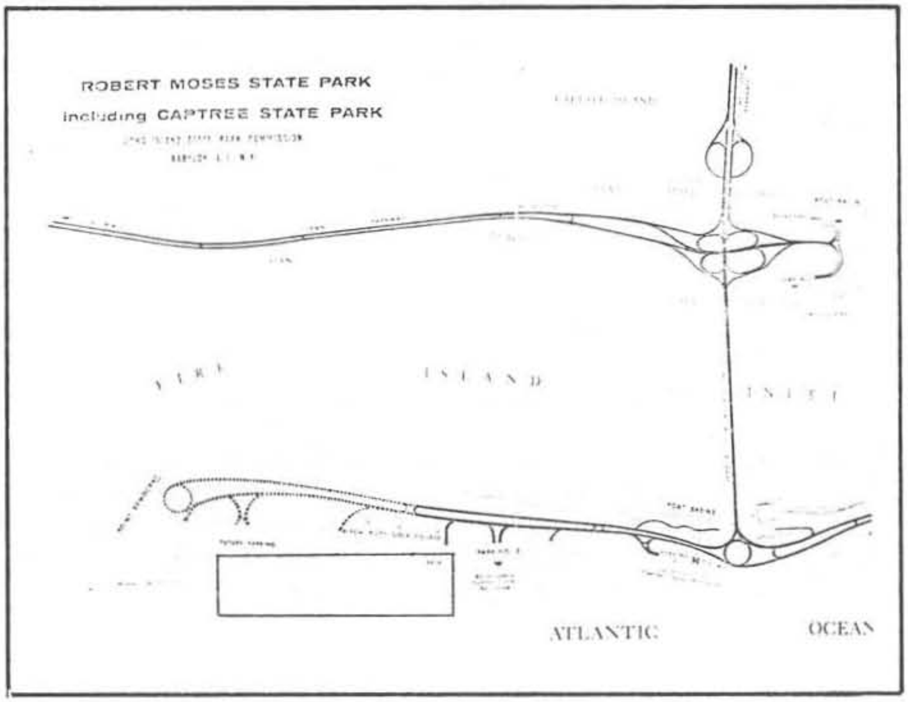

Figure 1. Stop 3 - Location of the study area.

scarps, vertical scarps up to 2m or more in height encountered in the berm and sometimes in the primary dunes. Scarps of various magnitude have often been described in passing (Thompson, 1937, Rosalsky, 1944, Ruzyla, 1972 among others). They have often been encountered by the author along the southern shore of Long Island - but no satisfactory explanation for their origin has ever been postulated.

The clue to the origin of these scarps was documented about 4 years ago when a scarp formation was observed and first recorded in detail by the author while in this area. Additional data resulted from the clear definition of events and the identification of the causes associated with the formation of these berm scarps. Finally, the storm of 1-2 December 1974 demonstrated the close-to-maximum erosional capability of this process in detail.

The following section describes the general wave and wind regime for the Fire Island area. Details of the weather pattern before and during the storm are also documented. A description of the subsequent loss of sand from the beach during the storm is followed by a brief explanation as to the nature of the erosional mechanism. The process of erosion, initially called "swash undercutting" (Baumgaertner, 1973) has been changed to "grazing swash undercutting" (Sanders and Baumgaertner, 1975) because of its sporadic nature on the beach foreshore.

DISCUSSION

Long Island is under the influence of northwesterly winds during the winter, and south to west winds during the summer. The frequency of easterly or north-easterly winds during the year is minor, but it is these infrequent winds that are associated with some major beach erosional events along the southern shore of Long Island.

A 2-mile section of Fire Island, extending from Robert Moses State Park on the east to Democrat Point on the west was chosen as a special study area by the Coastal Geology group of Columbia University-Barnard College in 1967 and since 1970, has been monitored at weekly intervals by the author (Figure 1).

The resulting collection of aerial photographs, plane-table maps, beach samples, cores, peels, beach photographs and field-notes supplemented with hourly weather reports not only demonstrate the complete sequence of events in the area but also give a better understanding of some detailed beach processes. Close monitoring of the beach was made possible by the fortunate location of our field-station at Freeport (M and C Environmental Consultants), a mere 5 minutes from the beach.

The nearest U. S. Weather Bureau is located in New York City and its weather records since 1921 were combined with more recent data from 1951-on to show the predominant wind pattern for this area (Table 1).

Table 1

Yearly average wind direction for New York City and Fire Island

N	14%
NE	5%
E	5%
SE	5%
S	13%
SW	14%
W	15%
NW	29%

Table 1 indicates the dominance of northwesterly winds. The monthly breakdown of wind direction statistics indicates offshore winds dominating during the winter months (October to April) and onshore winds for the summer months. The frequency of winds from the eastern sector is minor, but it is this wind direction that is associated with the highest speeds, and incidentally, with the large beach-erosion cycles. This correspondence of easterly winds, even of moderate speeds, and the erosion of the south shore's beaches, is not a recent event, but has also been documented in the historical records.

The wave data identifies 72% of all waves coming from the south-southeast sector (Panuzio, 1968). This wave approach, along the roughly east-west oriented beaches generates the predominant westerly longshore drift.

Mean wave height for the Fire Island area is about 36cm. The maximum observed wave height was 4m, but waves in excess of 3m were reported only 1% of the time between 1950 and 1954. Waves over 60cm in height occurred 20% of the time at the same time interval (Panuzio, 1968).

Weather data for the 10-day period directly preceding November 30, 1974 shows winds from the NW-SE at speeds up to 25 mph maximum. On November 30, a low-pressure area developed over the eastern United States; wind directions for the Fire Island area changed to NE and E with speeds up to 14 mph (Table 2). On December 1, a well-developed low-pressure cell centered west of Washington, D. C. and covered the eastern seaboard. Winds for the Fire Island area remained northeasterly with speeds ranging from 11 mph early in the day to 30 mph late in the evening. Gusts of up to 74 mph were reported. During the early hours of December 2, this pattern continued, with slowly decreasing speeds from a high 30 mph early in the morning to about 11 mph by 1700 hours when the direction of the wind changed to SE. At 1900 hours the wind direction changed to NW and became stabilized for the next 3 days at about 10 to 20 mph.

High tides at Fire Island Inlet occurred at 1750 hours and 2028 hours on December 1 and at 1842 and 2122 hours on December 2. The high tides for these days during the storm coincided with the declining spring tide that peaked on November 29.

Wave heights resulting from the strong easterly winds were estimated to be in excess of 1m, but individual wave heights of more than 2m were observed by the author. The angle of wave arrival at the breaker zone (α_b) was observed to be variable, but angles of around 45° to 60° were predominant. The powerful littoral current generated by the waves moved rapidly toward the west, in a manner similar to a river.

A combination of the declining spring tide plus the storm surge generated by the along shore wind resulted in abnormally high tides (2m above normal) along the ocean beaches and about 1m higher than normal behind the barrier island. The oceanshore communities along the southern shore of Long Island reported excessive flood and storm damage. The magnitude of flooding was summed up as being "the third highest recorded in the past 42 years" (Freeport Village News, January 1975).

Topographic Changes at Robert Moses State Park

Two topographic maps from the monitored area of Robert Moses State Park, Fire Island illustrate the magnitude of beach loss because of the storm (Figures 2 and 3). The pre-storm map is dated 15 August 1974 and illustrates the beach profile prior to the storm (Figure 2). It shows a well-developed berm with a wide, flat, berm-platform and a total beach width of about 150m (about 500 feet). The beach width in this study is defined as the width from the "dunes" to the 3 foot contour on the maps. With minor variations, the above conditions characterize the beach during late summer and the fall, as recorded in the weekly field-reports and by the established control points.

Table 2

Hourly Wind Directions and Speeds for New York City and Fire Island, N. Y.
for the Period of November 30-December 3, 1974

Time (EST)	(A) November 30		(B) December 1		(C) December 2		(D) December 3	
	Direction	Speed*	Direction	Speed	Direction	Speed	Direction	Speed
0100	N	8	NE	11	NE	28	NW	7
0200	NE	7	NE	13	NE	27	NW	8
0300	N	10	NE	12	NE	30	NW	7
0400	NE	9	NE	11	NE	30	NW	10
0500	NW	9	NE	14	SE	21	NW	9
0600	NW	9	NE	13	NE	9	NW	10
0700	NE	7	NE	14	SE	11	NW	12
0800	NE	10	NE	16	SE	10	NW	14
0900	NE	13	NE	17	SE	7	NW	10
1000	NE	14	NE	26	SW	10	NW	18
1100	N	8	NE	25	S	11	NW	15
1200	N	10	NE	26	S	8	NW	22
1300	NE	12	NE	24	SE	5	NW	20
1400	E	12	NE	25	SE	4	NW	15
1500	SE	11	NE	26	NE	7	NW	20
1600	E	8	NE	19	S	5	NW	18
1700	NE	10	NE	20	E	7	NW	16
1800	NE	8	NE	23	NE	7	NW	17
1900	NE	9	NE	13	NW	5	NW	19
2000	NE	11	NE	24	NW	8	NW	17
2100	NE	10	NE	27	NW	7	NW	15
2200	NE	11	NE	30	NW	7	NW	15
2300	NE	12	NE	28	NW	6	NW	16
2400	NE	11	NE	27	NW	7	NW	14

* All speed in MPH (Data from The New York Times and field-measurements at Freeport, N.Y.)

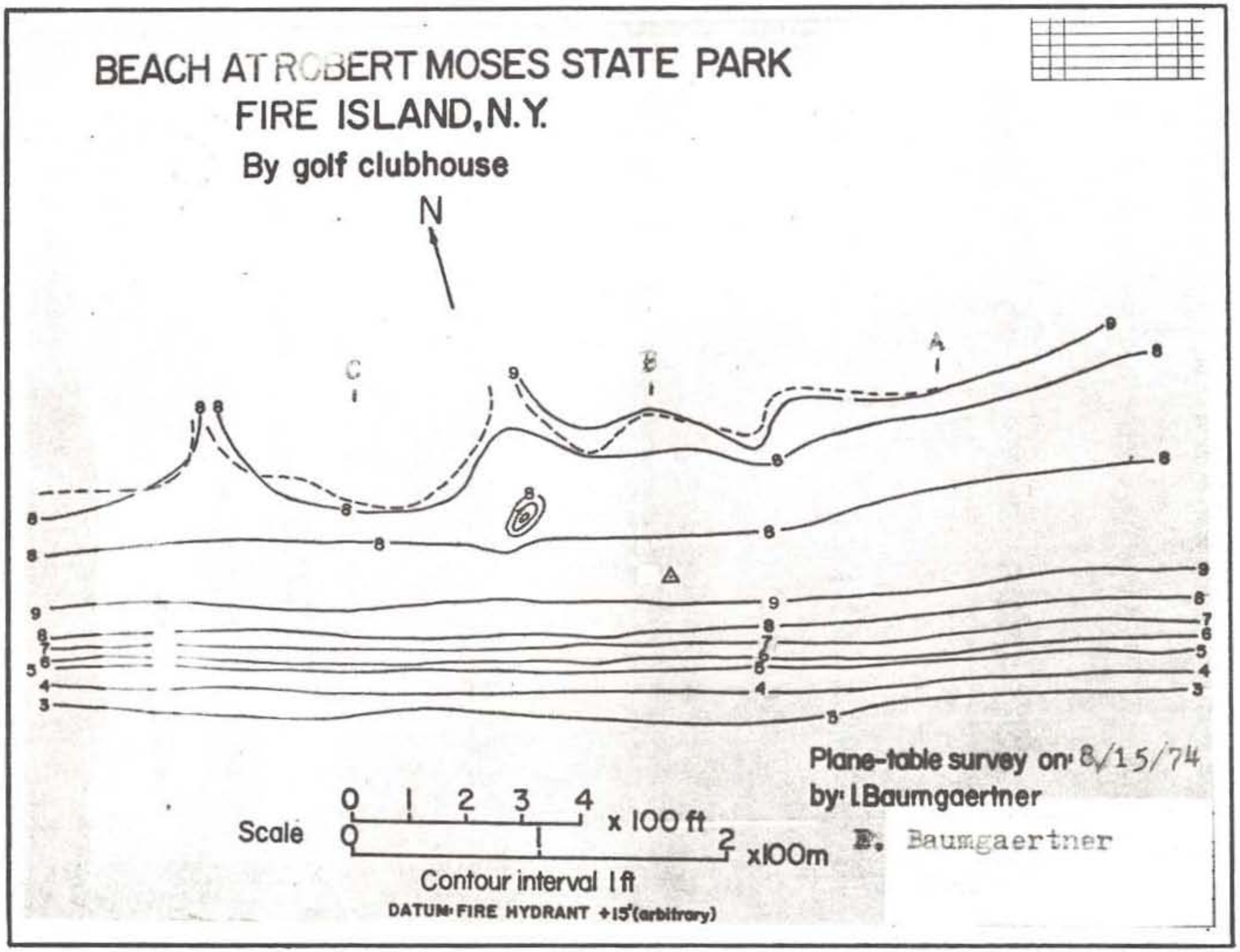

Figure 2. Pre-storm topographic map of the monitored section at Robert Moses State Park, Fire Island.

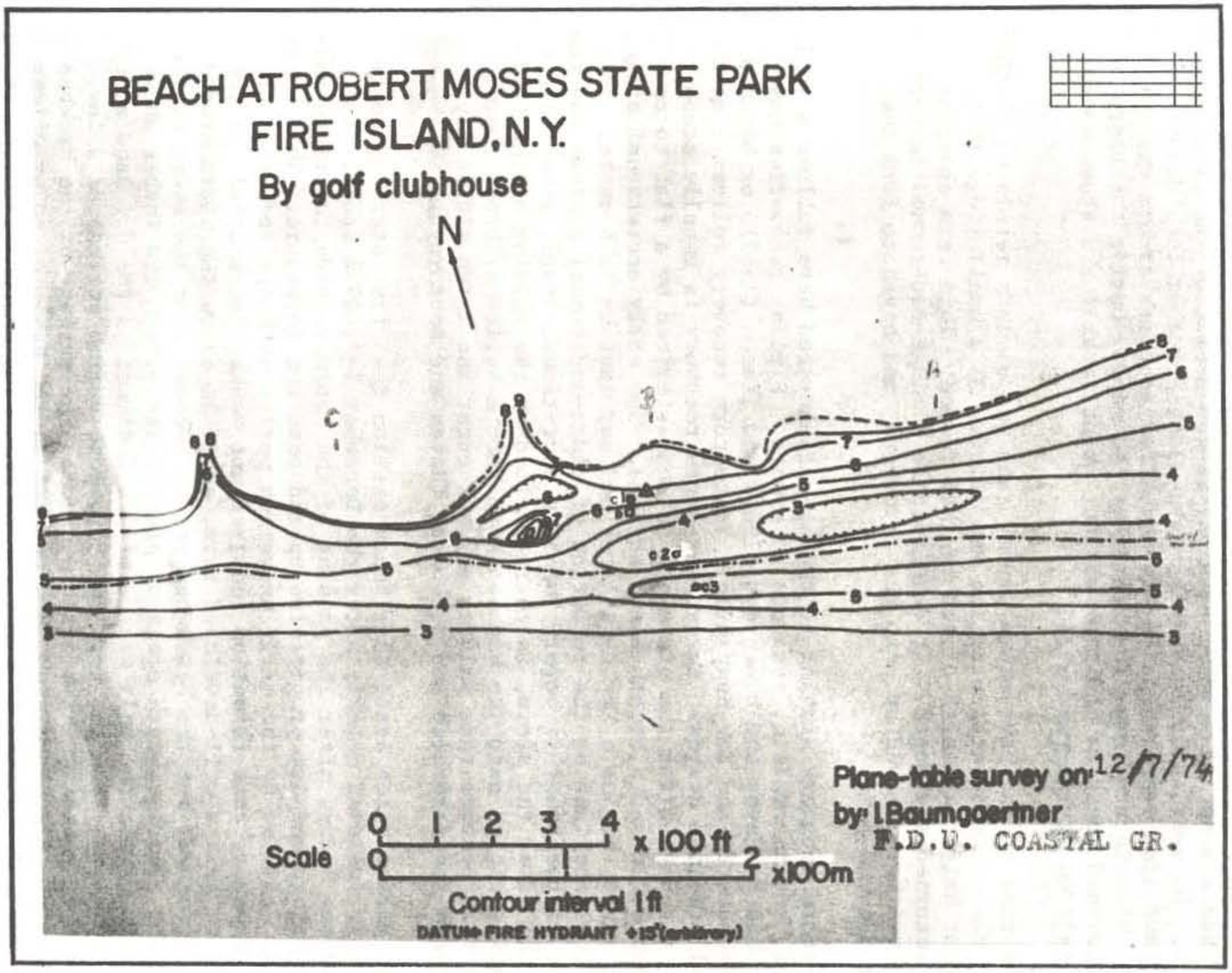

Figure 3. Topographic map of the monitored section at Robert Moses State Park, Fire Island on December 7, 1974.

The post-storm topographic map was made just 5 days after the passing of the storm (Figure 3). The width of the beach was reduced by about 60m (200 feet) from the migration of the foreshore toward the "dunes." The berm had completely disappeared and the height of the beach had been greatly reduced. Damage to the so-called "dunes" in this section, unlike adjacent dunes was not as severe, possibly as the result of the greater beach width. However, note the steep scarp along parts of the "dunes" (Figure 3) and also compare the before-and-after contours around the small topographic high located near the center of the maps. During the storm this well-defined mound of sediment was cut about in half - a steep scarp remaining only on its seaward side.

At the time of the post-storm survey sand was already returning to the beach. On the eastern section of the map (Figure 3) a small ridge that extends about half the length of the map had formed. This berm contains the newly-returned sediments. It developed as a ridge-and-runnel feature below the foreshore, moved up onto the foreshore, and began to form the nucleus of the new berm.

Post-storm recovery similar to the one illustrated here follows a well established, but incomplete, sequence of events. Similar recoveries have been described by Hayes and Boothroyd (1969) and Timson (1969) for beaches of NE Massachusetts and New Hampshire. Post-storm recovery follows 3 more-or-less well-defined stages. Early post-storm recovery is usually accomplished 3 or 4 days after the storm and is characterized by a flat to concave beach profile and a smooth beach surface. The early accretional stage, the second stage, begins a few days later and may last up to 6 weeks. This period is characterized by the formation of ridge-and-runnel systems and the development of the immature berm. The late accretional stage, commencing 6 or more weeks after the storm, is characterized by the welding of the landward migrating ridges onto the backbeach to form a series of broad convex berms. On some beaches this welding may not occur and large ridges may remain between the foreshore and backbeach (Hayes and Boothroyd).

At the Robert Moses State Park beach section the first stage of post-storm recovery followed quickly after the December 1-2, 1974 storm. The topographic map, 5 days after the passing of the storm, records the ridge-and-runnel morphology and its progression up and onto the foreshore. This early recovery was followed by the early accretion period with the formation of the berm. However, this formation required not weeks, but months! In the late summer of 1975 a well-developed berm, about 1m above the storm eroded surface, had formed, but the beach has yet to recover from the storm of the previous year. The backbeach areas at present are only a few inches above the post-storm level; the only source of new sediment is the dry sand added by aeolian processes from the berm and foreshore during periods of a low water table that coincides with onshore winds. The surface of the backbeach can be easily distinguished from the new berm on the basis of color differences; the newly added sand is light whereas the sand on the old backbeach surface is characterized by darker colors. This coloration is characteristic for heavy mineral concentrations. The presence of coarse-grained sediment concentrations intermixed generously with shells and shell-fragments is indicative of a deflation surface - thus the backbeach area accreted very little, if any at all, since the storm.

The fact that the recovery of the beach at Robert Moses State Park has not as yet been accomplished, almost a year after building began, categorizes the storm of 1-2 December, 1974 as a major erosional event - despite the fact that the storm never really reached hurricane proportions.

Northeasterly storms similar to this one have also been identified on the northeast Massachusetts and New Hampshire coasts as major generating forces of beach erosion cycles (Hayes and Boothroyd, 1969).

The easterly winds and the resulting serious beach erosion observed identifies the erosional process which removes the sediment from the beach. An easterly wind regime in the northern hemisphere, along a roughly east-west oriented shoreline, results in a temporarily elevated sea level. This accounts, in part, for the higher than normal tides in the bays and ocean front, and also establishes the prerequisite for the erosional mechanisms effectiveness in reaching the high areas of the beach - the backbeach and dune sections that are normally out-of-reach of everyday waves and swashes.

At Robert Moses State Park, the storm of 1-2 December removed 52,960 cubic yards of sediment from the map area. This averages out to about 90 cubic meters of beach sand removed from every meter of beach length. The width of the beach, as defined here was reduced by about 60 meters, or more than one-third of its total pre-storm width. This translates into 21,560 square meters of beach surface lost from the survey sector (about 700m in length).

The seriousness of sand loss at the survey area is also illustrated in the profiles obtained from the topographic maps (Figure 4).

The profiles, each of which is identified by letters on the topographic maps, illustrate the drastic changes that occurred on the beach. In particular, the backbeach areas show a loss of up to 4 feet in their surface elevations, resulting in the modification of a nearly flat pre-storm backbeach profile to that of a concave surface. The profiles also show the early post-storm accretion indicative of berm formation. This immature berm, already visible on the profiles, returned in a period of 5 days after the storm. The surface of the storm profile, as observed during and shortly after the storm, was smooth and inclined toward the sea.

Causes of Erosion

The process by which unconsolidated sediment is removed from beaches has previously escaped positive identification. Most articles dealing with the subject refer to some unspecified mechanism of wave activity as being directly responsible.

Wave research in the past has concentrated on seeking additional quantification and theoretical understanding of minute details of wave motion instead of concentrating on how these waves cause near shore and foreshore sand transport. At present we have numerous formulas, based on wave parameters that, on the basis of analytical schemes, predict longshore current velocities. Sonu and Russel (1966) evaluated the best known formulas, namely that of Putnam and Munk (1949), Inman and Quinn (1951),

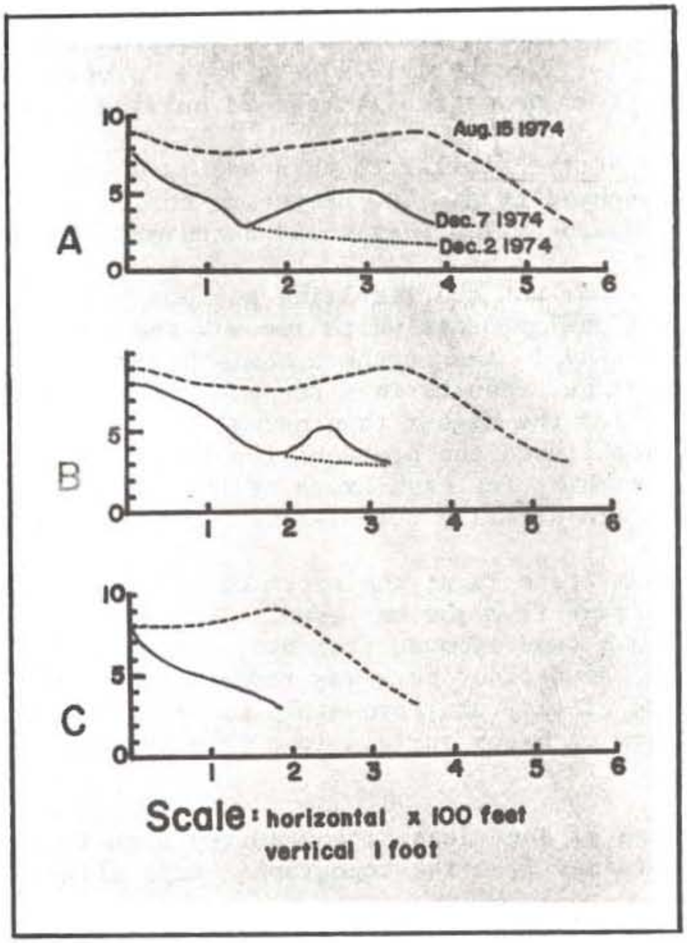

Figure 4. Beach profiles from the map area before (----), during (····), to immediately after the storm and 5 days after the storm (____). NOTE: Had it not been for our presence on the beach immediately after the storm, the profiles taken from the topographic maps (post-storm profile) would have given the wrong information about the nature of erosion. Another argument against profiles taken at "regular time-intervals" and used to describe changes in the beach.

Nagai (1954), Brebner and Kamphuis (1963), Galvin and Eagleson (1965), Inman and Bagnold (1962), Brunn (1963), Sitarz (1963), Shadrin (1961), and noted the great diversity of how the most important variable, the breaker angle (α_b) is handled differently by almost everyone. Additional empirical formulas have since been proposed by Sonu (1966) and Komar (1971).

Yet, despite this extensive research, we do not seem to be able to predict what will happen to beaches under given wave and wind conditions. Our most important missing information seems to be the exact value that the angle the breaking waves make with the shoreline and how to evaluate this information. Practical application of the many empirical formulas is almost useless, because "there are relatively few usable data showing the distribution of breaker direction", which results "mainly" from "the lack of reliable economical instrument to measure direction" (Galvin, 1970, p. 11). From a great number of studies carried out in the past we know that beaches are intermittently eroded and at most other times they accumulate sediment. However, given even the same wave conditions, beaches only a short distance apart may behave differently. These "anomalous" beaches have been reported by many from all parts of our coastlines (Shepard, 1948, 1950, Dolan and Godfrey, 1973).

One explanation proposed for systematic "beach cycles" or for the existence of "summer profiles" and "winter profiles" (an unfortunate term) is that there are systematic differences in the kind of water waves that arrive at the beaches during the different seasons (Shepard, 1948). The long, low swells of the summer, with periods of 6 to 7 sec. on the Atlantic coast tend to build the beach, whereas the short period storm waves during the winter season cause beach erosion. The apparent correspondence between the arrival of long swells and the time of beach accretion and that of short, steep storm waves with typical beach erosion periods have been taken as evidence that the type of wave arrival pre-determines whether there will be erosion or deposition.

Our research group first obtained evidence against the general validity of wave steepness relations to beach erosion - accretion cycles in 1971. The short, steep, locally generated waves from two passing hurricanes (Doria and Ginger), failed to erode the berm, as predicted by accepted concepts, but instead deposited sand over the berm (20 to 40cm and 40 to 60cm thick respectively) (Sanders and Baumgaertner, 1975). Thus the paradox of no losses of sand from the beach during the passing of the hurricanes while at other times, during "garden variety" storms, there is abnormally large erosion. This has now been clarified by the realization that one of the most powerful processes of beach erosion not directly related to wave action, is the grazing swash undercutting described earlier.

Swash is generated when waves (bores) are translated through the surf zone to become a thin sheet of water that flows up the beach slope. The path of the uprushing swash and its farthest advance up on the beachface is dependent on the energy and direction of the incoming waves.

Because the swash starts out at maximum speed at the base of the foreshore, its farthest advance is determined by the slope of the beachface. In contrast, the backwash (the return of excess water) starts at zero speed down the beachface and, under the influence of gravity, gathers speed as it moves downslope. Since the highest speed of both the swash and backwash is concentrated on the lower part of the foreshore, erosion usually dominates here, while on the upper part deposition may occur. This process may lead to a temporary steepening of the beachface (Ellis, 1962).

Under normal wave incidence the path of the uprushing swash is parabolic up the beachface while the returning backwash travels down the beachface in a more or less straight path. In general, the effect of the swash is to add sediment to the beachface and eventually, under favorable conditions, the berm is built up to 2 meters above high tide level. During some storms, when waves come straight toward shore, the berm accretes very rapidly (as was observed during the passing of hurricanes Doria and Ginger in 1971). Presumably the berm can grow no higher than the height of the breaker - a limit that is set by the waves and the slope of the beachface.

The berm on any beach which has a surf zone is cut back only on rare occasions. The berm becomes narrower only during the certain periods when the approach of the waves is at a critical angle. Now the swash no longer flows diagonally up the beachface, but instead tends to "graze" parallel along its edge. The greatly modified swash path results from the alongshore wind and from the unusual approach of the storm generated, short period, sea waves. Strong easterly-northeasterly winds along the southern shore of Long Island generate short period waves of 1 to 4 second. It is apparent from the phase velocity of an Airy wave ($C^2 = (g/k) \tanh kh$) that the speed of the wave is influenced by a water depth less than one-quarter of deep water wavelength. If this depth is taken as the boundary between deep and intermediate water (Shepard, 1963, p. 80) then a "refraction base" of about 6.2m for 4 sec. period waves, 3m for 3 sec. periods, and only 1.5m for 2 sec. period waves can be calcuated. The above depth already indicate that waves with periods of 4 sec. or less begin refraction very close to shore. The above water depths for a "refraction base" are even shallower if one considers that refraction is not as pronounced in intermediate water depths (between the depths of $1/4 \quad h/L_d \quad 1/20$, Shepard, 1963) than is shallow water where the water depth is at or less than 1/20 of the deep water wavelength. Calculating a "refraction base" for shallow water gives water depths about 1/5th of the above values.

For the southern shore of Long Island, and very much similarly for the barrier chain along the east coast of the U. S., water depth is such that short period storm waves are refracted very close to the beach. The last breaker bar, usually less than 100m from the beach and under a water depth of about 2m, is incapable of refracting waves with shorter periods than about 4 sec.

Because waves generated by easterly storms propagate along the beach and are first refracted very close to the beach they usually make a breaker angle (α_b) with the beach that has values close to about 60°. The speed of the littoral current generated by this very oblique wave approach is high - speeds in excess of 2m/sec. were often measured.

As the waves break, the bores generated by the breakers traverse the littoral current and emerge as swash with an added alongshore momentum transferred to them from the strong longshore current. Thus the swashes move up the beachface at very oblique angles. This oblique angle is further re-enforced by the alongshore wind that transfers energy directly to the swash, up to the top of its landward limit. Individual swashes with very oblique upbeach paths were observed to have their upper limit move parallel to the beach for distances of 20 to 50m.

The result of this concentration on the upper limit of the swash along a line on the beachface results in erosion and in the creation of a small (only a few millimeters high) beach scarp. The development of the small scarp at the base of the berm is the first sign of accelerated beach erosion.

The most favorable conditions for this development occur when the formation of elongated swash paths coincide with a relative standstill of the water level, namely during ebb tide.

With the formation of the initial scarp, subsequent swashes are "channeled" along the base of the scarp and, as the tide rises, the scarp is forced up the beachface as it is constantly eroded by the successive swashes (Figures 5 and 6).

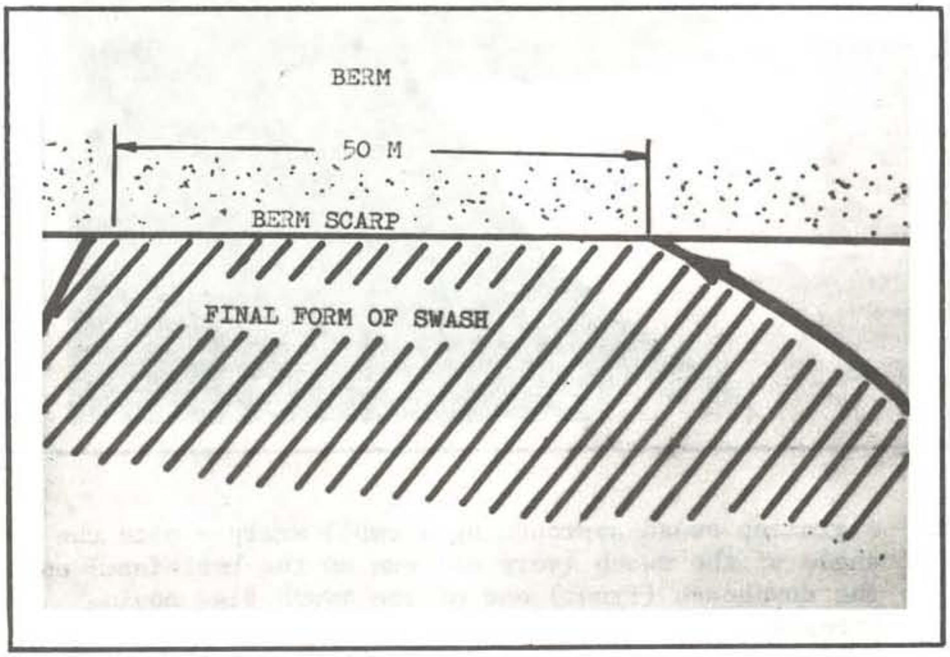

Figure 5. A newly formed miniature scarp forces subsequent swashes to move along the scarp and to erode the berm edge.

As the scarp migrates up the beachface, it grows in height as the base of the scarp continues to be undercut (Figure 7). The vertical face results from small cave-in, a process very similar to the bank-undercutting observed in rivers (Figure 8). Sediment eroded from the scarp is carried away by the next swash and the longshore current, and the scarp continues to grow until it terminates in the berm at high tide. During very high tides grazing swash undercutting may reach the base of the "dunes" and a dune scarp is eroded (Figure 9). Supporting evidence for this newly recognized erosional mechanism was presented and assigned the name "grazing swash undercutting" (Sanders and Baumgaertner, 1975) and is believed to be responsible for the creation of beach and some dune scarps.

The development of a moderately high berm scarp (1m) was first observed during a half tidal cycle on 17 October, 1971 at Robert Moses State Park. This high scarp was located about 30m (100 ft.) above the low tide line, indicating that during a 6 hour period, grazing-swash undercutting removed 30 cubic meters of sand for each meter of beach length. This quantity, when extrapolated, yields an erosional rate of about 30,000 cubic meters for each kilometer of beach length - or about 52,600 cubic yards per mile

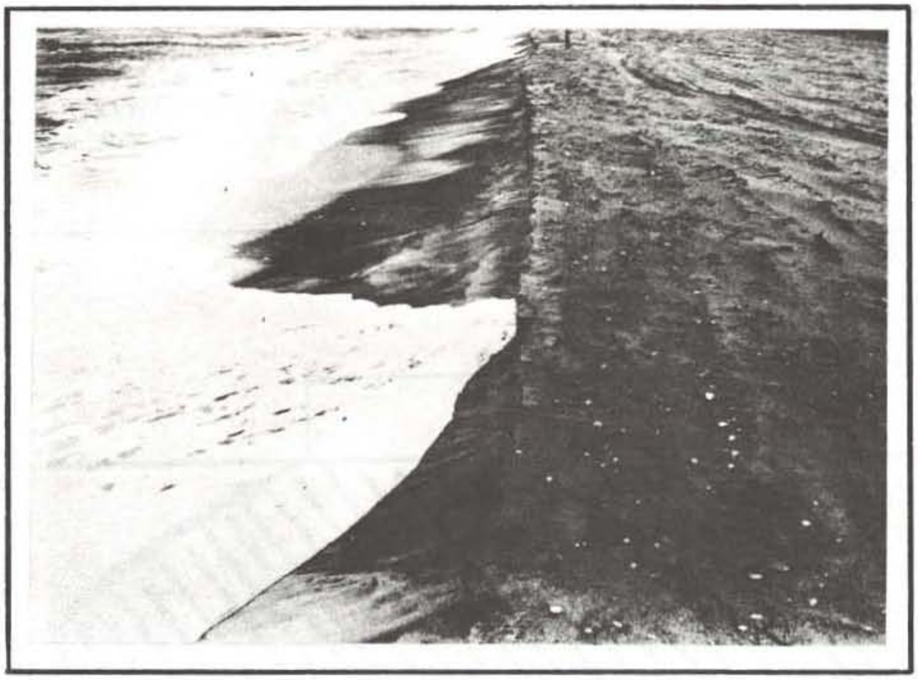

Figure 6. A grazing swash approaching a small scarp - note the angle of the swash (very oblique up the beachface) and the downbeach (front) end of the swash also moving upbeach.

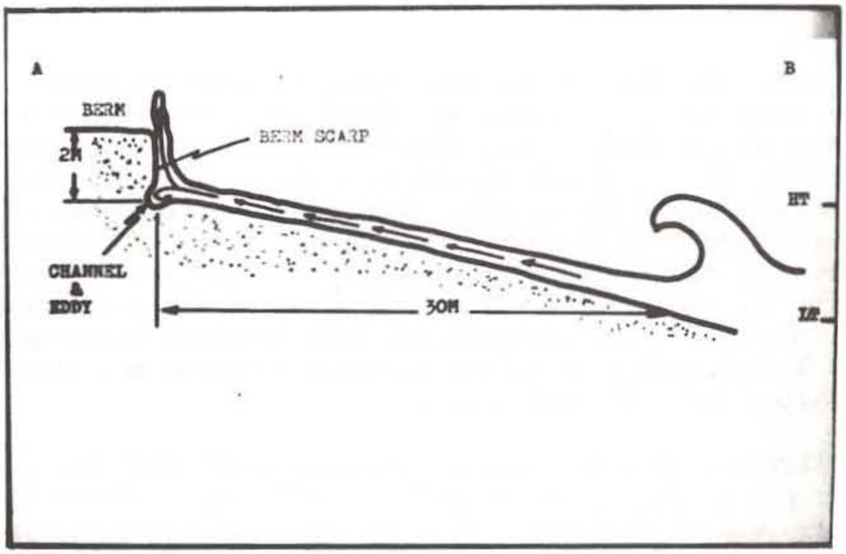

Figure 7. Details of the upbeach movement of the grazing swash at the base of the growing scarp.

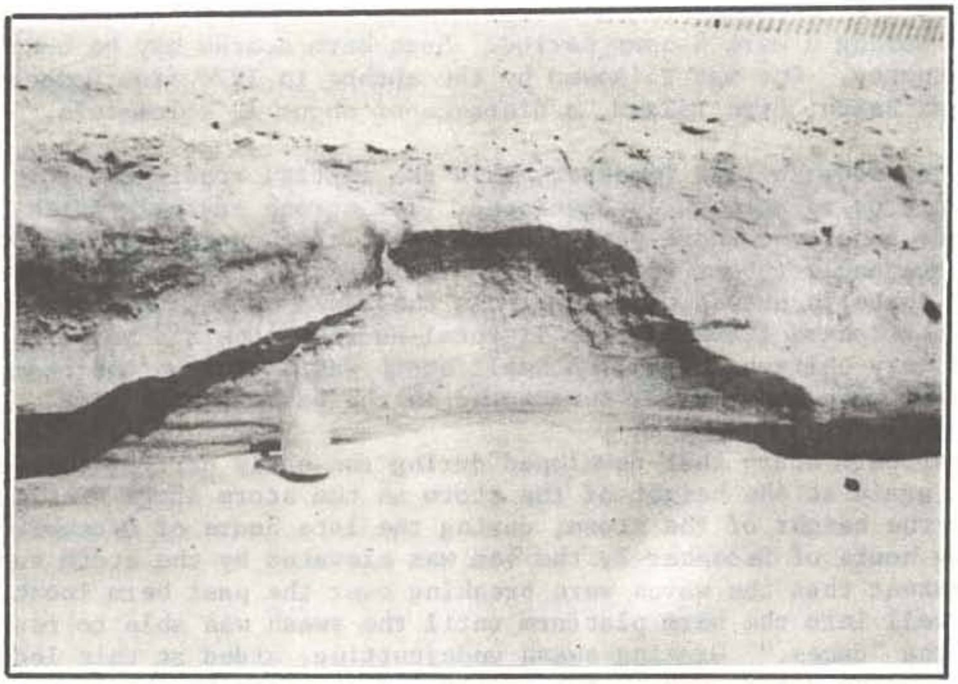

Figure 8. Small cave-in exposes the horizontal layers in the face of a scarp. Note the half-circle shaped channel undercut at the base of the scarp by the grazing swash. The height of the bottle is about 30cm (12 in.) and the height of the scarp, inactive by this time, was about 1 meter.

Figure 9. A scarp developed in the "dunes" at Gilgo Beach, Jones Island. Note the cave-ins leaving a vertical face and the small "alluvial-fan" shaped accumulations of sediment (on the right) resulting is the smoothing of the scarp's face.

of sand lost during a mere 6-hour period. Such berm scarps may be continuous for long distances. One was followed by the author in 1974 from Democrat Point to Ocean Beach, Fire Island, a distance of about 12 kilometers.

During the storm of 1-2 December, 1974 the initial conditions for maximum scarp erosion were fully developed. The strong easterly-northeasterly winds generated short period storm waves that approached the beach at a very large angle (about 60° for α_b). The speed of the littoral current was measured to be in excess of 2m/sec. As the waves broke, the bores generated by the breakers traversed the littoral current zone and moved up the beachface at very oblique angles. A small scarp was forced up the beachface with the rising tide and finally terminated in the berm at high tide.

The first berm scarp that developed during the early part of the storm was undercut again at the height of the storm as the storm surge continued to rise. At the height of the storm, during the late hours of December 1 and the early hours of December 2, the sea was elevated by the storm surge to such an extent that the waves were breaking over the past berm location, now eroded, well into the berm platform until the swash was able to reach the base of the "dunes." Grazing swash undercutting, aided at this location by longshore moving water, eroded the vertical dune scarp by the same mechanism that created the berm scarp.

As the swash reached the landward limit of the beach, water was also forced into the backdune areas through the lower points in between the "dunes." A circulation system behind the "dunes" was established that pulsated according to the arrival of water at different times at the different entrances. Sediment brought into this area was deposited at the mouth (landward) of these openings in the form of deltaic lobes. This pulsating water circulation also cut scarps into the sides of the passageways of the backdunes.

The existence of this behind-the-dunes circulation system was terminated by the ebb tide at the end of the storm as water was eventually drained from these channels and a thin layer of dark colored muddy sediment was deposited over the current rippled surface.

CONCLUSION

Although the dynamics of grazing-swash undercutting have been described earlier on the basis of the formations of smaller berm scarps, the storm of 1-2 December, 1974 provided the first opportunity to actually observe the near-maximal limits attributable to this erosional process.

Some additional aspects were also clarified during this storm. First, the role of the berm in governing sedimentation and erosion on the beach became more evident. The position and height of the berm determines deposition in the sense that it provides a topographic high at the landward limit of the foreshore over which overwash moves and deposits sediment. This sediment is deposited behind the berm either as lag-deposit, left dry as the water seeps into the drier sand of the berm platform, or in the form of small deltas if the complete saturation of the beach is followed by the establishment of a berm-top-pond between the berm and the dunes. During moderate undercutting by grazing swash the height of the berm determines the magnitude of erosion.

Secondly, grazing swash undercutting is favored by the presence of steep foreshore slopes and a well developed berm. On a gentle slope the upper limit of the swash cannot be concentrated along a well-defined line and the initial miniature scarps fails to form despite the full development of the necessary atmospheric and wind conditions. This suggests that while the berm is instrumental in trapping sediment on the beach, there are occasions on which the mere presence of a well developed berm facilitates the removal of large volumes of sand from the fore and backshore. Some experiments carried out during the past few years indicated that erosion on the beach during the operation of grazing swash undercutting can be prevented by reducing the slope of the beachface. On several occasions the initial small berm scarps were destroyed, and the undercutting temporarily ceased. Undercutting resumed after a short time, but it appears that if the foreshore's slope could be reduced to below critical (as yet not well known) values by the removal of sand from the foreshore and its deposition on the backshore, total erosion by grazing swash undercutting can be greatly reduced.

Thirdly, because "there are relatively few usable data showing the distribution of the breaker direction" (Galvin, 1970, p. 11), it is suggested that wind speed, duration, direction and fetch parameters are needed to predict scarp undercutting erosional events on the beaches. These parameters can be measured precisely and are readily available. They can be combined with values of the beachface's slope to arrive at a usable empirical formula to predict the time and magnitude of beach erosion by scarp undercutting. During the past year our group has correctly predicted the time and magnitude of beach scarp formation with 90% success (scarp heights were sometimes underestimated).

In conclusion: a) scarp undercutting and scarp retreat are the most important processes of berm erosion; b) grazing swash undercutting is the process that controls the origin of berm scarps; c) oblique approach of sea waves is the key to grazing swash undercutting.

During the past 5 years of weekly monitoring of the beach at Robert Moses State Park the study found that grazing swash undercutting is a major erosional process. (Wind erosion is important during dry periods of the winter when winds from the northern sector blow the sand back into the water.)

The observations at Robert Moses State Park indicate that, under the experienced wave and wind regime, the direction of the waves is a primary factor that governs erosion or deposition. Neither wave period nor steepness seem to be important, although these factors may be operating through the wave properties that determine the "refraction base."

It is believed that some of the "anomalous" examples of eroding and accreting beaches located close to each other and under the "same" wave and wind conditions might be explained if wave approach is used in connection with the trend of the shoreline, instead of wave steepness or period.

Postscript: At the time this report was typed moderate E-NE winds (10 to 15 mph) eroded a small scarp (30 to 40cm) on 18 September, 1975.

On September 14-15, 1975 stronger (up to 35 mph) winds generated storm waves rejuvenating the scarp from the previous week and grazing swash undercutting enlarged the scarp until it measured up to 1m in height (Figure 10). The volume of the eroded sediment was similar to values given in this report for a 1m high scarp in 1971.

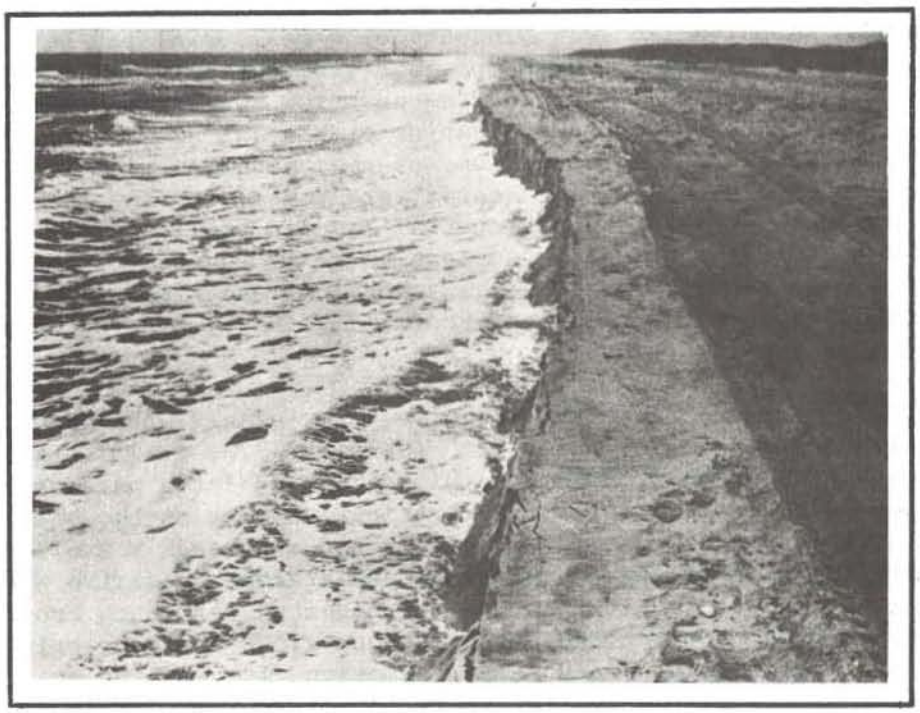

Figure 10. A berm scarp is still being undercut on 26 September, 1975. E to NE winds by this time declined to only 10 mph, but at high tide the scarp still continued to grow. On the photograph the scarp is about 1m high. Note the thin crevasses in the berm surface indicating soon-to-follow slumping. Also note the return of a bore from the scarp (middle, lower portion).

REFERENCES CITED

Bascom, W., 1964, Waves and beaches, Anchor Books, Doubleday & Co., Inc., N.Y., 267 p.

Bagnold, R.A., 1968, Deposition in the process of hydraulic transport, Sedimentology, V. 10, pp. 45-56.

Baumgaertner, I.v., 1973, New ideas on causes of beach erosion (Abstract), 5th Ann. Long Island Sound Conference.

Dolan, R., Godfrey, P., 1973, Effects of hurricane Ginger on the barrier islands of North Carolina, Geol. Soc. Am., V. 84, pp. 1329-1334.

Ellis, C.W., 1962, Marine sedimentary environments in the vicinity of the Norwalk Islands, Conn., State Geol. and Nat. History Survey of Conn., Bull. No. 94, 89 p.

Everts, C.H., 1972, Beach profile changes on Western Long Island, pp. 279-301, in Coastal Geomorphology, ed., Coates, D.R., 404 p.

Galvin, C.J., Jr., 1970, Wave climate and coastal processes, Lecture delivered at the Symp. on Water Env. and Human Needs, 1 Oct. 1970, Mass. Inst. Tech., Transcript, 44 p.

Hayes, M.O., Boothroyd, J.C., 1969, Storms as modifying agents in the coastal environment, pp. 245-256, in Coastal Env. of NE Mass., and N.H., Field Trip Guide Eastern Sec., S.E.P.M., May-11, 1969.

King, C.A.M., 1961, Beaches and coasts, Edward Arnold Publ., Ltd., London, 403 p.

Komar, P.D., 1971, The mechanics of sand transport on beaches, Journal Geoph. Res., V. 76, No. 3, pp. 713-722.

Kraft, J.C., 1971, A guide to the geology of Delaware's Coastal Env., Publ. 2GL039 Coll. Marine Studies, U. Delaware, 22 p.

Panuzio, F.L., 1968, The Atlantic coast of Long Island, Proc. 11th Conf. Coastal Eng., pp. 1222-1241.

Rosalsky, M.B., 1944, A study of minor beach features at Fire Island, Long Island, N.Y., Trns., N.Y. Acad. Sci., Ser. 2, V. 12, pp. 8-16.

_____________, 1964, Swash and backwash actions at the beach scarp, Rocks and Minerals, V. 39, pp. 5-14.

Ruzyla, K., 1972, Effects of erosion on barrier island morphology at Fire Island, N.Y., pp. 219-239, in Coastal Geomorphology, ed., Coates, D.R., 404 p.

Sanders, J.E., Baumgaertner, I.v., 1975, Origin of beach scarps by Grazing Swash Undercutting: Major Process of Beach Erosion, Ms. Science, 12 p.

Shepard, F.P., 1948, Submarine Geology, Harper and Row, N.Y., 338 p.

____________, 1950, Beach cycles in Southern California Tech. Memo., No. 20, Beach Erosion Board, U.S. Army Corps of Engineers, 24 p.

____________, 1963, Submarine Geology (2nd edition), Harper and Row, N.Y., 557 p.

Sonu, C.J., Russel, R.J., 1966, Topographic changes in the surf zone profile, pp. 502-524, in Coastal Engineering, Proc. 10th Conf. Coast. Eng., Tokyo, Japan, Sept. 1966, Am. Soc. Civ. Eng., N.Y., 790 p.

Tanner, W.F., Stapor, F.W., 1972, Accelerating crisis in beach erosion, Int. Geogr., V. 2, pp. 1002-1021.

Thompson, W.A., 1937, Original structures of beaches, bars and dunes, Bull. Geol. Soc. Am., V. 48, pp. 723-752.

Timson, B.S., 1969, Post-storm profile and particle-size changes of a New Hampshire gravel beach: A preliminary report, pp. 392-402, in Coastal Environments of NE Mass. and N.H., Field Trip Eastern Sect. S.E.P.M., May 9-11, 1969, Coastal Res. Group, U. Mass., 462 p.

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