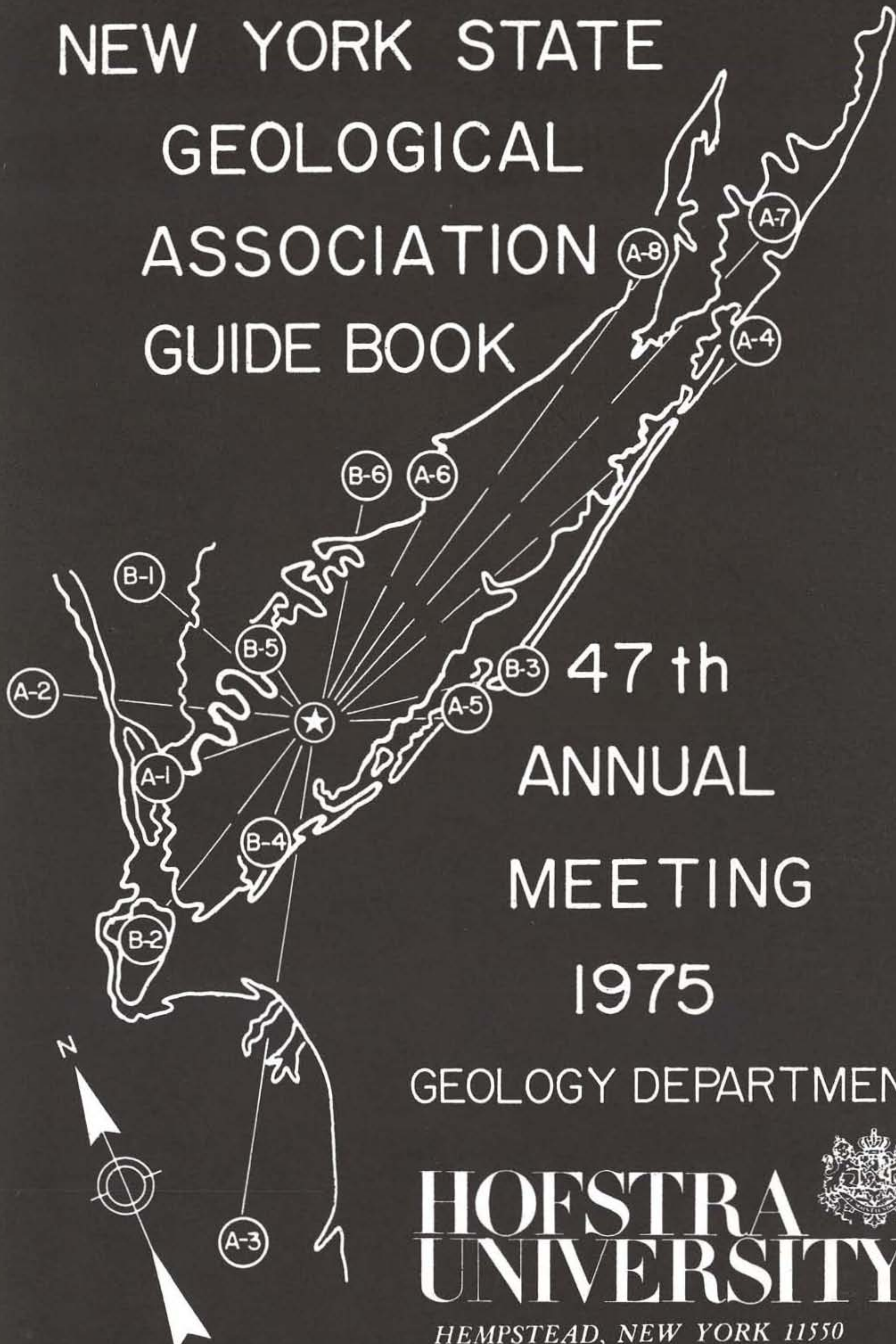
NEW YORK STATE GEOLOGICAL ASSOCIATION GUIDE BOOK



47th ANNUAL MEETING 1975

GEOLOGY DEPARTMENT
HOFSTRA UNIVERSITY
HEMPSTEAD, NEW YORK 11550

GUIDEBOOK

to

FIELD EXCURSIONS

conducted at the

47th MEETING

of the

NEW YORK STATE GEOLOGICAL ASSOCIATION

October 31-November 2, 1975

Manfred P. Wolff, Editor

Host

Hofstra University
Department of Geology
Hempstead, New York

Additional copies of this guidebook may be purchased from the secretary of the New York State Geological Association: Dr. Daniel Merriam, Department of Geology, Syracuse University, Syracuse, N. Y. 13210, or: Dr. Manfred P. Wolff, Department of Geology, Hofstra University, Hempstead, N. Y. 11550.

ACKNOWLEDGEMENTS

This guidebook provides a permanent record of the 47th meeting of the New York State Geological Association. The papers and road logs are presented to enhance the various field trips, to allow participants to read through them at their leisure, and to later make a return visit whenever they desire. For the most part they summarize previous information and/or provide new data and concepts that reflect continuing research in the New York City-Long Island-New Jersey region.

The trips vary from bedrock geology and stratigraphy to coastal and glacial geomorphology - to excursions of areas containing earth, energy, and environmental resources - to ocean voyages. Because of time implications some trips (particularly on Long Island) cannot later be completed in the exact manner described herein. The interplay between man-made and geological influences will continue to alter these areas, for better or worse, and whenever possible, modern management techniques and environmental considerations have also been included.

The shortness of available time for preparing the guidebook has not given the authors an opportunity to see proofs of their articles, and the editor accepts any responsibility for errors that may appear. Editorial changes were kept minimal in most instances. Special acknowledgement is made to the many authors from neighboring institutions without whose help this guidebook and meeting would not have been possible. The effort can only be appreciated by those who have made similar contributions to this meeting over the years.

For individual efforts in organizing the format of the guidebook and logistics for the meeting, special thanks to Dr. Kurt E. Lowe, Professor Emeritus at City College of the City University of New York. Dr. Lowe has long been a prominent figure in the association and consented to be our guest lecturer for the banquet at this meeting.

For her assistance in preparing the guidebook, and making all the detailed arrangements for transport, food and lodging, special thanks and appreciation also go to Mrs. Margaret L. Johnson, the Geology Department secretary who took it upon herself to gather the information for organizing the field excursions.

The editor would also like to thank Ms. Christine Anderson (President), and the other geology majors and members of the Long Island Geological Society (Hofsta's Geology Club) who contributed their time and effort toward making this a successful meeting, and Dr. Usman A. Sayeed for drafting the guidebook cover.

Manfred P. Wolff
Editor and President, 1975

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TABLE OF CONTENTS

STRATIGRAPHY, STRUCTURE AND PETROLOGY OF THE NEW YORK CITY GROUP

Simon Schaffel

ROAD LOG

Cumulative Miles	Miles from last point	Description
0.0	0.0	Assembly point: Hofstra University. Route is indicated on Figure 1. Proceed west on Fulton Avenue (Hempstead Turnpike, NY 24 West) leaving Hofstra campus.
1.2	1.2	Right turn (north) onto Clinton Street (avenue, road) in town of Hempstead.
1.9	0.7	Pass through Garden City.
2.5	0.6	Pass Stewart Avenue.
2.9	0.4	Clinton Water Works on east side of road.
3.5	0.6	Cross Old Country Road, town of Carle Place. Clinton Road becomes Glen Cove Road. Proceed north on Glen Cove Road.
4.4	0.9	Pass under Northern State Parkway, village of Old Westbury. Glen Cove Road becomes Guinea Woods Road. Proceed north on Guinea Woods Road.
6.3	1.9	Right turn. Entrance onto Long Island Expressway (I-495 West). Proceed west towards New York City.
7.6	1.3	Proceed west on Long Island Expressway. Pass Willis Avenue exit. Terminal moraine occurs directly to the right (north). The moraine is either the Ronkonkoma capped by the Harbor Hill or an undifferentiated mixture of both.
7.8	0.2	Proceed west on Long Island Expressway. Terminal moraine on left (south) with Port Washington delta on right (north). The latter feature formed as a result of a periglacial lake forming behind moraine and fronting the ice.
11.3	3.5	Proceed west on Long Island Expressway. Pass onto top of moraine. Typical glacial knob and kettle, hummocky-type topography.

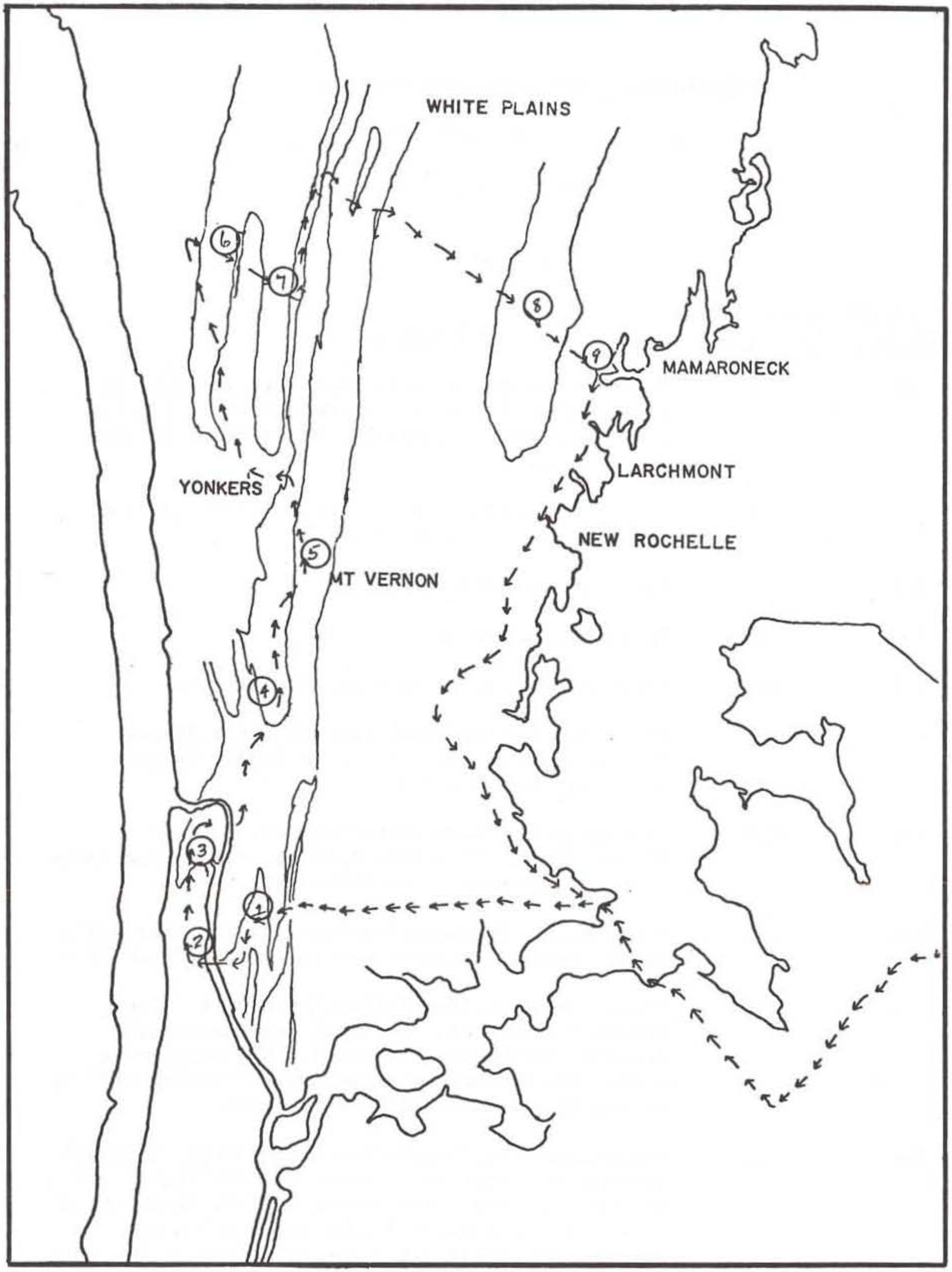

Figure 1. Map indicating stops and route to be followed on field trip.
1" = approximately 5.3 miles.

13.3	2.0	Proceed west on Long Island Expressway. Pass through valley of Little Neck Bay, which lies north-south of the expressway. This valley, although covered with a veneer of glacial till represents an initial preglacial valley. It is one of several north-south trending valleys which occur along the north shore of Long Island and undoubtedly represent obsequent valleys to the subsequent valley occupied by Long Island Sound. Pass Cross Island Parkway.
14.0	0.7	Pass Springfield Boulevard.
15.0	1.0	Bear right onto exit 27-28. Entrance onto Clearview Express (I-295 North) to Throgs Neck Bridge.
18.0	3.0	Approach ramp onto Throgs Neck Bridge.
20.6	2.6	Toll station exit of Throgs Neck Bridge (Bronx). Proceed north bearing left.
22.1	1.5	Bruckner traffic circle. Junction of I-95 and I-278. Bear left onto I-95 West (Cross-Bronx Expressway) toward George Washington Bridge.
23.6	1.5	Pass Westchester Avenue. Continuous exposures on both sides of expressway. Lithology composed of mica schists with subordinate amounts of sillimanite schists and biotite-quartz gneisses. Minor folds common exhibiting chevron pattern. Fold axes and other linear elements plunge northward (15 - 50°). These units have been designated as "undifferentiated schists and gneisses" on the 1961 edition of the New York State Geological Map. Hall (1968b) referred to them as Hartland-Manhattan undivided. Seyfert and Leveson (1969) placed them in their own coined "Hutchinson River Group."
24.3	0.7	Pass exit for Bronx River Parkway.
24.8	0.5	Bronx River valley. Boundary between the eastern undifferentiated schists and gneisses and the New York City Group to the west. Boundary is believed to be a major stratigraphic-structural break.
25.1	0.3	Continuous exposure of Manhattan schist on both sides of expressway forming Crotona Park synclinal ridge (Figure 2).

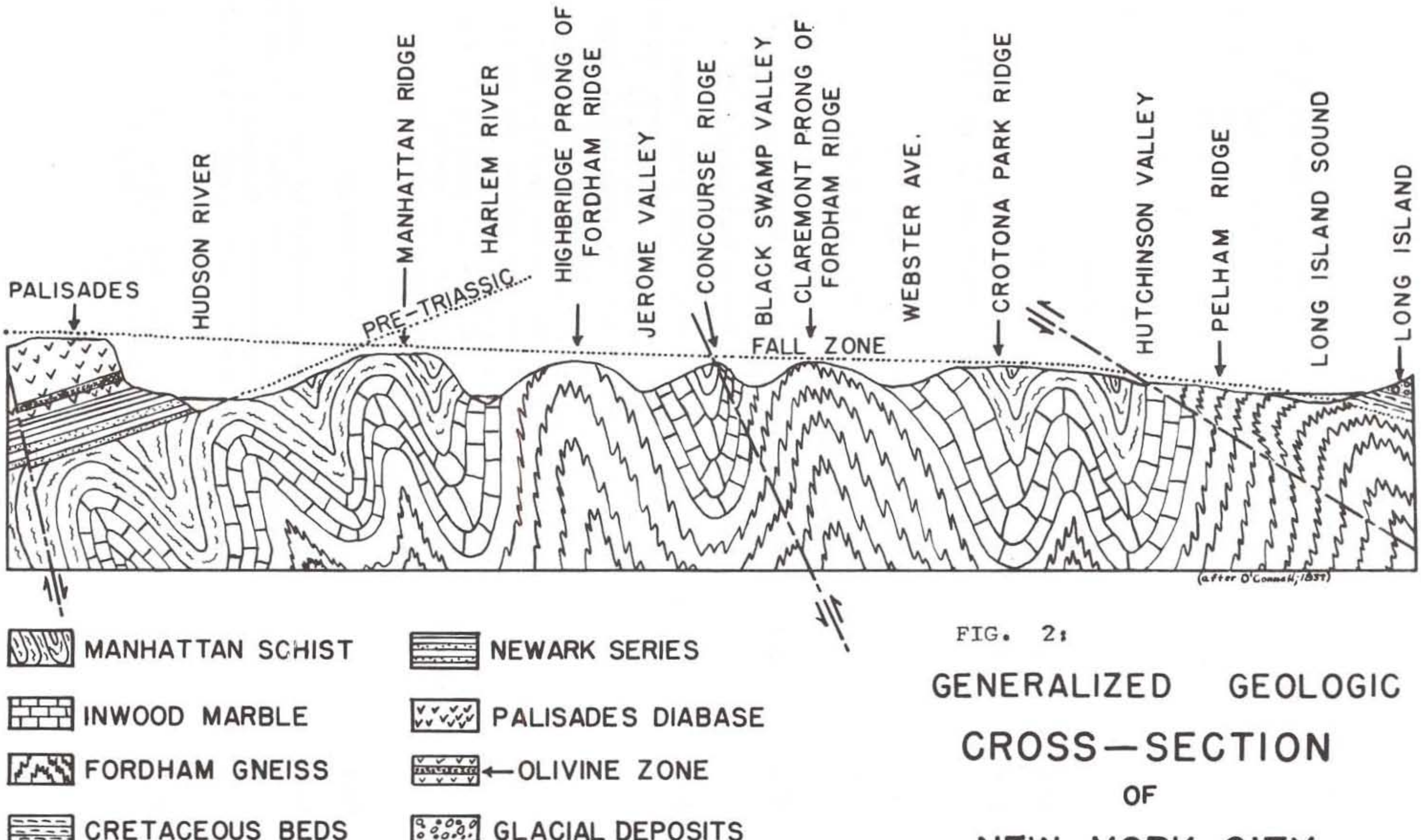

FIG. 2:

GENERALIZED GEOLOGIC CROSS—SECTION OF NEW YORK CITY

THE CITY COLLEGE—DEPARTMENT OF GEOLOGY

4

25.8	0.7	Third Avenue exit. Leave expressway and continue ahead paralleling expressway. Cross Park-Webster Avenue valley. The valley is underlain by Inwood marble. This north-south low is the former valley of the Bronx River. The stream was evicted from its original course further north into its present valley.
26.1	0.3	Left turn onto Webster Avenue.
26.2	0.1	Right turn onto entrance ramp to Cross Bronx Expressway (I-95 West). Anticline of amphibolite member of Manhattan schist immediately to right. This unit is approximately 20-30 feet thick and about 50-60 feet above the Inwood-Manhattan contact.
26.6	0.4	Exit onto Jerome Avenue. Bear left for turn onto Jerome Avenue.
26.7	0.1	Left turn onto 174th Street.

STOP #1: GRAND CONCOURSE SYNCLINAL RIDGE

Manhattan schist occurs along the north-south trending Grand Concourse forming a ridge while the lesser resistant Inwood marble forms the valleys on both sides of the ridge. Manhattan schist-Inwood marble contact is present along south side (east bound lane) of Cross-Bronx Expressway. Typical interbedding of Inwood and Manhattan along west ridge slope can be seen.

Inwood marble is a gray to buff-colored, medium to coarse textured marble and dolomitic marble. Bed thickness varies from 1/2" to 6 feet. Minor amounts of graphite, pyrite, phlogopite, tremolite and diopside have been found. Thickness of the formation varies but here it occupies the entire Jerome Avenue valley - approximately 1000 feet. Repetition of beds by folding is possible.

26.8	0.1	Return to bus. Right turn onto Jerome Avenue and right turn onto Cross-Bronx Expressway (I-95 West). Proceed west, keep right.
27.2	0.4	Continuous exposure on south and north side of expressway. FORDHAM GNEISS forming Highbridge prong of Fordham ridge. This ridge is one of the type localities for the Fordham in New York City. The ridge is an overturned anticline to the west. Lithologically the unit is a biotite-feldspar-quartz gneiss. The three minerals form

		alternating bands which vary from inches to three feet. Band is very uniform and consistent. Plagioclase feldspar is common but subordinate to the potash feldspar. Intercalated bands of granite pegmatites, amphibolites, and marbles occur. Bands (layers) are steeply dipping (60-90°) to the east. Small minor folds are common. Larger isoclinal and asymmetrical folds can be detected with axial planes overturned toward the west. All fold axes plus other linear elements plunge south at approximately 15°.
		Exit onto ramp of Major Deegan Expressway (I-87 South) toward Triborough Bridge.
28.2	1.0	Junction of ramp and Major Deegan Expressway (I-87 South). Keep right.
29.1	0.9	Exit onto ramp for West 155th Street Bridge.
29.2	0.1	Right turn onto bridge, proceeding west. Cross Harlem River, separating Manhattan and Bronx. The Harlem is not a river but a strait. The entire valley is underlain by steeply dipping, tightly folded beds of Inwood marble.
29.4	0.2	Oblique right turn onto 155th Street ramp. Proceed west.
29.7	0.3	Intersection, St. Nicholas Avenue and 155th Street. Right turn onto St. Nicholas Avenue. Proceed northward downhill. Coogan's Bluff on left.

STOP #2: BASE OF COOGAN'S BLUFF NEAR JUNCTION WITH HARLEM RIVER SPEEDWAY

Carefully cross the highway to base of cliff and walk north to fresh exposure of Manhattan schist, Amphibolite (Hornblende schist), and Pegmatites.

Merrill et al. (1902) cites this as a type locality for the Manhattan schist. The principal lithology is a coarse textured light to dark-grey biotite muscovite quartz schist with sporadic high concentrations of garnet. Other minor minerals in order of abundance include plagioclase (oligoclase), potash feldspar (orthoclase), magnetite, pyrite, and sillimanite. Pods (augens) of quartz and feldspar, where quantitatively significant, may develop a gneissoid appearance. Axes of minor and major folds within the schist as well as other linear elements plunge south about 15°.

The Amphibolite (Hornblende schist) here is a dark grey to black medium texture rock. Principal minerals include hornblende and plagioclase (andesine) feldspar with local high concentrations of epidote. A rhombohedral-type jointing is the result of the dense and close parallel arrangement of the prismatic shaped hornblende crystals. This jointing contrasts with the block type peculiar to the Manhattan schist and Fordham gneiss. The Amphibolite bed here is approximately 30-60 feet from the Manhattan-Inwood contact and is believed to be the same bed viewed at Mile 26.2 earlier. This Amphibolite appears to be an excellent horizon marker for locating the Manhattan-Inwood contact in the region.

The "Pegmatites" found in the New York City Group are composed of granites, granite pegmatites, graphic granites, aplites, and quartz veins. These concordant and discordant bodies occur in all formations with varying widths up to 10 feet. Quartz, pink microcline feldspar, greenish oligoclase plus moscovite are the common principal minerals. Biotite, hornblende, magnetite, garnet, black tourmaline are some of the minor constituents.

31.9	1.9	Left turn onto Dyckman Street. Dyckman Street fault. One of the few cross faults found in New York City resulting in an east-west cross valley.
32.5	0.6	Right turn onto Seaman Avenue. Proceed north on Seaman Avenue four blocks.

STOP #3: INWOOD PARK-ISHAM PARK

Proceed west into Inwood Park. The canoe-shaped valley underlain by Inwood marble is an anticline while the two adjacent Manhattan schist ridges are synclines (Figure 3). Amphibolite exposure occurs along the path leading to the western ridge. Spuyten Duyvil, the water body immediately to the north is at present a strait connecting the Hudson River (an estuary) with the Harlem River (a strait). Prior to being modified by glaciation and subsequently by man, a true stream flowed here controlled by the existing lithology and structure. A fuller discussion will be presented.

Return to Isham Street and Isham Park.

The marble here and in this area is the type locality named after the village of Inwood. The marble is gray to buff-colored medium to coarse textured marble and dolomitic marble. Essentially the same lithology as the Inwood found at Stop #1. Graphite, pyrite, phlogopite, tremolite and diopside (malacolite) may be found here and elsewhere in the neighborhood. Quartzite, interbedded with the marble, indicates original sandy beds. These quartzite layers plus aplites often occur as disconnected boudins. An occasional thin schistose layer suggests original mud or limey mud sedimentation. Folding and plastic deformation are present. Possibly the only example of a residual soil in New York City is present at this stop.

Return to bus. Proceed east on Isham Street.

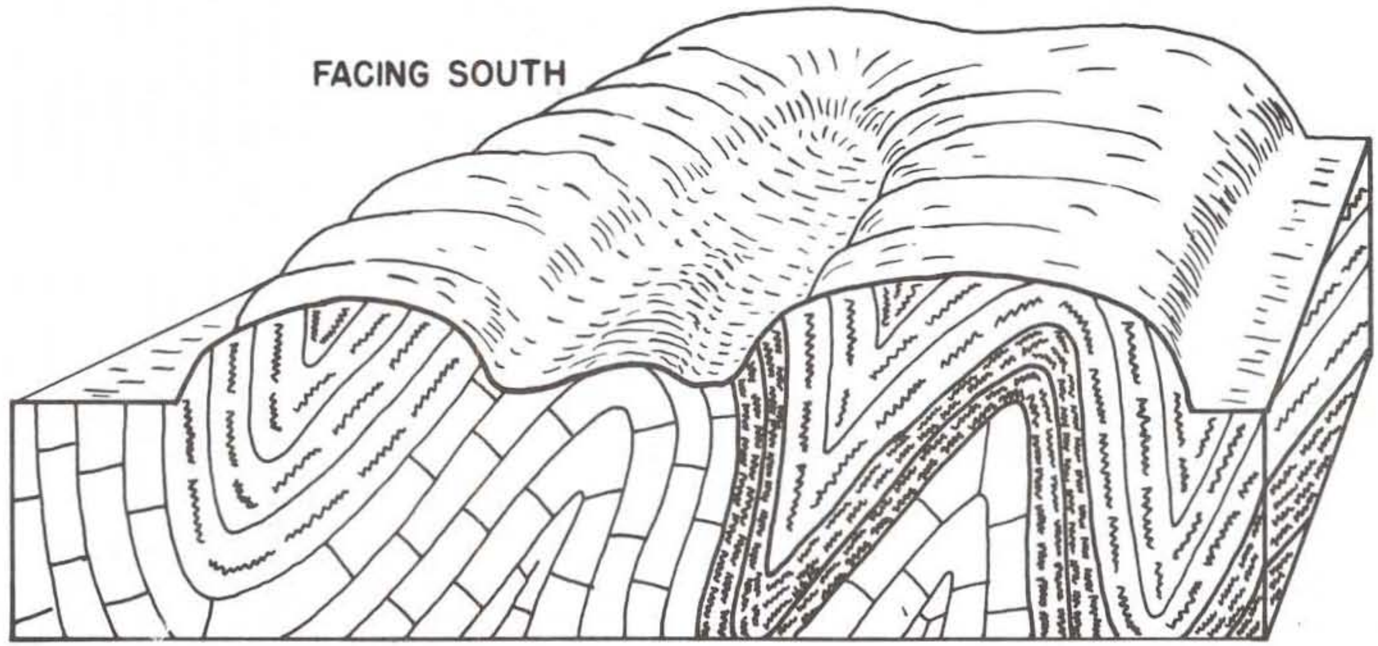

Figure 3A: Cross-section at Inwood Park showing canoe valley

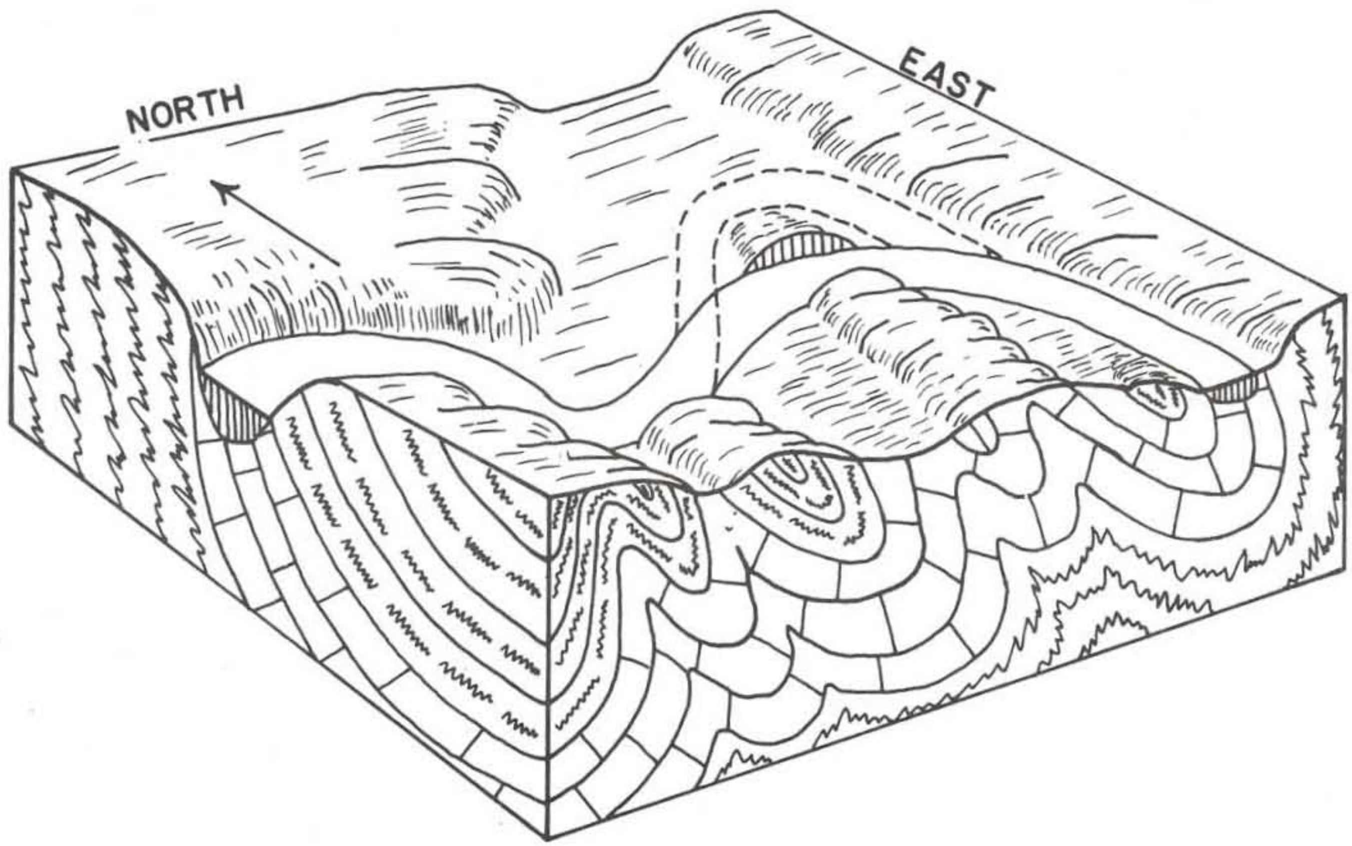

Figure 3B: Spuyten Duyvil and the Inwood Section.

33.2	0.3	Right turn onto 10th Avenue. Proceed south to 207th Street.
33.3	0.1	Left turn onto 207th Street. Proceed east crossing Harlem River and entering the Bronx. 207th Street becomes Fordham Road. Proceed to Major Deegan Expressway (I-87 North).
33.7	0.4	Left turn onto Major Deegan Expressway (I-87 North). Proceed north to exit 5 of the New York State Thruway.
39.8	6.1	Bear right and exit at exit 5. Keep right.
39.9	0.1	Right turn onto curving ramp immediately after underpass.
40.0	0.1	Right turn onto Midland Avenue. Proceed west on Midland Avenue passing over New York State Thruway.
40.3	0.3	Right turn onto Fullerton Avenue. Proceed north on Fullerton Avenue.
40.5	0.2	Dead end.

STOP #4: DI RIENZO STONE QUARRY

Yonkers granite gneiss.

PLEASE BE CAREFUL IN THIS QUARRY. DO NOT COLLECT ANY SPECIMENS FROM THE TRIMMED AND STACKED ROCKS. THESE ARE THE FINISHED PRODUCTS OF THIS QUARRY AND THE LABOR OF THOSE WHO WORK HERE.

Collect specimens from floor and walls of quarry.

Merrill et al. (1902) states that the Yonkers is "technically a gneissoid granite." The rock is composed of quartz and microcline feldspar with lesser amounts of orthoclase. The feldspars are responsible for the striking pink-red color. Although not obvious, foliation, caused by the presence of biotite, is present. The biotite occurs as clumps, which are usually discoidal but occasionally spindle shaped. When the latter phenomenon occurs a lineation is also present. The foliation here is at a high angle (vertical) and is normal to the close-spaced horizontal sheeting. Minor amounts of hornblende, apatite, and zircon are also found. A single amphibolite layer occurs in the quarry. The Yonkers is invariably associated with the Fordham and almost without exception occurs as central masses surrounded by the Fordham. Contacts between both are sharply defined and gradational.

LUNCH STOP.

Return to buses. Proceed south on Fullerton Avenue.

40.7	0.2	Left turn onto Midland Avenue. Proceed east on Midland Avenue passing over New York State Thruway.
41.1	0.4	Left turn onto curving ramp leading to service road of New York State Thruway and NY 100 (Central Avenue).
41.3	0.2	Bear right onto NY 100 North.

STOP #5: FORDHAM GNEISS

Almost 1000 feet of Fordham is exposed on both sides of the highway. The Fordham here exhibits great variation and the lithologic divisions of this formation as advanced by Hall (1968a, 1968b) is appropriate.

Return to bus. Proceed north on NY 100.

42.0	0.5	Overpass Sprain Brook Parkway. Keep right.
42.3	0.3	Bear right onto ramp leading toward Tuckahoe Road.
42.6	0.3	Left Turn onto Tuckahoe Road. Proceed west on Tuckahoe Road.
43.1	0.5	Overpass Grassy Sprain Parkway. Continue west on Tuckahoe Road.
43.5	0.4	Pass entrance and underpass of New York State Thruway. Continue west on Tuckahoe Road.
43.9	0.4	Bridge overpass over railroad tracks. Proceed west on Tuckahoe Road.
44.2	0.3	Right turn onto service road of Saw Mill River Parkway. Service road is NY 9A and Saw Mill River Road. Proceed north on service road. The service road follows the contact between the Inwood marble which underlies the valley to the west and the Manhattan schist which forms the ridge on the right (east). Exposures of the Manhattan can be seen periodically.
46.3	2.1	Mt. Hope Cemetery. Intersection of NY 9A and Jackson Avenue. Right turn onto Jackson Avenue proceeding east.

STOP #6: FORDHAM GNEISS

Three subdivisions of the Fordham were tentatively identified by Hall

(1968a) at this site. The Fordham body occurs as a northward plunging anticline. Sprain Lake valley immediately to the east contains Inwood marble. Numerous exposures of the marble are found along the east side of the valley paralleling the parkway.

Return to bus. Proceed east on Jackson Avenue. The ridge which we cross between Sprain Lake valley and NY 100 to the east is underlain by Manhattan schist which forms a north plunging anticline.

47.6 0.9

STOP #7: MANHATTAN SCHIST

Manhattan schist plus Amphibolite layer near contact with Inwood marble in valley of NY 100.

Return to bus. Left turn onto NY 100 North. Continuous exposures of Manhattan schist on west side of road.

47.9	0.3	Exposure of Inwood marble on east side of road. Proceed north on NY 100.
48.6	0.7	Right turn onto Ardsley Road toward Scarsdale. Proceed east on Ardsley Road.
48.7	0.1	Core of Yonker granite occupying center of hill.
48.9	0.2	Intersection with Old Army Road. Proceed east on Ardsley Road. Continuous outcrop of Yonkers granite on crest of hill.
49.1	0.2	Fordham gneiss outcrops occupying side of hill.
49.3	0.2	Cross over Bronx River Parkway. Intersection with Garth Road. Proceed east on Ardsley Road.
49.4	0.1	Railroad station, Scarsdale. Ardsley Road becomes Popham Road. Proceed east on Popham Road.
50.0	0.6	Intersection, left turn onto Post Road (White Plains Road). Proceed north.
50.1	0.1	Intersection, oblique right turn onto Heathcote Road. Proceed east on Heathcote Road.
50.9	0.8	Intersection with Morris Lane. Continue east and south on Heathcote Road.
51.3	0.4	Pass Scarsdale Medical Center on left.

51.5	0.2	Intersection Heathcote Road and Palmer Avenue. Oblique right onto NY 125 South (Weaver Street). Pass to right of gas station.
52.5	1.0	Overpass on Hutchinson River Parkway. Proceed south on NY 125.
53.3	0.8	Pass Quaker Ridge Road. Continue on NY 125 South.
53.5	0.2	Pass Bonnie Briar Country Club on left. Proceed on NY 125 South.
54.0	0.5	

STOP #8: HARRISON DIORITE

Merrill et al. (1902) lists quartz, hornblende, feldspar and biotite as the principal constituents in this unit. Feldspar includes orthoclase and plagioclase (oligoclase-andesine). An igneous origin is indicated for the unit. Merrill further suggests that the Ravenswood granodiorite found in Queens County to the south may be a correlative equivalent.

Return to bus. Continue on NY 125 South.

54.3	0.3	Road fork. Bear left, continue on NY 125 South (Weaver Street).
54.5	0.2	Intersection, Forest Avenue and NY 125 South. Continue on NY 125 South.
55.1	0.6	Overpass New York State Thruway, Westchester spur.
55.2	0.1	Cross Palmer Avenue.
55.5	0.3	

STOP #9: EASTERN UNDIFFERENTIATED SEQUENCE

Intersection of NY 125 South and US 1. Park in bank parking lot. Freshly exposed schist along rear of parking lot. The unit here is part of the larger area of undifferentiated schists and gneisses first mentioned at Mile 23.6 on the Cross-Bronx Expressway.

Return to bus. Proceed south on US 1.

56.0	0.5	Pass Larchmont Road. Proceed south on US 1.
56.8	0.8	Enter New Rochelle. Proceed south on US 1 (Main Street, New Rochelle).

57.4	0.6	Road fork, bear right on US 1.
57.7	0.3	Right turn onto Echo Avenue-River Street, New Rochelle.
57.8	0.1	Road fork, bear left onto I-95 South entrance.
58.0	0.2	Right turn onto I-95 South.
64.8	6.8	Road fork, bear left onto I-295 South toward Throgs Neck Bridge and New York City.
66.7	1.9	Toll gate, Throgs Neck Bridge.
88.3	21.6	Return to Hofstra University.
		End of Trip

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Additional information is available in the 1958 (Peekskill) and 1968 (Queens) N.Y.S.G.A. Guidebooks.

Structure and Form of the Triassic Basalts in North Central New Jersey

Michael Sichko Jr.
Nassau Community College

General Geology

Introduction

The structure and form of the Triassic basalts in north central New Jersey is exposed in the First, Second, and Third Watchung Mountains, and the Palisades Sill.

The First, Second, and Third Watchung Mountains are tholeiitic basalt flows that are topographically prominant ridges in northern New Jersey (Fig. 1). They strike N 40° E and have a gentle dip of approximately 17° NW. Their north-eastern and southwestern sections exhibit curved terminations, thus giving the ridge system a synclinal trough appearance. They are also terminated in the northwest by a border fault that separates the Triassic basin from the Pre-Cambrian gneisses that lie to the northwest. The three extrusive sheets are interbedded with Triassic sedimentary rocks (shales, sandstones, and argillites) of the Newark Group. The extrusion of the successive lava flows took place at the time of deposition of the Newark Group (Lewis, 1908).

The Palisades Sill is emplaced in a structual and stratigraphic basin called a taphrogeosyncline by Kaye (1951). It has intruded the Newark Group and where it has concordant contacts the intrusion has a general strike of N 30° E., and dips between 10° and 15° NW (Walker, 1969). The Palisades Sill also has satellite intrusions above it, such as the small laccolith or sill at Granton Quarry. The Palisades Sill is probably in part concordant and in part discordant (Thompson, 1959; Lowe, 1959).

The Palisadian Igneous Province

The igneous rocks and their counterparts in the other Triassic basins record the emplacement of basic magma on an enormous scale, 1,000 miles in length and about 200 miles wide. Significantly they correlate broadly with the vast Karoo dolerites and equivalent basic rocks in the Southern Hemisphere, and like them, apparently were emplaced during an episode of tension attending the widening of the Atlantic basin (Van Houten, 1969).

The stratigraphic sequence of the Palisadian igneous rocks within the Newark Group is:

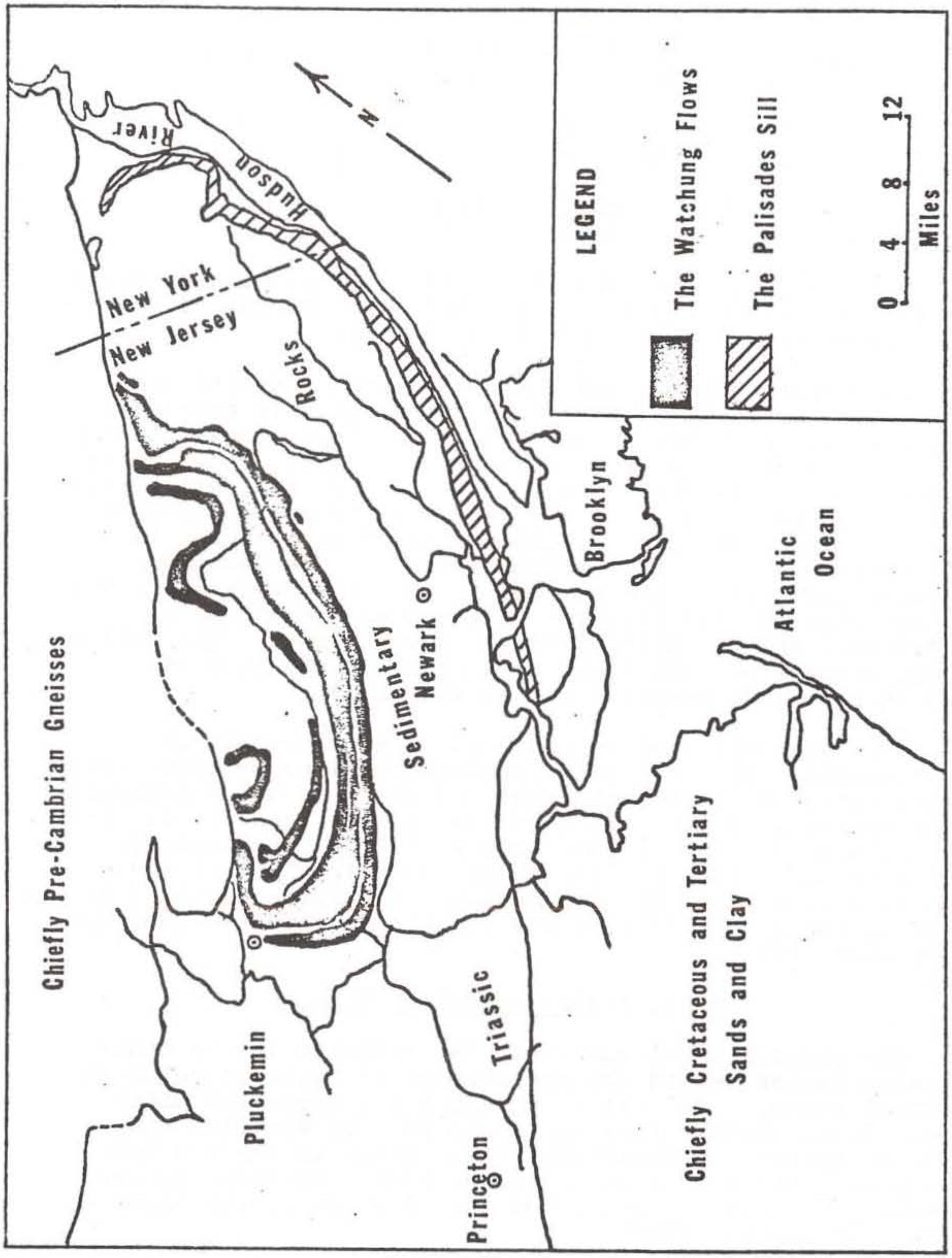

Figure 1. Index Map of Northern New Jersey, Showing the First, Second, and Third Watchung Mountains and the Palisades Sill.

TABLE I

	THE NEWARK GROUP	THE PALISADIAN IGNEOUS ROCKS
UPPER TRIASSIC PERIOD	Brunswick formation-consisting of soft red shales and sandstones	1st, 2nd, and 3rd WATCHUNG BASALT FLOWS
	Lockatong formation-consisting of red to black argillite and sandstone layers	GRANTON LACCOLITH OR SILL
	Stockton formation-consisting of gray to red arkosic sandstone, conglomerate and red shale	*PALISADES SILL

*The age of the Palisades sill has been determined by Erickson and Kulp (1961) at 190 ± 5 m.y by a K-Ar determination on biotite from dolerite at Fort Lee (Walker, 1969).

Differentiation Trends and Order of Emplacement of the Upper Triassic Watchung Flows and the Palisades Sill

It has been established that the Palisades Sill is a multiple intrusion comprising at least two magma phases, into which late-stage dikes intruded after the main phases consolidated. This seems reasonable, as the contemporaneous Watchung basalt flows, with three main basaltic successions, show that igneous activity at the time was protracted and comprised a number of phases (Walker, 1969).

The differentiation of the sill is a complex one of interacting processes, both mechanical and chemical. The conditions and processes responsible for the differentiation of the sill are outlined below:

1. temperature
2. pressure
3. magma composition
4. settling by gravity
5. upward displacement of the liquid phase
6. gas streaming
7. convection
8. flow differentiation
9. filter pressing
10. partial pressure of oxygen
11. volatile content, particularly water

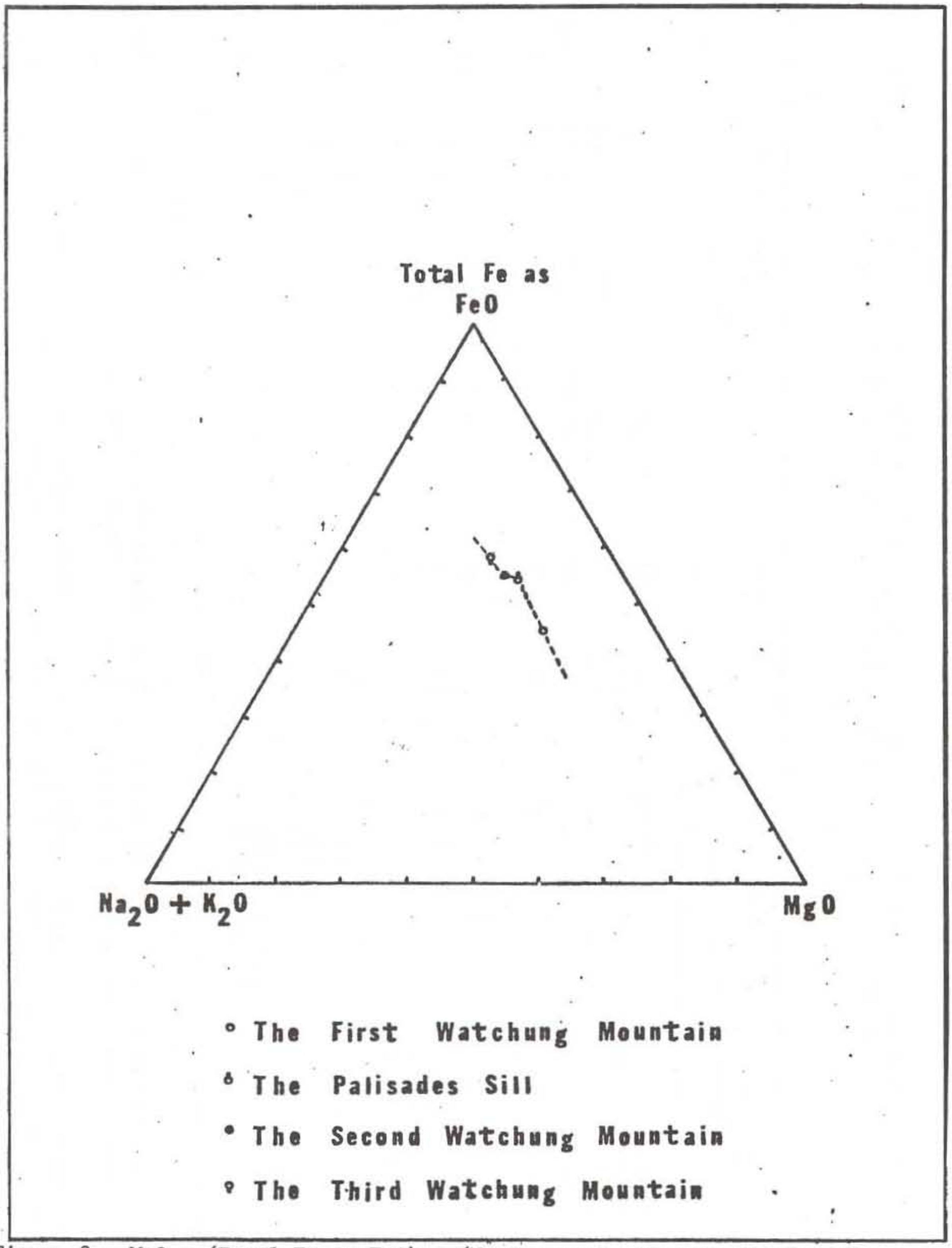

Figure 2. MgO – (Total Fe as FeO) – ($Na_2O + K_2O$) Diagram Showing the Differentiation Trend in the Palisadian Province. A quantitative chemical analysis was used for the Second Watchung Mountain data point. The percentages are as follows: Fe_2O_3 – 3.75; FeO – 7.15; MgO – 5.35; Na_2O – 2.79; K_2O – 0.85.

TABLE II

CHEMICAL COMPOSITION AND NORMATIVE MINERALS OF THE UPPER TRIASSIC WATCHUNG FLOWS, THE PALISADES SILL, AND OTHER REPRESENTATIVE BASALTS

	Chemical Composition						Norms				
Constituent	1	2	3	4	5	Constituent	1	2	3	4	5
SiO_2	50.8	52.35	51.35	47.21	49.52	Q	3.6	4.6		4.30	1.44
TiO_2	2.05	1.6	0.99		1.47	Or	5.0	5.4	3.89		4.45
Al_2O_3	14.1	14.0	14.83	13.58	13.82	Ab	18.85	21.0	20.44	19.40	28.31
Fe_2O_3	2.9	2.65	2.34	6.78	5.12	An	25.85	24.2	27.53	27.50	20.30
FeO	9.1	9.2	7.87	10.00	9.88	Di	20.0	17.1	15.15	16.20	12.56
MnO	0.2	0.15	0.11			Hy	17.25	19.3	23.51	19.22	19.95
MgO	6.3	6.15	7.72	6.39	5.65	Ol			5.40		
CaO	10.4	9.35	9.47	9.65	7.40	Mt	4.2	3.8	3.23	11.55	7.41
Na_2O	2.25	2.5	2.44	2.14	3.40	Il	3.9	3.0	1.82		2.73
K_2O	0.8	0.85	0.74		0.77	Ap	0.5	0.5			0.31
P_2O_5	0.25	0.25	0.13		0.18	H_2O	0.9	1.3	1.07	1.65	1.22
H_2O	0.9	1.3	1.07	1.69	1.22						
Totals	100.05	100.35	100.18	97.44	98.43		100.05	100.35	102.67	99.82	98.68
			Pl/Px ratio				1.19	1.24	1.22	1.33	1.49
			% An in Norm Plag.				57	53	57	55	42
			MAFIC INDEX				65.5	65.7	56.9	75.5	75.0
			FELSIC INDEX				22.6	26.4	25.2	18.1	36.0

1. Average tholeiitic basalt and dolerite. (S.R. Nockolds, Average Chemical Compositions of Some Igneous Rocks, Geol. Soc. Amer. Bull., V. 65, pp. 1021, 1954).

2. Average composition of the Palisades intrusion, composite section a planimetric estimate from 0 to 1000 feet. (K.R. Walker, The Palisades Sill, New Jersey; A Reinvestigation, Geol. Soc. Amer. Special Paper 111, P. 83, 1969).

3. Average of five analyses of the lower, middle, and upper layers of the First Watchung Mountain sheet. (J.V. Lewis, Petrography of the Newark Igneous Rocks of New Jersey, New Jersey Geol. Surv. Ann. Rep., St. 6, p. 159, 1908).

4. Average of six analyses of the Second Watchung Mountain sheet. (Thin sections 3, 9, 13, 17, 18, 29; chemical compositions determined by petrographic modal analysis).

5. Average of three analyses of separate layers of the Third Watchung Mountain shell. (Lewis, op. cit. p. 159, 1908).

In conclusion, the differentiation trend and degree of fractionation, implies that the order of emplacement of the rocks of the Palisadian province may have started with the extrusion of the First Watchung flow, followed by intrusion of the Palisades Sill into the Newark Formation of New Jersey, and then extrusion of the Second Watchung flow, which was finally followed by the extrusion of the Third Watchung flow.

ROAD LOG FIELD TRIP A-2

Leader: Michael Sichko Jr.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
0.0	0.0	Hofstra University parking. Exit parking lot, left turn for 0.1 miles, making a right turn onto Hempstead Turnpike.
1.2	1.2	Right turn to Meadowbrook Parkway North.
4.8	3.6	Bear left onto Northern State Parkway.
6.6	1.8	Right turn to the Long Island Expressway Westbound.
25.4	18.8	Toll booth, Queens Midtown Tunnel. Follow signs on 34th Street to the Lincoln Tunnel.
28.15	2.75	Right turn into the Lincoln Tunnel.
31.75	3.6	Exit, making a right turn onto U.S. 1-9 North.
34.65	2.9	Left turn from U.S. 1-9 (Tonnelle Avenue) at 77th Street into the Diana Stores Corp. parking lot. Proceed to the most northerly point at the rear of the parking lot.

STOP 1: Granton laccolith or sill:
In this exposure a satellite intrusion from the Palisades Sill, the Granton sill or laccolith, can be observed. The Granton sill has intruded the Lockatong formation of the Newark Group. In the easterly section of this exposure small appendages of the sill exhibit intrusive contacts with the

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		shales and sandstones of the Lockatong formation (Fig. 3).

Figure 3. Concordant and discordant contacts between the Granton sill and the shales and sandstones of the Lockatong formation.

		At the contacts the chilled diabase has an intersertal - intergranular texture, away from the contacts the diabase has an intergranular texture. The whole outcrop dips to the west at a gentle 15° to 17°.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		Fossils have been found in the black shale layers, they include fish remains of coelacanths, Diplurus longicaudatus, Diplurus newarki and the common branchiopod, Estheria ovata (Schuberth, 1968).
		Left turn out of parking lot onto U.S. 1-9 North (Tonnelle Avenue).
37.40	2.75	Right turn to route 5 East. Continue on route 5 East into the town of Edgewater, New Jersey.
40.65	3.25	Left turn into a trailer parking lot at Edgewater, New Jersey. Walk to the west on Dempsey Avenue, make a right turn onto Undercliff Avenue to a small park on the left. Proceed up an abandoned trolley track right of way.
		STOP 2: Basal contact of the Palisades Sill and the Mg-Olivine Layer. Below the basal contact of the Palisades Sill a small stream has eroded through the Stockton formation which consists of arkosic sandstone and black and green shales. The alternating sandstone and shale beds attest to the changing environmental conditions during the deposition of the Stockton formation. Continuing up the trolley track right of way the concordant basal contact between the Palisades Sill and the arkosic sandstone of the Stockton formation can be observed. The contact metamorphic zone at this outcrop can be observed by noting that the shale has been metamorphosed into a hornfels and the sandstone has developed

TOTAL MILES	MILES BETWEEM POINTS	REMARKS
		quartzitic characteristics. Columnar jointing has developed perpendicular to the basal contact at this outcrop. Further up the right of way a xenolith of shale plucked from the floor of the intrusion can be seen near the basal chilled zone. At the bend in the trolley route the Mg-Olivine layer comes into full view. The base of this layer is approximately 40 feet above the chilled diabase. The layer outcrops as a highly weathered zone due to differential weathering of the cliff face. It is believed that the Mg-Olivine layer formed at the junction between two magma phases (Walker, 1969). Columnar jointing is pronounced directly above this layer.
		Make a right turn from the trailer parking lot onto route 5 West.
42.05	1.4	Bear right onto route 67 going towards Fort Lee, New Jersey and the George Washington Bridge.
43.45	1.4	Left turn onto Cross Street, just beyond the George Washington Bridge underpass.
43.85	0.4	Left turn at sign for Interstate 80 West.
44.80	0.95	Just beyond viaduct park on the right shoulder of Interstate 80.
		STOP 3: Upper contact of the Palisades Sill: This exposure of the upper contact of the Palisades sill is concordant with the rocks of the Stockton formation (Fig. 4).

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		The chilled diabase is fine-grained here as compared to the course-grained diabase to the east of this outcrop. Although the metamorphism is less pronounced at the upper contact than the lower contact the shale has been metamorphosed into a hornfels and the sandstone has developed quartzitic characteristics. Both the contact and strata dip gently to the west.

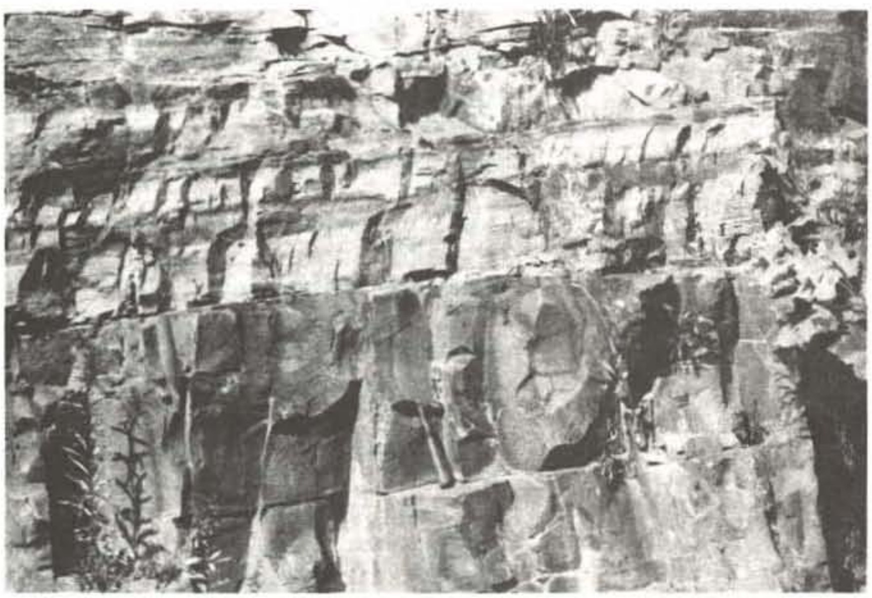

Figure 4. The upper contact of the Palisades Sill and the Stockton formation.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		Continue on Interstate 80 West towards Paterson, New Jersey.
57.75	12.95	Exit at Squirrelwood Road. Left turn at the stop sign onto Squirrelwood Road.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
57.95	0.2	Left turn into the Mobil Station parking lot. Walk for 200 yards on entrance ramp to Interstate 80 East. Outcrop on the right shoulder.

STOP 4: Pillow lava of 1st Watchung Lava:
The pillow lava of the 1st Watchung Mountain at this exposure represents the uppermost flow unit of a two unit system (Van Houten, 1969). Nichols (1936) defines a "flow unit" as a tongue shaped structure within a flow. The individual pillows are somewhat ellipsoidal in outline and have long dimensions of approximately 0.5 meters in length (Fig. 5). Adjacent pillows have adjusted their shape to fit together quite well. Some individual pillows exhibit vesicularity and radial jointing. The pillows lie in a matrix of tuffaceous material and weathered basalt. It appears that pillow lavas must generally form by a combination of the process of bulbous budding underwater and by the generation of an emulsion (Lewis, 1915; Fuller, 1940) in which the disperse phase consists of rounded "drops" of fluid lava and the disperse medium is water, very watery sediment, or water-saturated hyaloclastic debris (MacDonald, 1967).

TOTAL MILES	MILES BETWEEN POINTS	REMARKS

Figure 5. The pillow lava of the 1st Watchung Mountain.

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
58.40	0.45	Continue on Squirrelwood Road to New Street. Left turn at New Street.
58.50	0.10	Left turn onto Rifle Camp Road.
58.80	0.30	Left turn at sign for Garret Mountain Reservation.
59.10	0.3	Right turn and then a left turn onto Benson Drive.
59.55	0.45	Proceed on Benson Drive to the overlook on Garret Mountain Reservation.
		<u>STOP 5A: Upper Surface of 1st Watchung Lava Flow at Garret Mountain Reservation:</u> The Garret Mountain overlook

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		allows for a spectacular view of the Triassic Lowlands of northern New Jersey. From this vantage point the more resistant Watchung lava flows are seen topographically as ridges. To the northeast beyond the Paterson water gap, which is occupied by the Passaic River, the 1st Watchung flow is easily observed. To the northwest the 2nd Watchung mountain can be seen. On the walkway at the overlook evidence for glacial movement in this area is in the form of glacial polish, striations and erratics. The hackly appearance of the unglaciated portions of the lava flow are due to the differential weathering of the tops of columns which comprise a major section of the lower flow unit of the 1st Watchung mountain.
		Leaving the overlook, make a left turn onto Benson Drive.
60.65	1.0	Left turn onto Mountain Park Road.
61.10	0.45	Left turn onto Valley Road.
61.30	0.20	Left turn to Administration Building and Main Entrance to Garret Mountain Reservation.
61.75	0.45	Proceed to parking lot of Garret Mountain Administration Building. Walk along dirt road approximately 350 yards to the Northeast.
		<u>STOP 5B:</u> <u>Lower Contact of the</u>

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		1st Watchung Mountain: At this exposure the lower chilled contact of the 1st Watchung mountain lies directly over the red shales and sandstones of the Brunswick formation. In this lower flow unit, the chilled zone is highly vesicular, above this zone the colonnade and entablature are clearly visible. In the talus slope below this out-crop representative samples of each zone of the basaltic lava flow can be found. At the stop sign to Garret Mountain Reservation make a right turn onto Valley Road.
61.90	.15	Left turn at the sign for Garden State Parkway.
62.25	.35	Right turn at traffic light and sign for entrance to the Garden State Parkway.
62.45	.20	Left turn onto Garden State Parkway.
72.55	10.10	Exit for Interstate 280 West.
76.75	4.20	Stop on right shoulder of Interstate 280 West at road cut. STOP 6: Lower part of the 1st Watchung mountain: In this exposure of the lower part of the 1st Watchung mountain one encounters a well-developed lower colonnade zone and a curvi-columnar zone with markedly radiating slender joints (Manspeizer, 1969).

TOTAL MILES	MILES BETWEEN POINTS	REMARKS
		The flow units of the Garret Mountain section cannot be seen at this outcrop (Fig. 6).

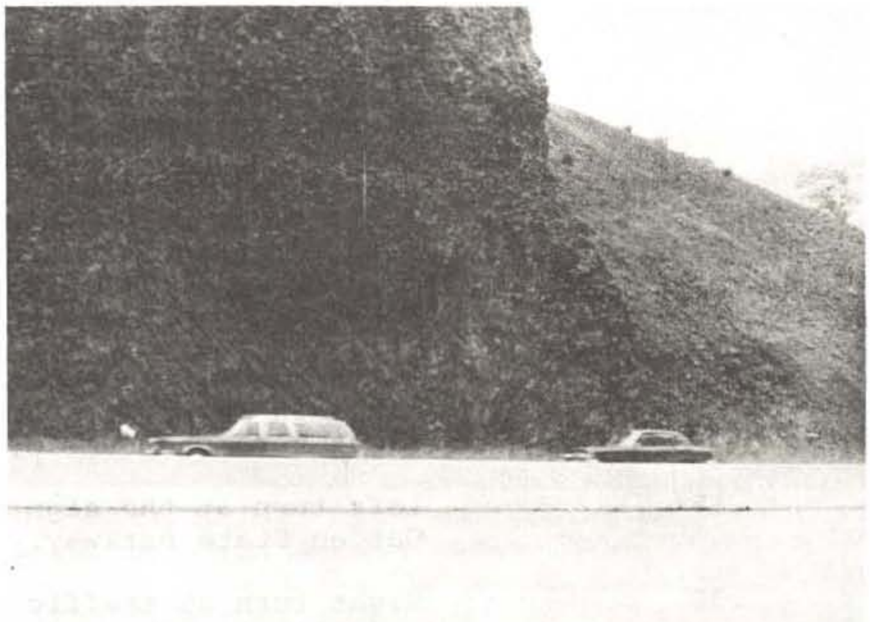

Figure 6. Radiating slender joints of the 1st Watchung mountain.

		End of trip. Proceed back to Hofstra University parking lot.

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NOTES

PLACER MINING AND MINERAL BENEFICIATION OF ILMENITE SAND DEPOSITS NEAR LAKEHURST, N.J.

Harold F. Roellig, Adelphi University
Dennis Radcliffe, Hofstra University

INTRODUCTION

Ilmenite ($FeTiO_3$) is used mainly in the production of white titanium dioxide. Because of its whiteness, high refractive index and resulting light scattering ability, synthetic titanium dioxide is unequaled as a non-toxic white pigment for paints, paper, rubber, dyes and ceramics.

Ilmenite and rutile (TiO_2) are used in the production of titanium metal. Titanium is one of the space age metals. One hundred years ago it was considered a vexing contaminant in magnetite deposits that often rendered the iron ore worthless. Today titanium is in demand as an alloy of aluminum to strengthen the skins of supersonic aircraft so that they can withstand the high temperatures generated by air friction. It is also used as a refractory alloy to withstand the intense heat of jet engines and rockets.

Titanium pigments were made originally by dissolving ilmenite in sulfuric acid, crystallizing to separate iron, then hydrolyzing the solution and calcining the precipitate. Newer plants utilize the Kroll process whereby titanium tetrachloride is produced in fluidized bed chlorinators. The tetrachloride is then either oxidized to the white dioxide pigment, or is reacted with magnesium under an inert atmosphere to produce titanium metal.

Although titanium is the ninth most abundant element in the earth's crust, it seldom is found in concentrations rich enough to be used as an ore. Thus, natural concentration processes especially placer formation are required to form a significant ore body. The mining of ilmenite in New Jersey by Asarco, formerly the American Smelting and Refining Company, occurs in such placer deposits.

The ilmenite concentrates generated at this operation are sold under a 10 year contract to E. I. du Pont de Nemours and Co. for manufacture of pigments.

Ore reserves are approximately 180 million tons assaying 1.95% total included TiO_2. The production rate is 185,000 tpy (tons per year) of ilmenite concentrates or about 20% of total U. S. production. At this mining rate, ore reserves should last about 20 years.

ACKNOWLEDGEMENTS

We would like to thank John F. Lord, Superintendent of the Asarco Manchester Plant, for his hospitality in expediting this field trip and for giving us access to internal company information regarding the mining property.

GENERAL GEOLOGY

The ilmenite deposits mined by Asarco lie on the Outer Coastal Plain of the Atlantic Coastal Plain Province. Outcropping on this coastal plain are a series of Tertiary deposits that dip gently to the southeast. Beneath the Tertiary deposits are a series of Cretaceous deposits which outcrop on the Inner Coastal Plain and which also dip gently to the southeast. In part covering both coastal plains is a discontinuous veneer of Quaternary deposits. These sediments are the result of the Pleistocene glaciation and sedimentation in the Recent.

THE ILMENITE BEARING DEPOSITS

Commercial deposits of ilmenite are found primarily in three formations: the Kirkwood Fm. of Miocene age, the Cohansey Fm. of late Miocene and perhaps Pliocene age, and the Cape May Formation of late Pleistocene age. Markewicz, Parrillo, and Johnson studied these formations and their titanium bearing sands, for the Bureau of Geology and Topography of New Jersey in the fifties, and the description of the formations and their view as to the origin of the ilmenite deposits which follows, is from their report published in 1958:

> It will be recalled by those familiar with the geology of northern New Jersey that the Delaware River and its tributaries drain a considerable area of Precambrian rock known to contain ilmenite, and the same stream also crosses thick sills of Triassic diabase which likewise are known to carry this mineral. Also, the Millstone River, which now flows north through the gap in Rocky Hill, at one time flowed south and laid down thick deposits of gravelly sand in the Kingston-Plainsboro-Cranbury area. It seemed reasonable to suppose, therefore, that it, too, must have carried ilmenite-bearing sands, and the problem of finding commercial deposits seemed to depend, therefore, on locating an area where waves, shore currents, or stream action had served to concentrate the ilmenite...
>
> Expansion of the investigation has shown that most of the material containing three percent or more of heavy minerals occurs in one or another of three geologic formations; namely, the Kirkwood sand of Miocene age, the overlying

Cohansey sand of the late Miocene or Pliocene age, and, in certain localities, the Cape May formation of late Pleistocene age. In this area they have the following characteristics.

KIRKWOOD FORMATION The outcropping material consists of light-colored, fine-grained, micaceous sand and dark clays; but both have a considerable range in color. The formation was deposited unconformably on a relatively level surface of the Shark River-Manasquan deposits of Eocene age. That the Kirkwood sea was rather shallow is evidenced by the contained marine fauna (Horace G. Richards, verbal statement, 1957) and the lack of glauconite. The original deposits possibly extended inland as far as the Triassic formations. Today, however, the maximum northwest extension of the formation is near Clarksburg, 12 miles southeast of the nearest outcrop of Triassic rocks. The fine, floury sand typical of the Kirkwood in the area of its outcrop appears to thin toward the southeast, being as thick as 40 feet in the north and entirely absent in wells to the southeast, at Toms River (see Figures 1, 2). Below this sand in the north are black, lignitic, sandy silts and clays in which pyritized diatoms (Actinoptychus heliopelta) have been found. These are not found in samples of this material from wells northwest of a line from Lakehurst to Lakewood. They do occur, however, to the northeast, southwest, and southeast. It is also significant that in the same area where diatoms are absent in the black silts and clays of the Kirkwood, the earlier Shark River-Manasquan deposits, and, in places, part of the Vincentown formation are absent. Farther down the dip, the Kirkwood consists of fine and coarse, black or dark brown sands and clays which contain a neritic fauna. The maximum thickness in the outcrop area is at least 100 feet and it thickens greatly to the southeast. Data from well borings show the approximate dip to be 11 to 25 feet per mile, the latter figure referring to the base of the formation.

COHANSEY FORMATION As the Kirkwood sea retreated, drainage developed on the newly exposed surface and deposition of continental origin began. It may well be that the major source of basal Cohansey material was the newly exposed Kirkwood. In general, it consists of medium-grained, poorly sorted quartz sand; with fine and coarse sands not uncommon and even predominating in some area. Yellow clay often coats the sand grains, and thin clay beds are also sometimes present although the percentage of clay to sand is small. These clays are sometimes lignitic, but never contain a recognizable fauna. Obscure casts of molluscan shells have been found in the Cohansey, but these are of no help in determining its age. A flora comparable with certain upper Miocene localities in Europe has been found near Bridgeton. It is common to find gravel at the

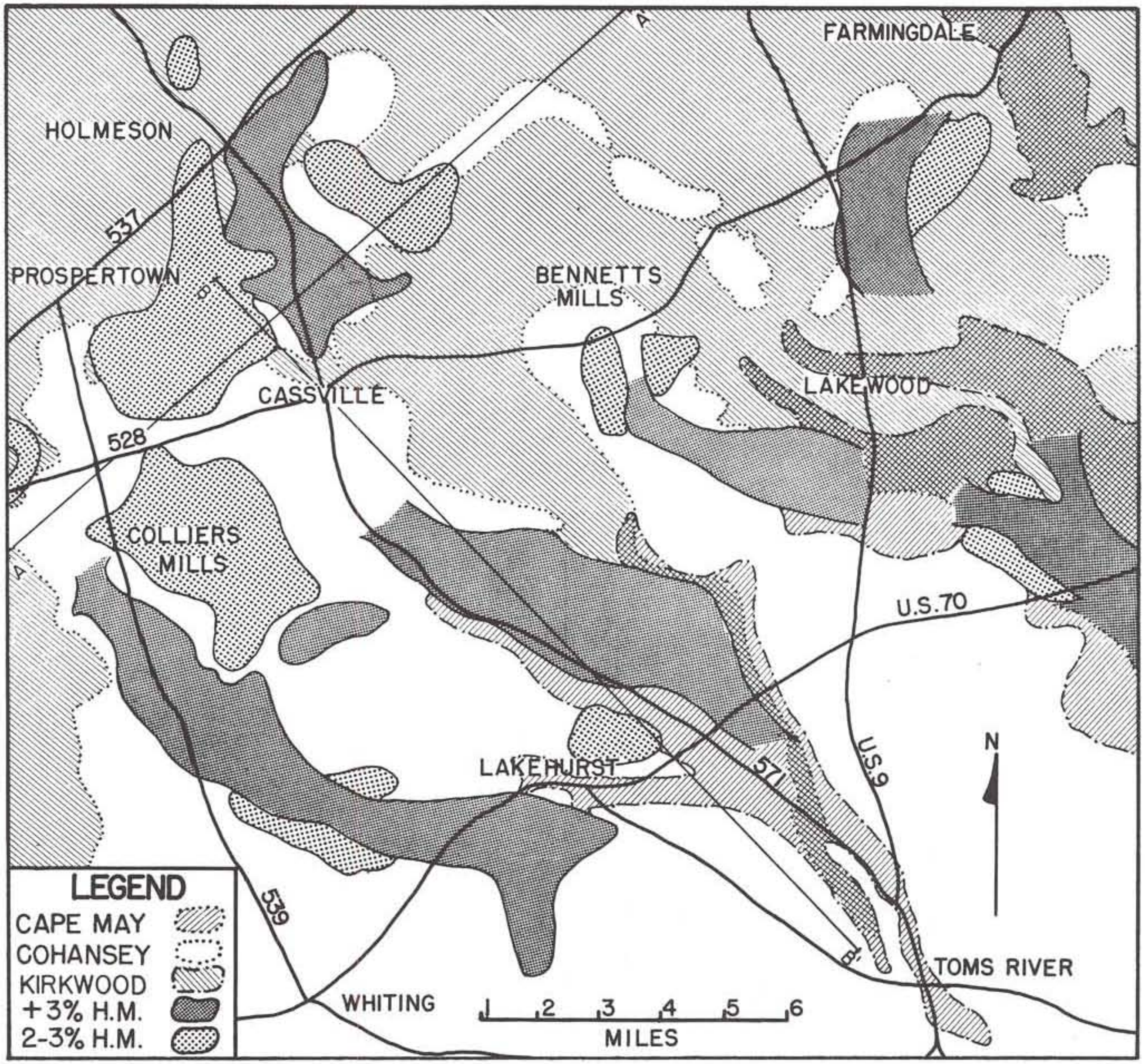

Figure 1. from Markewicz, Parrillo and Johnson, 1958.

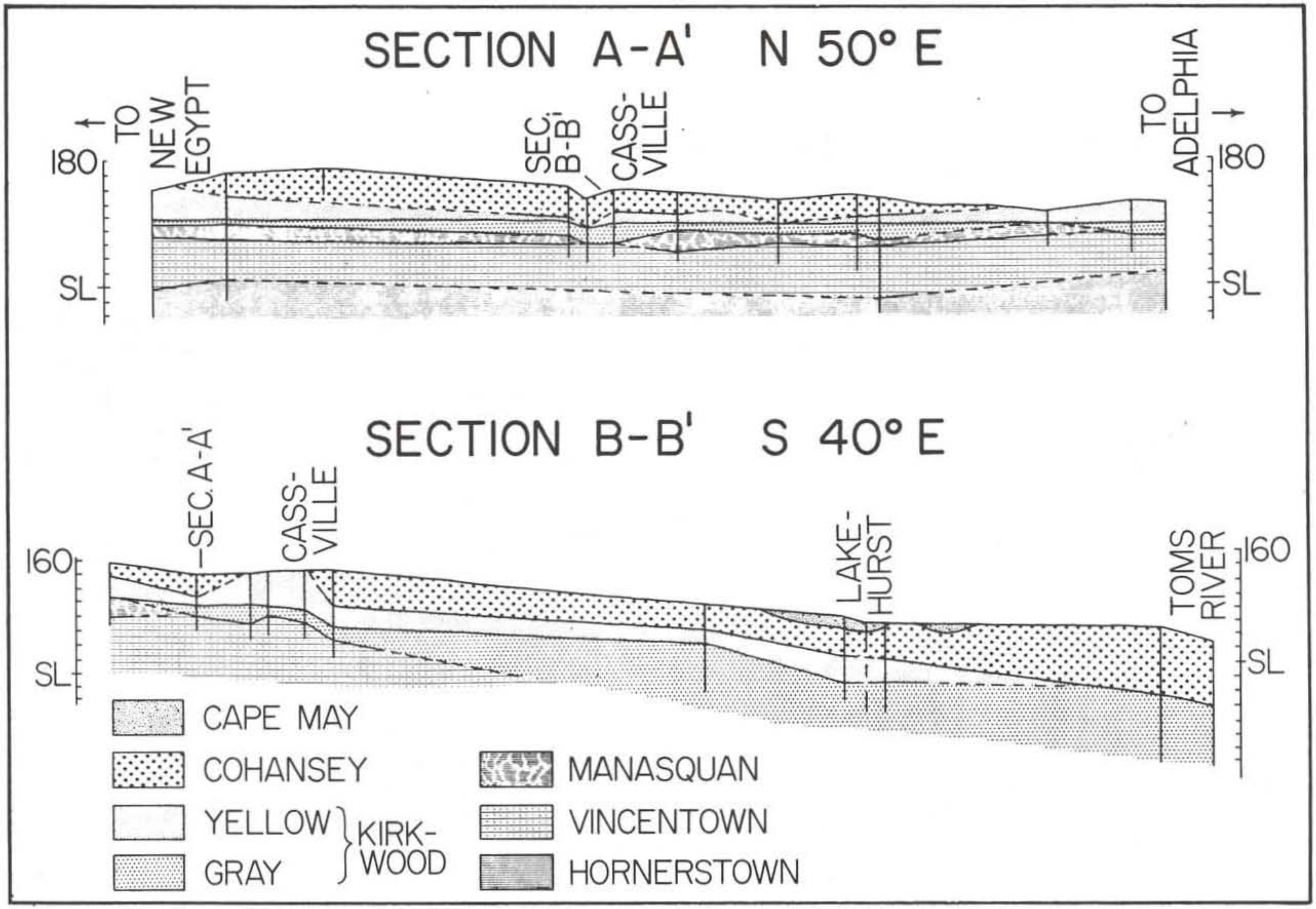

Figure 2. from Markewicz, Parrillo and Johnson, 1958.

surface of the Cohansey where it may be residual from younger formations; however, it is not uncommon to find scattered pebbles usually less than one-half inch in maximum diameter - well down in the section. The formation has a thickness of 100 to 250 feet where not thinned by erosion. There are no regular or continuous members which can be recognized over any appreciable area, all such members being in the form of lenses. Cross-bedding, characteristic of stream-channel deposits, is conspicuous of many exposures. Although there is an unconformity separating the Kirkwood from the Cohansey, the base of the latter has an average dip of 9 to 11 feet per mile to the southeast.

<u>CAPE MAY FORMATION</u> As stated by Kummel (1940), the terraces of Cape May material along the coast do not extend more than 40 feet above sea-level, "but along the tributary streams they rise to greater elevations ..." Thus, at the Eak Pit, one-fourth mile south of Route 70 and on the west bank of Toms River, the top of the gravel deposit is at elevation 50. There the deposit is 6 feet thick and is composed of medium to coarse yellow sand and scattered pebbles. Several gravel-filled channels were noted here; also, the layering of the gravel indicated that the depositing streams flowed towards Toms River.

The sand accompanying the gravel at this point is relatively rich in heavy minerals and the same is true of the thin deposit of Cape May gravel seen in excavations for the Brick Township High School 1-1/3 miles west-northwest of the Laurelton traffic circle. Where exposed in a pit 1/3 mile to the north, the gravel deposit is only 2 to 5 feet thick.

At each of the specific sites mentioned, the Cohansey sand contains a lower percentage of heavies than the overlying Cape May formation. It is therefore evident that the sand in the Cape May formation was derived from more distant sources which were richer in heavy minerals, or else the reworking of the Cohansey sand resulted in a greater concentration of heavies.

<u>ORIGIN OF ILMENITE DEPOSITS</u> From evidence now available, it appears that the Kirkwood sea may not have extended many miles farther northwest than the present outcrop limits of the Kirkwood formation. It follows that during Miocene time the sea was retreating from its maximum advance as evidenced by outcrops of the Raritan formation. The fine yellow sand of the Kirkwood therefore probably represents material that was eroded from the older sediments of the coastal plain lying to the northwest which was carried by sluggish streams down to the Kirkwood sea. Regression of the sea continued as the land slowly rose, and during this slow withdrawal it is believed that shore currents and waves worked over the sandy material and eliminated some

of the lighter grains. We believe it was this process which created the ten-mile width of yellow, fine-grained Kirkwood sand containing two percent or more of heavy minerals. In further support of this theory of concentration, it was noted in our mapping that heavy-mineral concentrations in the Kirkwood parallel the strike of the formation, trending northeast and southwest.

The continuing uplift of the land mass caused the withdrawal of the Kirkwood sea and a period of erosion followed. This uplift again increased stream gradients and permitted streams to erode and carry their loads to the southeast. It is believed that at this time the ancestral Delaware contributed much of the material now composing the northwestern part of the Cohansey formation. As this major stream reached the Colliers Mills area, its velocity was reduced and its load was spread out in a broad fan as alluvial sheet sands (Figure 1). Growth of this fan undoubtedly caused distributaries to shift their courses from time to time and some of these flowed in a southwesterly direction. Eventually a tributary of the Schuylkill River with somewhat greater gradient worked its way northeast far enough to capture the Delaware drainage.

Though the Delaware deposited sands which undoubtedly contained some heavy minerals, it is believed that a later stage of events involving southeast drainage brought new materials and reworked the previously deposited alluvial sheet sands.

Terrace elevations indicate that during Pleistocene time the Millstone River flowed south because the Pensauken terraces bordering Millstone River decreased in elevation from north to south. More recently, the study of well samples has shown that in the Kingston-Plainsboro-Cranbury area an unusual thickness of gravelly sand exists which can be correlated with The Pensauken formation. It is evident, therefore, that Pensauken deposition must have continued for a considerable time, and finer materials were carried still farther to the south. We believe that the Millstone contributed to and reconcentrated the previous sheet sands by braided streams which constantly shifted their flow pattern across the huge alluvial deposits.

The writers recognize that there are alternate explanations for the origin of these deposits and that some who have studied them believe for example, that the ilmenite in the Cohansey sands may have been concentrated by marine action. This would imply, however, that the Cohansey is of marine origin, and the evidence against this is rather strong, although farther down dip it may be in part deltaic. Subsequent work may disprove some of the ideas as expressed herein, however, pursuit of these principles made possible the discovery and extended exploration of commercial ilmenite deposits.

THE LAKEHURST MINING AREA

There are two mining operations in the immediate vicinity of Lakehurst. Glidden Company lying to the northwest of the Lakehurst Naval Air Station operate a mine and mill. The reserves of this operation are now almost exhausted. The newer operation is that of Asarco lying south of Glidden.

The Asarco Manchester Unit has extensive land holdings southwest of Lakehurst, New Jersey (see Figures 3 and 4). The dredging operation by which the company mines is in the Kirkwood and Cohansey Formations. Overlying these formations in a few areas on the Asarco property is the Pliocene Beacon Hill gravel which is not ore bearing.

The ore occurs in heavy mineral beds ranging from less than one inch to several feet in thickness. They are difficult to correlate because of their lens-like structure except as broad zones (ten to forty feet thick) normal to the dip. Some lens range up to five percent heavy minerals.

Neither the very coarse sand and gravels nor the clay beds contain commercial quantities of ilmenite. Very rich concentrations of ilmenite, however, are sometimes found on top of the clay beds. The richest ilmenite concentrations are found within the very fine-grained sands.

THE MINING OPERATION

The mining and refining processes are shown in Figures 5 and 6. Mining consists of a 25 acre dredge pond, 45 feet deep, from which the sand is dredged and pumped at a recovery rate of 20,000 gpm (gallons per minute) at 20% solids. As the dredge advances across the pond, the mined area behind the dredge is infilled with mill tailings. This is approximately 90-95% of the original ore. The intake slurry of ore is monitored by a series of continuous measuring devices. The intake flow rate is sensed with a Fisher Porter Model 20 flow meter, while the specific gravity and wt.% solids are measured with an Ohmart nuclear density gauge.

The slurry is pumped to a dewatering barge, screened and dewatered in three 6x14 foot Allis Chalmers double deck vibrating screens. This is done to remove roots, clay balls and other extraneous materials. The +4 mesh material is returned to the pond and the -4 mesh material is further dewatered in a Humphrey plate thickener. The thickened slurry is then pumped to the mill at the rate of 12-13,000 gpm at 40% solids.

THE MILLING OPERATION

The plant consists of two distinct units: the wet and the dry plant. In the wet plant the primary purpose is to eliminate the sand (95%) and generate a heavy mineral concentrate. This consists of 75-85% ilmenite

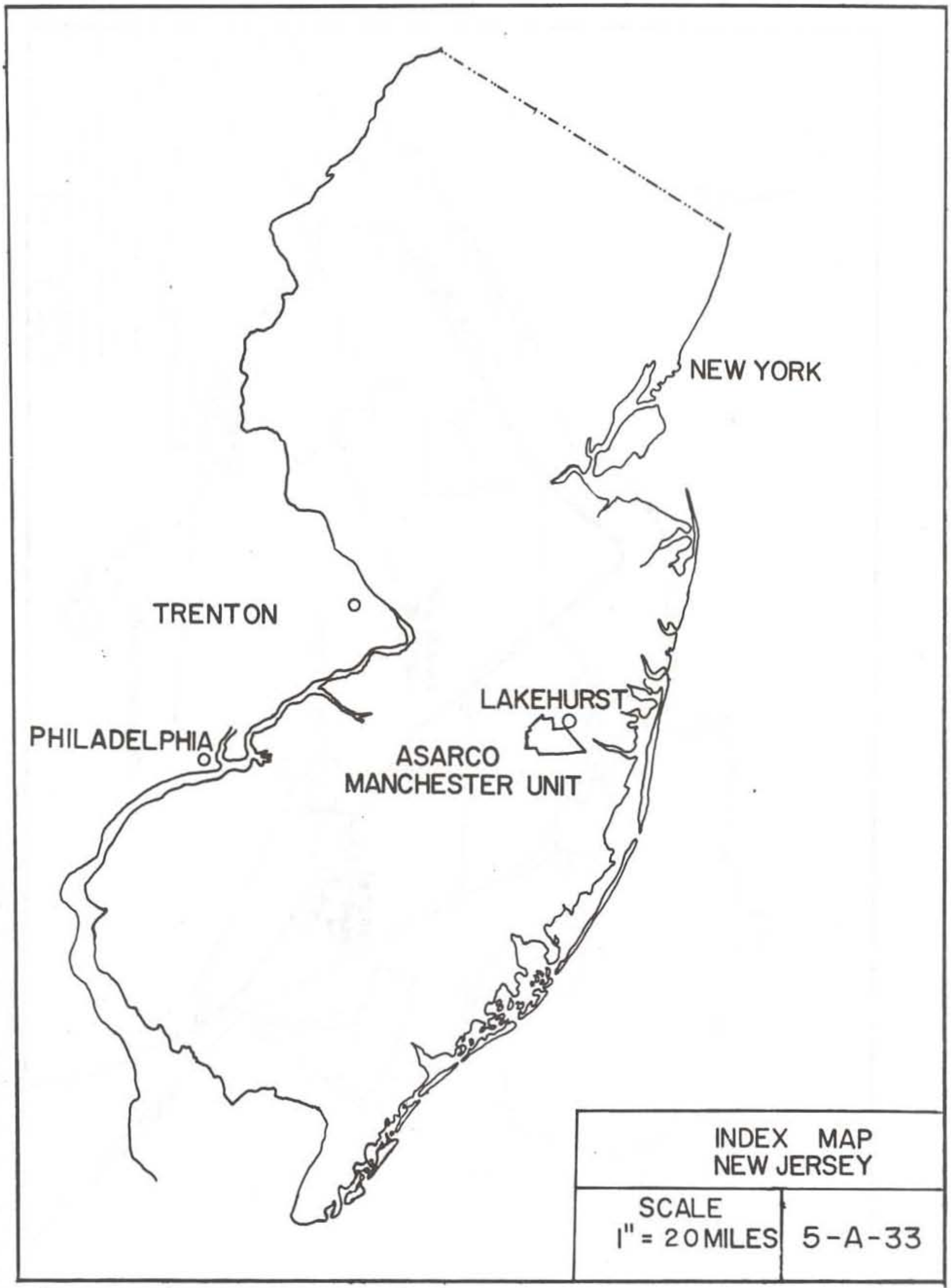

Figure 3. from Asarco internal report.

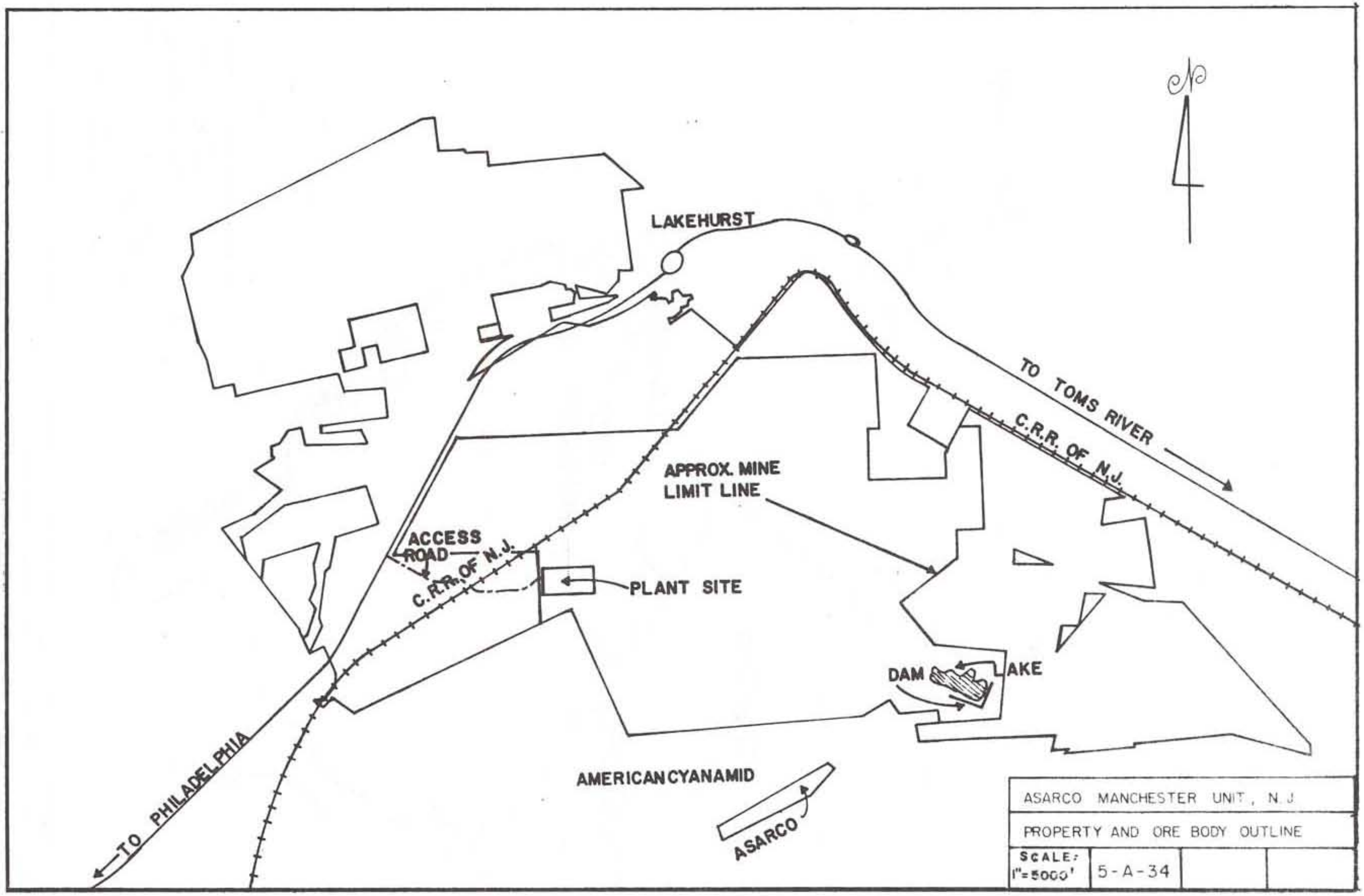

Figure 4. from Asarco internal report.

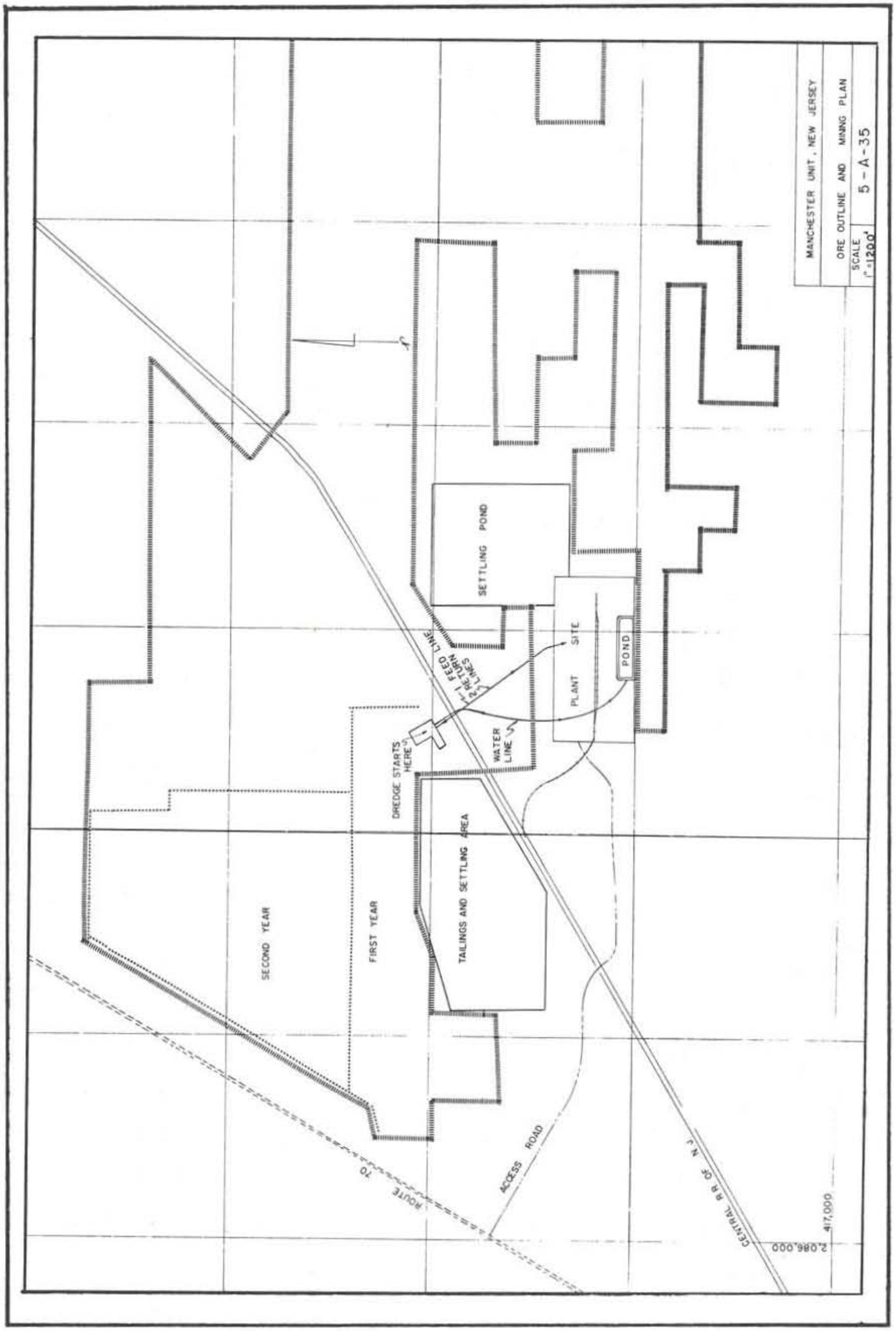

Figure 5. from Asarco internal report.

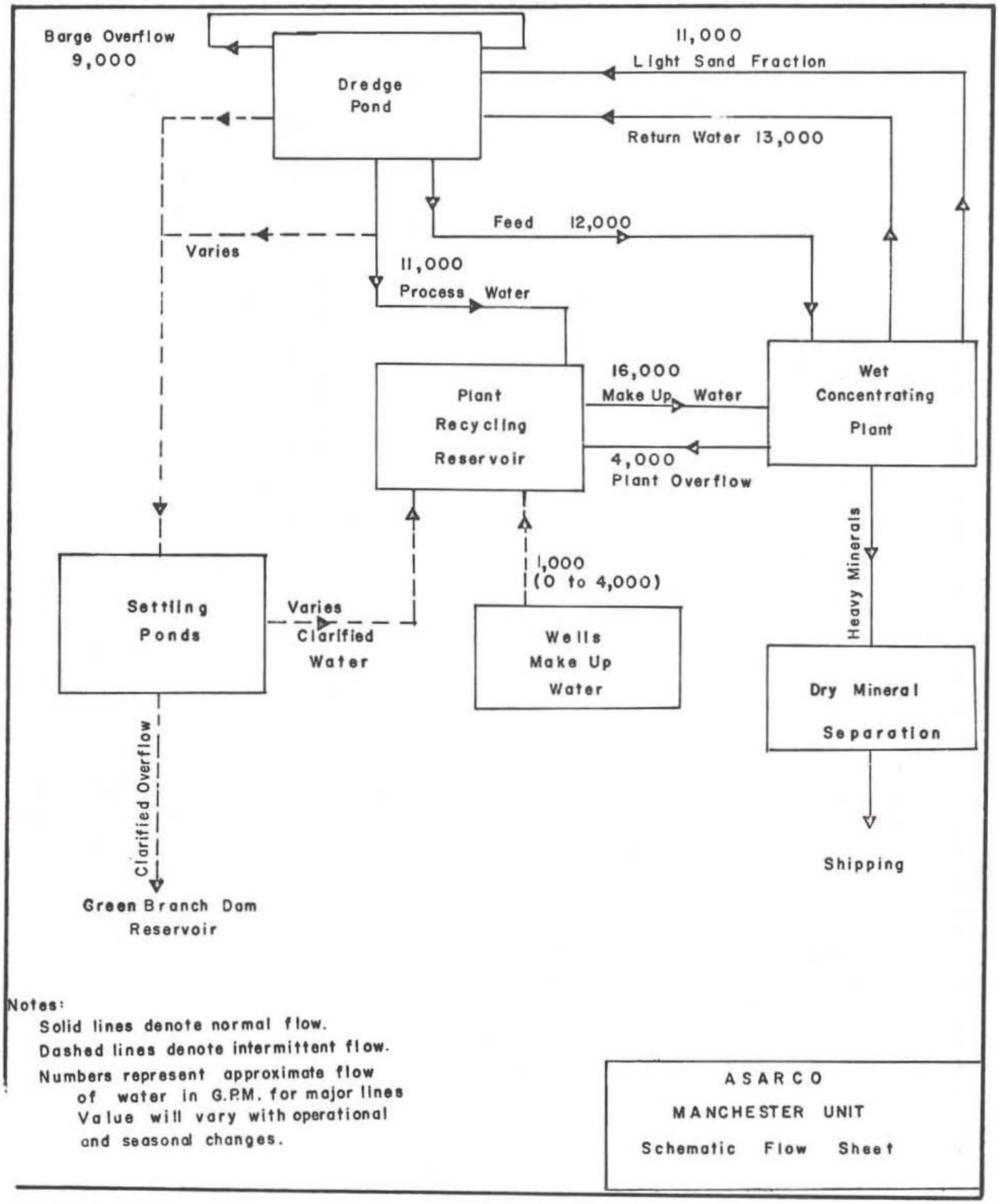

Figure 6. from Asarco internal report.

and leucoxene, with smaller amounts of rutile, zircon, staurolite, kyanite, sillimanite and some remaining quartz. In the dry plant a titanium-rich concentrate is produced by processing the feed through a series of magnetic and high tension machines.

In the wet plant the solids content of the slurry is upgraded to 43% TiO_2 using 1,024 Humphrey Spirals. The ore is separated from sand by differences in specific gravity. The higher density materials cling to the inside turn of the spirals while the lighter materials are washed to the outer wall by a combined centrifugal and sluicing action. The resulting slurry bands are discharged through a system of vaned ports which splits the pulp into 3 fractions: rougher concentrate, middling and rougher tails. The rougher tails are returned to the dredge pond to be used as backfill. The middlings are returned to incoming feed, and the rougher concentrate is passed to another bank of spirals to further purify the concentrate. The cleaner concentrate is then dewatered in Denver single pitch screws and stockpiled.

The stockpiled wet mill heavy mineral concentrate is then dried at 300°F to 0.5% moisture. This is followed by screening on 20 mesh. The oversize is wasted and the undersize is processed through the dry plant. The critical step in the dry plant is the processing through the Carpco High Tension separators when the difference in conductivity of rutile and ilmenite (high) with zircon and other silicates (low) is utilized.

Since rutile and ilmenite are conductors they proceed through the separator as though there were no static field. On the other hand the low conductive silicates become charged and are pinned to the rotor. In this manner a separation is achieved. Ilmenite is then separated from rutile in standard magnetic separators in which ilmenite passes into the magnetic fraction and rutile into the non-magnetic fraction.

The plant recovery efficiency is reported to be 97% in the dry mill. However this extremely high recovery is considerably offset by poorer recovery in the wet plant.

SOME ENVIRONMENTAL CONSIDERATIONS

The impact of the dredging operation on the landscape environment has been considerably reduced by use of the enclosed lagoon mining method plus the immediate return of mill tailings (sand) to the lagoon behind the advancing dredge. Some 95% of the original material is returned in very short time to the lagoon and the original topsoil which is stored separately, is easily reused during land reclamation. According to Asarco approximately 4,000 gpm of make-up water is added to the lagoon to maintain the lagoon water table which is independent of the general water table.

As a gesture of goodwill Asarco recruited more than 90% of its employees during plant startup from the local township and in addition donated 100 acres of land for the construction of a local high school.

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Li, Ta M. (1973), Startup of Manchester mine and mill boosts U. S. production of primary ilmenite, Mining Engineering #12, pp. 71-75.

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Markewicz, F. J., D. G. Parrillo, M. E. Johnson (1958), Titanium Sands of Southern New Jersey, Bureau of Geology and Topography, Dept. of Conservation and Economic Development, State of New Jersey, 19 pp., 3 figures.

Richards, H. G., F. H. Olmstead, J. L. Ruhle (no date), Generalized Structure Contour Maps of the New Jersey Coastal Plain, U.S.G.S. in cooperation with State of New Jersey Division of Water Policy and Supply.

ROAD LOG

Cumulative Miles	Miles from last point	Description
0.0	0.0	Assembly Point: Hofstra University. Drive west on Hempstead Turnpike to Clinton Street.
1.0	1.0	Turn right onto Clinton Street and proceed North to the Long Island Expressway, Route 495. Clinton Street will change its name to Clinton Road, Glen Cove Road, and Guinea Woods Road as you progress through the various communities on it.
6.8	5.8	Take cloverleaf and travel West on the Long Island Expressway to the Brooklyn Queens Expressway, Route 278.
23.4	16.6	Go South on the Brooklyn Queens Expressway over the Verrazano Bridge to Staten Island, and then over the Goethals Bridge to the entrance to the New Jersey Turnpike (all on Route 278 to the New Jersey Turnpike).
47.8	24.4	Take the New Jersey Turnpike South (Route 95) to Exit 7.
94.5	46.7	Take Route 206 South to its junction with Route 70.
111.5	17.0	Take Route 70 East to the Asarco Manchester Plant.
132.7	21.2	Arrive at Asarco Manchester Plant, turn into Asarco private road and drive South to the parking lot.
		Return to Hofstra University by reversing the above directions. Take Exit 13 off the New Jersey Turnpike for the Verrazano Bridge.

NOTES

Shinnecock Flood Tidal Delta and Coastal Stabilization Problems West of Shinnecock Inlet

Larry McCormick

INTRODUCTION

The shoreline along the south side of eastern Long Island changes regularly in character along an east-west traverse. From Montauk Point to Napeague Harbor it is characterized by cliffs up to 60 feet high overlooking narrow cobble beaches. A relatively short segment of the shore between Napeague Harbor and the village of East Hampton consists of a series of low dune ridges trending roughly parallel to the present water line. From East Hampton to Southampton Village is a sandy beach bordered landward by a single narrow dune ridge that rests on the truncated margin of a gently sloping outwash plain. Westward from Southampton the beach and dune ridge are separated from the rest of Long Island by a series of shallow bays. At one time this barrier island system was continuous to Fire Island Inlet, but is now interrupted by Shinnecock and Moriches Inlets.

Much of the shore zone from East Hampton westward is densely populated. The construction of numerous dwellings close to the water has caused much attention to be focused on the continual recession of the beaches in this area. This concern has resulted in periodic rather piecemeal beach nourishment programs as well as construction of groin fields to trap sand from the prevailing westerly littoral drift. Shoreline recession results from both natural processes and from works of man. An understanding of the causes should be helpful in determining where beach stabilization programs are needed, and to some degree, guide the selection of the kind of remedial action necessary.

On this trip stops will be visited along the segment of barrier island from Southampton to Moriches Inlet. The stops are designed to emphasize the nature of the problems facing this portion of the barrier island and the actions taken to solve these problems.

STOP #1 is located at the intersection of Halsey Neck Lane and Meadow Lane in the Village of Southampton. This stop is most easily reached via Route 27A which intersects Halsey Neck Lane at the western margin of the Village of Southampton.

This portion of the shoreline has experienced rapid recession over the last four years, and is an interesting locality to examine the buried record of storm events.

The second house to the east is owned by Nelson Levings and was located immediately behind the partially destroyed bulkheading that now extends out onto the beach. The house was moved during the winter of 1971 to avoid destruction. This occurred only two years after the construction of the protective bulkheading. Slightly further east is the beach pavilion of

Southampton Town, now perched at the edge of the dune line. To the west several large mansions are now dangerously close to the front of the dune line.

During the fall of 1972 a rather unique protective device was installed in front of the large pinkish buff home located nearest the dune line to the west. A trench was excavated in the dune and plasticized bags of woven nylon were pumped full of beach sand. The filled bags were placed in the trench and stacked up to provide a riprap for the dune face. The dune was then reconstructed over the riprap to protect them from vandalism. At the time of this writing they are not exposed but might be visible by the time this field trip is taken.

Excavation of the beach at this point usually exposes thick layers (2-6 inches) of heavy minerals (Plate 1A). These thick layers represent storm lag deposits and provide a handy reference of the beach profile under storm conditions. The location of the storm beach is of considerable importance when considering the depth to which bulkheading or riprap is to extend.

These layers are usually local, pinching out quickly along the stroke of the beach, but when present are useful indicators of storm conditions.

Thin heavy mineral layers (less than 2 inches) are common and frequently represent a wind lag deposit generated on the beach berm. In Plate 1B these berm layers have been truncated by a storm beach that has in its turn been buried by a wedge of light buff colored sand characteristic of rapid beach accretion.

Heavy mineral storm layers may be simple lenses rich in garnet and magnetite or they can exhibit the rather complicated scour and fill structure illustrated in Plate 2A and B. The latter are produced as a wave cut scarp which migrates up the beach face under storm conditions. Waves strike the scarp and scour out a shallow trough carrying off the lighter minerals and leaving behind a thin apron of heavy minerals. As the scarp and trough migrate up the beach the thin aprons of heavies coalesce to form the thick upper heavy mineral layer.

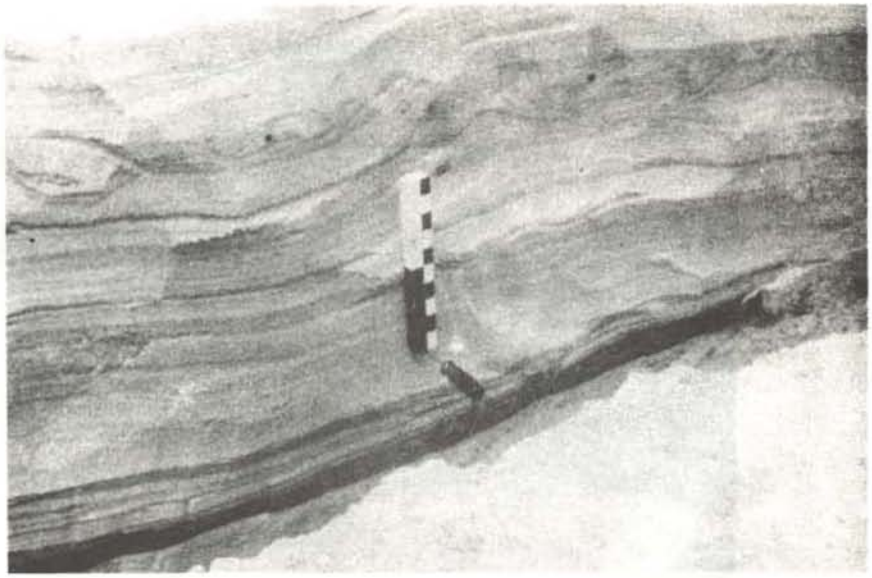
Layers of coarser sediment do not appear to be related to high energy conditions. Size seems to depend more on availability than energy on south shore beaches.

STOP #2 is the flood tidal delta at Shinnecock Inlet. The vehicles will proceed to the Marine Station at Southampton College where trip participants will board a boat for a trip to the tidal delta. The vehicles will then proceed to the west side of Shinnecock Inlet via Ponquogue bridge and wait for participants to return.

INTRODUCTORY STATEMENT

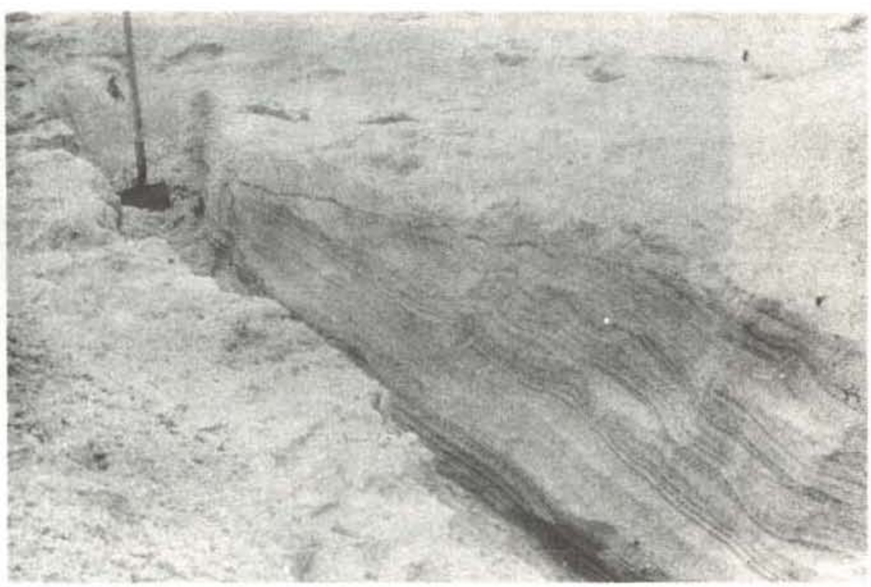
Prior to the first careful surveys of the Shinnecock area in 1838 an inlet existed about two miles east of the present location of Shinnecock Inlet. However, a map of the U. S. Coast and Geodetic Survey shows that it

PLATE 1A



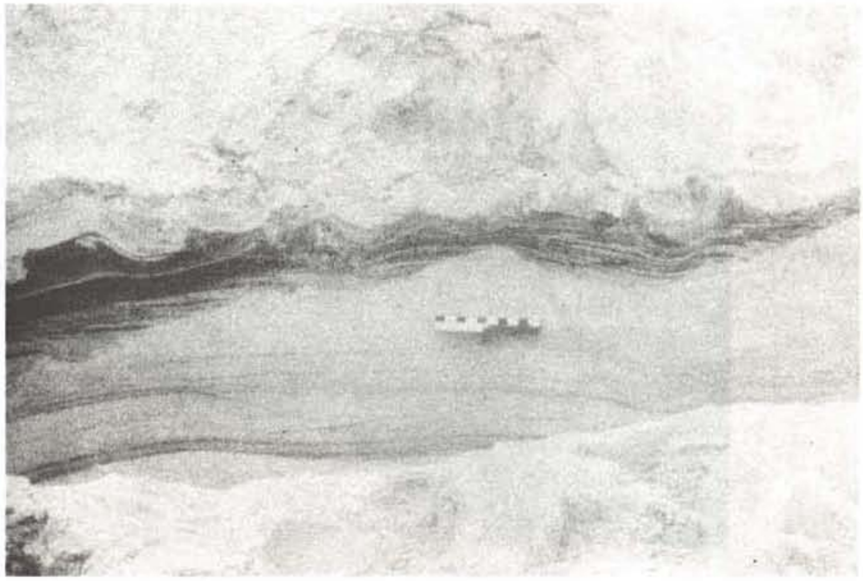
Storm lag layer of heavy minerals cutting across lighter color of sand in bottom of trench.

Plate 1B



Berm wind lag layers cut by storm beach profile which is overlain by recent depositional packet of sand.

PLATE 2A



Scour and fill structure produced by retreat of scarp up the beach.

PLATE 2B

Close-up of scour and fill structure. Up beach is the right in photograph. Coin gives scale.

had closed by 1838. From Southampton west to Round Dune the barrier island was unbroken from 1838 until the hurricane of 1938.

During the storm of 1938 a washover channel developed and cut rapidly downward to produce a narrow channel that was ultimately deepened, widened and stabilized to form Shinnecock Inlet. Details of the change in the Inlet since 1939 are given in Figure 19 of Taney's publication "Geomorphology of the South Shore of Long Island." That figure is included here for the purpose of completeness. A small revetment was constructed on the west side of the Inlet in 1947, but it was not until 1952 that construction on the presently existing jetties was begun. Dredging of the channel before and after jetty construction has been carried on intermittently.

In 1938, when the Inlet was opened, some sand was carried inside the Inlet and deposited by the storm surge. Tidal currents sweeping in and out have added to that original sand mass and modified it to create the vast flood tidal delta that exists today. Similarly, sand being carried by the longshore currents was swept seaward to form a large asymmetric ebb tidal delta. The historical development of these deltas and the distribution of sediment on them is the subject of this stop.

DEVELOPMENT OF THE FLOOD TIDAL DELTA

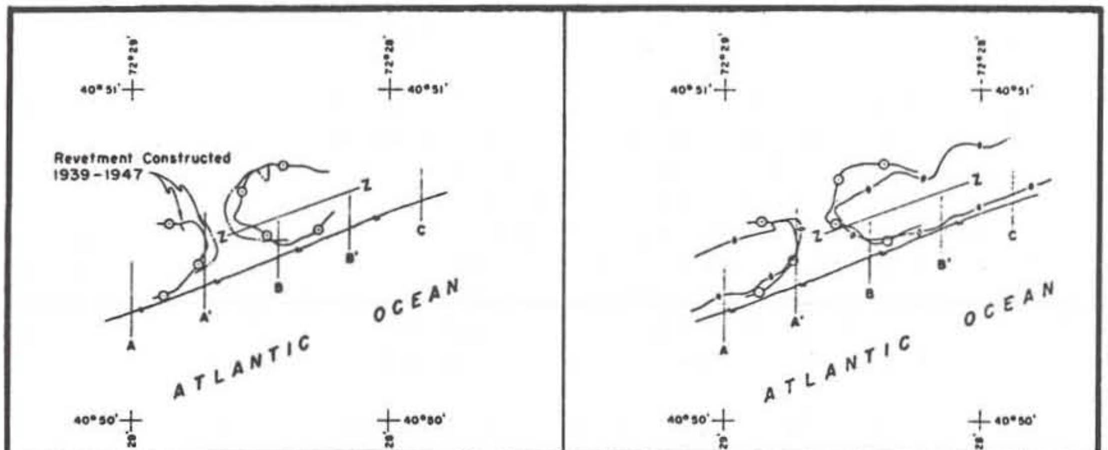
In 1950 Shinnecock Inlet was slightly less than half its present width (Plate 3A). The revetment constructed in 1947 is plainly visible in the aerial photo as well as a part of the flood tidal delta. A broad sand flat had encroached westward from the east side of the Inlet which would probably have closed the channel if it had been left unmodified. The sharp east margin of the channel suggests dredging took place at a relatively short time before the photo in Plate 3A was taken.

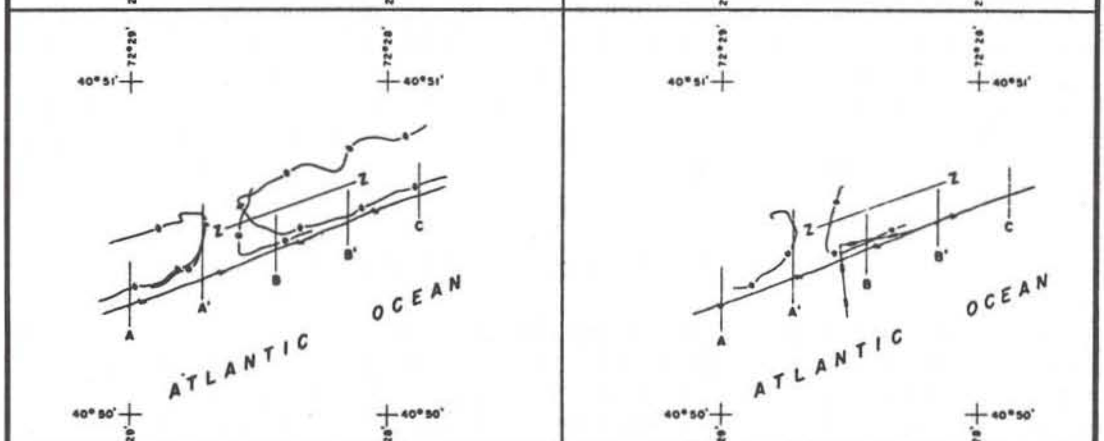
Part of the flood tidal delta may not be visible in Plate 3A due to the height of the tide. Nevertheless, a comparison of the 1950 photograph with one taken in 1955 (Plate 3B), after completion of jetty construction shows a number of interesting changes.

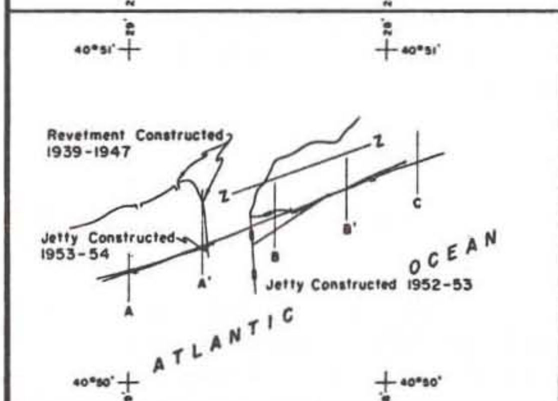
The tidal delta has approximately doubled its size during the five-year period between photographs. The broad shallow channel between Warner's Island and the delta shoaled to an intertidal sand flat and most other channels narrowed. The large area immediately north of the present jetties filled in closing the broad channel that existed in this area in 1950. The northern margin of the delta continued to build out into the bay.

It seems logical to conclude that increase in size of the Inlet and the broad channels that cut through the 1950 delta sharply increased the tidal flow into the bay. The increased tidal flow allowed for the transportation of a larger volume of sand through the Inlet. As water spread over the delta, current velocities were reduced and the sand came to rest. The upward growth of the delta and constriction of channels probably reduced the tidal flow and decreased the accretion rate so that changes in the delta following 1955 did not occur as rapidly.

To show the gross changes that have taken place on the tidal delta







AVERAGE HIGH WATER SHORE LINE CHANGE (IN FEET)

Interval	Range A	Range A'	Range B	Range B'	Range C	Mean
1933 - 1939		- 300	- 300			
1933 - 1949	- 290			- 50	- 185	
1939 - 1940		- 295	+ 40			
1940 - 1949		+ 40	- 65			
1949 - 1951		+ 30	+ 255			
1949 - 1955	+ 250			+ 30		
1951 - 1952			- 30			
1951 - 1955		+ 590				
1952 - 1955			+ 355			
* Net Change	- 40	+ 65	+ 255	- 20		

* From earliest to latest survey for each range
\+ Advancing shore line — Retreating shore line

APPROXIMATE SCALE
1000 0 1000 2000 3000 FEET

LEGEND
HIGH WATER SHORE LINE

1955	U.S.C.& G.S.
1952	"
1951	"
1949	"
1940	"
1939	"
1933	"

AVERAGE GROWTH PER YEAR OF SHINNECOCK INLET (LINE ZZ)

Interval	Growth in Feet	Average Growth Per Year in Feet
1955 - 1952	153	51
* 1952 - 1951	- 270	- 270
1951 - 1949	320	160
* 1949 - 1940	- 158	- 18
* 1940 - 1939	- 112	- 112
1955 - 1939	- 67	- 4

* Minus denotes retreat of point during interval.
Inlet opened September 1938

FIGURE 19. MIGRATION OF SHINNECOCK INLET, LONG ISLAND, NEW YORK AS SHOWN BY HIGH WATER SHORE LINE CHANGES 1938 - 1955

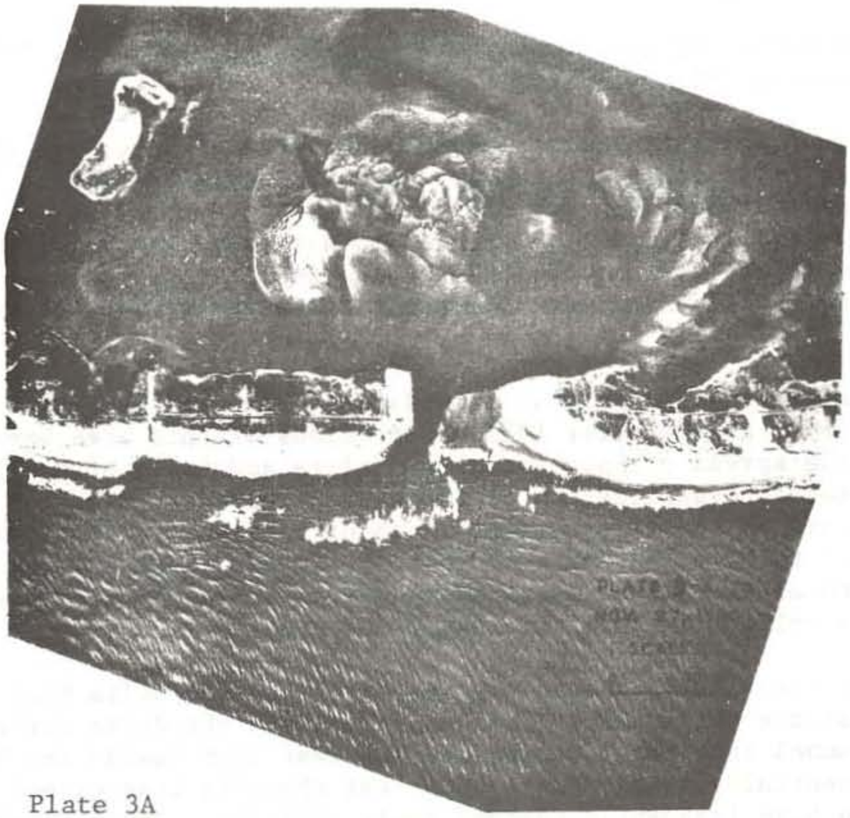


Plate 3A

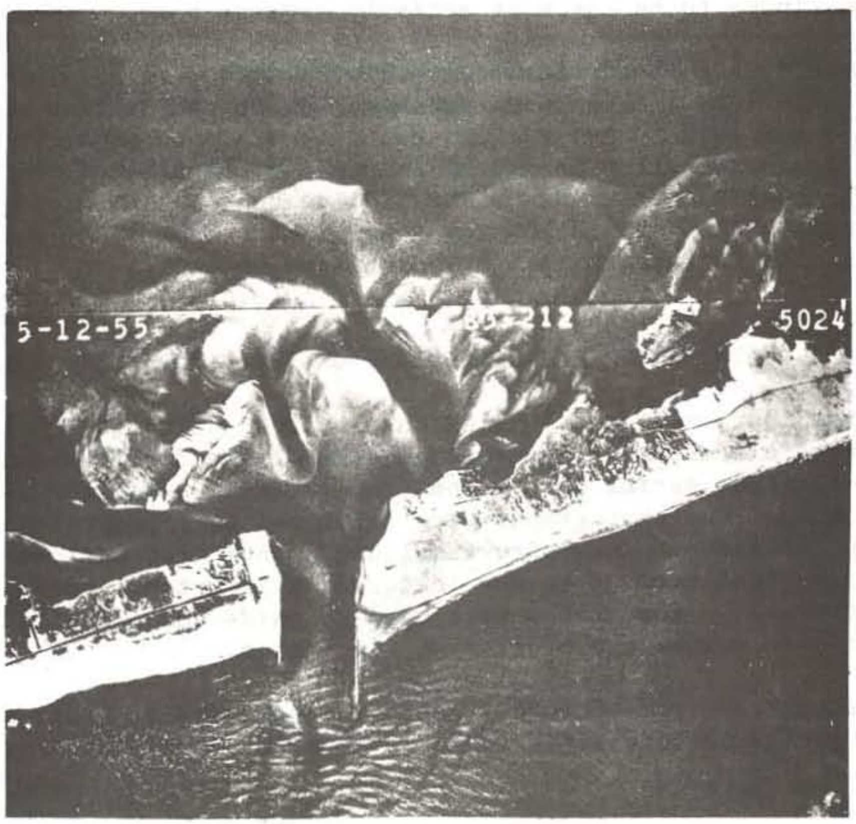


Plate 3B

since 1950 a series of aerial photographs taken in 1950, '55, '59, '61, and '69 were compared (Figure 1).

While the greatest changes occurred between 1950 and 1955 the northern margin of the delta migrated steadily into the bay after 1955. By measuring the area added between 1955 and 1969, and using a water depth of 10 feet at the delta margin, the volume of sand added was found to be 1.6 million cu. ft. /year. This figure does not include any vertical accretion over parts of the delta present in 1955, and must represent a minimum figure for total accretion.

The massive shoal area that extends eastward from Warner's Island did not undergo much change after 1955 and portions of this area have been stabilized by the spread of *Spartina alterniflora* and banks of *Mytilus edulis*. The first step in stabilization of these areas appears to be the growth of algal filaments in the first quarter inch of sediment. The algae act as a binding agent to hold the sediment until *S. alterniflora* can gain a foothold. Upward growth of stabilized areas continues as roots and rhizomes of salt marsh plants collect to form thin layers of peat.

Some of the tidal channels that pass through the delta have remained relatively stable while others have migrated over the delta surface (Figure 2). The channel that bends sharply to the west just inside the Inlet has remained essentially static since 1950, but channels that extend north to the delta margin have frequently changed their position. The area of most frequent change is within the zone that exhibited most of the accretion since 1955 and continues to be the most actively growing portion of the delta.

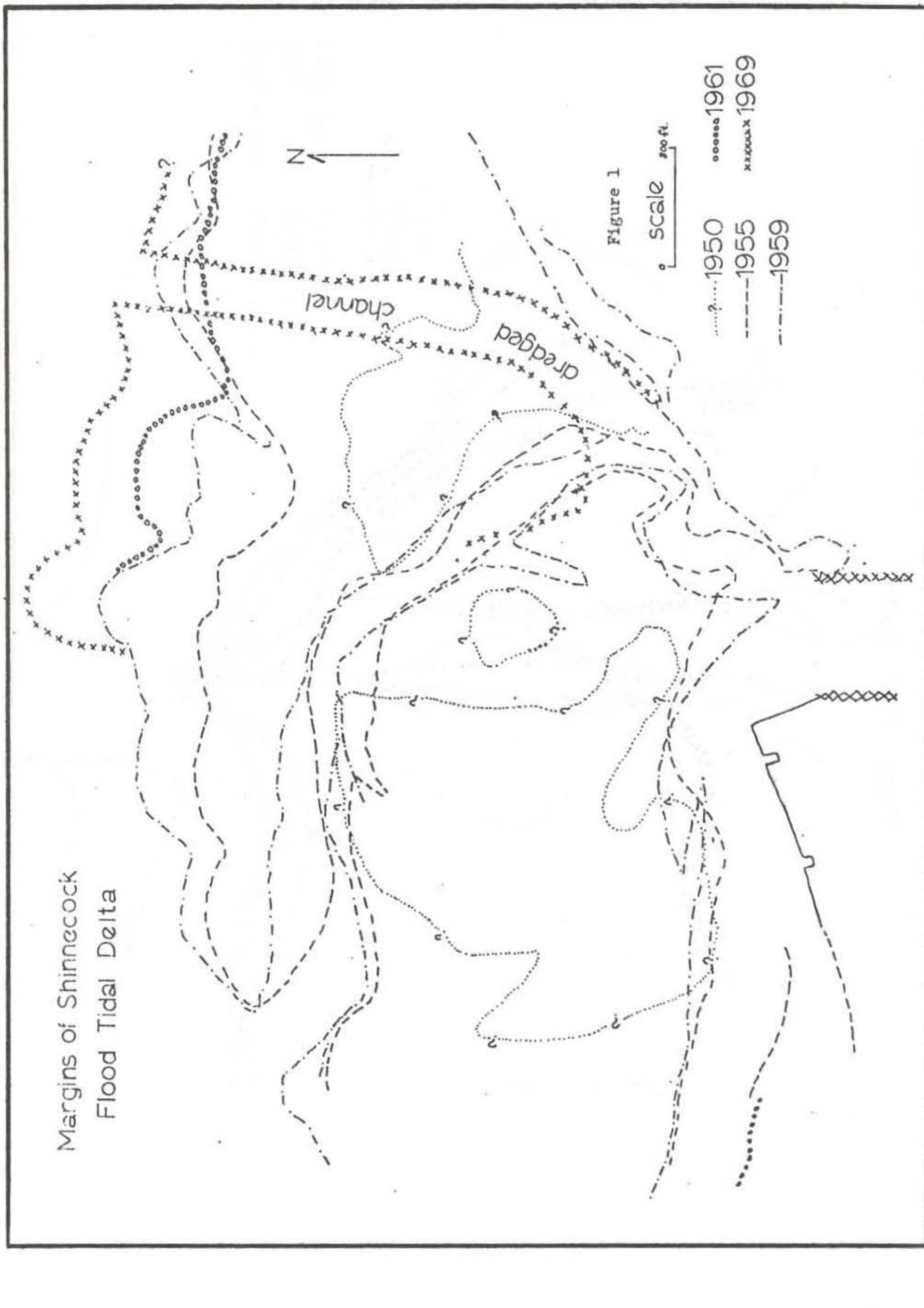
In summary, the flood tidal delta experienced slow growth from its beginning in 1938 until 1952 when construction of the jetties was begun. Between 1950 and 1955 it experienced rapid growth approximately doubling in size. The rapid accretion caused by increasing the size of the Inlet was slowed by gradual constriction of the tidal channels that cross the delta. The western portion of the delta was stabilized by spread of salt marsh grasses, but the northern margin has continued to grow.

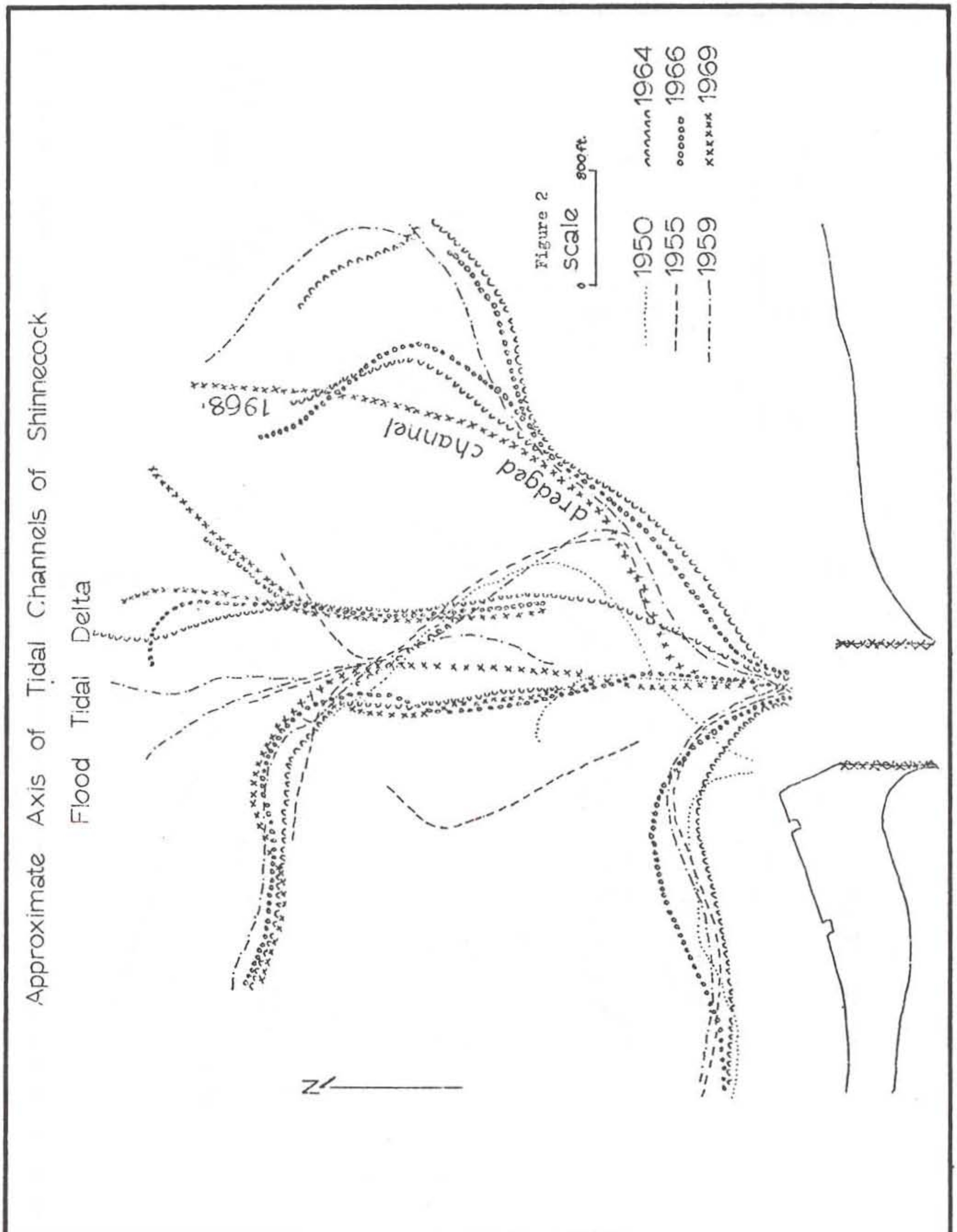
DISTRIBUTION OF GRAIN SIZES ON THE FLOOD TIDAL DELTA

The distribution of grain sizes on the flood delta is complex. In an effort to give a reasonably accurate picture of the distribution of grain sizes, low altitude aerial photographs were used to guide sampling and final map preparation. The photographs were taken one week prior to sampling the sediment on the delta. A cursory examination indicated a close correlation between grain sizes present on the delta and slight tonal difference on the aerial photographs. The photos were used to guide the sampling and the location of each sample was plotted on the photos.

Each sample was run through a rapid sediment analyzer and all references to size of grains in this field guide is made in terms of hydraulic equivalence.

Final preparation of the sediment distribution maps relied heavily on aerial photographs to determine the boundaries of grain size classes.


Margins of Shinnecock
Flood Tidal Delta
Figure 1
scale
0
800 ft.
1950
1955
1959
1961
1969
N
dredged
channel


Approximate Axis of Tidal Channels of Shinnecock
Flood Tidal Delta
Figure 2
scale
0
800ft.
1950
1955
1959
1964
1966
1969
1968.
dredged channel
N

For the purpose of explanation, the delta is divided into four parts, a western lobe, eastern lobe, northern lobe, and a rather small crescent shaped lobe located between the east and west lobes (Figure 3). Except for the north lobe and the curving shoal of sand that connects the east and central lobes, the areas mapped are usually slightly emergent at low tide. The channels were not sampled but the grain size distribution of the channel sediment is probably closely related to the sizes determined for the continuously submerged portions that were sampled.

The western lobe is bounded on the west by salt marsh vegetation. The rest of it is bordered by tidal channels. The mean grain size tends to decrease to the north and toward the center of the lobe. The decrease to the north is probably the result of lower current velocities associated with the distal portions of the delta. The decrease toward the center is related to the sharp reduction in current velocities over shoal areas. The protected interior of the west lobe acts as a settling basin for fine grained sediment, which is stabilized by growth of filamentous algae. The complex pattern along the east margin of the west lobe is created by several large scale sand waves that are migrating slowly to the north.

The same general pattern occurs on the east lobe. The area closest to the inlet is coarsest and grain size tends to decrease northward. The finest material is located centrally on the lobe, but in this instance the mud that covers much of the interior of the east lobe was deposited by the filtering action of *Mytilus edulis*.

The coarsest sediment occurs on the south margin of the east lobe, on the connection between the east and central lobes, and on the north lobe. These are the lowest areas on the flood delta exclusive of the channels. The association of the coarsest constituents with lower elevations on the delta surface suggests a vertical separation of grain sizes. If, as the data suggest, the finer sizes (mean size less than 1.5 phi) are restricted to areas toward the interior of sand flats that have built slightly above the level of mean low water one would expect the finer sediment to be only a surface veneer recording the last stage in the up-building of the delta surface before encroachment of salt marsh grasses. If this is the case, the coarser grain sizes (1.5 to 1.0 phi) are volumetrically much more important than the finer sizes.

The significance of this observation is that most of the material composing the delta is as coarse as material usually found on the beach and would be an excellent source of sand for beach nourishment programs. Figure 4 is a bar graph of the mean grain sizes of 81 samples taken at different times during 1970 and at locations scattered on the beach either side of the Inlet. The means that occur most commonly are in the range from 1.3 to 1.7 phi, very common sizes on the flood tidal delta.

EBB TIDAL DELTA

The form of the ebb tidal delta is much simpler than the flood delta. Its surface slopes gently seaward and is completely below sea level. Viewed from the air the margin of the delta is asymmetric beginning abruptly at the east jetty of the inlet and stretching westward far beyond the west jetty.

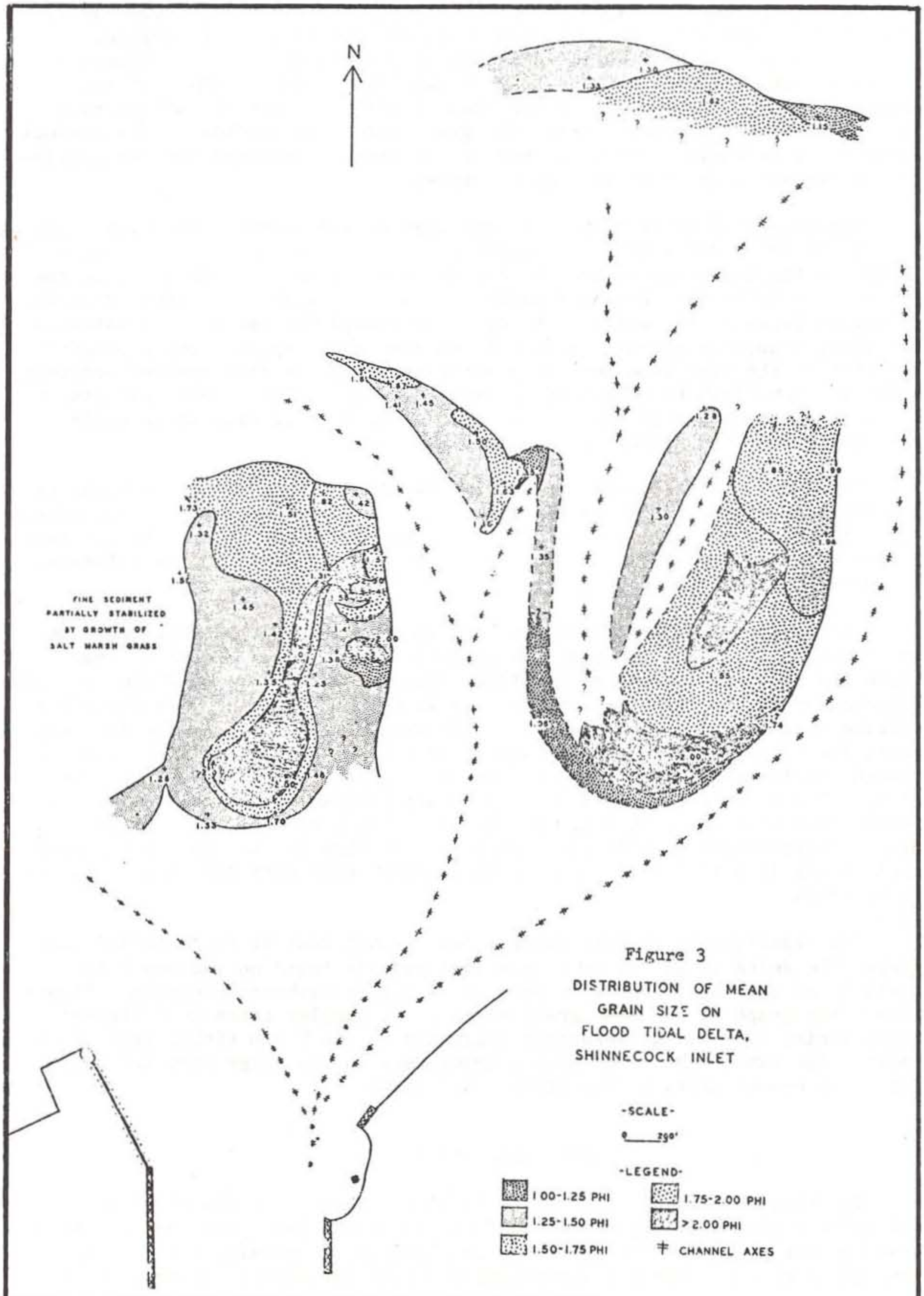
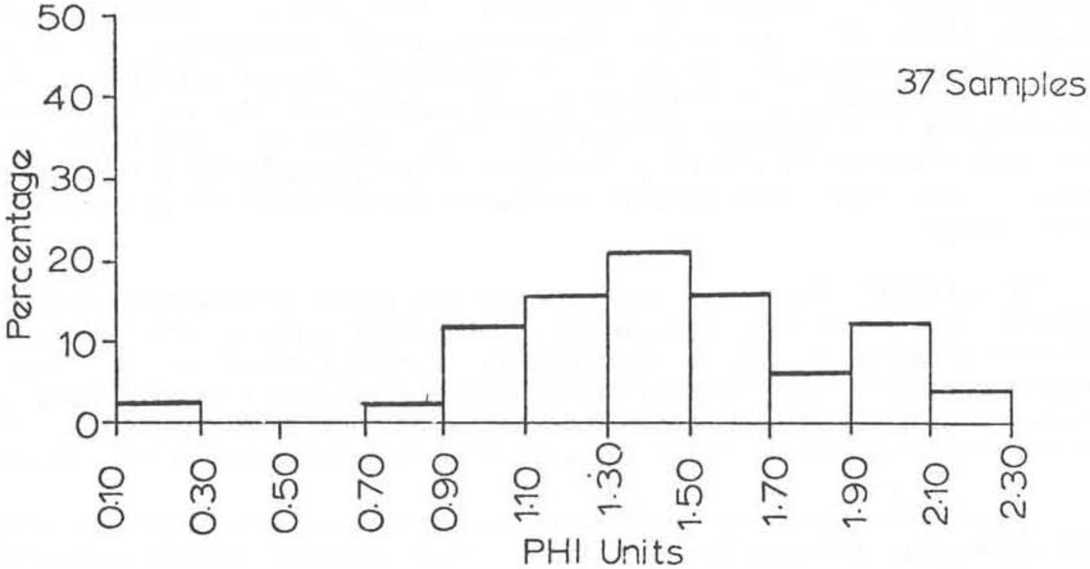


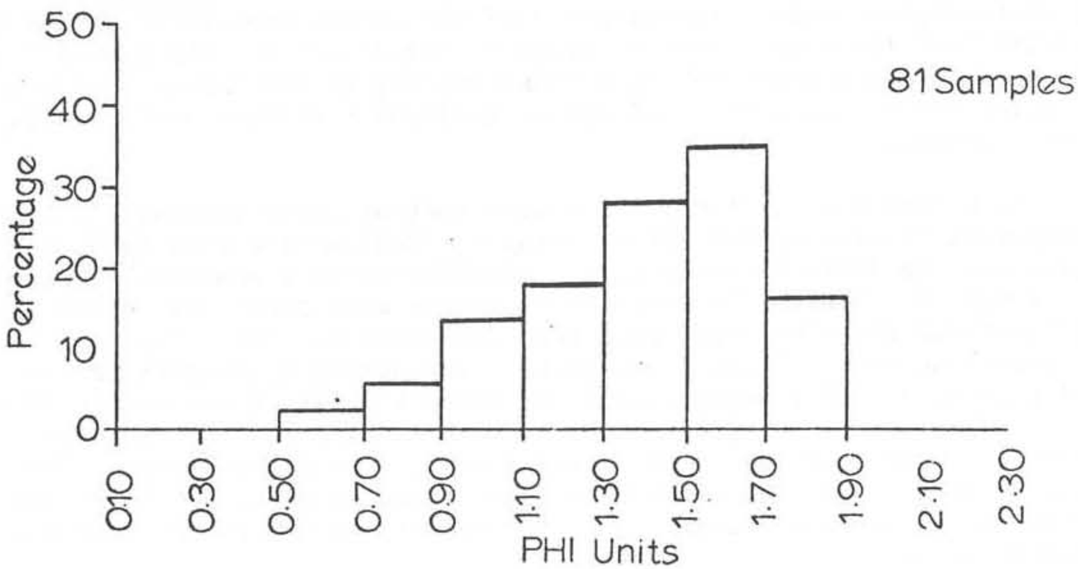
Figure 3

DISTRIBUTION OF MEAN GRAIN SIZE ON FLOOD TIDAL DELTA, SHINNECOCK INLET

Figure 4 HISTOGRAMS of MEAN GRAIN SIZES for BEACH and EBB DELTA SAMPLES



MEAN GRAIN SIZES for EBB DELTA SAMPLES



MEAN GRAIN SIZES for BEACH SAMPLES

The outer margin of the delta is frequently defined by a line of breakers that result from a rise at the edge of the delta. Much of the delta surface is within 10 feet of the surface at mean low water. It is shallower than this at the breaker line where incoming waves have piled up a lip of sand. The asymmetric form of the delta testifies to the dominance of westerly drift.

Little is known about the growth of the ebb tidal delta because it has not been carefully mapped and is usually not visible on aerial photographs. In 1950 (Plate 3A), the breaker line occupied the approximate position of the end of the present west jetty. On a 1966 aerial photograph (Plate 4A), the breaker line marking the delta margin is clearly visible and occurs approximately 2,400 feet seaward of the west jetty. Like the flood tidal delta, most of the ebb delta growth probably occurred immediately after stabilization of the Inlet, but slower continuous growth after inlet stabilization seems likely.

The distribution of sediment on the ebb tidal delta exhibits a simple pattern compared to the flood delta. Grain sizes grow progressively finer offshore (Figure 5). The isopleth lines of mean grain sizes are subparallel to isobath lines. The correlation of depth, distance from the Inlet, and decrease in grain size suggests that waning ebb tidal currents are responsible for the marked decrease in grain size at the margin of the delta.

The coarser sizes are restricted to the axis of the Inlet and a narrow zone extending westward from the Inlet. The coarsest samples were a mixture of sand and gravel size material too coarse to be run in the rapid sediment analyzer. To examine the nature of this unusual bimodal mixture, an underwater traverse was made from east to west across the delta surface. The mixture results from the bedform shown in Plate 4B. It shows small wave crests of sand with troughs of coarse gravel. Scattered Mytilus shells give the photograph a scale. Encrustation of the larger pebbles by marine growth indicate that the gravel size material is rarely moved. The gravel fraction represents a lag deposit that has found its way to the lowest position in the Inlet and occupies areas of active sediment transport just outside the Inlet entrance.

The westward bend of the grain size contour lines suggest the pattern of movement of sand at the Inlet entrance. Medium size sand (1.0 to 2.0 phi) approaches the Inlet from the east. Flooding tides sweep some of this material in through the Inlet. The coarsest fragments work their way to the bottom of the Inlet and the finer sand size fraction comes to rest along the sides of the Inlet and on the flood tidal delta. The ebbing tides jettison the fine sand (2.0 to 3.0 phi) seaward until it comes to rest on the margin of the delta. The location of the mixture of sand and lag gravels suggests that the thread of highest velocity ebb currents swings sharply westward. The sharp westward arch in the ebb currents may be caused by the high lip at the edge of the delta restricting seaward flow, and the stress applied by westerly moving longshore currents.

The ebb delta would make an excellent source of sand for beach nourishment programs. Except for sand at the extreme margin of the delta, the mean grain size of ebb delta sand is as large or larger than the most frequently encountered beach sand adjacent to the inlet.

Plate 4A

Plate 4B

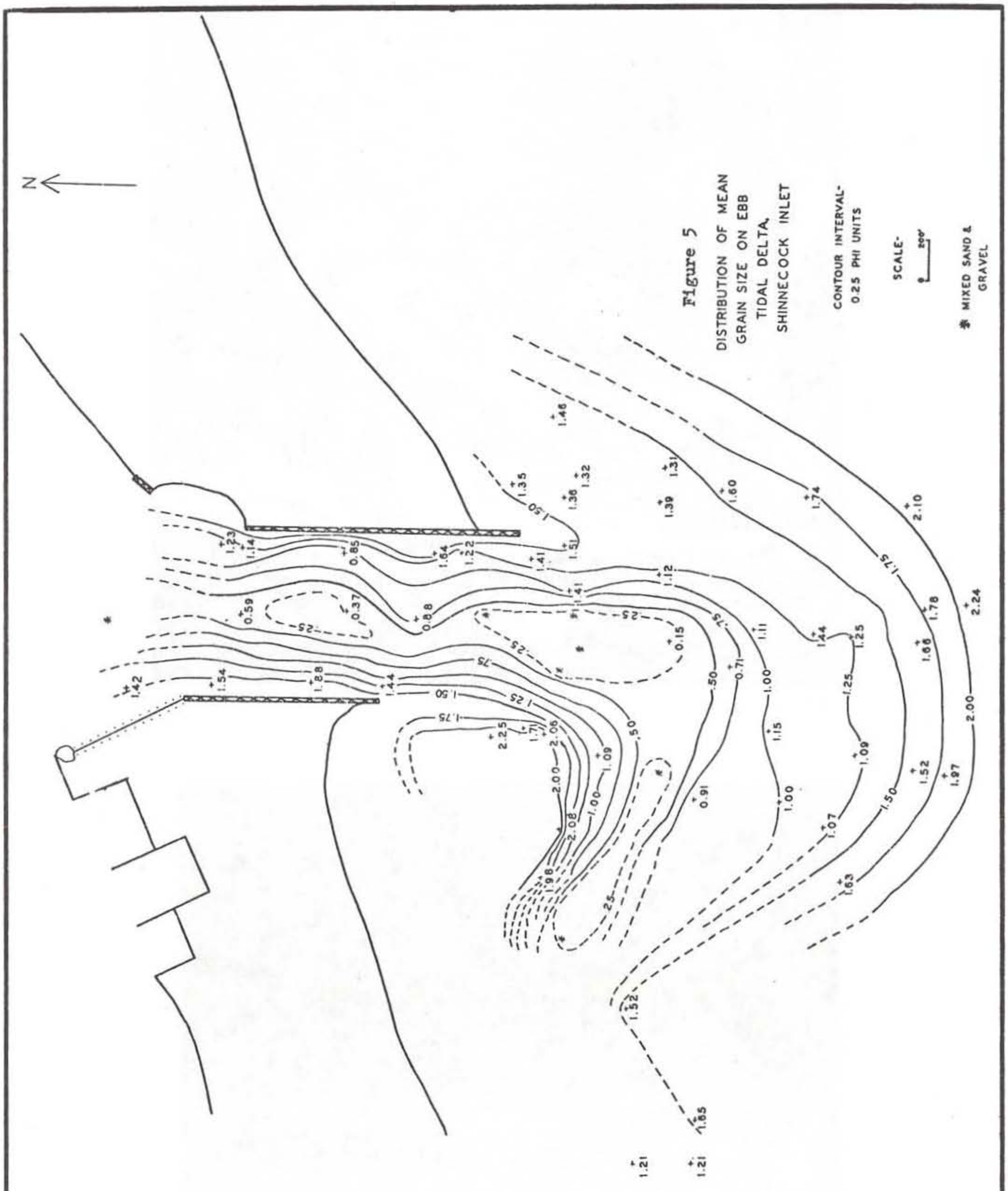


Figure 5
DISTRIBUTION OF MEAN GRAIN SIZE ON EBB TIDAL DELTA, SHINNECOCK INLET

A comparison of the standard deviations of samples from the beaches, flood delta and ebb delta exhibit marked differences. From Figure 6, it is apparent that sand from the ebb and flood deltas is not as well sorted as beach sand.

In other words, the mean grain size of deltas and beaches is nearly the same while the deltas tend to have a broader range of sizes than the beaches. This fact may be of considerable importance in interpreting paleoenvironments, but it is probably of little significance in the consideration of the deltas as a sediment source for beach nourishment programs. In general, the delta sediment is only 1/10 phi unit less well sorted than beaches. While the difference is recognizable, it is unlikely that this small difference would cause significant variations in behavior between delta and beach sand.

STOP #3 is reached by proceeding westward on dune road from Shinnecock Inlet. Travel 1.1 miles west of the Inlet and stop on the newly paved section of Dune Road.

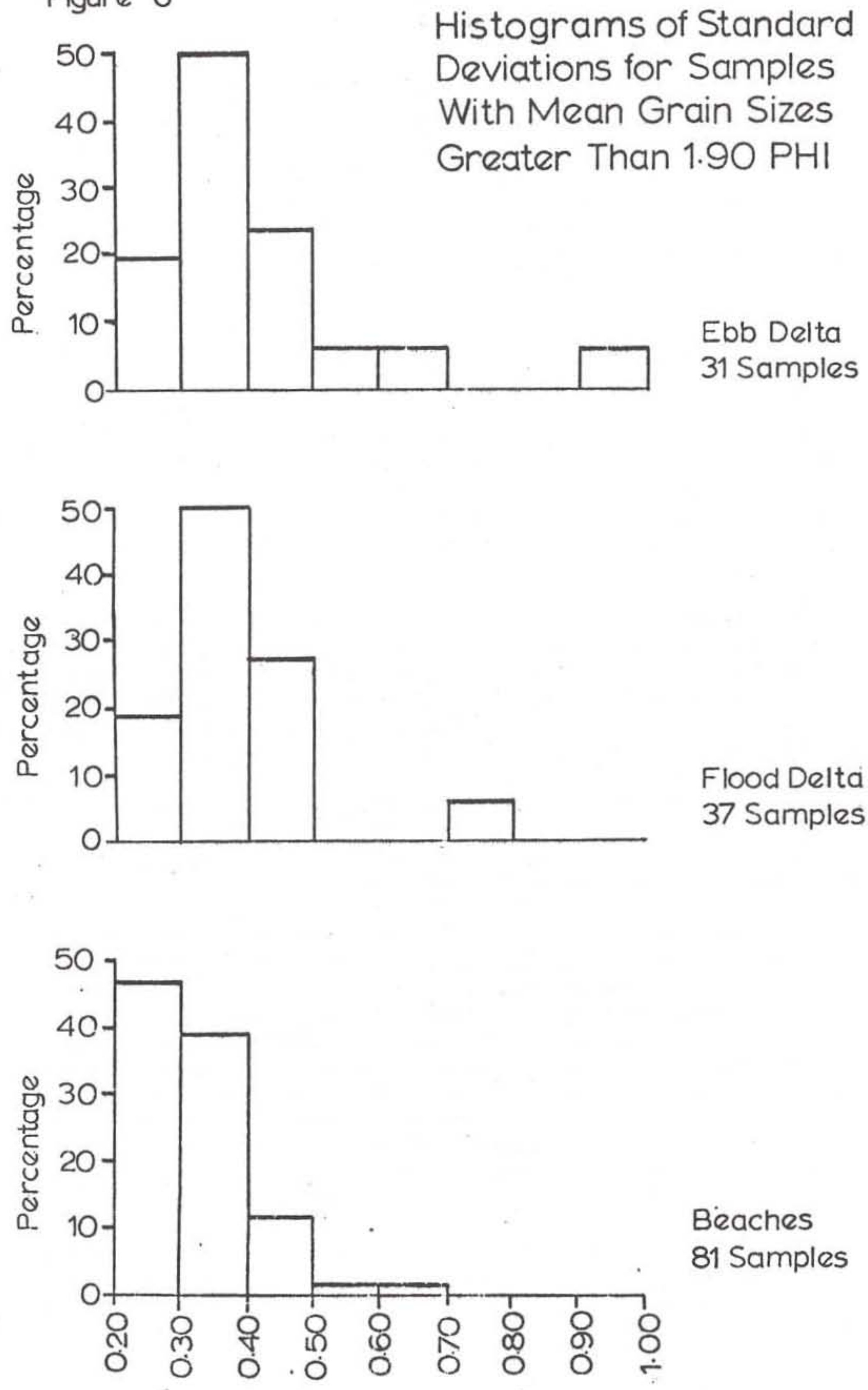
This is the site of a major storm washover created during the storm of February 18, 1972. The actual washover channel has been dammed with two parallel mounds of artificial fill and the road, destroyed during that washover, has been repaved. A small washover fan extends to the north of the road. The dune ridge normally present along the barrier island is nonexistent at this point.

This weakened segment of the barrier island provides an excellent setting to discuss the dynamic nature of the barrier island system on eastern Long Island and causes of that dynamism. All of the basic elements that make up the barrier system are present at this spot or are visible nearby. The beach face, berm, washover channel and washover fan are present and dune ridges are visible a short distance to the east and west.

In order to provide information on this particular segment of the south shore barrier island and on barrier islands in general, I have quoted some information from a paper by McCormick (1973). These data should provide a basis for discussion of barrier island migration.

> Five surveys of the high water line from Montauk to Moriches Inlet were conducted by the United States Coast and Geodetic Survey and the Army Corps of Engineers in 1838, 1891, 1933, 1940 and 1956. The data pertinent to these areas are listed in Table 1. These figures represent changes in the shoreline for 41 points spaced approximately 1 mile apart between Napeague Harbor and a location 6 miles west of Moriches Inlet.
>
> Due to the short time interval the data for the 1933 to 1940 interval and 1940 to 1956 interval were combined into one time period from 1933 to 1956. The variations in character of the shoreline and the locations of the two artificially maintained inlets suggest a natural grouping of the data into three segments: (1) Napeague Harbor to East Hampton; (2) East Hampton to Shinnecock Inlet; (3) Shinnecock Inlet to a location 6 miles west of Moriches Inlet. The amount of advance or retreat for all points in each of the three areas was averaged and the yearly rate of advance or retreat was calculated for each interval

Figure 6


Histograms of Standard Deviations for Samples With Mean Grain Sizes Greater Than 1.90 PHI
Percentage
50
40
30
20
10
0
Ebb Delta
31 Samples
Flood Delta
37 Samples
Beaches
81 Samples
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

between surveys. These rates and time intervals are given in Fugure 2. The shoreline westward from East Hampton has continuously retreated for the 188 year period between 1838 and 1956. During this period the rate of retreat between East Hampton and Shinnecock Inlet varied within the relatively narrow limits of 0.9 ft./yr. to 1.4 ft./yr. During the first 95 years of this period the erosion rate for the Shinnecock to Moriches segment varied from 1.6 ft./yr. to 0.7 ft./yr. However, during the period from 1933 until 1956 the Shinnecock to Moriches portion of the beach exhibited a dramatically increased rate of 6.8 ft./yr.

By comparison of aerial photographs from 1933 to 1960, the Soil Conservation Service reported a recession rate of 2.5 to 4.5 ft./yr. one mile east of Shinnecock Inlet and 8 to 12 ft./yr. at Tiana Beach west of the Inlet. This unpublished study corroborates the marked difference in erosional rates in the areas east and west of Shinnecock Inlet since 1933.

The first permanent natural break in the barrier island beach system west of Montauk Point is Fire Island Inlet and this opening has constantly migrated to the west in historic times. During the period since 1838 storms have caused breaks through the island at several points but none were stabilized by works of man and all have long since drifted closed.

Moriches Inlet opened in 1931, and except for a one year period, has remained open to the present. If it were not for attempts to stabilize this inlet in 1947 and 1952 it would probably have closed. Shinnecock Inlet has a similar history, it was opened in the hurricane of 1938 and by 1952 was stabilized by the construction of stone jetties. The close correlation between the time the inlets were opened and the abrupt change in the erosional rate of the beach between the inlets strongly suggests a causal relationship.

The artificially maintained inlets appear to have acted as barriers to the normal movement of sediment in the littoral drift. While the net littoral drift is to the west, easterly drift is experienced as well. As sediment is shifted past the mouths of the inlets, ebbing and flooding tides distribute it over ebb and flood tidal deltas. The sediment trapped by this process represents a net loss to the littoral drift and may explain the greatly accelerated erosion rate between the inlets ...

Perhaps the most apparent natural cause of shoreline recession is that material is being removed from a particular beach more rapidly than it is being supplied. This is certainly the case for the cliffs at Montauk where the prevailing westerly drift sweeps the finer detritus away and the only source for replacement is the cliff section backing the beach.

It is not possible to apply this explanation to the barrier island portion of the shoreline west of Southampton. The age of a peat layer at a depth of minus 7-1/2 feet mean sea level in Shinnecock Bay indicates that the bay and consequently the barrier island have been in existence for at least 2,300 years (personal communication Edward Belt, 1972). If the recession rate of the shore prior to establishment of the inlets is extrapolated backward and the barrier island has been in existence for several thousand years, it is not reasonable to explain recession of the beach as a function of the balance between erosion and deposition. This would have totally destroyed the island some time in the past. The only explanation that seems consistent with these observations is that the island is a migrating topographic form.

Onshore winds remove sand from the berm and carry it into the dunes. Waves replenish this material and during storms may carry large quantities of sand through the dunes to form washover fans. The movement of material by these processes from the ocean side to the landward side of the island can be considered as a constant pressure applied to the island that results in the establishment of a natural migration rate. Viewed in this way a profile of the island represents a moving wave form, the details of which are in equilibrium with local climatic conditions and incident wave energy.

A prerequisite for barrier island migration is that arrival and removal of sand on the beach face by longshore transport be in balance. An imbalance in either direction for a prolonged period will result in either advance of the shoreline or destruction of the barrier island. Because the source of sand for the barrier island is supplied by erosion of the cliffs to the east and the shoreline must be relatively straight to permit balance between arrival and removal of sand by longshore drift, the migration rate of the island must be dependent in large part upon the erosion rate of the Pleistocene deposits to the east.

The suggestion here is that the island migrates by the natural processes of dune growth and overwash, and it is now receding at an abnormally rapid rate due to the sand trapping effect of the inlets.

In addition to these causes, the shoreline might owe part of its recession rate to the "Bruun effect" (Schwartz, 1967). It is not possible at this time to assign values to the contribution each of these factors makes toward the total recession rate, but it seems fairly obvious that man's actions have had a substantial impact.

STOP #4 is located 11.0 miles west of Shinnecock Inlet on Dune Road. Any point along the road that allows access to the beach will satisfy the requirements for this stop.

The purpose of this stop is twofold: First to observe the solution that has been adopted to stem the problem of shoreline recession, and second, to allow participants an opportunity to contrast the condition of this protected segment of the barrier island with the unprotected portion downdrift of the last groin (STOP #5).

The groin field observed at this location was constructed under the authorization of the 1960 River and Harbor Act for the area from Fire Island Inlet to Montauk Point. The 1960 Act provided for the establishment of a continuous dune line to defend against flooding from storm surge and the establishment of sand bypass plants at Shinnecock and Moriches Inlets. In addition, provision was made for the construction of several groins and for a beach nourishment program. The federal government assumes the major share of the expense in construction of these groins in view of the broad protection that the hurricane protection portion of this program implies (approximately 70% federal funds). The level of federal funding is much reduced for erosion control (approximately 30% federal funds). The author is on public record as criticizing the 1960 plan for acting as an umbrella for local beachfront owners to obtain a high percentage of federal funding for what is essentially erosion control.

The piecemeal enactment of the 1960 plan which included groins almost as an afterthought, is brought about by the necessity for state and local authorization of funds prior to construction. At present none of the local governments have seen fit to provide the funding that would complete the broader aspects of the plan, and it is probably safe to assume public opinion will bar the complete enactment of the plan in the foreseeable future.

It is obvious that the structures protected by the present groins enjoy a more secure position on the barrier island than homes in unprotected areas. The abundance of shell material in the sediment of the dune ridge at this point is the result of being derived from dredged bay bottom, a practice often abhorrent to local baymen.

STOP #5 is located 13.9 miles west of Shinnecock Inlet on Dune Road immediately west of the last groin in the Westhampton Beach groin field. Here you will see evidence of recent washover, damage to local homes, and the absence of any substantial dune ridge. Of course all of this is directly attributable to the position of this beach with respect to the groin field. Starved for sand, it has receded at a very rapid rate.

Currently there is considerable pressure from homeowners and local government for the construction of six additional groins in this area in order to stabilize the beach to Moriches Inlet. The cost of this work will be approximately 10.5 million dollars and would be completed as part of the 1960 plan.

Consideration of how the natural system operates, the interference of man in this system, and interests of local property owners prompts a number of interesting questions.

Can local governmental units with sharp political boundaries deal intelligently with the management of natural systems that do not have the same boundaries?

Should federal projects of the type seen today be allowed to progress without any real assurance that funding will be provided to complete the project?

What will be the likely effect of the construction of six additional groins?

Can the public justify further coastal modifications on the basis of a realistic cost benefit ratio?

If the groin field were to be extended to Fire Island Inlet, would there be enough sand in the system to nourish the westernmost groin?

Does the public owe local homeowners west of the last groin for damages to their property?

To what extent is the damage produced by natural island migration and to what extent produced by the works of man?

ACKNOWLEDGMENT

The Town of Southampton provided the financial support for gathering most of the data presented in this field trip.

REFERENCES

McCormick, C. L., 1973, Probable causes of shoreline recession and advance on the south shore of eastern Long Island, in Coastal Geomorphology, D. Coates, ed., Publications in Geomorphology, S.U.N.Y., Binghampton.

Schwartz, M. L., 1967, The Bruun theory of sea-level rise as a cause of shore erosion; Jour. of Geol., V. 75, p. 76-92.

NOTES

A.M. ENVIRONMENTAL GEOLOGY OF DEMOCRAT POINT, FIRE ISLAND, N. Y., AND INFLUENCES ON ADJACENT BARRIER ISLANDS - Manfred P. (Fred) Wolff, pp. A-5-AM 1 through A-5-AM 16.

P.M. ENVIRONMENTAL GEOLOGY OF THE JONES BEACH BARRIER ISLAND - Coordinator: Peter J. R. Buttner; Lecturers: Richard A. Brady, Francis A. Hyland, Robert Johnson, Manfred P. (Fred) Wolff, pp. A-5-PM 1 through A-5-PM 10.

Cumulative Miles	Miles from last stop	Description
0.0	0.0	Assembly point: Hofstra University. Head East on Hempstead Turnpike toward Meadowbrook Parkway.
0.5	0.5	Cross California Avenue.
1.5	1.0	Junction with Meadowbrook Parkway (Southbound) to Southern State Parkway, bear right onto Meadowbrook.
4.0	2.5	Pass over junctions with Southern State Parkway - continue on Meadowbrook - follows signs to Jones Beach.
9.9	5.9	Tool booth at entrance to Jones Beach State Park.
10.9	1.0	Leave Jones Island and cross Jones Inlet and State Boat Channel to Jones Beach State Park.
11.8	0.9	Bear left - follow signs to Jones Beach Parking Fields 1, 2, 6 (not West End!)
12.8	1.0	Pass Parking Field #2 (Jones Beach water tower in distance) on Ocean Parkway.
13.4	0.6	Pass half way about traffic circle at tower - follow signs to Field #6 and Theatre.
14.1	0.7	Pass Field #6 - follow signs to town beaches, Field #9 and Robert Moses State Park (i.e. remain on Ocean Parkway).
26.6	12.5	Junction to Robert Moses State Park - bear right.
27.0	0.4	Cross bridge over Fire Island Inlet.
27.8	0.8	Bear right at traffic circle (Fire Island water tower) - follow signs to Parking Field #2.
28.9	1.1	Circle about loop at end of road.
29.1	0.2	Enter Parking Field #2, park in SW (right diagonal) corner near beach.

STOP #1 - Robert Moses State Park
(Trucks will transport you along the beach for one mile to the jetty at Democrat Point. Walking time is about 35 minutes.)

INTRODUCTION

This area, located at the federal jetty on the western end of Fire Island (and Robert Moses State Park) has been mapped since 1825 when it was located at the tip of the Fire Island Lighthouse - 4.6 miles (7.4 km.) east of its present position. The growth rate now averages 212 feet (71 meters) per year (Figure 1).

The purpose of this stop is to view the effects of the accretionary processes of spit formation from littoral drift and wave refraction associated with a laterally migrating barrier island. A more detailed analysis of the features, processes, and history of this migration is presented in article B-3 of this guidebook.

Because of the necessity for beach nourishment and inlet stabilization, the area is now dredged once every 2-3 years and the accumulated sands transferred to an adjacent feeder beach (Cedar Island and Gilgo beaches) on the west side of Fire Island Inlet. It is unfortunate, that this trip follows shortly after such a period, when only a few features are present. However, participants are invited to return at other intervals during the next few years when all of the characteristic sediment features will again reappear. You are now seeing the initial growth stages of a new intertidal

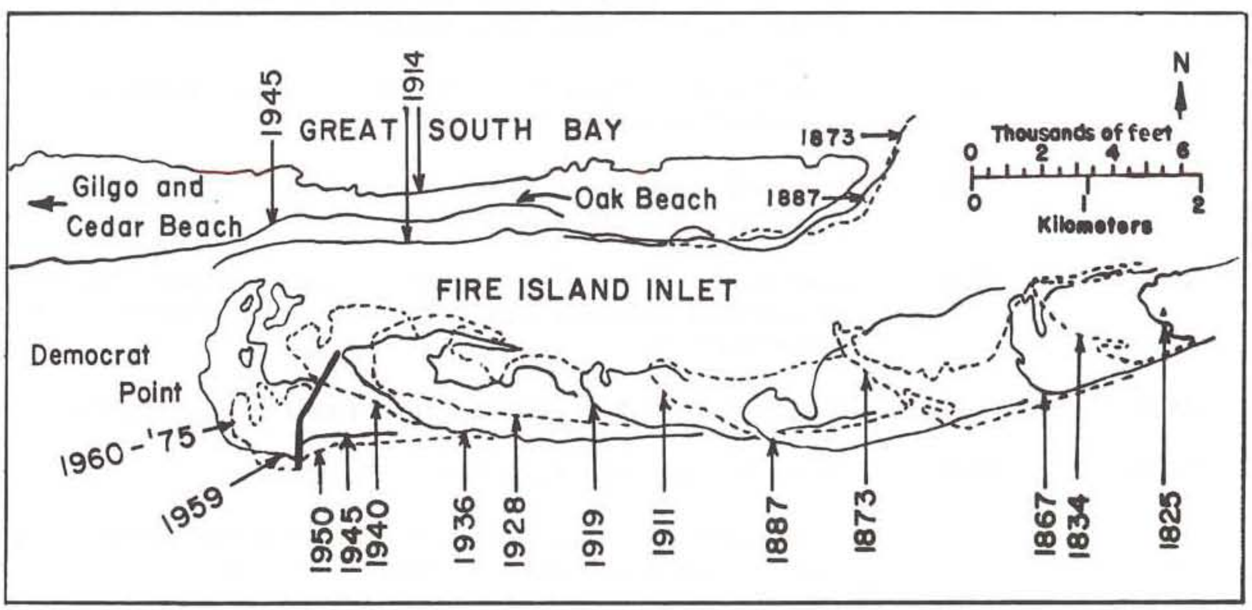


Figure 1. Progressive growth of Democrat Point (1825-1975) between Fire Island Lighthouse and federal jetty.

spit platform, but the development of the extensive primary and modified spits and their migration across embayments and lagoons will not reappear until the subtidal spit platform has been built seaward - as was the case once before (Wolff, 1972).

OCEANOGRAPHIC DATA

Tides

Fire Island Inlet is characterized by short-range, semidiurnal tides with a mean range of 4.1 feet (maximum storm surges of 9.4 feet). The ranges are 1-2 feet in the inlet and 0.6-0.8 feet in the Great South Bay. Flood tides sweep sand around Democrat Point into the S-shaped inlet while strong ebb currents dominate near the revetted sand dike at Oak Beach on the opposite side (Figure 1). The volume of water transferred through the inlet at each tidal cycle is 2 billion cubic feet, but the amount of "new" water is negligible (House Document #115, 1965). The short tidal range allows wave energy to be concentrated in a narrow swash zone, causing the vertical development of the major accretionary features just beyond the plunge point of the breaking waves.

Winds

Most of the south shore is characterized by summer winds from the southwest (April-October) or winter winds from the west (November-December) or northwest (January-March). The most dynamic changes occur during the periodic extratropical "northeasters" or during hurricanes. Hurricane frequency averages 3/100 years; moderate-strong "northeasters" average 30/100 years (House Document #191, 1967). While not a principal erosional factor, the frequency of such storms is increasing (Ruzyla, 1973).

Waves

Surf height is usually 0-4 feet with 4-10 feet waves during storms. Wave period averages 7 seconds with ranges from 12 (maximum) to 3.5 (minimum). Spilling or plunging waves are both common. Most waves approach from the southeast or southwest (81% of the time) with some increment from the south (17%) and east (2%) (House Document #411, 1957). The refraction of these wind waves establishes the characteristic pattern of littoral drift which moves toward the west two-thirds of the time and toward the east the other 33%. Most of the deep and shallow water wave energy also comes from the east-northeast, and east.

Currents

On the lower beachface steep refracted waves in the surf zone laterally transport sand as westward pulsating currents. On the upper beachface flat waves, refracted from the swash zone, transport sediments by zigzag beach drifting and by lateral transport and erosion. Tidal currents in the inlet have surface velocities of 4-6 feet/second with a maximum of 8 feet/second in the gorge near Oak Beach on the opposite side of the inlet (the velocity increases as the channel becomes constricted). At depth, inlet velocities average 2-2.5 feet/second (House Document #411, 1957).

Sand Supply

Seasonal changes in wave frequency along the south shore provide for onshore sand transport and berm accretion in the late spring and summer, and offshore movement with berm erosion in the fall and winter. At Democrat Point accretion dominates in the spring and summer while spit migration and refraction are more characteristic during the fall and winter. Analysis of the -6, -12 and -18 submarine contours near the inlet indicate an average westward migration of 197 feet (66 meters) a year (House Document #115, 1965). There is a landward movement of these contours in areas of berm accretion and a seaward movement in areas characterized by erosion.

Most of this sand is supplied by the littoral drift from the eastern end of Long Island (the opening of Moriches Inlet in 1930-34 produced no net accumulation of sand at Democrat Point - the only such "gap" in its recorded history of nearly 150 years). Besides the erosion of cliffs along the Montauk Peninsula, which can only supply part of the sand to the littoral drift, another possible source comes from the storm generated wave surges to the south and west, but this sand may not reach the breaker zone and remain offshore (Taney, 1961). The only other source of sand for littoral drift is on the existing beaches, and this accounts for the present extensive beach erosion.

ACCRETIONARY FEATURES

After the construction of the federal jetty in 1940 sands continued to be trapped behind it until 1950 when littoral bypassing began (Figure 1). By 1959 sediment accumulation was again closing the inlet. Since then, periodic dredging has removed the sand from the jetty and transferred it to the beaches on the other side of the inlet. Detailed studies of this region were initiated by Sanders, Friedman and Kumar (1972) and Kumar (1973) particularly for the channel, subtidal platform and offshore areas of Fire Island Inlet. Monthly mapping of the intertidal spit platform (spit of Kumar, 1973) was initiated shortly thereafter (Wolff, 1972) and this led to the recognition of a migration pattern of the refracted overlapping spits (Figure 2), and the development of distinct spit features and sub-environments (Figure 3).

The effects of tides, littoral currents, and refracted waves initially produce a subtidal spit platform as sands spread northwestward across the previous dredge site. Within a few months, a series of small spits develop and extend west of the jetty into the inlet. Tidal inlet currents prevent extensive lateral migration, but the small swash bars and spits continue to develop and coalesce against the remaining beachface and berm of the old spit platform, as is the case at present (Figure 4).

Once the sediment on the subtidal spit platform reaches wave base, the breaker zone becomes more extensive, and littoral sands begin to develop more extensive spits within the intertidal zone. Wave refraction also causes refraction of the spits, and the pattern of barrier island growth, based on maps from earlier years, is initiated (Figure 5A and 5B).

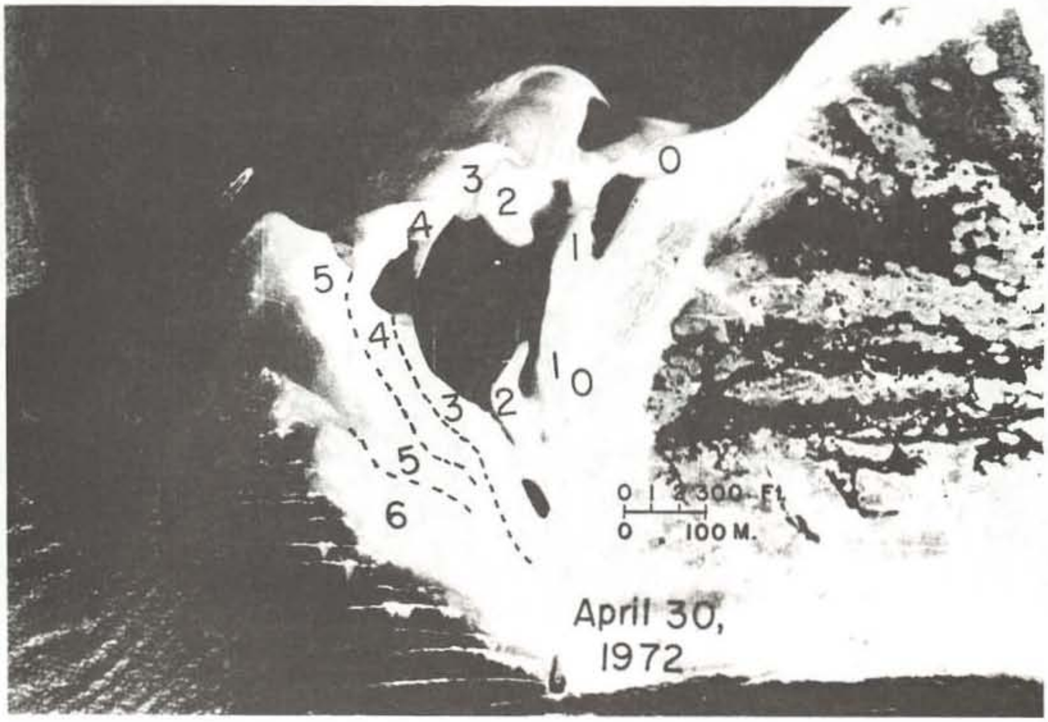


Figure 2. Progressive development of refracted spits across the intertidal spit platform between 1970 and 1972.

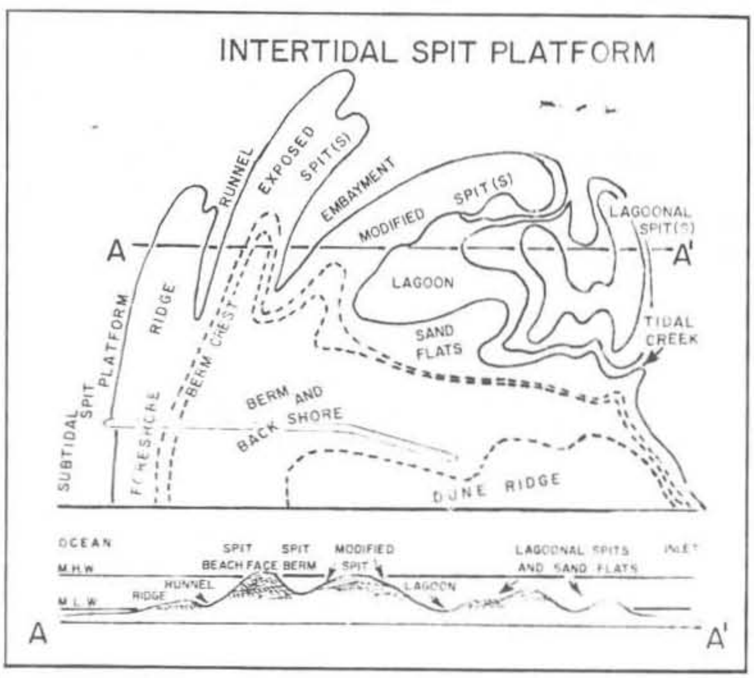


Figure 3. Schematic plan view and cross-profile of features formed on a well-developed intertidal spit platform.

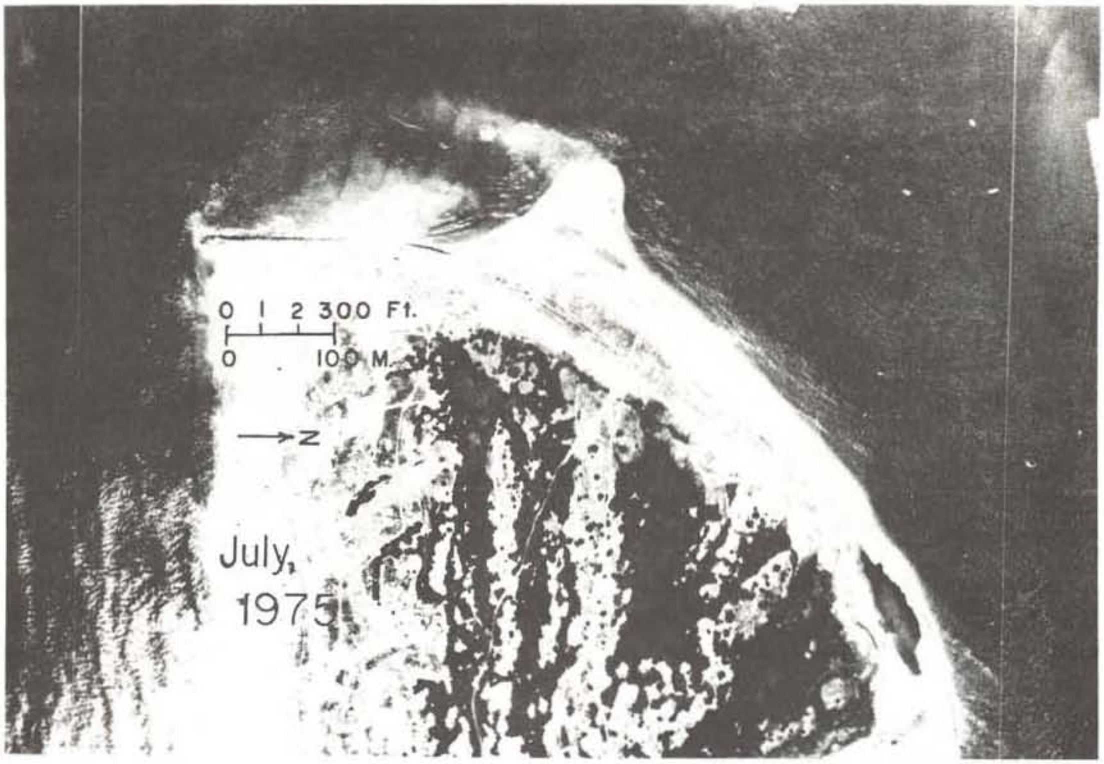


Figure 4. Initial growth of spit at Democrat Point after a period of extensive dredging (July, 1975).

The initial swash bars or ridges continue to accrete on the beachface of the spit until there has been enough refractive transport across the intertidal zone to cause a temporary separation. This could be due to storms, spring tides, or fluctuations in the amount of sand brought in by littoral drift. The result is a runnel or trough between ridges, or on a larger scale, the development of embayments between major spits. The spit noses continue to sweep over the platform and gradually becoming flattened, distended, or separated by washovers, as they close off the embayments into a series of ponds or lagoons (Figure 5C and 5D).

While vertical accretion is rapid near the jetty, lateral migration (up to 100 feet or 33 meters/week) dominates along the outer edge of the area when the spits, swept across the platform, accrete against the inlet edge of the barrier island, and continue to be modified by tides and currents to produce a series of lagoonal spits and tidal creeks (Figure 6A and 6B).

Once the modified and lagoonal spits have formed an effective barrier on the inlet side of the platform, extension of the exposed spit continues, and the process of northwestward and then eastward accretion of spits and enclosure of ponds and lagoons continues - unless removed by dredging (Figure 6C and 6D).

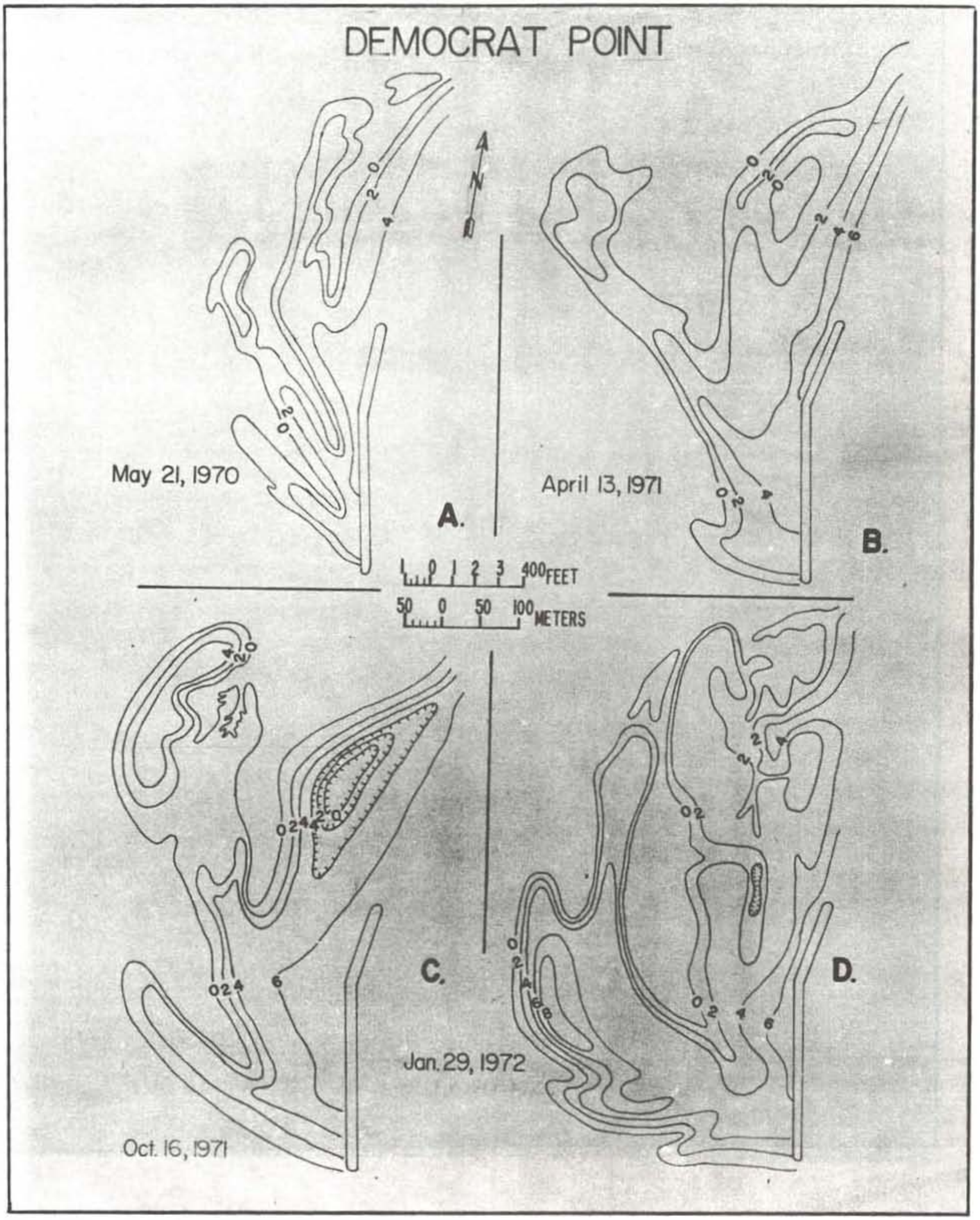


Figure 5A, B, C, D. Position of intertidal spit platform features at periodic intervals (1970-72). Contour interval 2 feet; datum mean low tide.

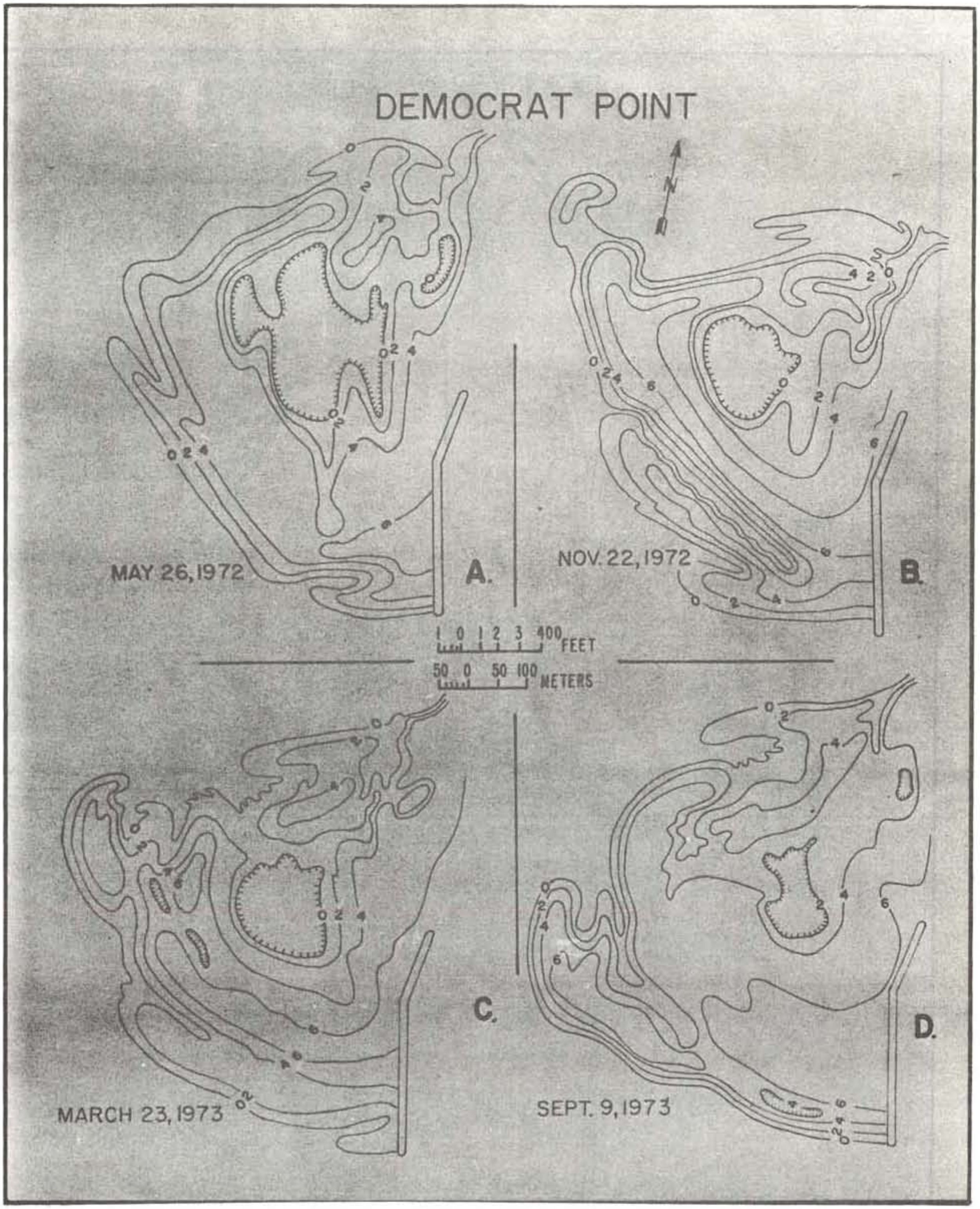


Figure 6A, B, C, D. Position of intertidal spit platform features at periodic intervals (1972-73). Contour interval 2 feet; datum mean low tide.

INLET MANAGEMENT AND STABILIZATION

Several projects proposed by the U. S. Army Corps of Engineers for stabilization and navigation improvement of the inlet along with control of beach erosion include (Bobb & Boland, 1969):

1) a 3000 ft. revetted sand dike (completed).
2) a 1000 ft. extension of the federal jetty (probably not needed).
3) a littoral reservoir directly west of the jetty with a capacity of 1.2 million cubic yards of sand.
4) a rehandling basin or depositional reservoir in the mouth of the inlet with a capacity of 2 million cubic yards.
5) a connecting navigational channel between the reservoir and depositional basin.

Dredging would be two-fold - first, hopper dredging from the littoral trap into the rehandling basin and finally a hydraulic pipeline dredge would pump this sand onto the adjacent feeder beaches (Figure 7). These last three items have never been constructed because of the expense involved (especially for the double-handling of the sediment) and because of the lack of a hopper dredge and its accessory equipment.

Sand bypassing by periodic dredging has been carried out since 1959. About 2 million cubic yards have been transferred from Democrat Point to the adjacent feeder beaches in 1959, '64, '70, and '73-'75. The most recent sediment bypassing was completed on April 18, 1975, and the depositional features present indicate the "new" growth since then.

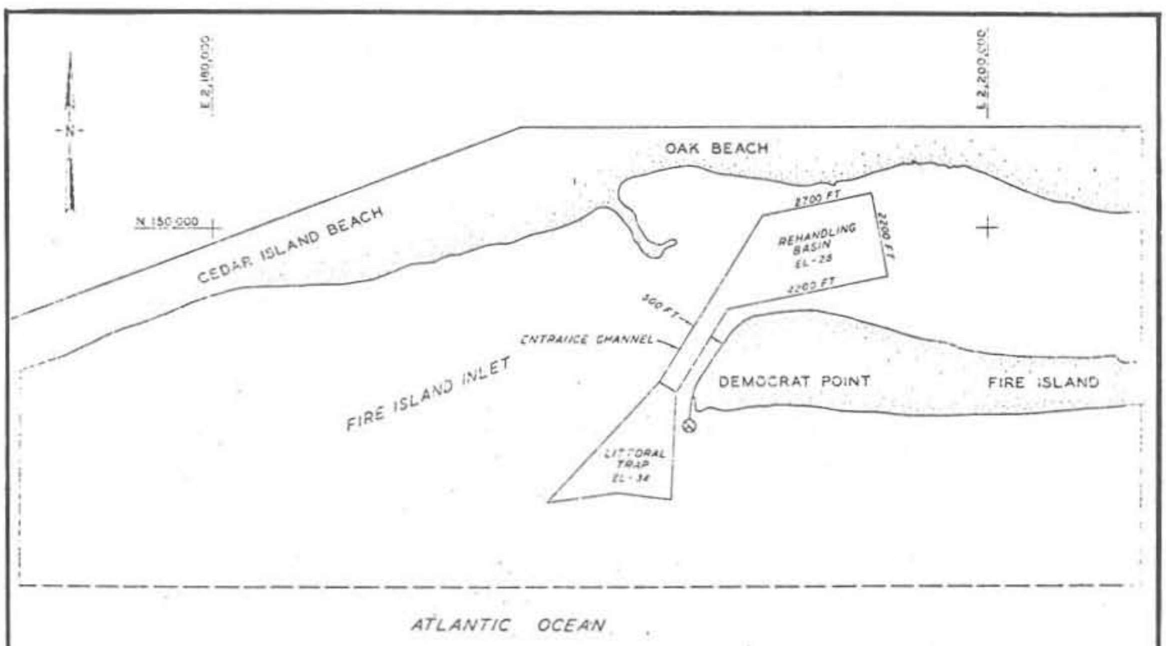


Figure 7. Proposed littoral reservoir, connecting channel, and rehandling basin (from Bobb and Boland, 1969).

While stabilization of the inlet and beach nourishment through sand bypassing are vital to the economy and recreation of Long Island residents, they are also expensive. The most recent project averaging $2.20 per cubic yard of dredging or $2 million per mile ($1.2 million per kilometer) for feeding - with prices expected to almost double by the time the next bypass operation becomes necessary. Beach nourishment at Fire Island Inlet may now be initiated once every three years to replace the sand continually lost from the western feeder beaches. Loses now average 600,000 cubic yards annually (Everets, 1973). However, inlet stabilization does not imply barrier island stabilization, and the present horizontal rates of erosion, averaging 2-3 feet (.8-1.0 m.) per year will also continue. The only remaining source of sand is in the offshore zone, seaward of the 30 foot (10 m.) depth contour, but at present the associated costs make this resource prohibitive.

While inlet stabilization and sand bypassing is a reliable and successful engineering accomplishment, it demonstrates the economic futility of short-term goals for long range problems. Any man-made "permanent" alteration emphasizing stability of natural geologic features, particularly in the coastal zone, may be unsuccessful when viewed through the span of one generation. The progressive growth at Democrat Point and its importance as a sand reservoir to the western barrier islands cannot be overemphasized - but this will occur at the expense of further erosion of Fire Island and areas to the east. What is needed is a long range (25-50 year) master plan, for the barrier islands, that could even include the (man-made) opening and closing of inlets. However because of all the diverse interests and investments, this is no longer probable since no solution would be acceptable to any majority. Since the natural closing of the inlet has more deleterious consequences than its present stabilization, it will remain stabilized until there is an acceptable alternate solution.

BEACH MANAGEMENT AND STABILIZATION

Natural Versus Man-made Processes on the Barrier Beaches

The history of Fire Island Inlet, and, on a smaller scale, even the present accretion-migration patterns at Democrat Point demonstrate progressive lateral and vertical changes of barrier island features. Democrat Point, and indeed all of Fire Island, provides an example of lateral extension of a barrier by spit accretion (Hoyt, 1967). However, a rising (or stable) sea also has an effect on the vertical or shoreward migration of the barrier island (Sanders & Kumar, 1975).

If a large sand supply is available, even with a stable sea level, storm effects will produce a shoreface retreat of the barrier island (Johnson, 1919). As the island migrates landward the dune and overwash deposits will override the lagoonal deposits, decrease the size of the lagoon, and shift the barrier toward the mainland (Figure 8A and 8B). If sea level rises, and the rate of barrier accretion by onshore-offshore or longshore transport remains higher than the amount of sand lost to the offshore zone by storms and the rising sea, the barrier island still migrates landward. But the lagoon remains of constant width since it migrates with the barrier (Fischer, 1961). In either case, lagoonal

If the sand supply is small, a rising sea will cause the shoaling of the barrier, the creation of extensive washovers, low dunes, and more tidal marshes and inlets. The result is an in-place "drowning" of the original barrier island and the creation of a new one nearer the mainland by jumping of the surf zone (Figure 8C and 8D - after Gilbert (1885)). Now nearshore massive sediments will overlie and preserve the backbarrier lagoonal deposits.

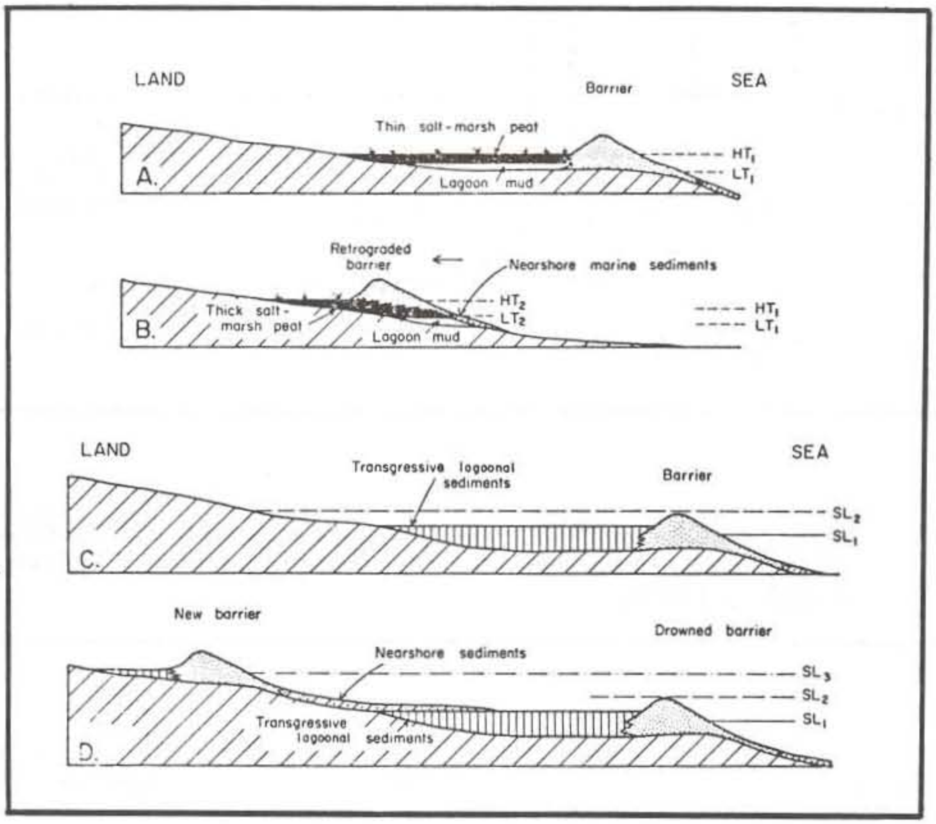


Figure 8A, B. Johnson's (1919) concept of barrier shoreface retreat during a rising sea (level 1 to level 2) as barrier overrides lagoonal sediments (HT=high tide; LT=low tide).
8C, D. Gilbert's (1885) concept of in-place "drowning" during a rising sea (level 1 through 3) causing a "transgression" on the landward side of the lagoon (after Sanders & Kumar, 1975).

Recently, evidence from cores on the continental shelf (Sanders & Kumar, 1975) indicate that Fire Island has undergone both drowning and migration (Figure 9). During the change from sea level I to II 8,500 years ago, in place drowning with surf zone jumping took place. For the past 7,500 years there has been shoreface retreat through landward migration. This pattern should persist into the future (200 years) and even distant future (500 years) as the bay and barrier islands continue to migrate landward (Figure 10) - but only if a continued reservoir of sand from the offshore zone or eastern Long Island remains available.

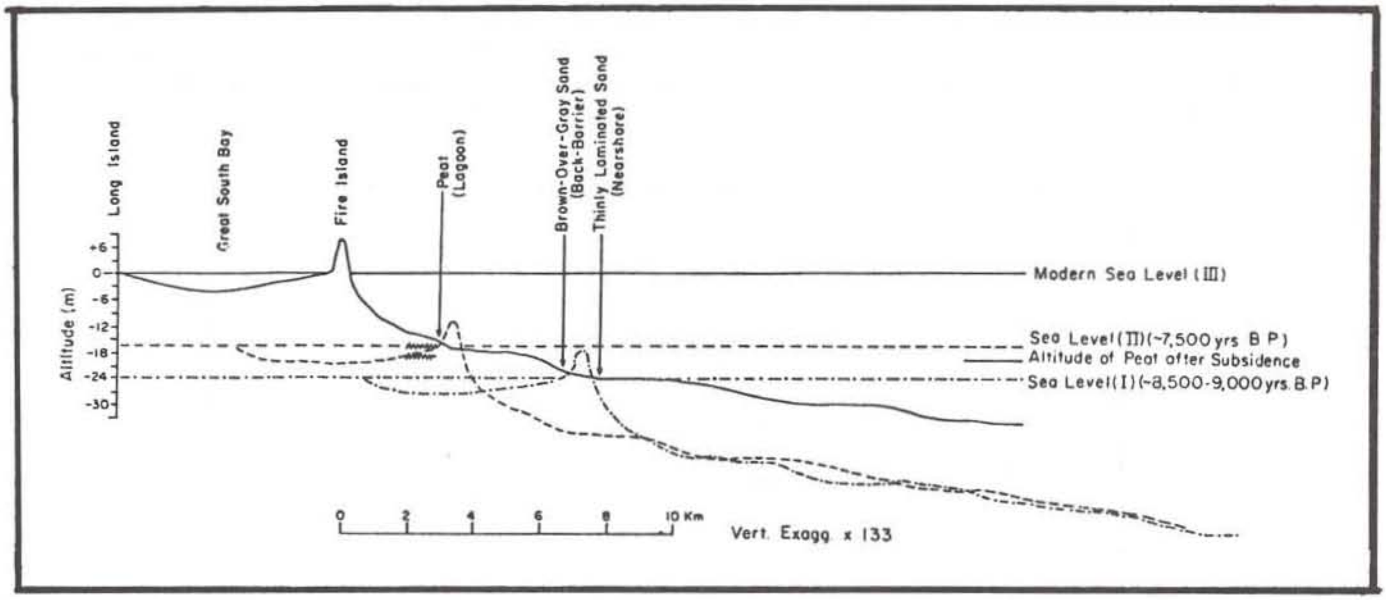


Figure 9. Effects of submergence on the former positions of Fire Island on the continental shelf. Explanation in text (after Sanders & Kumar, 1975).

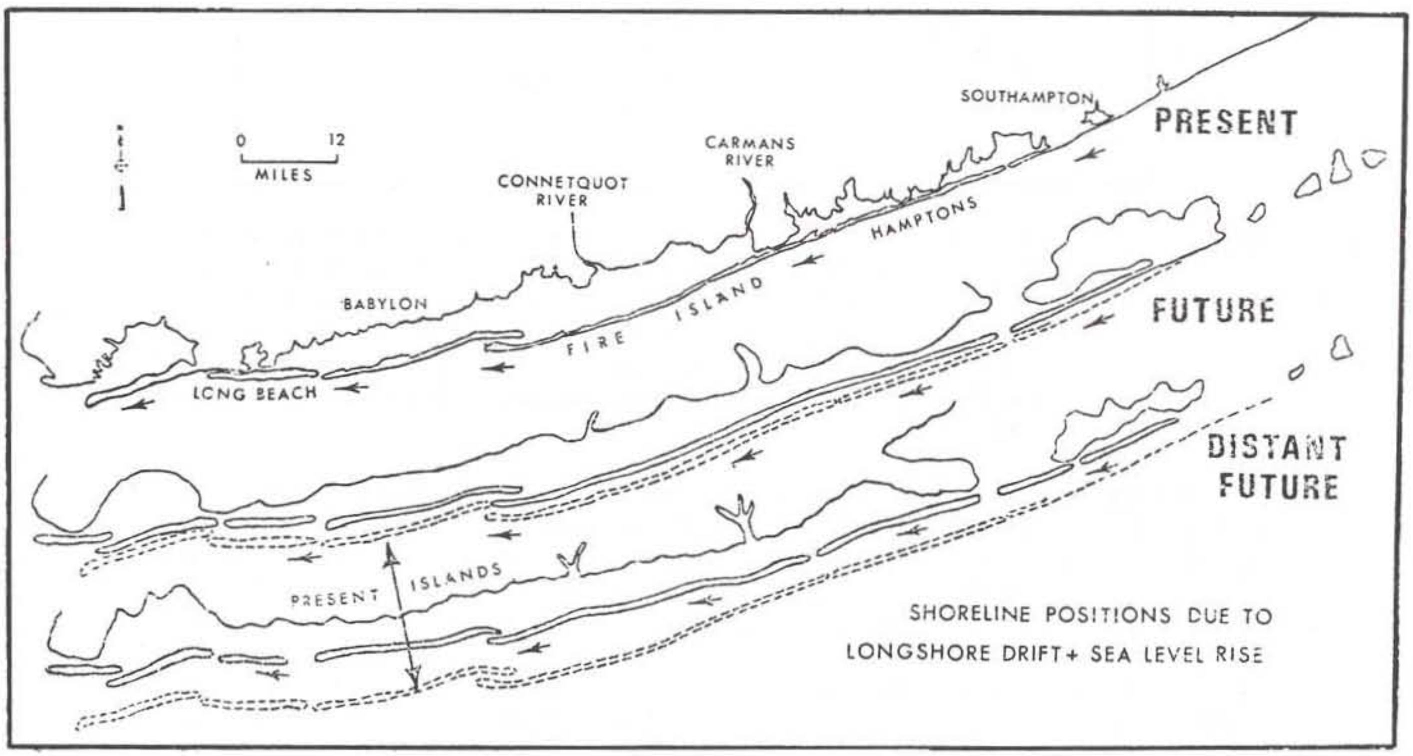


Figure 10. Schematic projection of changing positions of Great South Bay and south shore barrier islands (dashed lines at arrow indicate present barrier islands). Inlets assumed constant.

This new evidence suggests that the previous concepts regarding inlet and barrier island stabilization must be altered - Fire Island and the other barrier islands cannot continue to migrate landward without the return of some natural migration processes. Though the rate of sea level rise is about 4 inches/100 years (Fairbridge and Newman, 1968), the wide inlets and extensive marshes of the western barrier islands are not characteristic on Fire Island. During the past 200 years, the closing off of small embayments and the erosion of glacial cliffs from eastern L. I. indicate that a large amount of sand, coupled with the strong littoral drift, has enabled wide beaches and high and extensive dune fields to develop (i.e. the rate of shoreface retreat has slowed down, though the rate of sea level rise continues). People began occupying this island during this interval, and now, further shoreface retreat is prevented by beach and dune stabilization. The result, as at Cape Hatteras, is that the stabilized dunes act as a wall against overwash deposition during storms and thus lead to implement the beach erosion (Godfrey & Godfrey, 1973). Instead of bringing sand onto the backbarrier by the natural effects of storms and hurricanes, periodic beach nourishment and marsh dredging must be initiated and maintained (Figure 11).

Continuing westward from Fire Island (the main sand reservoir) the remaining barrier islands indicate, in progressive order, further stages of shoreface retreat through landward migration. Thus, there is a direct contrast between the (originally) wide beaches, high dunes, few inlets, and lack of tidal marshes on Fire Island with the (originally) narrower beaches, lower dunes, more inlets and extensive marshes of the western barrier islands (Wolff, 1973).

This again demonstrates the need for a long range coastal zone management plan. While the rate of beach erosion continues at about 2 feet (63 cm.)/year (Shepard & Wanless, 1971) or reaches 4-5 feet/year in some instances (House Document #191, 1967) there is no corresponding rate of backbarrier migration because of stabilization. Further, with a reduced sand supply, an effect from initial stabilization, the pattern of coastal retreat changes to one of in-place drowning as sea level rise continues.

Though the rate of beach erosion remains at 2-4 feet/year, the rate of westward inlet and barrier island migration is 150-200 feet/year (Taney, 1963) - about 75 times faster, under natural conditions. A return to these conditions, aided by sand bypassing near the inlets, would transfer much of the sand now locked behind groins and jetties toward the western barrier islands. Yet, the "buffer mechanism" of littoral transport is waning. Most of the sand supply that should occur on Fire Island has already been "lost" to the sea because of dune stabilization, and is now located in the offshore zone. While it may be another 50-100 years before in-place drowning is recognized, some of the effects, through beach erosion have already taken place. The only remaining major source of sand for natural beach replenishment and barrier island migration occurs along the glacial cliffs of eastern L. I. Who will decide if and when this area will be "sacrificed" to provide sand for the western barrier islands, or will the slow process of "in-place" drowning be allowed to continue?

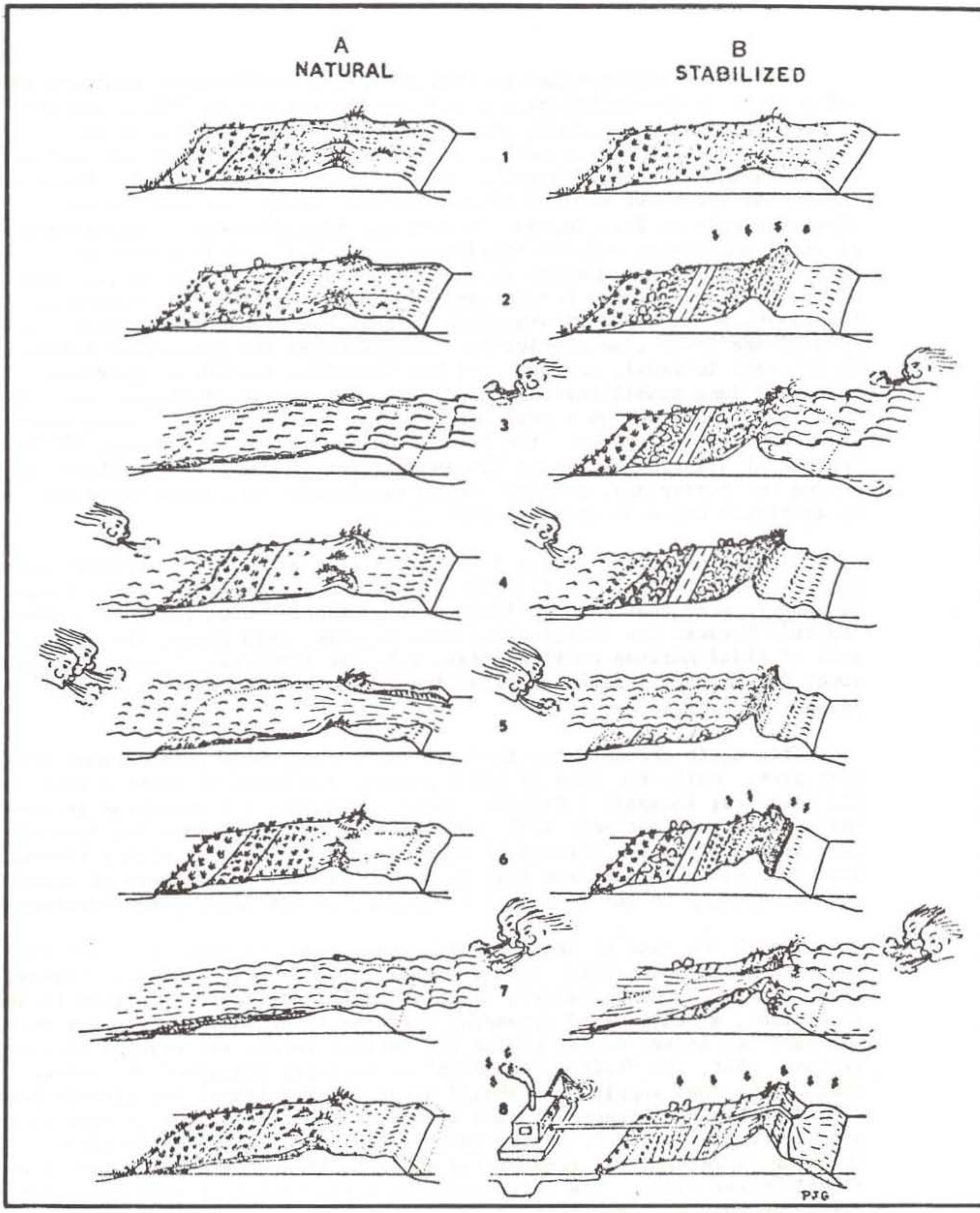


Figure 11. Changes (1-8) between natural and stabilized barrier islands. Under natural conditions storms permit overwash and inlets and with a rising sea, shoreface retreat. Under stabilized conditions this is not possible and periodic maintenance is necessary (After Godfrey & Godfrey, 1973).

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NOTES

ENVIRONMENTAL GEOLOGY OF THE JONES BEACH BARRIER ISLAND

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and

LONG ISLAND SOUTH SHORE SALT MARSH DYNAMICS

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Over the last several years, New York State Parks and Recreation has begun a state-wide review of the environmental context of all aspects of the management of public recreational facilities. Included in this review is the complete range of activities including planning, acquisition, development operation and maintenance of each element of the New York State Park System.

The Jones Beach Barrier Island, with its bay-side wetland complexes, tidal channel estuary systems and classic coastal dynamics presents a collage of special problems to the recreational resource manager. He must rely on assistance from many disciplines to define and analyze these problems. A key part of this information concerns the past, present and future environmental geology of the barrier system, both its land and its water components. As with such natural resources as the gorge of the Genessee River at Genessee State Park and the meromictic lakes at Green Lakes State Park, the Jones Beach Barrier Island system owes its existence and continuance to the interaction of complex geological processes. Each of these natural resources is defined by unique morphological, terrestrial and aquatic systems that reflect a special geological setting. Water and sediment and their hydrodynamic effects, both short and long-term, are the main geological fluxes of these settings. Any changes in the quantity or quality of these, in time or in space, will bring about modifications to various components of the morphological, terrestrial and aquatic systems. The Jones Beach-Fire Island Barrier Island system is especially sensitive to any changes in the quality of water and in the quantity of sand; it occupies the surface and near-surface interfaces between the marine waters of the New York Bight, the tidal waters of Great South Bay and the barrier islands.

Perhaps one of the most important aspects of the environmental geology of the Jones Beach Barrier Island is its effect as an energy sink and dispersant. Without this protective buffer, coastal storms would significantly modify the shore of the mainland.

Since 1970, with the passage of PL 91-190, the National Environmental Policy Act of 1969, the development of environmentally-sensitive management policies for such natural resources, as the Jones Beach Barrier Island, has become of great interest and concern. Moreover, with the passage of the New York State Environmental Quality Act (SEQA), additional attention is to be given to the environment of such sensitive areas as the Jones Beach-Fire Island barrier islands.

With the introduction to long-range barrier island migration patterns completed (Wolff, Stop 1 - previous article, A-5-AM), let us now move from the primary sediment doner (Fire Island Robert Moses State Park) to an important sand receiver (Jones Beach Barrier Island and State Park) and consider the importance of environmental geology with regard to the planning, development and operation of public recreational resources. We will discuss environmental aspects of sand nourishment and beach protection, pollution control and waste management, and marsh ecology with wetlands preservation. We hope to maintain a balance between the desire for natural environmental resources and the needs of public recreational resources through long range land use planning and the analysis of environmental impacts.

ROAD LOG

Cumulative Mileage	Miles from last point	Description
0.0	0.0	Leave Parking Field #2 of Robert Moses State Park (Stop #1 of A-5-AM trip). (Figure 1.)
0.8	0.8	Drive about circle at Fire Island water tower and cross bridge to Jones Beach-Captree Island.
1.9	1.1	Leave bridge and follow signs to Captree Beach State Park.
2.5	0.6	STOP #2. Captree Beach State Park

Walk east across dunes to area of highest elevation. From this point one can see the end of the Jones-Captree Beach barrier island, remnants of an earlier extension of Fire Island (Sexton Island and the Fire Islands), and the position of the old and new inlets. All of this area was once exposed to the open ocean. The lighthouse on Fire Island indicates the western edge of that island and the wide inlet that was present over 140 years ago. The barrier beach west of the lighthouse and the now parallel inlet indicate the changes that have occurred since that time. (Wolff, Article A-5-AM.)

Captree Beach and its extensive backbarrier salt marsh (partially dredged for the state boat channel) is the first area in western Great South Bay with this development, and this initiates the pattern that characterizes the remainder of the barrier island chain to Jamaica Bay. The extension and overlap of Fire Island has curtailed most erosion, though some modification by the ebb and flow of tidal currents continues. Note the bulkheads and the position of the dense scrub vegetation and trees on the dunes near the inlet. Though protected by Fire Island, it also receives no sediment from that source and some erosion continues to persist.

Captree is an important bird nesting area and, because of its proximity

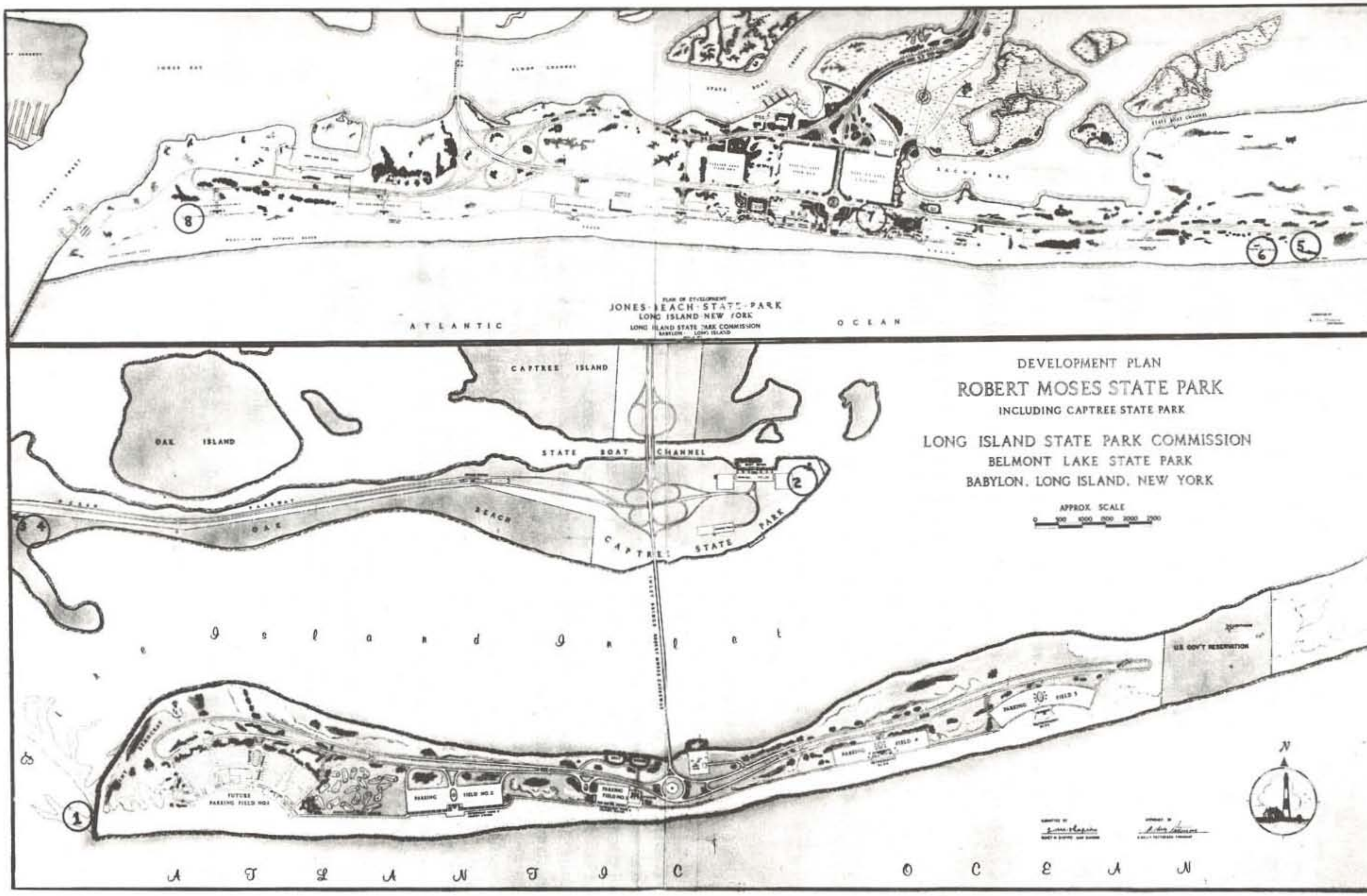

Figure 1. Field Trip stops and proposed development plans for Robert Moses and Jones Beach State Parks.

to the mainland and the inlet, an important area for bathing, boating, fishing and picnicking. Each morning a fleet of fishing vessels leave the boat basin for points within the bay, in the inlet, or in the ocean.

3.2	0.7	Leave Captree Beach and continue west on the Ocean Parkway. Junction with ramp to Fire Island - continue straight on Parkway.
5.1	1.9	Oak Island on right (private ownership) with town of Oak Beach on left (you are now near the mouth of Fire Island Inlet).
6.5	1.4	Cedar Beach Overlook and Cedar Beach on left.
9.9	3.4	Gilgo Beach - continue west on Ocean Parkway.
10.9	1.0	Hamlet of West Gilgo on right; park near western edge of this developed area after crossing Suffolk-Nassau County border.
11.3	0.4	STOP #3. Erosion of dunes near West Gilgo Beach.

It is normally dangerous and unlawful to stop here on the road during the summer and parking in the West Gilgo Beach Parking Lot is advisable - but for the sake of completeness there will be a "quick stop" at this point.

This area is characterized by previous beach and dune erosion to the extent that this process has almost reached the position of the Ocean Parkway. Many areas on the adjacent barrier islands - from Fire Island to Rockaway - exhibit similar effects. The sand bypassing from Fire Island Inlet, coupled with the littoral drift, still assures the preservation of a broad, well-nourished beach at this point and indicates the positive effects of man-made intervention without the necessity of groins. However, the lack of natural sand supply for the more western barrier islands (especially the Rockaways) continues to impose a serious problem. Should attempts at stabilization continue or, considering the long-range effects, should "nature take its course?" These are questions that have important social, economic, and political as well as environmental consequences, and must be handled both on a local and on a regional basis.

11.8	0.5	Leave West Gilgo and continue to Tobay Beach. As you enter the Parking Lot, turn left and follow the signs to the Bird Sanctuary.

STOP #4. Tobay Beach and Bird Sanctuary.

This area will illustrate the creation, development, and maturation of backbarrier tidal salt marshes.

LONG ISLAND SALT MARSH DYNAMICS

Dr. Robert Johnson

Coastal marshes occur as a result of estuarine sedimentation and are now included as a class of distinct landforms. On the south shore of L. I. these marshes, originally well south of this area, are superimposed over the drowned lower coastal plain that extends seaward as the nearshore continental shelf. This region, including past and future sites of salt marsh development, is underlain by a layer of glacial outwash that has been modified into barrier beach-estuarine environments by the rising sea.

The estuary forms a partially enclosed body of water where mainland fresh-water and sea water meet to form a region of shallow brackish water with variable salinity, water temperature, and sediment load. The Great South Bay Estuary System is a 70 mile long "bar-built estuary" extending from Lawrence in Nassau County to Southampton in western Suffolk.

Suspended sediments are washed into the estuary by mainland stream flows, enter through the inlets from the open ocean, or are picked up and resuspended within the system by waves and tidal currents. At any given time the total suspended particle load consists of some proportion from all three sources. In areas of low energy the settling and accretion of the flocculated clays along with intermixed sand produce intertidal flats - vast areas of shallow shoals and salt marshes that are drained by channelized networks of creeks, leads, and channels.

Typically there are three distinct types of salt marshes: the first (backbeach) type is associated with the ocean and occurs on the backside (in this case north) of the barrier island. The second (mainland) type occurs on the bay edge of the mainland, and is associated with the fresh-water wetlands and streams. The third (bay) type occurs as isolated islands or hassocks within the estuary. Sediment transport and deposition account for all three types, but each has its own peculiarities.

The "back beach" on the estuary side of the barrier beach is often fairly protected from wave action. Its intertidal zone is covered by water containing considerable suspended organic and inorganic particles. The back beach may be a relatively fertile area conducive to the establishment of the salt marsh cord grass *Spartina alterniflora*.

Patches of this tall cord grass soon occupy much of the upper part of the intertidal zone and act as effective sediment traps since their stems decrease current velocities during the last stages of the high tide. Often the increased sedimentation in the proliferating grass may result in a shelf at its bay edge. This shelf is short lived as the cord grass fringe extends out into the intertidal zone until water depth becomes prohibitive or currents make further outward movement through sedimentation difficult. (Marshes are also building out in the bay, although somewhat differently, and as bay hassocks and back beach marshes approach each other the bay circulation is forced through narrower channels.) Back beach marshes may extend far out into the bay and perhaps even join with bay hassocks if the intermarsh currents are not strong enough to keep them separated.

Simultaneously, the marsh grass area at the upper end of the intertidal zone has continued to receive sediments and is in the process of building up to a table-like surface about level with the elevation of the usual high tide. Two things now happen: First, deposition slows down since particles can only be carried up on the marsh by the highest tides, such as full moon (spring) and storm tides. Secondly, salt marsh cord grass is replaced by salt meadow cord grass and salt grass (Spartina alterniflora, Spartina patens and Distichlis spicata). These secondary plants will dominate the marsh as long as it exists, however, a number of other species will invade and co-exist with the dominants.

If the marsh is extensive, or as it becomes extensive, a sheet flow or movement of outgoing tidal water drains off the marsh. Any slight variation in the marsh floor at this stage will channelize the outgoing tidal water. Erosion will occur and a system of tidal creeks will develop. These creeks will reach a depth about equal to the usual low tide elevation.

If the barrier beach is moving (as is often the case - Wolff, Article A-5-AM) because the source of its maintenance material is waning or being transported landward, the entire barrier island may migrate landward over the estuary. Proof of such a northerly movement on Long Island exists in the form of salt marsh peat exposures along the ocean front (Wolff, Article B-3-AM). Since salt marshes cannot form in the surf area, the wave energy associated with the rising sea cuts northward, eroding the older estuarine deposits. Histori al records indicate that extensive back barrier type marshes existed behind Fire Island - "hay cutting" expeditions were commercially feasible during the 18th and 19th centuries. Virtually none of these marshes still exist.

The back beach marsh can be heavily effected by inlet formation, and. in turn, can effect or deter permanent inlet formation. If the marsh is extensive, the peat is thick and marsh creek development is not concentrated in the area where storm waters have broken through the dunes, the subsequent littoral drift will "heal" the break. The break usually occurs outward in any case. A great deal of water will build up in the estuary during these extraordinary storms.

The build up of water is due to low atmospheric pressure during storms as well as wind driven water. The tide drops quickly on the ocean side of the barrier beach. It drops faster than it can run out through the existing inlets and the variation between bay and ocean elevation results in enormous outward pressure. If the dunes were breached previously in some area, a flood of this extra high water will escape into the ocean at that point, tearing its way through the barrier beach sand and creating a channel which may persist for years.

If an extensive salt marsh protects the back beach it will resist this occurrence once the outflowing storm water reaches the upper level of that marsh. Salt marsh peat, particularly that formed by the secondary dominant plants S. patens and D. spicata, is tough, resiliant material. The living marsh will take an enormous beating before it disintegrates. This is particularly true if the estuary level is dropping via area subsidence and new marsh peat is superimposed on old. The tough. resistant-to-decay root systems of the secondary dominants may be several to many feet thick depending on subsidence rates.

If the marsh is broken at any point the breach through the barrier beach will quickly widen as sand washes out to sea. The marsh adjacent to the break will be lost as the peat is undercut by a loss of underlying sand. This process occurs along every narrow boat channel in the estuary as boat wakes undercut the adjacent marshes at low tide.

From the preceding discussion one can build a case for encouraging salt marsh development on the natural areas of Jones Beach and Fire Island back beaches. It also seems that cutting mosquito control drainage ditches into the back beach marsh is somewhat risky. One might want to encourage as complete a marsh coverage in this area as possible; even to the point of filling in larger natural waterways and minimizing weak points in this system.

The processes of erosion, sedimentation, and the importance of plants in marsh formation and maintenance is easily seen in the developmental history of a salt marsh island or hassock. In this second major type of salt marsh we can start with the relatively flat bottom of some open water portion of the estuary. Presently, and on and off historically, areas of bay bottom support heavy growths of eel grass Zostera marina. This species is really a pond weed adapted to a saline environment and in no way a true grass. It flourishes in patches or extended coverages between depths of about eight to one feet below mean low water. In deeper water it does not receive sufficient light and in very shallow water it is subject to too much light and probably too much wave action.

A patch of eel grass is a sediment trap due to the frictional "baffling effect" of its profuse long thin fronds. In some areas it is possible to observe a ridge around the periphery of the patch caused by the concentration of particles coming out of suspension as water enters the grass and slows down. Eel grass is self-limiting in the sense that the depositional process it accelerates leads to depths too shallow to support the plants. It is at this point when sediments have brought the bottom elevation close to the lower intertidal zone that salt marsh development may begin. Typically Spartina alterniflora invades the higher areas and, as in the case of the back beach marsh, acts as a sediment trap. Sediments continue to build up around the salt marsh cord grass until what was once a patch of submerged eel grass is now a young marsh. Usually the marsh will extend bayward, but not in a concentric pattern. One side or another will receive more sediments due to the local current patterns and the marsh will build in that direction.

As before, sediments will continue to arrive and marsh elevation changes at first occur rapidly. They occur very slowly as we approach the high tide elevation. Once the usual (modal) high tide elevation is reached the primary salt marsh cord grass will be replaced by the secondary salt meadow cord grass and salt grass (S. patens and D. Spicata again). As this table-like surface is extended to the point of significant coverage some sort of channelization of runoff during a falling tide will lead to a typical dendritic marsh drainage system. Some marsh islands or hassocks are miles long and miles wide. They may also "grow into" or adjoin back beach marshes or mainland marshes. They can never form a complete dam across a bay by joining both, since, high current velocities (in a sense caused by the constrictions of marsh growth) in creeks and arms of bays will prevent this.

The hassock is a very stable place. It will maintain its elevation (which is about equal to the higher high tides) as long as the subsidence rate of the area is not too great (or sea level is not rising too quickly). Again, the longer the duration of inundation during a tidal cycle the more sediments a marsh will receive. As the marsh level approaches that of the usual high tide, gains in elevation are minimized. As the marsh level approaches that of the highest tides, inundation becomes rare and sedimentation is almost non-existent. Thus an equilibrium is reached a few inches above the usual high tide "mark."

Leaving the ecology of the hassocks and forsaking the snails, worms and crabs that are very important to marsh stability, we are finally ready to discuss the mainland salt marshes. These formerly existed along the entire south shore of Long Island's mainland where the outwash plain dips into the bay or, conversely on the north side of the Great South Bay Estuary System. This gently sloping sandy outwash plain extends north across Long Island to the moraines near the North Shore. This outwash that forms so much of Long Island is one enormous reservoir of formerly cool, clean water. At any significant depression in the outwash surface the high water table (resulting from 40 to 50 inches of annual precipitation) intersected the surface as a stream. Dozens of relatively constant flowing streams flowed south across the outwash to enter the estuary.

Like the native brook trout the mainland salt marshes of the Great South Bay Estuary System are largely gone or going. Unlike the hassocks and back beach marshes they were privately owned. Nassau County's mainland salt marshes have been planted to cape cods and split levels and Suffolk marshes are severely threatened with this development. Recent tidal wetland legislation on New York State's part has slowed the process but as Long Island's human population continues to grow toward New York City - densities of habitation in wetlands will increase and the outlook in the long term appears grim.

These mainland marshes existed as thousands of acres of points of marsh between dozens of fresh-water streams entering the bay. Their formation started with the colonization of the intertidal zone by S. alterniflora. The presence of rich sediments of inland origin must have accelerated the process of marsh growth and development. One suspects that these marshes appeared earlier than the other two types. They were extensive and fringed with S. alterniflora when they existed. The immediate areas away from the bays and marsh drainage systems were dominated by the shorter secondary dominants. The processes leading to marsh formation and stabilization are exactly as described earlier.

There is one important difference in the equilibrium vegetation of the mainland salt marsh and that is the occurrence of fresh-water marsh vegetation along the upland border. Often a full blown fresh-water marsh occurs in that area. The fresh-water table of the adjacent mainland is often exceedingly close to the surface along the salt marsh mainland border. This water tends to move down hill and when confronted by the soils of the salt marsh it tends to flow out over it. It is contained in areas away from salt marsh plants and their replacement by fresh-water species (or at least plants that do well in brackish water of very low and variable salinity). These conditions may also occur on a back beach marsh or even a hassock where a great deal of dredging spoil was dumped. All that is required is a sufficient water shed and the reservoir capacity of sandy soil adjacent to a marsh. The interesting thing is that the salt marsh must develop first. Recently various agencies on Long Island have had considerable success in the artificial development of salt marshes where none previously existed.

13.6 1.8 Leave Tobay Bird Sanctuary and continue west on Ocean Parkway to area with construction buildings on left.

STOP #5. Area for sewage outfall line from Cedar Creek Sewage Treatment Plant.

In order to curtail estuarine pollution, a series of sewage outfall lines extending across the bay and beneath the barrier islands into the ocean have been proposed - this is one of the first to be completed (1973). While there is little that can be observed on the surface, the vegetation across the dredged zone (the pipe was 8 feet in diameter) clearly demonstrates the progressive succession of different barrier island species and the return of the native flora.

14.1 0.5 Leave the sewage outfall area and, within 0.5 miles, stop at the entrance to Parking Field #9 (now closed to the public).

STOP #6. Parking Field #9 of Jones Beach State Park.

This area is similar to Stop #4. Note the position of the Parking Lot versus the line of the primary dunes and the successive zones of berm accretion. Originally intended to handle the overflow from neighboring Parking Lot #6, after at least two attempts to repair the area, the project has been abandoned. The collapse of the southern edge of the parking lot was due to undermining by lateral erosion. As with Stop #4, each of these areas of extensive erosion are near old inlets. (Wolff - Article A-5-AM.)

16.1 2.0 Continue west on Ocean Parkway toward the Jones Beach water tower. Swing about the traffic circle and follow the signs to Parking Field #5 - Administration area.

16.4 0.3 STOP #7. Parking Field #5 and Administration Area.

The previous stops have emphasized some of the dynamic natural and man-made changes that are occurring on the barrier islands. Administrative personnel will review some of these processes and explain how the L. I. State Park Commission, is trying to achieve a balance between the requirements of the natural environments and the importance of the maintenance and development of public recreational resources (Figure 1). Any man-made structure has a limited life expectancy, usually measured within 1-3 human generations. Coastal zone management with regard to public recreation cannot consider long-range (100-year) changes since the demand for recreational resources varies within 10-20 year intervals. By working within these intervals useful environmental and recreation resource management policies can be established and these can be modified to fit the long-term coastal changes.

16.7	0.3	Leave Parking Lot #5 and continue west on Ocean Parkway toward the West End of Jones Beach.
17.7	1.0	Pass Parking Field #3 and #2 and follow signs to "West End", Parking Lots #1 and #2.
19.0	1.3	Enter Parking Field #2 at West End, go to southwest corner.

STOP #8. West End of Jones Beach, Parking Lot #2.

As with Democrat Point (Stop #1) this area exhibits all the characteristic features of lateral and vertical sand accretion. The construction of the jetty in the 1950's now provides a very wide beach and a wide zone of dune development. Note in particular the type of vegetation associated with these recent dunes.

Leave Parking Lot #2 and follow the signs to the mainland and Meadowbrook Parkway - return to Hofstra University.

NOTES

Geological Oceanography of a Segment of Long Island Sound

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11794

The field trip will be conducted aboard the Marine Sciences Research Center's new 55 foot research vessel, R/V ONRUST. The ONRUST, completed in 1974, was designed specifically for work in coastal and continental shelf waters. It is well equipped for work on biological, chemical, geological, and physical oceanographic problems of the coastal environment.

The primary objective of this cruise is to introduce the participants to some of the tools and techniques used by oceanographers in their quest to understand, interpret, and predict the processes that characterize the coastal marine environment. A secondary objective is to use some of these tools and techniques to make a cursory examination of several different sedimentary sub-environments of Long Island Sound. The shortness of the trip precludes a detailed look at any particular area and requires that the cruise be concentrated in the Sound off Port Jefferson Harbor. The actual shiptrack will be dictated largely by weather and sea state, and therefore no specifics are given in this brief report.

After a variety of methods and instruments have been demonstrated by MSRC staff members, participants will be encouraged to use the devices to collect their own samples, and to make their own measurements. The methods and instruments to be employed; the measurements to be made; and the samples to be collected, fall into several broad categories:

I. Navigation

   A. Electronic
      1. Loran A
      2. Loran C

   B. Optical
      1. Horizontal Sextant

II. Shape and Structure of Coastal Basin

   A. Precise and Accurate Bathymetry
   B. Shallow Sub-structure
      1. High Resolution Continuous Seismic Profiler
         a. E. G. & G. Uniboom

III. Sediments

A. Suspended Sediments
   1. Various water bottles and filtration techniques

B. Surficial Bottom Sediments
   1. Shipek grab smapler
   2. Van Veen grab sampler

C. Sub-surface Sediments
   1. Gravity corers
      a. Benthos
      b. Phleger

IV. Physical and Chemical Properties of Sea Water

A. Temperature
   1. Thermistor
   2. Reversing Thermometer

B. Salinity
   1. Electrical Conductivity

C. Nutrients
   1. Autoanalyzer

D. pH
   1. Electrode

E. Dissolved Gases
   1. Oxygen
      a. Winkler Titration
      b. O_2 electrode

F. Optical Properties
   1. Transmissometer
   2. Fluorometer

V. Circulation

A. Current Measuring Devices
   1. Eulerian
      a. ENDECO current meter with deck readout
   2. Lagrangian
      a. Drogues
      b. Dye Diffusion

VI. Plankton

A. Towed nets

B. Pumped samples

C. Water bottles

Each participant will be provided with a set of oceanographic data from Long Island Sound and a suggested reading list for possible classroom use in oceanography courses at the undergraduate and beginning graduate levels.

NOTES

TRIP A-6 AFTERNOON

SEDIMENTARY DYNAMICS OF A COASTAL POND: FLAX POND, OLD FIELD, LONG ISLAND, NEW YORK

by

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INTRODUCTION

Flax Pond is a small estuarine marsh located on the north shore of Long Island, New York (Fig. 1). Since 1966 the Flax Pond marsh has been owned by the State of New York and administered by the Department of Environmental Conservation and the Marine Sciences Center of the State University of New York. Under this administration the marsh has been utilized as a research site for studies dealing with salt marsh flora and fauna, estuarine hydrology, nutrient cycling and coastal sedimentation. The protected nature of the Flax Pond marsh and its similarity to other intertidal marshes in the northeast make it a unique scientific resource for the region. In addition to the advantages conferred by state protection, the Flax Pond marsh is situated in an area which was settled early in the history of New York. Historical records which mention Flax Pond date back well into the 18th century, maps showing the pond date from 1797, and accurate coastal charts of the region were first issued in 1852. Thus, the existence of historical records and maps provides an opportunity to study the development of man's interaction with this coastal pond and permits the documentation of the natural and manmade coastal changes of the past 200 years.

The objectives of our research on the sedimentary dynamics of the Flax Pond marsh include the understanding of the processes, rates and environmental controls of sedimentation and marsh growth. We have, to date, utilized information derived from historical records, maps and charts, the stratigraphy of the marsh sediments, and marker bed studies to arrive at estimates of the rates of marsh accretion. A summary of this work is presented in this paper and will be illustrated while in the field. Future projects will utilize radiometric techniques and suspended sediment budgets to arrive at additional estimates of the rates and environmental controls of marsh growth.

Throughout the settlement and development of the coastal zone, marshes have been altered to varying degrees. Among these alterations are the physical changes resulting from ditching, bulkheading, dredging and partial or wholesale infilling. In recent years the value of marshes in providing food, sites for recreation, natural flood protection, and habitats for wildlife has been realized and many coastal wetlands are now protected by law from further alteration. Many previously altered marshes are now recovering from an era of abuse. Our studies will provide an estimate of the rate at which marshes can grow under natural conditions and may serve to predict the rate of recovery of disturbed marshes. Furthermore, an assessment of the relative importance of the factors governing wetland growth may indicate ways in which marsh growth and recovery may be initiated or stimulated.

THE FLAX POND MARSH: GENERAL FEATURES

The Flax Pond marsh is a small (0.5 km^2) salt marsh located on the north shore of Long Island, New York (Fig. 1). The marsh is a "pocket" marsh facing Long Island Sound and is situated between two long hills formed by the Harbor Hills moraine of Wisconsinan age. The two hills terminate in bluffs known as Crane Neck and Old Field Points.

The total drainage area of Flax Pond is only 1.68 km^2 (Woodwell and Pecan, 1973) and no substantial fresh water streams enter the marsh. The salinity in Flax Pond is about 26 ‰, approximately equal to that of Long Island Sound water in this region. The average tidal range in the marsh is 1.8 meters and the low tide is delayed by approximately two hours by a sill near the inlet. The marsh itself is predominantly intertidal. Further details on the hydrology of Flax Pond are given by Woodwell and Pecan (1973).

The dominant vegetation in the marsh is the tall form of *Spartina alterniflora*, a grass which is capable of colonizing intertidal mudflats and sandflats and which may form accumulations of peat. In the Barnstable, Massachusetts marsh *S. alterniflora* grows through two-thirds of the entire tidal range (Redfield, 1972). Small stands of the shorter, or "dwarf" form of *S. alterniflora* are present in the upper intertidal areas of the marsh. Essentially all of the peat in the Flax Pond marsh is formed by *Spartina alterniflora*. The other species of *Spartina*, *S. patens* is found associated with *Distichlis spicata* (spike grass) along the high water periphery of the marsh with especially extensive stands in the north-central parts of Flax Pond. Several species of *Salicornia* (marsh samphire or glasswort) are common in the sandier parts of the marsh near the high water line. At elevations slightly above mean high water, but in areas which are still subject to the influence of storm tides, are stands of *Juncus gerardi* (black grass) and *Iva frutescens* (marsh elder). This association is characteristic of the upland periphery in the north-central parts of the marsh.

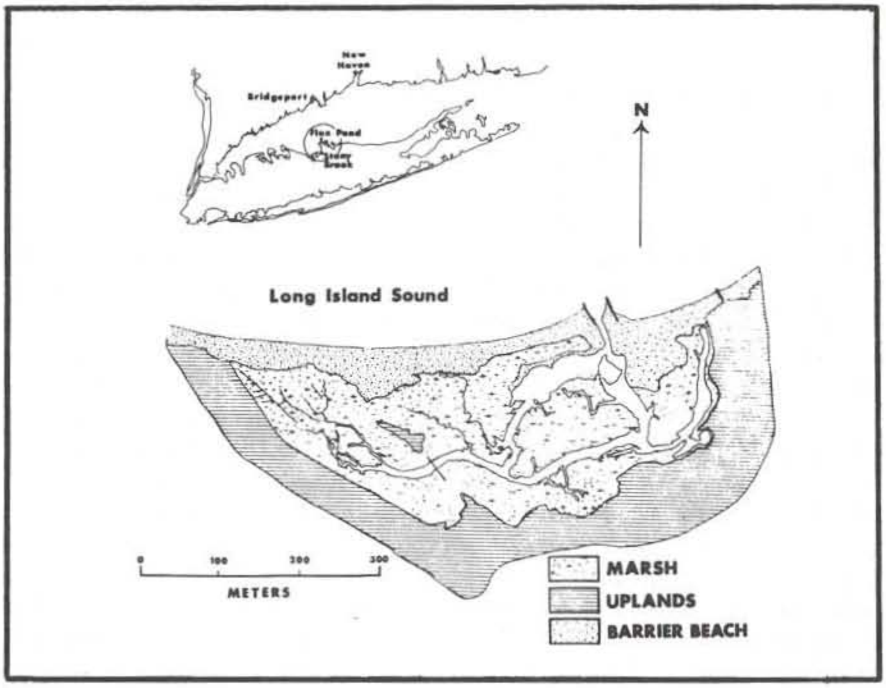

Figure 1: Location and physiography of the Flax Pond marsh

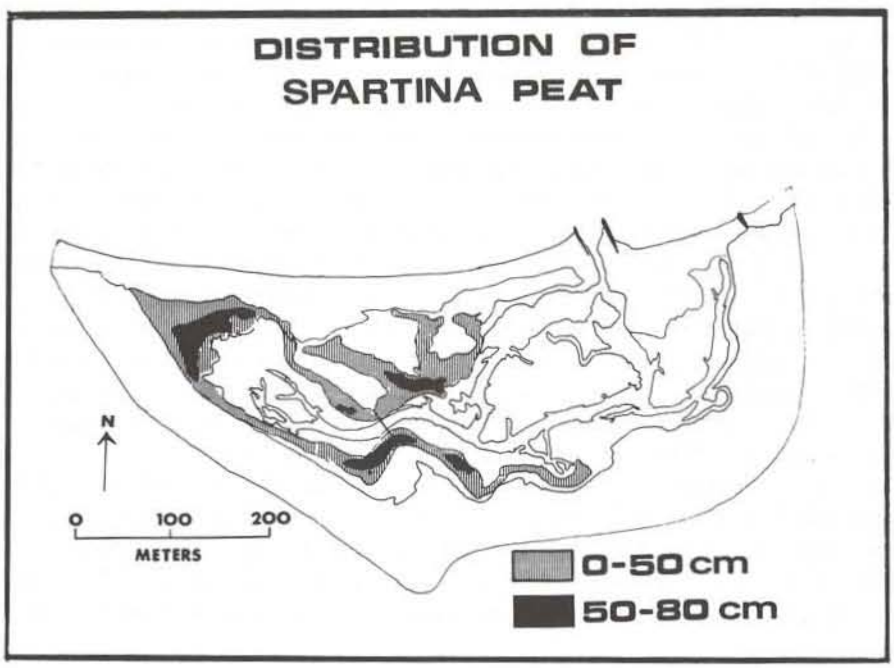

Figure 2: Distribution and thickness of *Spartina* peat in Flax Pond.

Surface sediments in the Flax Pond marsh range in size from coarse gravel to fine silts and clays. The beach facing Long Island Sound is composed of coarse sand and gravel derived from the cliffs of glacial sediment to the east and west of the marsh. In the central and eastern parts of the marsh a broad band of coarse sand and gravel, just slightly above the level of spring high water, forms the barrier between the marsh proper and the waters of Long Island Sound. The inner margin of this band is in the form of small lobes of gravel which appear to be encroaching upon the marsh surface. The movement of these lobes apparently takes place during severe storms. We have not yet been able to actually observe the movement of the lobes and do not know the rate at which this phenomenon occurs. Coarse sediments are also found inside the inlet to the marsh where an extensive tidal delta of sand and gravel is exposed at low tide. Within the marsh itself, sandy sediments are generally confined to the center of the tidal channels. The finer grained sediments, the muds and peaty muds, cover extensive areas in the eastern and western portions of the marsh. The finest grained sediments are located in the western parts of the marsh, the area farthest removed from the tidal inlet. The marsh peat is most extensive in the western and north-central parts of the marsh. Figure 2 shows the distribution of the Spartina peat.

The sediments within the Flax Pond marsh may be delivered by way of four mechanisms: stream inflow, aeolian input, sediment derived from storm washovers, and net tidal input of sediment. Only two small streams enter the Flax Pond marsh. The small area that they drain, and the fact that the salinity within the marsh is approximately the same as that of the open Sound indicates that sediment input from stream inflow is insignificant. The typically coarse beach sediment of the area and the absence of a dune field at Flax Pond argues against a significant aeolian input of sediment to the marsh. Because of the periodic nature of severe storms, the amount of sediment derived from storm washovers of the barrier beach is difficult to assess. The material thus delivered, however, is characteristically very coarse sand and gravel, easily recognizable in cores, and is generally confined to a relatively narrow strip behind the active beach. For the reasons cited above, we assume that the chief source of sediment is via net tidal input from Long Island Sound. Sediment delivered to the marsh by way of tidal exchange may be transported as either bottom load or suspended load. A gravel delta inside the mouth of the marsh is evidence of some contribution via bottom load, but because of the predominance of fine grained sediment within the marsh, we suspect that this transport mechanism plays a relatively minor role. The dominantly fine-grained nature of the sediments in the marsh supports the interpretation that the suspended sediment input controls the rate of sediment supply. Indeed, coastal wetlands are generally considered to be the major sink for suspended sediment on the Atlantic coast (Meade, 1972).

Further description and discussion of the marsh sediments may be found in the section on sedimentation rates.

FLAX POND: THE HISTORICAL RECORD

Town Records

Table 1 lists excerpts from the Brookhaven town records between 1712 and 1899 which mention Flax Pond. Many of the 18th century passages refer to Flax Pond as "freshpon" or "fresh pond". The 1751 excerpt reveals the origin of the name Flax Pond - the pond was used for the wetting of flax, a procedure which ideally requires "pure, soft water" (Anon., 1910). All of the historical references prior to 1801 clearly indicate that Flax Pond was a fresh water pond and was not connected to the marine waters of Long Island Sound. In 1801, however, the town sold a portion of the pond but reserved, for the town residents, all rights to fishing, clamming and oystering. This notation indicates that the pond was connected to Long Island Sound and that salinities in the pond were sufficiently high to allow the growth of clams and oysters. The pond is also referred to as a "Marsh" in 1801, but this term is ambiguous and does not necessarily imply a marine connection. The remainder of the pond was sold in 1819, also with the stipulation that fishing and clamming rights were to remain with the town trustees. In 1870 the first mention is made of a salt meadow in the Flax Pond area. By at least 1870 then, a stand of Spartina had become established within the marsh. Salt meadows along the north shore of Long Island are not especially unusual features and thus the Flax Pond "salt meadow" may have been in existence for some time prior to its mention in the town documents. In 1899 an individual applied for a permit to open an inlet to Flax Pond. Nautical charts from that same period, however (see next section), show a connection to Long Island Sound. We assume, therefore, that the intention was to deepen an existing inlet to allow for easier navigation or to increase tidal exchange in the marsh and thereby improve the fishing and clamming. A small area west of the inlet was dredged for sand and gravel, probably sometime during the 1940's.

The historical records pertaining to Flax Pond indicate that the pond contained fresh water through much of the 18th century. The pond was connected to marine waters sometime between 1751 and 1801. The first indication that the pond was connected with marine waters is a stipulation, made in 1801, that clamming and oystering rights were reserved for town residents. Town records do not, unfortunately, indicate whether the opening of the pond to Long Island Sound was a natural or man made occurrence.

Table 1: History of Flax Pond, 1712-1899.

1712-	Road laid "to ye freshpon in ye olde feild tu Rod wide" - Records, Town of Brookhaven, Book C, p. 62.
1725-	Purchase by the Trustees of "a cartayn dwelling Hows and home lot with ye garding orchard - ffencings and other Improvements there unto belonging or in any wise apertayning together with a three acre Lot in ye old field near ye ffresh pond..." - Documents, Town of Brookhaven (1693 - 1947) p. 1.
1728-	a highway 4 rods laid out "to ye flax pond" - Records, Town of Brookhaven, Book C, p. 131.
1738-	a road laid out from the mill dam (in Setauket) to the Clay hole and also a road to Crane Neck "and oute of that Rode to ye flack pon ass it was formerly layd out" - Records, Town of Brookhaven, Book C, p. 189.
1751-	"a highway to ye fresh pond in the Old Field two Rods wide" to be "laid open for publick use two Rods wide as it was laid outt and Entred on Record begining at and turning out of a road which leads from ye said Oldfield Gate unto Crains Neck", running "untill it comes to ye Common land and into said pond att the usuall place of wattring flex: We also order that all other roads hereto fore laid out to said pond shall be void and remain shut up Excepting this above Said roade as we have now Laid out to be and remain an open public free highway forever..." - Records, Town of Brookhaven, Book B, p. 481-482.
1801-	The Town Trustees sell to Richard Floyd, Vincent Jones, & Jonathan Mills, "the one equal undevided half part of a certain Pond or Marsh- in the Old Field- Fifty nine Acres one quarter and twenty one Rods," described according to a map and survey but reserving "the sole and exclusive right of Fishing, Clambing, & Oystering for ever unto said Trustees and their successors and the Inhabitance of said Town of Brookhaven for ever."- Records, Town of Brookhaven, 1798-1856, p. 49-51.
1815-	a record of the division of Flax Pond where by Vincent Jones, William Wickham Mills, and Stephen Hulse, deceased, are to have the west section and the Town Trustees the east sections. - Records, Town of Brookhaven, 1798-1856, p. 193-194.

Table 1, cont.

1819-	Town sells to some individuals "all the Right in the flax pond belonging to said town, excepting and reserving the right of fishing and clambing in said pond for the Inhabitance of said town to be under controul of said Trustees or their successors..." - Records, Town of Brookhaven, 1798-1856, p. 219.
1855-	Individual makes application to Town to lay down oysters in Flax Pond. Board appointed someone to view the premises and report at next meeting; appears no action taken. - Records, Town of Brookhaven, 1798-1856, p. 537.
1865-	Town agrees "to sell to highest bidder, the common land belonging to the Town, at or near the foot of Flax pond lane and adjoining said Pond." - Records, Town of Brookhaven, 1856-1886, p. 270.
1870-	reference to a "salt meadow" in this area. - Unrecorded Deeds and Land Papers in Brookhaven Town, North. (notebook, pages unnumbered).
1894-	Trustees deny individual oystering privileges. - Records, Town of Brookhaven, 1886-1900, p. 360, 364.
1897-	Capt. Daniel Smith applies for Flax Pond purchase, stating that there were 20 acres more or less, but the committee reports the pond was sold in 1819 but "the rights of fishing and clamming" were reserved to the people. - Records, Town of Brookhaven, 1886-1900, p. 360, 364.
1899-	Individual applies to open inlet to Flax Pond; Cannot be granted as property through which inlet would be cut is privately owned. - Records, Town of Brookhaven, 1886-1900, p. 437.

Maps and Charts

Three types of maps are available which illustrate the Flax Pond marsh:

1) Atlases and road maps - Although these maps constitute the longest and most continuous map record, road maps may not accurately represent shoreline features simply because the objective of the map is to illustrate the location of roads and villages. Even recent oil company maps show Flax Pond either connected to Long Island Sound, isolated from the Sound, or simply not there at all. Earlier, especially 19th century, maps were often copies of other earlier maps. This common practice resulted in out of date maps and maps which perpetuated earlier errors. For these reasons, we consider such maps to be the least accurate in their depiction of the Flax Pond marsh. 2) Topographic maps - these maps, published by the U.S. Geological Survey, are very accurate maps which show elevations, distances and landmarks. It is frequently not clear, however, in dealing with topographic maps which show tidal marshes, what stage of the tide is represented. The maps also have a relatively limited historical range. Flax Pond is depicted in topographic maps issued in 1922, 1955 and 1967. 3) Navigational charts - the coastal charts issued by the U.S. Coast and Geodetic Survey and its parent and daughter agencies are supposed to accurately show shoreline features and are, therefore, the most reliable source of information regarding coastal changes. The first of the charts which shows Flax Pond was issued in 1852. Subsequent editions were issued at intervals ranging from three months to ten years. Each edition, however, may not be a complete resurvey, but often merely updates the position of lights, buoys and other navigational aids. New base maps which show shoreline and depth changes were prepared at approximately 15 to 20 year intervals. Actual shoreline changes can take place during much shorter intervals and may not appear on the chart at all, or an ephemeral shoreline configuration may be shown on a chart for up to 20 years despite the fact that that shoreline configuration was very short-lived.

In addition to the information provided by maps and charts, aerial photographs provide direct, unequivocal information concerning the state of the shoreline. Aerial photographs which include Flax Pond were taken in 1938 and in 1969. The maps, nautical charts and photographs referred to in this paper were examined and copies from originals housed in the National Archives, the Library of Congress and the American Geographical Society.

Figure 3 shows 10 maps, charts or photographs which illustrate the major coastal changes which have taken place in the Flax Pond area since 1797. Figure 3-A is part of a 1797 survey of the town of Brookhaven and shows Flax Pond as a roughly circular pond isolated from the waters of Long Island Sound. This configuration is consistent with historical records which indicate that the Pond was fresh during much of the 18th century. This map's accurate depiction of other harbors and marshes in the area have convinced us that the 1797 map is a reliable one. Figure 3-B is a portion of an 1836 map which was designed to show the location of roads and villages. It, too, shows Flax Pond isolated from Long Island Sound, but in this case, the map is not consistent with records

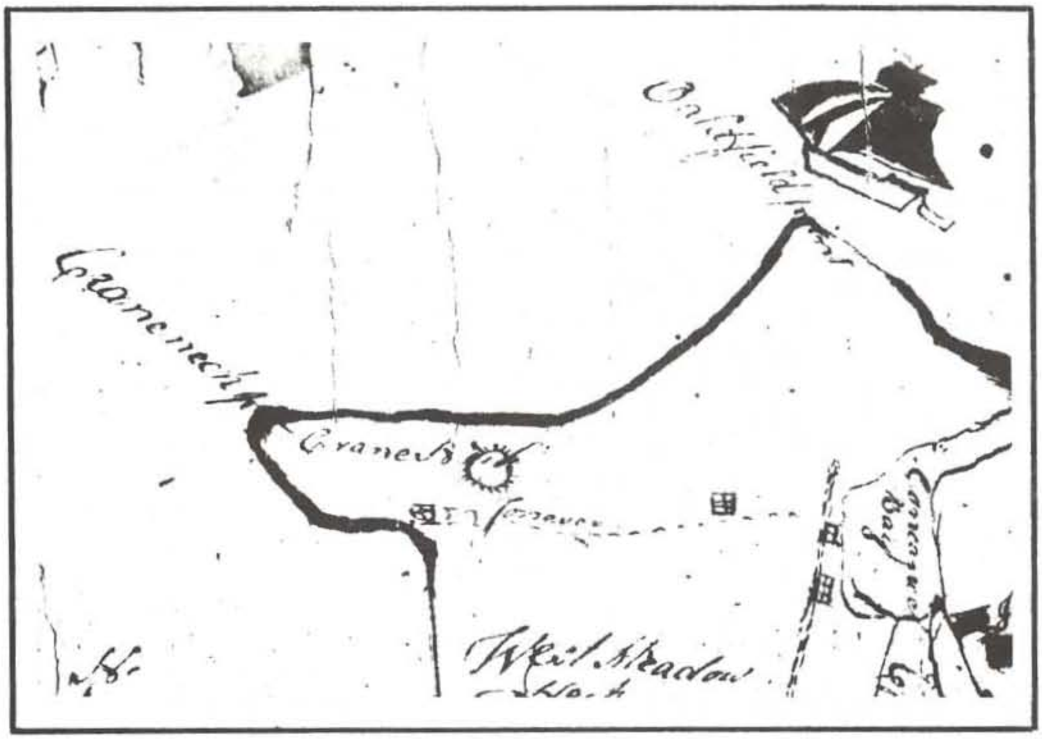

Figure 3-A: The 1797 map.

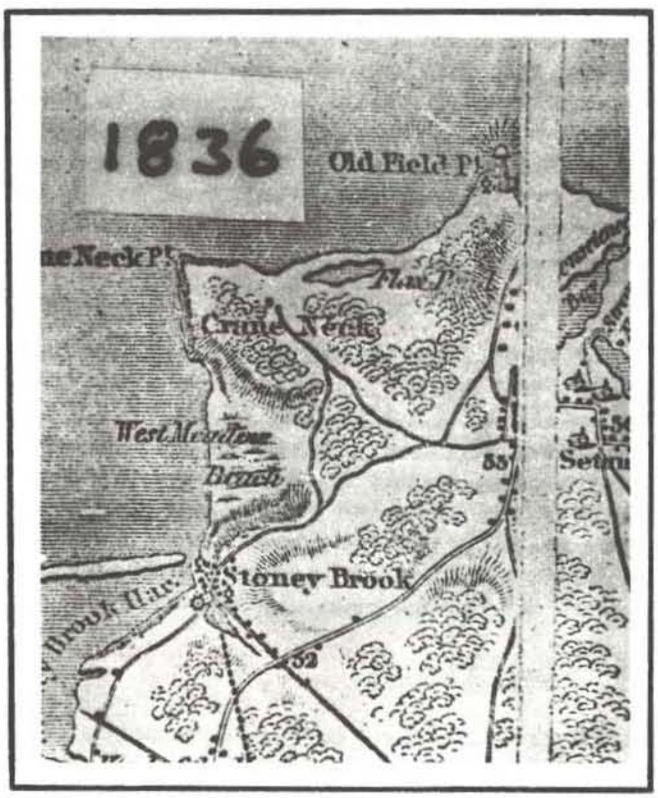

Figure 3-B: An 1836 road map.

which indicate that the Pond had been opened to tidal waters by 1801. We assume that this map is a copy of an earlier map made when Flax Pond was isolated from the Sound. Figure 3-C is from the first nautical chart of the region, issued in 1852. Although the quality of the reproduction is not good, it shows Flax Pond connected to the Sound via an inlet trending northwest-southeast and situated near the east central part of the barrier beach. The 1853, 1855, 1878 and 1880 editions of this chart are all essentially the same, differing only in information regarding the position of navigational markers. The 1890 edition (Fig. 3-D) shows two significant changes in the configuration of Flax Pond. The inlet is oriented in an east-west direction, due, presumably, to a persistent westerly longshore drift of beach sediment. The other change is the appearance of a tidal creek in the extreme eastern margin of the marsh which trends north-south and then turns abruptly to the west at the inner margin of the barrier beach. The configuration shown on this 1890 chart continues essentially unchanged through the 1931 edition. In 1933 a major change is evident in the outline of the marsh. The 1933 chart is not shown but is the same as the 1938 edition in Figure 3-F. Two inlets are apparent, one near the center of the barrier beach, the other situated on the extreme eastern margin of the marsh. Apparently, sometime between 1931 and 1933 a storm had broken through the beach on its eastern end and connected the tidal creek there with Long Island Sound. The 1938 chart does not, however, show the true state of the Pond at that time. Figure 3-G, an aerial photograph taken in July, 1938, shows the central inlet closed off and the eastern inlet extended in an east-west direction by the effects of the westerly longshore drift. The 1938 chart is apparently a largely unrevised version of the 1933 chart. The 1947 nautical chart (Fig. 3-H), while still a largely unrevised edition of the 1933 chart, shows two jetties, one positioned on each side of a central inlet. An artificial inlet had apparently been dredged by 1947 and the eastern inlet had been closed. The inlet has been stabilized by the jetties since 1947. The 1955 and 1967 topographic maps (Figs. 3-I and J) show the Flax Pond marsh essentially as it is today. Interestingly, however, the sand accumulations around the jetties indicate a predominantly easterly longshore drift, opposite that implied in the 1938 photograph.

The sequence of maps, charts and photographs illustrates three major facts about the Flax Pond marsh. 1) Prior to 1797, Flax Pond was isolated from the waters of Long Island Sound; 2) The position and orientation of the inlet changed several times between 1852 and 1947. Longshore drift and storms appear to have been the dominant natural processes responsible for the changing configuration of the inlet; 3) The direction of longshore drift has not been constant since 1852. Between 1852 and 1947 the dominant flow of littoral sediments was westerly. Since 1947 the direction of drift has been easterly.

Summary of the historical records

The information provided by historical records, maps and nautical charts indicates that Flax Pond was opened to marine waters between 1797 - the date of a map which shows the Pond isolated from the Sound - and 1801 - the date of a deed which reserves clamming rights for the town

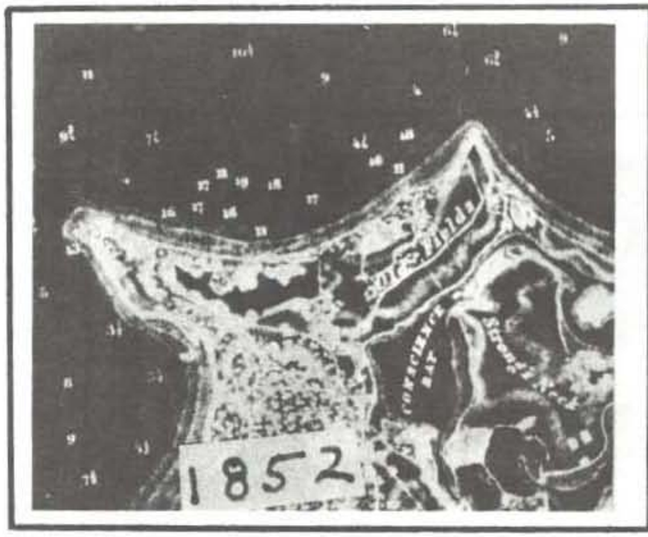

Figure 3-C: An 1852 nautical chart.

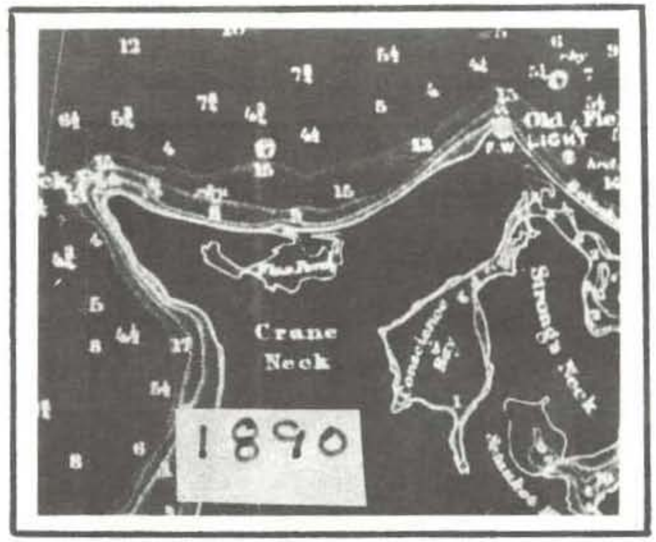

Figure 3-D: An 1890 nautical chart.

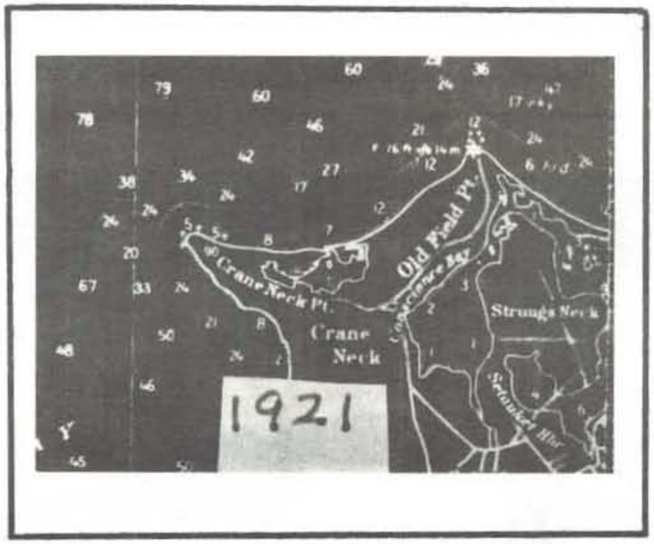

Figure 3-E: A 1921 nautical chart.

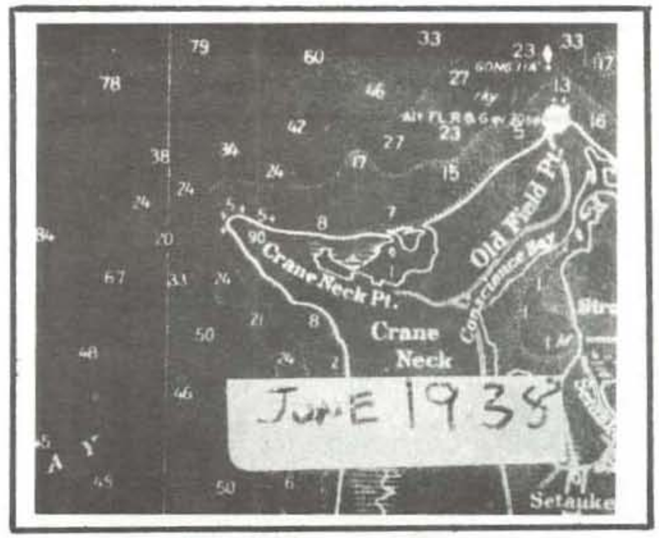

Figure 3-F: A 1938 nautical chart.

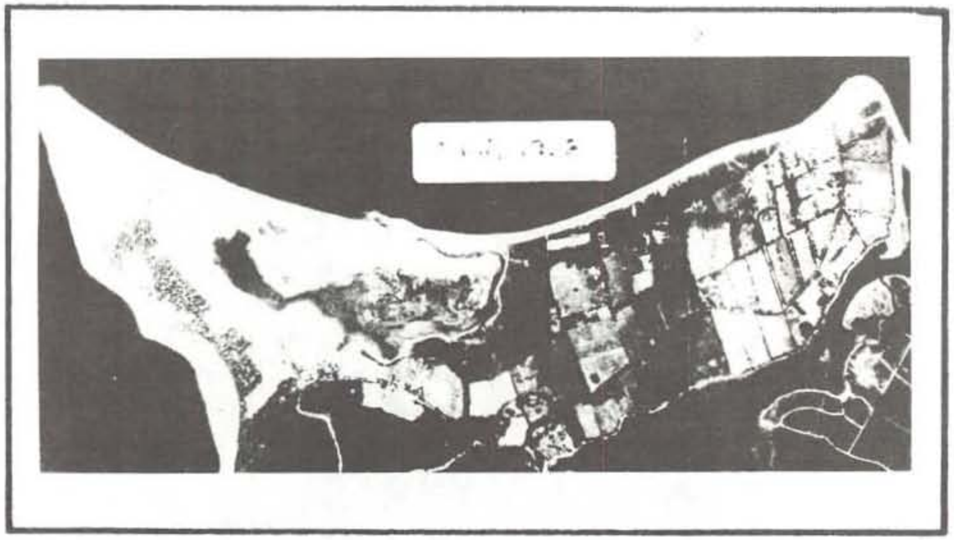

Figure 3-G:: A 1938 aerial photograph.

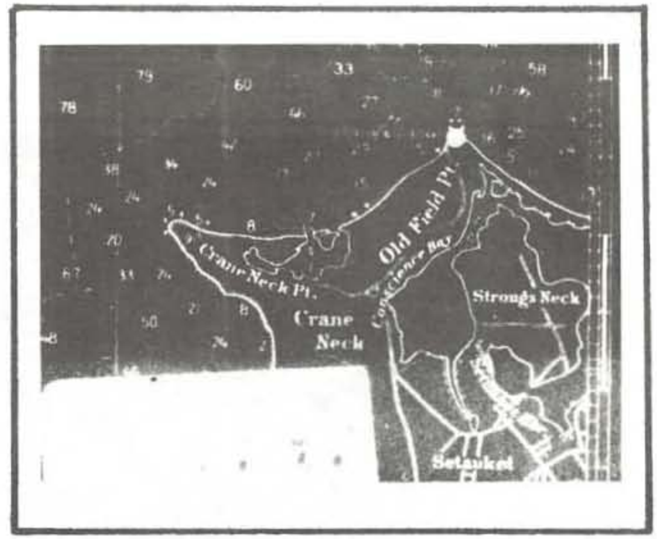

Figure 3-H:: A 1947 nautical chart.

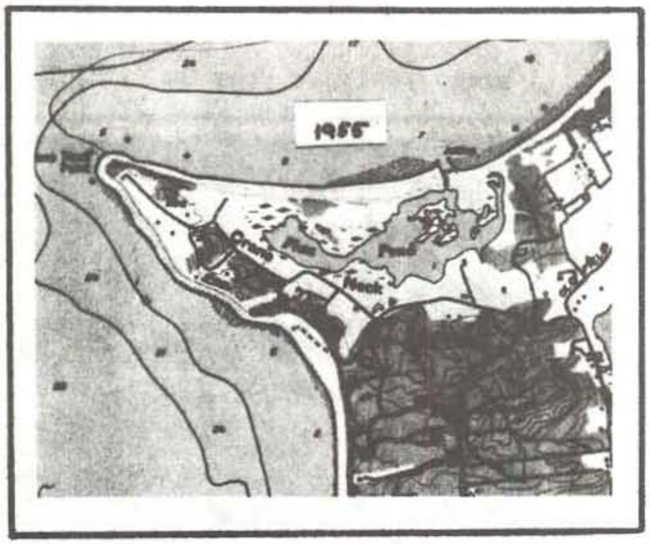

Figure 3-I: A 1955 topographic map.

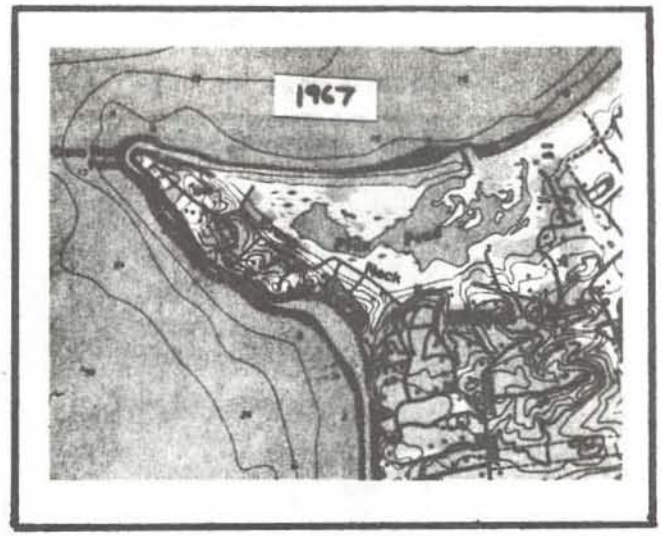

Figure 3-J: A 1967 topographic map.

residents. Subsequent to its connection with Long Island Sound the configuration and position of the inlet changed frequently as a result of longshore drift and storms. Since 1947 the inlet has been stabilized by the construction of two jetties.

SEDIMENTATION RATES

Introduction

The salt marshes of the east coast of the United States are the product of a distinctive interaction between the rate of rise of sea level, the rate of mineral sediment input, the rate of production of organic detritus and the rate at which the marsh grasses are able to trap and stabilize the sediment. In considering rates of accretion in coastal marshes it is important to distinguish between rates characteristic of the mature marsh, the elevation of which is adjusted to the level of mean high water, and rates typical of the young, immature marsh (Ranwell, 1972). The limiting factor in marsh accretion for the mature surface is the rate at which sea level rises: the marsh is at equilibrium with sea level. Studies of sedimentation rates in mature marshes have used the record of marsh peat as a tracer of sea level variation over the past hundred to seven thousand years (Redfield and Rubin, 1962; Bloom and Stuiver, 1963; Bloom, 1964; McCaffrey, 1975). In the immature marsh much of the surface is intertidal, thus the marsh can accrete at a rate faster than the rate of rise of sea level. Marker beds of various sorts (Richards, 1934; Steers, 1948; Ranwell, 1964; Bloom, 1967) and the recently developed lead-210 radiometric technique (Armentano and Woodwell, 1975) have been used to estimate accretion rates in immature marshes.

We report here on estimates of vertical and lateral rates of accretion in Flax Pond, a young, dominantly intertidal marsh. Our estimates are based on historical records which indicate the time of the marsh's first continuous connection with marine waters, an event recorded in the stratigraphy of the marsh sediments. We have also estimated vertical accretion rates through the use of marker beds located in three sedimentary environments within the marsh.

Sedimentation rates determined from historical records

Methods: During the summer of 1974 we used a 3.8 cm. (1.5 in) diameter extendable auger to sample the marsh sediments. We drilled over 340 boreholes of approximately one meter's depth every 12 meters along north-south transects spaced 75 meters apart. The sediment types and thicknesses encountered in each boring were noted in the field. A compensating polar planimeter was used to measure the area covered by *Spartina alterniflora* peat.

Stratigraphy: Four different sedimentary units were encountered during our sampling program. These units are shown schematically in Figure 4 and are described below.

Pleistocene Outwash

At the base of sections along the periphery of the marsh is a poorly stratified, poorly sorted, brownish-orange sand. Small pebbles are common in this unit. Fuller's (1914) map of Long Island shows the Flax Pond area underlain by the Manhasset formation, a unit dominated by sandy outwash deposits of upper Wisconsinan (Woodfordian) age (Mills and Wells, 1974; Sirkin, 1971). This Pleistocene deposit was encountered only along the upland margins of the marsh.

Sand and Gravel

Above the Pleistocene unit are deposits of moderately well sorted light gray sand and gravel. These sediments vary in thickness from zero near the periphery of the marsh to over one meter in the central parts of the marsh. We were frequently unable to penetrate the entire thickness of this unit because the walls of the borehole would collapse upon retraction of the auger. This layer may be the product of post-Pleistocene fluvial deposition in the small valley now occupied by the Flax Pond marsh or may represent a strand deposit laid down before the barrier spit closed off the Pond.

Sedge Peat

In the central regions of the marsh and in a few other isolated locations, a bed of fibrous, dark reddish-brown peat overlies the sandy deposits. The organic content of this peat is approximately 50 percent (Armentano and Woodwell, 1975). Florer-Heusser et al. (1975) have identified the pollen and remains of such brackish and fresh water plants as Scirpus (sedge), Phragmites and Typha in this peat. Large wood fragments and roots of the marsh elder, Iva, are also common. This layer has an average thickness of 14 cm, with a maximum of 49 cm. Sedge peat may compact to between 13 and 44 percent of its original thickness (Bloom, 1964). However, the thin overburden of Spartina peat (average of 42 cm) suggests that compaction has been minor. The lateral distribution of the sedge peat is shown in Figure 5. The sedge peat does not extend laterally to the present high water periphery of the marsh and, where present, is always overlain by Spartina peat. The sedge peats described by Bloom (1964) are time transgressive units which mark the migration of brackish water plants near the high tide line as the sea level rises. Because the Flax Pond sedge peat does not extend to the high water line and because the plants which form the sedge peat are currently rare or absent in Flax Pond, we conclude that the sedge peat reflects the depositional conditions within Flax Pond prior to its opening to Long Island Sound. Flax Pond was most likely a small, swampy area dominated by the plants listed above, plants which are not able to tolerate open Sound salinities. Because of the proximity

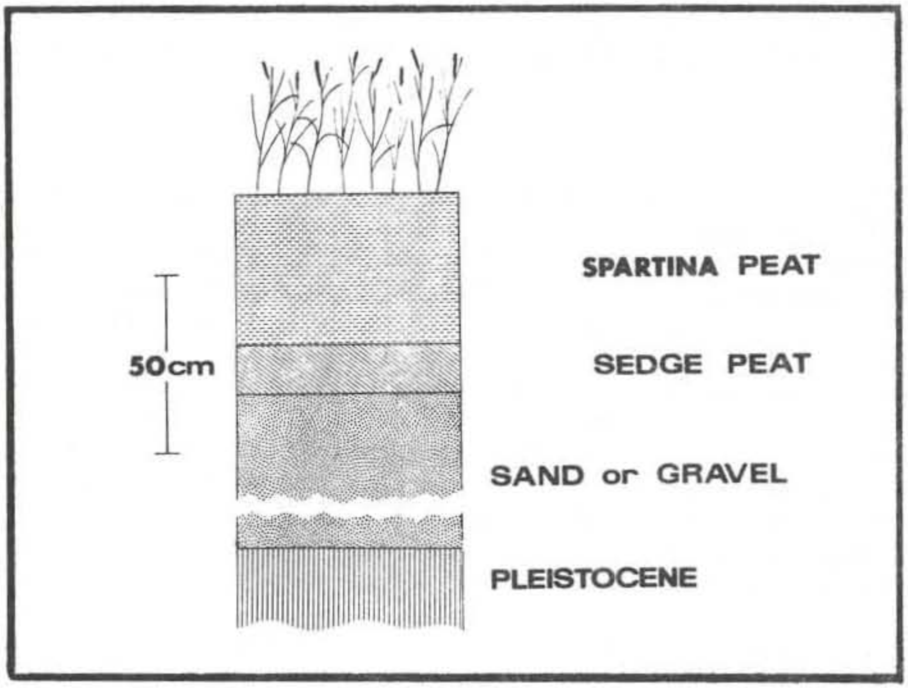

Figure 4: Schematic stratigraphic section of the Flax Pond sediments.

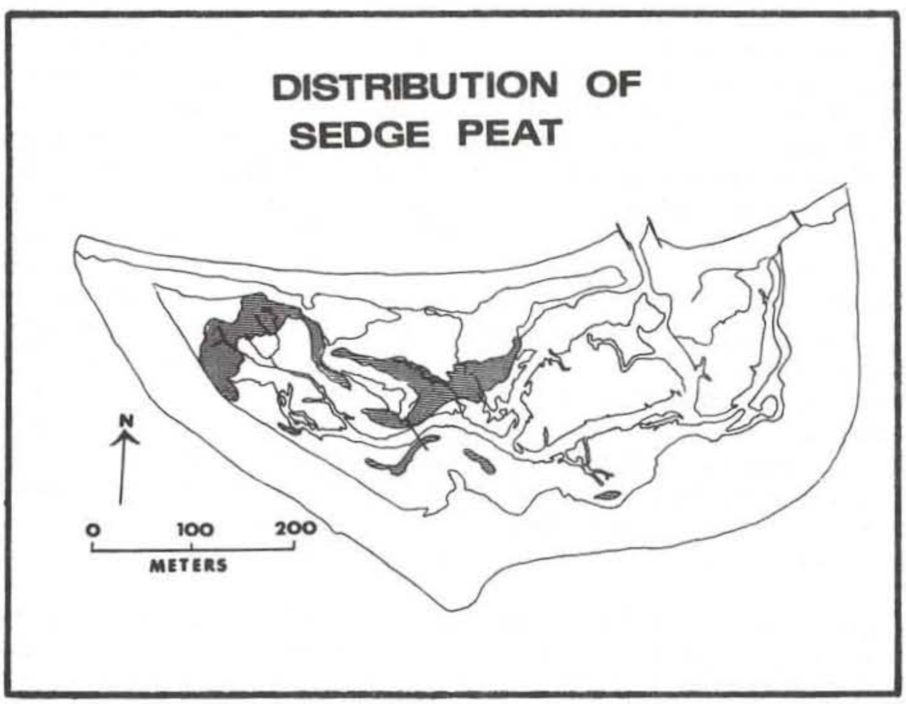

Figure 5: Subsurface distribution of sedge peat in the Flax Pond marsh.

of the area to the Sound and the likelihood of storm washovers, the water in the Pond probably ranged from fresh to brackish in character.

Spartina Peat

The Spartina, or salt marsh peat is a gray, fibrous mixture of clay, silt, Spartina alterniflora roots, rhizomes and stems and other organic matter. The organic content ranges from 20 to 30 percent (Armentano and Woodwell, 1975). The thickness of the salt marsh peat ranges from zero at the high water periphery and the newly colonized mudflats to 80 cm in the western part of the marsh. The lateral distribution and variation in thickness of this layer are shown in Figure 2. Armentano and Woodwell (1975) report no systematic variation of bulk density with depth, indicating that little compaction has taken place. Large areas in the eastern part of the marsh are not yet covered by a layer of Spartina peat, even though the region has a dense stand of Spartina alterniflora. Apparently, this area has only recently been colonized by the grass.

Vertical and lateral accretion rates: The boundary between the sedge peat and the Spartina peat marks the permanent opening of Flax Pond to marine waters. Taking 1801 as the year of the Pond's opening (the date of a document which stipulates that clamming rights were to be reserved for the local residents), 173 years had passed between the earliest possible time of deposition of Spartina peat and 1974, the year in which we measured the salt marsh peat's thickness. The average depth of Spartina peat which overlies the datable horizon is 42 cm. This yields an average accretion rate of 2.4 mm/yr. The maximum thickness of Spartina peat in the marsh is 80 cm, indicating a maximum accretion rate of 4.6 mm/yr. The rate of lateral growth of the salt marsh peat may be calculated by dividing the area now covered by Spartina peat (27,300 m^2) by the 173 years since the Pond's first connection to Long Island Sound. Lateral accretion of Spartina peat proceeds at the rate of 158 m^2/yr. These figures underestimate the actual accretion rates for several reasons: 1) Spartina alterniflora may not have become established in the marsh until a few years after its opening to the Sound; 2) peat may not have begun to accumulate immediately after Spartina colonization and; 3) erosion may have removed some of the salt marsh peat during the 173 years of net marsh growth. Some small amount of peat was undoubtedly removed by dredging operations during the 1940's. The figures of 2.4 mm/yr. and 4.6 mm/yr. for vertical accretion and 158 m^2/yr. for lateral accretion should be considered minimum rates of accretion over the past 173 years - rates during shorter intervals may have been quite different.

Discussion: Bloom (1967) and Harrison and Bloom (1974) used marker beds of metallic "glitter" to measure sedimentation rates in several Connecticut marshes. Accretion rates, based on an observation period of ten years, within the dwarfed S. alterniflora zone of two of the

Connecticut marshes are 6.5 mm/yr. and 6.7 mm/yr. (Harrison and Bloom, personal communication). These values are higher than the values we report for a marsh located on the opposite shore of Long Island Sound. The difference may be due to our underestimation of the actual rates (see above); the difference in vegetation type (Flax Pond is dominated by the tall form of S. alterniflora; or differences in the hydrology of the different marshes. Future work will evaluate the relative importance of elevation, vegetation, tidal range and rate of inorganic sediment input as determinants of marsh accretion rates.

Armentano and Woodwell (1975) have calculated sedimentation rates for two sections of Spartina peat from the Flax Pond marsh. They used the lead-210 method to date the sediments. One section of marsh peat yields a sedimentation rate of 4.7 mm/yr., while another indicates a rate of 6.3 mm/yr. The latter figure is suspect, however, because it is a rate computed from a regression line of lead-210 activities and depth which is based on only three points. Furthermore, other samples from the same section show unexpectedly constant levels of lead-210 activity. Their value of 4.7 mm/yr. is close to the range that we have calculated from our interpretation of the stratigraphy and the historical record. Any difference may be due to real differences in the sedimentary regime within the marsh. Curiously, however, the extrapolation of their sedimentation rate indicates that marsh growth began in approximately 1870, 18 years after a chart was made that shows Flax Pond connected to the Sound, and 69 years after clamming rights were ceded to local residents. Either peat accumulation at the site of their section was delayed up to 69 years or their analysis is subject to some unknown error.

We know of no studies which quantitatively estimate lateral rates of marsh accretion. Redfield (1965) shows, by a series of maps, the growth of the Barnstable, Massachusetts marsh during the past 3300 years. Redfield (1972) also compared a Coast and Geodetic Survey chart made in 1859 to one issued in 1957. Erosion and accretion appeared to be equal in the intertidal parts of the marsh during that interval.

Sedimentation rates determined from marker bed studies

Methods: Three sedimentary environments were chosen for a study of short term sediment accretion at Flax Pond: 1) bare mud flats; 2) areas where Spartina alterniflora is beginning to colonize, but has not yet formed a dense stand; and 3) areas where S. alterniflora has established a dense stand and a layer of peat has accumulated. Two one meter square plots within each environment were covered with a marker layer of either brick dust or aluminum glitter. Since mid-November, 1974, cores of sediment have been taken monthly at each plot, frozen and cut lengthwise. The position of the marker beds in relation to the upper surfaces of the cores has been used as an indicator of the total amount of sediment accretion that occurred in each environment during each month since October, 1974.

In June, 1975, four dowels were marked with millimeter scales and were placed in the plots representing the colonizing Spartina and the mud flat environments. Four metal plates were buried on the contact between the mud and the underlying sand, two plates in the mud flat environment and two in the colonizing Spartina environment. Mud depth above each plate is determined by lowering a thin cylindrical ruler into the sediment down to the level of the plate. Data on sediment accretion determined by these two methods will be compared with the data obtained by coring to determine whether the three methods yield consistent results.

Results and discussion: Monthly increments of sediment accretion are shown in Figure 6, and Figure 7 shows the cumulative sediment accretion up to July, 1975. Sediment accretion is most rapid on the bare mud flats and the least rapid where S. alterniflora has established dense stands, with intermediate values occurring where S. alterniflora is still colonizing. This pattern can be explained by elevation and distance effects. The peat surface on which the established S. alterniflora grows is at an elevation only slightly below mean high water. The other sedimentary environments are at lower elevations and therefore may receive suspended sediment for a longer time period. Mud flats are generally lower in elevation than areas where S. alterniflora is beginning to colonize and, therefore, show a higher rate of sediment accretion. The established S. alterniflora is also more distant from the main tidal channel than the other two environments, and a large portion of the suspended sediment load may become deposited on the mud flats and areas of colonizing S. alterniflora before it can reach the established S. alterniflora. Therefore, in spite of the fact that S. alterniflora aids in trapping and binding sediment (Redfield, 1972), the lowest accretion rates occur where Spartina growth is densest.

Previous studies of sedimentation rates at Flax Pond have concentrated on determining average sedimentation rates over much longer time periods. Armentano and Woodwell (1975) estimated, through Pb-210 dating, a peat accumulation rate in the western end of Flax Pond of 4.7 to 6.3 mm/year. Flessa and Constantine (1975) calculated an average rate of peat accumulation of 2.4 mm/year and a maximum rate of 4.6 mm/year by measuring the thickness of Spartina peat that has accumulated since Flax Pond was opened to marine waters in 1801.

The marker beds in the areas of established Spartina growth indicate that 3.5 mm of peat have accumulated during the past 9 months. If this rate is extrapolated to a period of one year, an annual accretion rate of 4.7 mm/year is calculated, which is slightly higher than the range of sedimentation rates reported by Flessa and Constantine (1975) and is at the lower limit of the range reported by Armentano and Woodwell (1975).

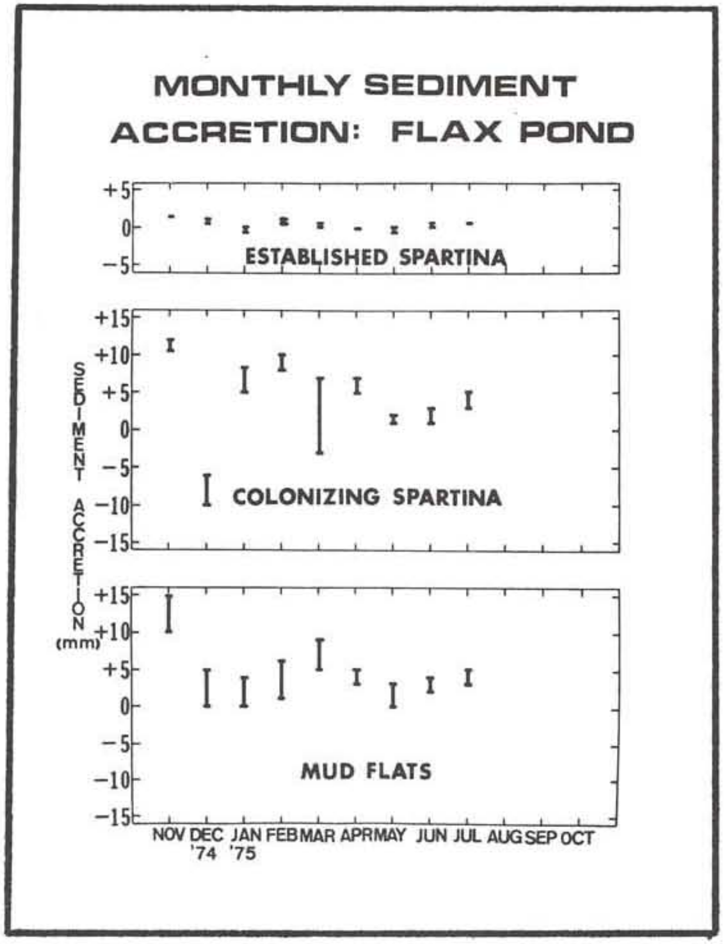

Figure 6: Monthly sediment accretion at Flax Pond. Bars indicate the range of accretion measured at the two stations in each environment.

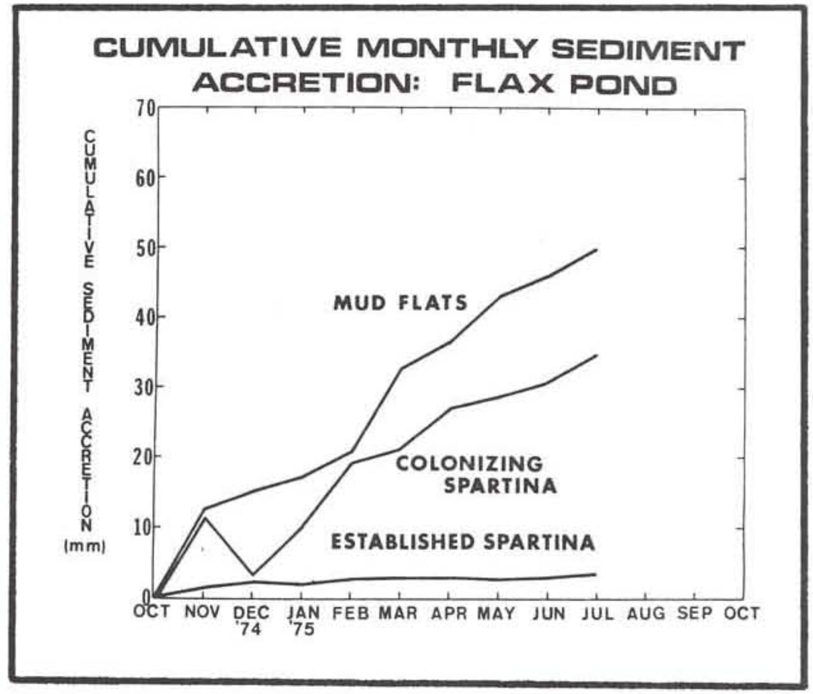

Figure 7: Cumulative monthly sediment accretion at Flax Pond since October, 1974. Values plotted are the mean of the two stations in each environment

The apparent discrepancy has a number of possible explanations, including intermittent periods of erosion and deposition, peat compaction, or a recent increase in the sedimentation rate brought about by an increase in the rate of sea level rise.

Long term peat compaction at Flax Pond was ruled out by Armentano and Woodwell (1975) who found no large-scale increase in peat density with depth. However, if compaction occurs rapidly in the top few centimeters of peat, a sedimentation rate of 4.7 mm/year may result in a much lower true accretion rate.

Bloom (1964) found that sea level rise during the past 3000 years averaged 1 mm/year. However, Meade and Emery (1971) found that the rate of rise in sea level increased to 3 mm/year since 1930 and Harrison and Bloom (1974) determined a sea level rise of 1 cm/year from 1964-1970. The recent rise in sea level may have resulted in a recent increase in the rate of peat accumulation.

Ranwell (1964) found seasonal variations in sediment accretion rates at Bridgewater Bay in southern England. Accretion rates were highest at most of Ranwell's sites from August to October, 1960. In this study, most of the accretion where Spartina has become established has, thus far, occurred between October and December, with almost no peat accumulation between February and June. Since accretion is seasonal, cores taken in October, 1975 may show that annual accretion is not actually 4.7 mm/year. Ranwell (1964) found that erosion occurred at most sites at some time during the year. In this study the only pronounced incidence of erosion, thus far, has occurred between November and December where Spartina is colonizing.

Final interpretation of the data obtained in this study must await collection and examination of the October, 1975 sediment cores. The sediment above the marker layers in these cores will represent a full year's accretion. Comparisons can then be made of seasonal and spatial differences in sedimentation rates. An attempt will then be made to devise a quantitative model of sedimentation at Flax Pond which incorporates changes in sedimentation rates that occur as the marsh surface is built upward.

CONCLUSIONS

Historical records and maps indicate that prior to 1801 Flax Pond was a fresh water pond isolated from the marine waters of Long Island Sound. Since 1801 the Pond has been connected to tidal waters by an inlet whose orientation and position have changed as a result of longshore drift and storms.

The opening of the Pond to marine waters is recorded in the stratigraphy of the marsh sediments by a sharp transition from Sedge (brackish or fresh water) peat to Spartina (salt marsh) peat. This dated horizon was used to calculate minimum estimates of vertical accretion ranging from 2.4 to 4.6 mm/yr. Lateral accretion of the marsh peat proceeds at the rate of 158 m^2/yr.

Marker bed studies show that sedimentation is most rapid on mudflats, slightly lower in areas newly colonized by Spartina alterniflora and slowest on the peat surface. On the peat surface vertical accretion proceeds at the rate of 4.7 mm/yr. These estimates may predict the rate at which Spartina marshes are able to recover from physical disturbance.

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FIELD TRIP GUIDE

You will be picked up near the pier in Port Jefferson harbor and taken to the Flax Pond marsh in a bus. The trip to the marsh is a short one and passes through the hilly topography characteristic of the Pleistocene Harbor Hills moraine.

The bus will park near the Department of Environmental Conservation's research lab and we will walk west along the road for about 0.25 mi. to reach the trail to the marsh. Beware of the Rhus radicans (poison ivy) at the trail entrance.

STOP ONE: The footbridge over the main channel provides an overview of the marsh and its geologic setting. The lighthouse to the ENE is situated atop Old Field Point, a bluff composed of the morainal sediments of the Harbor Hills moraine. The hills to the WNW, terminating in Crane Neck Point, are also composed of this glacial sediment. These bluffs are the source of the sediments on the barrier beach. Topographic, vegetation and surface sediment maps will be displayed on posters at this stop and will provide an opportunity for a description and discussion of the general features of the marsh. See also the section in the paper entitled "The Flax Pond marsh: general features".

Proceed to the northeast through a stand of Iva (the marsh elder) and Juncus (black grass), across a sandy patch which shows how the common marsh grasses spread via rhizomes, and onto a stand of Distichlis spicata and Spartina patens. Note how sharply these vegetation zones are bounded. Continue SINGLE FILE (to minimize the damage to the marsh) across the Spartina alterniflora zone to the bank of a small tidal creek. The far bank exposes the stratigraphy of the marsh sediments.

STOP TWO: Note the three distinct strata that are exposed here: the Spartina peat at the top, the reddish-brown, finely textured sedge peat, and the underlying coarse sand. Historical records indicate that the transition from sedge peat to Spartina peat took place in 1801. This datable horizon permits the calculation of sedimentation rates for the Spartina peat. Calculated estimates for vertical accretion range from 2.4 to 4.6 mm/yr. Lateral accretion proceeds at the rate of 158 m^2/yr. At this site a poster which summarizes the historical information in Table 1 will supplement the discussion of the environmental significance of these strata. Additional background information for this stop is in the article sections entitled "Flax Pond: the historical record" and "Sedimentation rates determined from historical records". Proceed back along the trail toward the footbridge. Instead of crossing the bridge turn to the northwest and walk along the periphery of the wooded upland (probably a submerged kame) to Stop Three.

STOP THREE: To the south and west of this stop are bare mudflats, hummocks of Spartina alterniflora, mudflats newly colonized by

S. alterniflora, and areas with well established stands of the grass. These areas include the sites of our marker bed studies. A poster showing monthly increments of sediment accretion since October, 1974 and cumulative accretion since that time will provide the basis for a discussion of the rates, environmental controls and seasonal patterns of marsh accretion. For additional information regarding this stop see the text section entitled "Sedimentation rates determined from marker bed studies".

Proceed to the east along the margin of the wooded area. We will pass through an extensive stand of *Juncus* and *Iva*. On the inner margin of the barrier beach you should note the lobate appearance of the gravel deposits. These lobes appear to be encroaching upon the marsh surface. Their movement is presumably due to extreme storm waves. The area immediately to the west of the inlet was dredged during the 1940's for sand and gravel. Present depths in this area are about 3 meters at low water.

STOP FOUR: The inlet, stabilized by jetties since 1947, has not been a stable feature of the Flax Pond marsh. Longshore drift and storms have been responsible for changes in the character and position of the inlet. The maps and charts also indicate a change in the dominant direction of longshore drift from westerly prior to 1947 to easterly since that time. A series of maps, charts and photographs dating from 1797 to 1969 will illustrate the major changes in the configuration of the inlet over the past 178 years. For further discussion see the section titled "Maps and charts".

Return to the bus by walking back along the trail to the footbridge and the road.

NOTES

THE LATE QUATERNARY GEOLOGY OF THE MONTAUK PENINSULA: MONTAUK POINT TO SOUTHAMPTON, LONG ISLAND, NEW YORK

By William Nieter[1], Bronius Nemickas[2], Edward J. Koszalka[2], and Walter S. Newman[1]

ABSTRACT

The Montauk Peninsula is composed of several glacial, periglacial and interglacial units including the Gardiners Clay(?), Montauk Till Member of Manhasset Formation, late Wisconsin drift, and loess. The stratigraphy of these units is complicated by large-scale glacial tectonic structures. The occurrence of two or more drifts in several localities suggests that this area underwent multiple glaciations and that the morainal features may, in part, be diachronous. The surface of much of the late Wisconsin drift is mantled by aeolian sediments that closely resemble loess. Accumulation of the loess is believed to have occurred under true periglacial conditions which created thermokarst features such as the Scuttlehole depression.

INTRODUCTION

Long Island is long and narrow, reaching east-northeastward from New York City to form a fishlike eastward extension of New York State. The island lies south of and is approximately parallel to the Connecticut shore and is separated from it by Long Island Sound. Long Island also forms a north shore of that ocean reentrant known as the "New York Bight".

Although part of the Atlantic Coastal Plain physiographic province, Long Island features a topography almost completely modified by glacial, proglacial, and periglacial processes. Two conspicuous terminal moraines extend almost continuously along the length of the island. The Harbor Hill Drift traverses the northern length of the island. The Ronkonkoma Drift traverses the central length and constitutes a major part of the south fork. The island abounds in other glacial and proglacial features, such as the coalescing outwash fans and aprons that form much of the southern part of the island.

THE MONTAUK PENINSULA

The Montauk Peninsula, as here defined, extends east from the Shinnecock Canal to Montauk Point (figure 1). All trip stops and geographic localities mentioned in the text are located on figures 2 and 3. The Shinnecock Hills, just east of the Shinnecock Canal, are part of the morainal complex of the Ronkonkoma Drift and are the west end of a ridge of coalescing hills traversing the area from west to east. The knob and kettle topography of the

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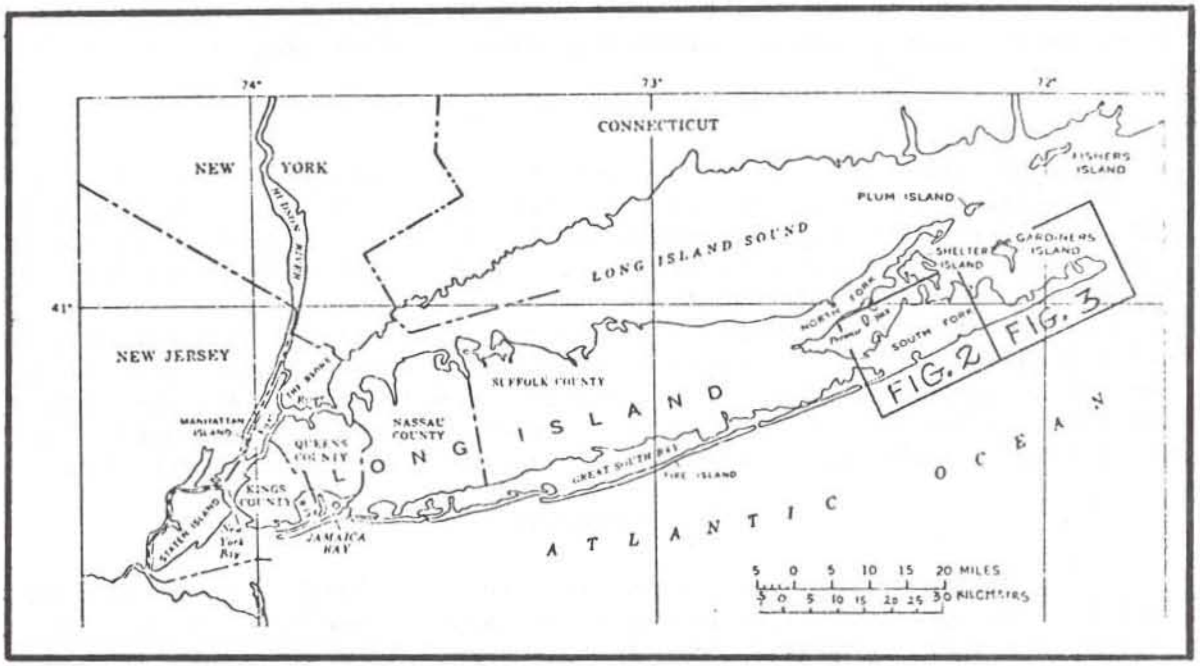

Figure 1. Location of study area and general geographic features of Long Island, N. Y. (Modified after Franke and McClymonds, 1972.)

Ronkonkoma Drift strikes northeast from a point north of the village of Southampton, arcs toward the east, north of Bridgehampton village, and finally strikes southeast, north and northeast of the village of Easthampton. This morainal segment abruptly terminates at the Bluff Road sea cliff. The terminal moraine reappears once again 4 miles east-northeast of Beach Hampton, at Hither Hills, where it strikes northeast and terminates once again at Fort Pond Bay. Another segment of knob and kettle morainal topography occurs between Fort Pond Bay and Lake Montauk. A final segment of morainal topography is found around Prospect Hill, northeast of Lake Montauk. East of Montauk Village and generally south of Route 27 (figure 4) the topography is relatively subdued. The south coast is fronted by bluffs up to 80 feet high, and the south-southwest trend of the south shore of Long Island is lost. Distinct kettles are relatively rare, although bogs are not uncommon.

The Ronkonkoma Drift forms the "backbone" of the Montauk Peninsula. It is as much as 3 miles (4.8 km) in width and achieves a local relief of more than 100 ft (30.5 m) in some places. A maximum elevation of more than 280 ft (85.3 m) is reached about 3 miles (4.8 km) northwest of Bridgehampton.

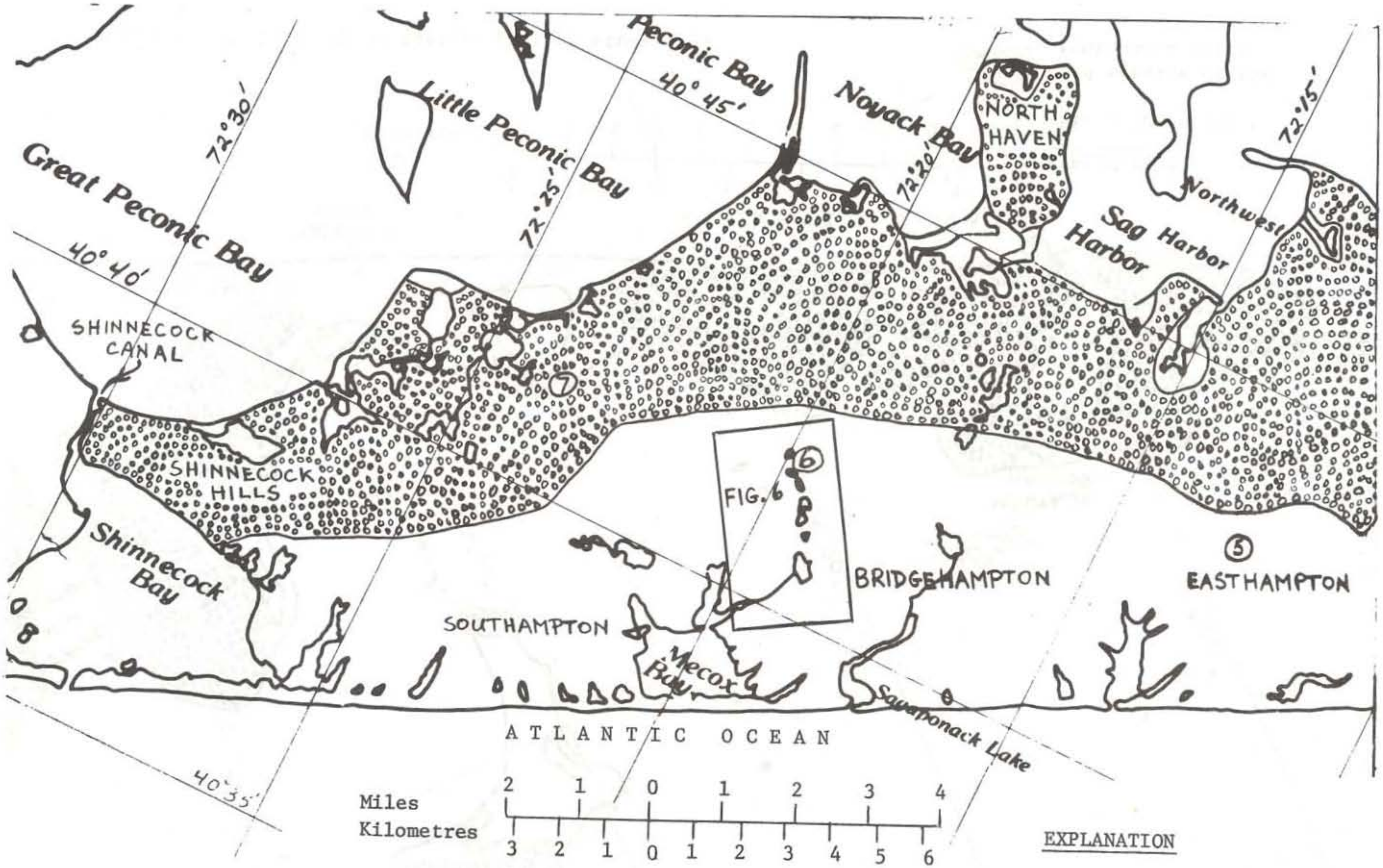

Figure 2. Outline map of western part of study area.

EXPLANATION

6 Field Trip Stop

End moraine of the Ronkonkoma Drift

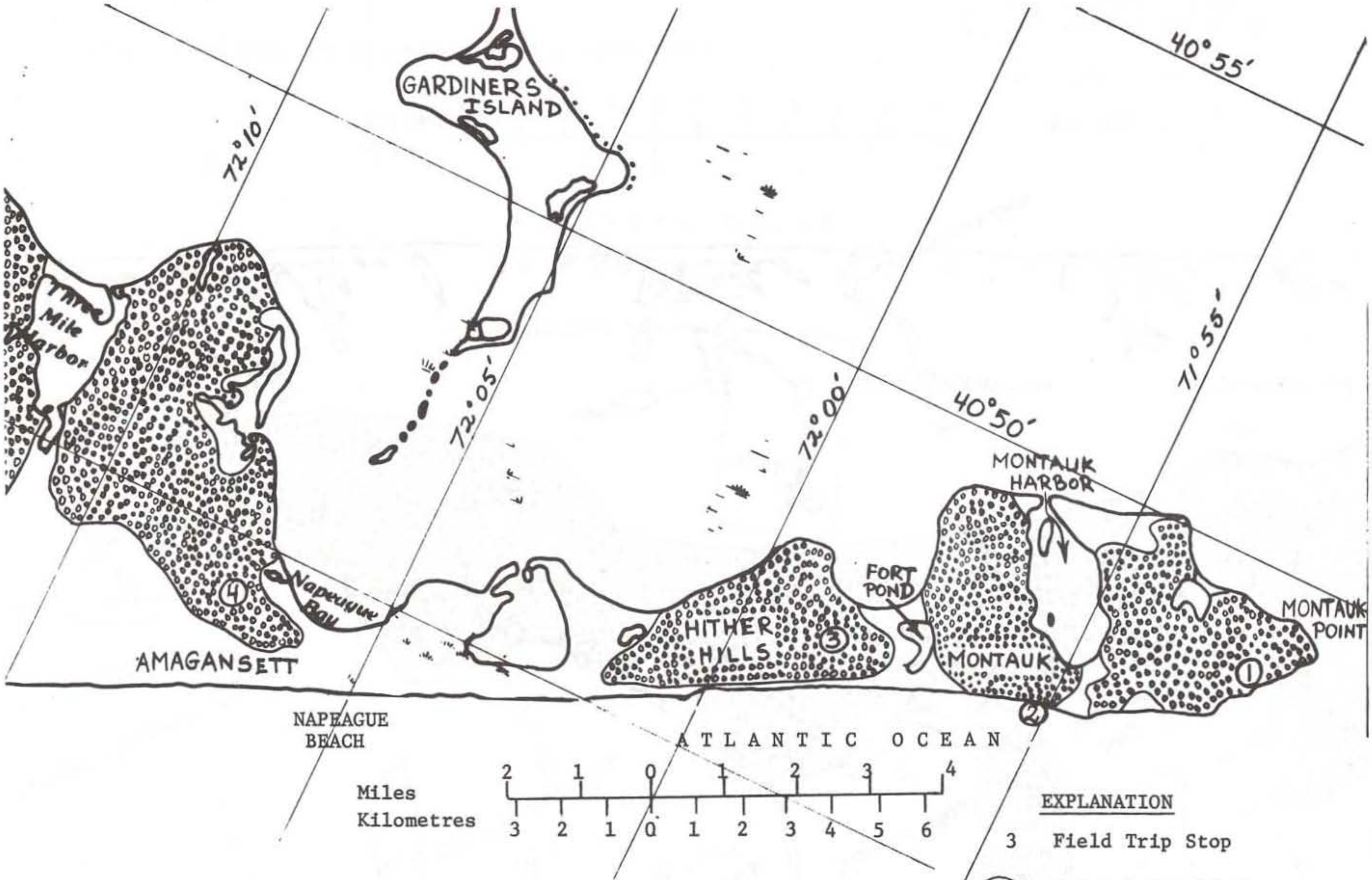

Figure 3. Outline map of eastern part of study area.

Figure 4. Aerial photograph illustrating changes in morainal topography along route 27, east of Montauk Village. Note conspicuous and relatively fresh ice contact deposits north of Route 27 which contrasts with the more subdued topography mantled by loess to the south.

Although traceable across the study area, the moraine should not be thought of as a stratigraphic unit. At several of our field stops, the moraine seems to be a composite feature that is composed of many different materials, often possessing a wide variety of structural relationships and probably originating at different times.

An outwash plain, generally consisting of coalescing alluvial fans, abuts the south edge of the Ronkonkoma Drift. The plain is nearly 5 miles (8.1 km) wide in the vicinity of Bridgehampton and narrows to a feather-edge both to the west-southwest and east-northeast of that village. In the vicinity of Bridgehampton, the outwash plain appears to be a large alluvial fan whose head is located at the lake-studded defile through the terminal moraine south of Sag Harbor. The maximum sill elevation of this defile is about 30 ft (9.1 m) above mean sea level. The village of Easthampton is located on a smaller alluvial fan, which heads in a defile south of Threemile Harbor. The maximum sill elevation here is also about 30 ft (9.1 m). The west end of the outwash plain terminates at Shinnecock Bay; the east end is cut off abruptly at Bluff Road in Beach Hampton. Farther east, there is no feature equivalent to the outwash plain.

The glacial drift that constitutes most of the Montauk Peninsula has been extensively modified by littoral and aeolian processes. East of Montauk Village, steep wave-cut bluffs rise abruptly from 30 to 80 ft (9.1 to 24.4 m) above the narrow boulder-strewn beaches. Fronting the ocean, from the village westward, are increasingly wide sandy beaches; from Montauk Village west to Easthampton, a wide beach is backed by a dune field, which has, in places, covered a fossil wave-cut cliff (see Bluff Road) onto the outwash plain to the north. From Easthampton west, the shoreline consists of fringing beaches at the distal edge of the outwash plain and several baymouth beaches. Along the north shore, littoral spits, baymouth beaches, and tombolos are common. Coastal sand dunes, which have migrated inland to distances up to 1.5 miles (2.4 km) cover much of the area directly behind the south-shore beaches from Hither Hills west to Southampton.

QUATERNARY STRATIGRAPHY

Fuller's (1914) mapping and description of eastern Long Island's Quaternary terrane is largely unassailable, although his interpretation of the areal geologic history requires extensive revision. Fuller recognized and described the deformation of Pleistocene and older strata in many exposures on Long Island. However, it remained for Mills and Wells (1974) to document the profound role that glacial tectonics has played in complicating the island's stratigraphy. Mills and Wells found that glacial movement onto Long Island caused large-scale thrust faulting and folding of Cretaceous and Pleistocene strata; for example, the transport of detached blocks of Cretaceous sediment over Pleistocene deposits in northwestern Nassau County (see trip B5).

Indeed, klippe and imbricate stacking of strata appear pervasive in much of the Montauk Peninsula (stops 1, 2 and 3) (figure 5). Glacial tectonics were responsible for most of the Pleistocene stratigraphic disagreements encountered in the geological literature concerning Long Island. With the recognition of the stratigraphic confusion caused by glacial tectonics, the stratigraphic sequences encountered in the field become more explicable, permitting some simplification of Long Island's Pleistocene stratigraphy.

The Gardiners Clay Problem

"The Gardiners Clay derives its name from Gardiners Island... on which several clay beds with included sands are well exposed at a number of points" (Fuller, 1914, p. 92). Fuller specifically restricted the term to interglacial clays. In western Long Island, the Gardiners Clay is consistently encountered under the south coast at depths of 50 or more ft (15.2 m) below sea level. It yields marine and brackish-water fossils similar to forms presently living along the Long Island littoral. According to Fuller (1914, p. 105-106), two localities on Gardiners Island contained fossils: (1) a locality just east of Cherry Hill Point, and (2) another unspecified locality. MacClintock and Richards (1936) visited the Cherry Hill Point locality and confirmed the presence of an interglacial fauna. However, de Laguna, in Suter and others (1949), although confirming the previous findings by MacClintock and Richards, found that the Gardiners Clay on Gardiners Island is, in large part, varved and therefore is probably lacustrine rather than marine in origin. Upson (1966) reported that many of the silt and clay exposures along the eastern part of the north shore of Long Island are lacustrine rather than marine in origin and believes they are glacial rather than interglacial. Further compounding the "Gardiners Clay Problem", was the discovery of another fossiliferous marine deposit of greenish-gray silt and clay above the Gardiners Clay under the southwestern shore of Long Island. Called the "20-foot" clay by Perlmutter, Geraghty and Upson (1959), this unit appears interbedded with outwash of Wisconsin age, is 5 to 20 ft (1.5 m) thick in most places, and its top is generally at about 20 ft (6.1 m) below mean sea level. Its fauna is similar to that of the Gardiners Clay.

Upson (1970) while mapping the Mattituck Quadrangle northeast of Riverhead, Long Island, recognized the three-fold nature of the problem.

> "As seen by this writer (Upson, 1970, p. B158), the typical Gardiners is tough clay in massive beds 10 or more feet thick and is nearly always deformed, with distortions ranging from broad folds to minute contortions. The clay is nearly always overlain by the Jacob Sand through a transitional phase; that is, where the sequence is well exposed, the Gardiners Clay becomes less tough in the upper part and is laminated with seams of fine sand and silt. Upward these seams become thicker and coarser, and the clay laminae become thinner and farther apart until the whole inter-laminated zone gives way to massive, or finely bedded fine to medium sand. This is the Jacob Sand."

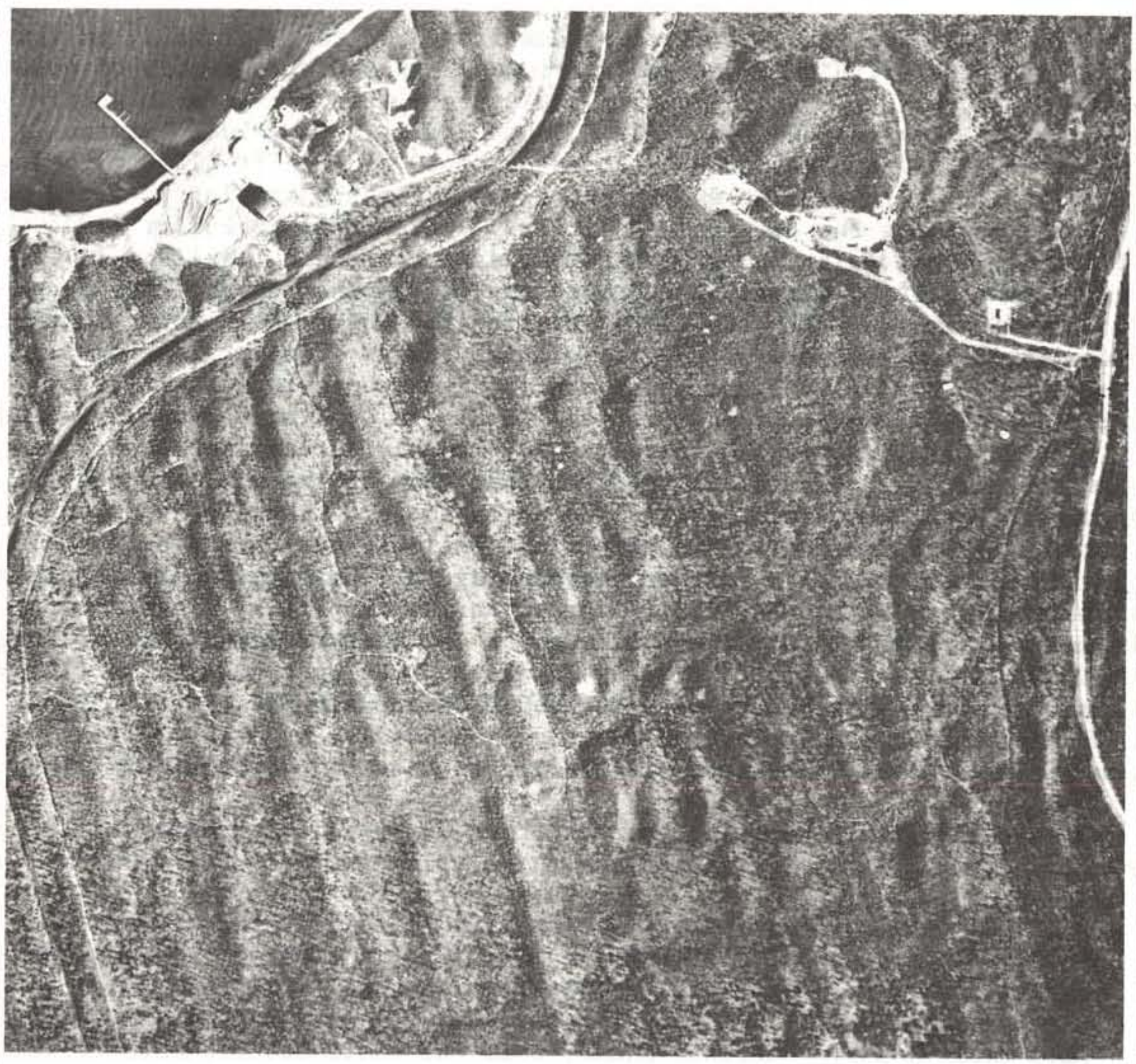

Figure 5. Aerial photograph illustrating the push moraine topography in the area of the Montauk sanitary landfill site.

Upson (op. cit.) further observes:

> "The overall stratigraphic sequence exposed in the cliffs of the Mattituck quadrangle and the eastern part of the adjoining Riverhead quadrangle consists from bottom to top of (1) dark, ordinarily red clay, ordinarily near the bottom of the exposures and visible only in places, (2) fine to medium, massive to faintly stratified sand and silt, gray or faintly yellowish, to faintly stratified sand and silt, gray to faintly yellowish, and characterized by more or less abundant white mica in tiny flakes, (3) thick and rather uniform coarse sand and pebble gravel, light gray to yellowish, and (4) compact gray till. The clay grades upward through interlamination with the fine sand and silt, these two representing the Gardiners Clay and Jacob Sand. Bedding of both these units is distorted to a greater or lesser degree. Except where strongly distorted the sand and silt pass upward through a gradual transition into the coarse sand and gravel. This unit is most conspicuous in the higher cliffs, where it is several tens of feet thick, and represents the Herod Gravel of Fuller. The overlying till is the Montauk Till of Fuller (1914, pl. I). The contact is sharp at some places and gradational at others. Some still younger deposits, present locally, are thought to represent the Harbor Hill Moraine and post-Harbor Hill outwash, but these are not discussed here."

Upson's Mattituck-Quadrangle stratigraphic sequence is remarkably similar to the sequence encountered in the southshore cliffs of the Montauk Peninsula east of Montauk village (stop 1). Upson (op. cit.) believes that:

> "In the Mattituck quadrangle the sequence indicates glacial conditions. The few pebbles of appreciable size occurring randomly in both the clay and the fine sand suggest ice rafting. The overall sequence is clearly a transitional one culminating in till, and in general the grain size increases upward...In the large cliff about a quarter of a mile from the northern edge of the quadrangle, the clay clearly interfingers with the sand and gravel that lies beneath the Montauk Till."

Although the laminated silts and clays exposed in the south shore bluffs of the Montauk Peninsula are clearly proglacial lacustrine deposits, at least one exposure of fossiliferous marine Gardiners Clay has been found in the area. Fuller (op. cit.) found a large block of allochthonous fossiliferous Gardiners Clay in the Ronkonkoma Drift north of Bridgehampton. The fauna was analyzed in detail by Gustavson (1972). He reported the occurrence of two foraminifers, one coelenterate, three bryozoans, and twenty-five molluscan species, five of which mollusks are restricted to more southerly waters. Gustavson (1972) concluded that the presence of a warm-water fauna suggests that deposition of the Gardiners Clay took place probably during the Sangamon Interglaciation, and that the climate at that time was slightly warmer than at present.

The authors sampled the "Gardiners Clay" at Montauk Point and examined it for microfossils. Although most samples were devoid of microfossils, several samples did contain lean assemblages of cool Pleistocene flora including Pinus (pine), Picea (spruce), and Betula (birch) as well as reworked Cretaceous and Tertiary spores and pollen. The small number of pollen grains suggest that they were transported into the depositional site by wind and glacial meltwaters. The contrast between Gustavson's locality at Bridgehampton and the Montauk site suggests that the "Gardiners Clay" represents a diachronous diversity of depositional environments.

The Problem of the Montauk Till Member of the Manhasset Formation

In his attempt to fit Long Island stratigraphy into the classical fourfold divisions of the American mid-west, Fuller (1914) assigned the Montauk Till Member of the Manhasset Formation to be Illinoian in age. Fuller's assignment has long since been corrected by MacClintock and Richards (1936). Nevertheless, the distinctive banding and lamination of compactness of the Montauk Till Member in its type area near Montauk Point (stop 1) led both Woodworth and Wigglesworth (1934) and Kaye (1964) to correlate tills of similar aspect, which they encountered on Martha's Vineyard with the Montauk Till Member of Long Island. The distinctive fabric of the Montauk Member is exposed in the coastal bluffs of the south shore east of Montauk Village and at one locality in the Port Washington sand pits of northwestern Long Island. Newman and others (1968) erroneously assigned the Montauk Member to the Ronkonkoma Stade of Wisconsin age. It is clear at stop 1 that a younger till overlies the type Montauk Till Member since a radiocarbon dated log found between these tills indicates that the Montauk Member is pre-Woodfordian in age.

Perlmutter and DeLuca (1963) investigated the Pleistocene stratigraphy of the Montauk Air Force Station (stop 1). Borings in the area disclosed a lower unit of stratified drift composed of nonmarine grayish-brown medium to coarse sand and gravel and some thin lenses of clay and silt. Perlmutter and DeLuca (op. cit., p. B11) found:

> "Immediately above the lower unit of stratified drift is an undifferentiated unit of varied lithology composed of interbedded deposits of till and stratified drift about 30 to 100 feet thick...the lower 20 to 40 feet of the undifferentiated deposits consists of interbedded gray and brown clay, laminated green and gray silt and clay, and some lenses of fine brown sand."

The latter sequence resembles the proglacial Gardiners Clay-Jacob Sand sequence of Upson (1970). Perlmutter and DeLuca (op. cit., p. B11-B12) continue:

> "The middle part of the undifferentiated deposits is probably composed largely of gray and brown compact clay and gravelly till, which grades laterally into fine-grained stratified drift in some places. Immediately above the compact till (read "Montauk Till Member") is generally stratified drift, which ranges in thickness from a featheredge to about 30 feet and is composed chiefly of beds and lenses of brown and gray silt, fine to medium sand, and clayey sand. The upper-

most part of the undifferentiated unit is generally a loose brown clayey till, about 5 to 20 feet thick, which contains some boulders. In some outcrops the intervening stratified drift is missing, and the upper till apparently rests directly on the lower till."

Robert Matarese, then an undergraduate geology student at Queens College, discovered a one-foot thick peaty silt lense between the two tills at stop 1. The lens contained wood, which yielded a C-14 date of 38,800 + 5600/-3200 years B.P. (sample no. RL-318). Mary Whiting Goldberg, currently a graduate student at Queens College, found a boreal pollen spectrum in the silt adhering to the wood, whereas silt above and below the wood showed largely N.A.P. spectra. The lens appears to represent a mid-Wisconsin interstade and suggests the Montauk Till Member to be pre-late Wisconsin. If this is a correct evaluation, earlier Wisconsin Glaciation was as extensive as in the late Wisconsin Glaciation along this segment of the Laurentian ice front.

The Montauk Till Member is commonly exposed in the sea bluffs along the south shore east of Montauk Village. Although the Montauk Member is usually mantled by younger drift, the latter sediment is mostly thin, and the morainal topography south of Route 27 east of Montauk Village appears distinctly more mature, as compared to the relatively fresh appearance of the late Wisconsin Drift north of Route 27.

Late Wisconsin Drift

As noted earlier, the Ronkonkoma Drift extends as a terminal moraine ridge almost completely across the area. The moraine is best described as a series of coalescing kames composed of foreset beds of sand and some gravel. Surficial till is relatively inconspicuous, although, occasionally, massive lenses and layers of till are encountered in the moraine at depth. Some of the till appears to resemble flowtill (stop 4). Exposures in the moraine frequently reveal folds and faults due to some combination of glacial tectonics and slumping. Although we, as yet, have no absolute date, the undissected terrain suggests to us that most of the Ronkonkoma Drift in the area is late Wisconsin in age.

The outwash plain between Southampton and Amagansett slopes gently south-southeast at approximately 20 ft/mi. (6.1 m/km). Near the Atlantic shore, the outwash plain is truncated by wave erosion and the prevailing westerly longshore drift. In its northern reaches the outwash plain grades into the moraine of the Ronkonkoma Drift, neither feature being dissected to any great degree. The moraine and outwash plain appear to be intimately linked and probably coeval in origin. Large parts of the outwash plain in this area are covered by loess.

The problem of loess

Late-glacial aeolian activity has been reported from the New England-Long Island area (de Laguna 1963, Schafer and Hartshorn 1965, Hartshorn 1967). A late-glacial loess was first reported from the eastern Montauk Peninsula by Newman and others (1968). Further field work and laboratory analysis by Nieter (1975) confirmed the occurrence of loess, and its distribution and thickness in the western Montauk Peninsula (Shinnecock Canal to Amagansett) was mapped. Scanning electron microscopy of the silt and sand components and grain-size analyses of the samples showed marked similarities between the deposits on eastern Long Island with the classic loess of Europe and the midwestern United States.

The loess on the Montauk Peninsula is best developed south of the terminal moraine of the Ronkonkoma Drift on the outwash plain between Southampton and Easthampton, where it extends from the moraine to the Atlantic shore. Discontinuous patches of similar loess are known from the eastern Montauk Peninsula but their relationships to the western loess are unclear. The deposits are similar in appearance over widely separated areas and cover the last glacial outwash in blanketlike fashion. Thickness of the loess ranges from about 7 ft (2.1 m) near Easthampton to less than 2 ft (.6 m) near Southampton. Light colors predominate, most commonly beige and white where it is thicker and olive green where it is thinner. Texturally, the deposits are coarse silt with minor admixtures of fine sand and fine silt. The contact between the loess and the glacial outwash below is interpreted by the authors as being erosional. A lag-gravel concentrate is usually found at the contact and seems to represent a very widespread episode of deflation prior to the deposition of the loess. Gravel clasts in this layer commonly show evidence of strong aeolian abrasion. Many of the clasts are highly polished and etched ventifacts, but true dreikanter forms are only rarely developed.

Over large areas on the Montauk Peninsula the loess and the soils developed on them are the youngest significant geologic deposits and form the surficial materials for approximately 40 mi^2 (103.6 km^2). However, in the Easthampton area parts of the loess have been buried by a later aeolian deposit of dune sand (stop 5). The dune sand is discontinuous but can be traced on the surface and also on topographic maps and aerial photographs into the dunes that are now developing behind the fringing beaches on the south shore. To the west of Easthampton, the dune forms have been blown inland some 2 miles (3.2 km) and are now stabilized by mature forests and thin soil.

The authors tentatively conclude that, after a period of aeolian deflation, the loess was deposited on the outwash plain in blanketlike fashion. The deposition occurred shortly after the last glacial retreat from the area, possibly under a true periglacial regime, but certainly before the area was stabilized by vegetation. Although not conclusive, changes in the grain size and thickness of the deposit indicate a northerly or easterly source area.

The Scuttlehole depression - evidence of former periglacial activity?

The Scuttlehole depression is a large topographic feature on the outwash plain in the central part of the Sag Harbor Quadrangle (see figure 6). The depression is actually a series of semi-isolated basins approximately 2 mi (3.2 km) in total length and has a marked linearity trending N25°W, almost

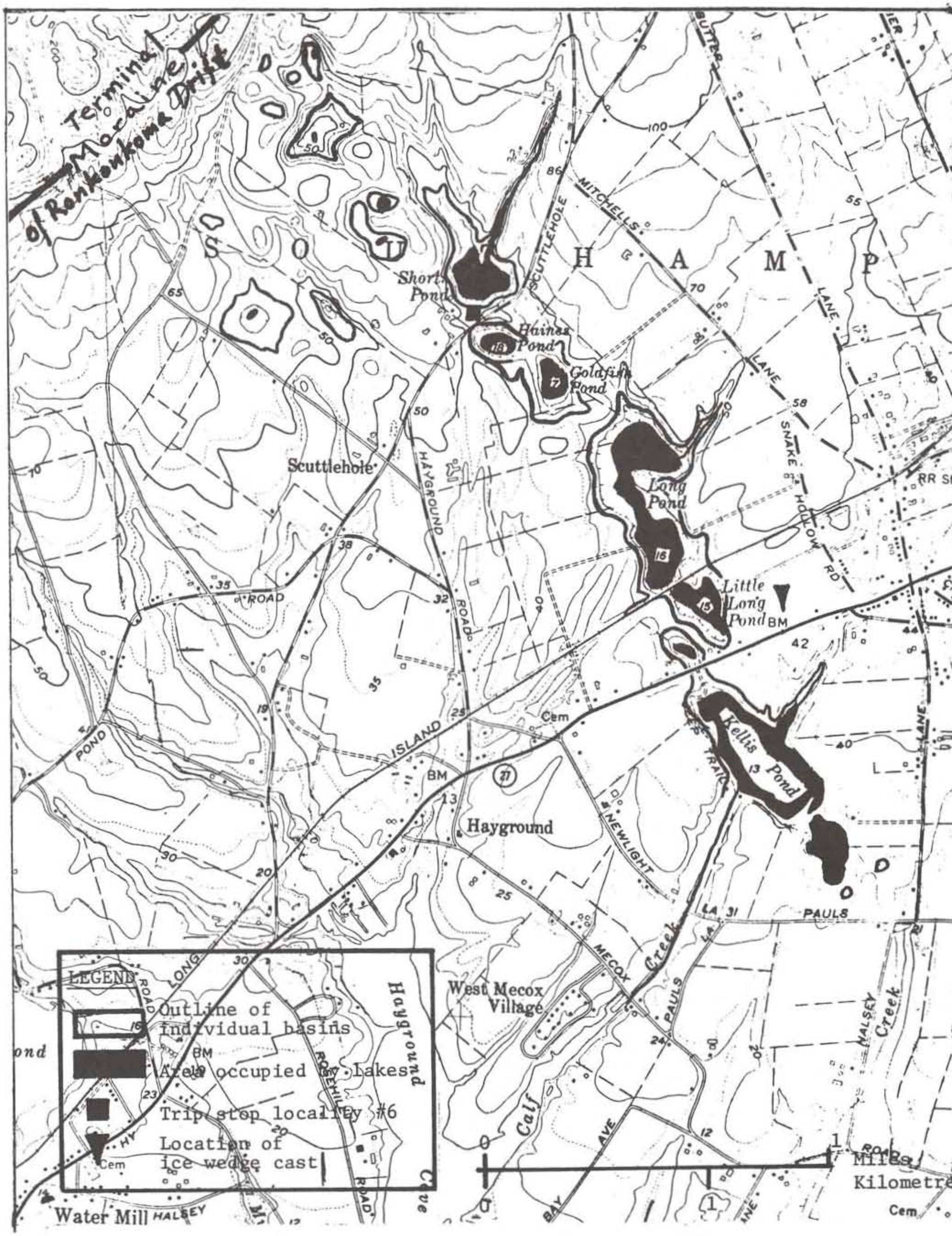

Figure 6. Detail of Sag Harbor quadrangle topographic map showing location of the Scuttlehole depression.

perpendicular to the terminal moraine of the Ronkonkoma Drift. The depression heads near the terminal moraine, where individual basins are small and elliptical in outline. As it extends to the southeast, the depression is larger, and the basins are irregular to elliptical in outline. The bottoms of many of the basins are flat, and several contain lakes, the largest being Kellis, Long, and Little Long Ponds. Although through-flowing drainage does not presently exist, a slight increase in the level of the water table would initiate a through-flowing drainage system from lake to lake; i.e. a beaded drainage course.

Fuller (1914, p. 42-43) discussed the Scuttlehole depression and its topographic expression and attributed its origin to the burial of stagnant glacial ice, which had filled a pre-existing valley. This hypothesis requires that glacial ice somehow moved past the Ronkonkoma Drift for at least 2.5 mi (4 km) onto the outwash plain. There is no obvious evidence of this event as, for example, erratics, ice-contact deposits, or ground moraine. On this basis alone, Fuller's hypothesis of origin appears doubtful. Fuller carefully noted, however (p. 43), that there exists on Long Island a large number of depressions for which glacial ice is obviously not the answer. In fact they were inexplicable at that time to quote (Fuller, 1914, p. 44). "and it may be that they (kettles of doubtful origin) have resulted from some unknown peculiarity of deposition."

In recent years research in the high latitudes has revealed an entire suite of features that would most certainly qualify as "peculiarities of deposition". A number of these features can be referred to by the term "thermokarst", which is applicable to topographic depressions that result from the formation and subsequent thawing of ground ice. Thermokarst features commonly range in size from small ice wedges up to several feet across, to collapsed pingos up to several tens of feet across, to thaw lakes and alas valleys in which collapse features are so numerous that they coalesce and dominate the topography. The large thermokarst features called alas valleys commonly range in size from 0.06 to 9 mi (.1 to 15 km) in length and are 10 to 130 ft (3 to 40 m) deep. They are characterized by beaded drainage systems of pools and channels that are straight or consist of series of straight segments separated by angular bends. Individual depressions are usually oval in outline and have flat floors and steep sides, and many of them contain lakes. Association with small-scale features such as ice wedges and polygons is common (Czudek and Demek 1970, Washburn 1973).

On the eastern rim of the Scuttlehole depression, about 330 ft (100 m) from the edge, a single relict ice-wedge cast was observed in an excavation during the summer of 1972. The wedge cast occurred in the uppermost glacial outwash and had been filled in with loess that had drifted in from above. The wedge itself was not a large feature, measuring 32 cm (13 in) in width and 90 cm (35 in) in depth. The presence of an ice-wedge cast marginal to the Scuttlehole depression implies that, for at least a short time, the area was subjected to a permafrost regime. Such structures in the present day periglacial regions are created in places where the mean annual air temperatures range from -6 to -8 C°, Pewe (1966).

In addition numerous "floating" pebbles, some highly polished by aeolian abrasion, are found in the loess that covers the depression. These pebbles are much too large to have been entrained and transported by wind action. They were probably lifted to their present location by frost heaving (cryoturbation) from the lag-gravel-concentrate layer below.

Although the evidence is not conclusive, the presence of the Scuttlehole depression on the outwash plain, its oriented nature, its straight beaded drainage course, the size and shape of the individual basins, and its close association with periglacial phenomena, suggest that this feature originated from the formation and degradation of ground ice (thermokarst).

HOLOCENE SHORELINE MODIFICATION

The shoreline-configuration of the Montauk Peninsula has undergone significant change in Holocene time. Krinsley and others (1964) and Newman and others (1968) noted that the headlands of the Montauk Peninsula have been eroded and truncated by wave and littoral processes, and the derived sediments have generally moved westward. As the littoral sand moved westward, a narrow beach formed, abutting the headlands for several miles to the south and east, and has been eroded back to its present location because of its exposure to the ocean.

The postglacial marine transgression drowned swales in the Ronkonkoma Drift moraine, separating parts of the peninsula into a series of islands in mid-Holocene time, some 2000 to 6000 years ago. Presumably, Orient Point, on Long Island's north Fork, is a modern analogue of the ancestral Montauk archipelago. The Hither Hills area and the region east of Montauk Village presumably were islands separated from the Easthampton area. An additional strait may have trended north at Ditch Plains. Bluff erosion and longshore drift converted the archipelago into a peninsula by means of single and double tombolo construction during later Holocene time.

The conspicuous gap in the terminal moraine of the Ronkonkoma Drift in the vicinity of Napeague Beach has been filled principally with sand derived from the high bluffs to the east (Taney, 1961; Krinsley and others, 1964). The area from Montauk Village west to Easthampton Village and including the Napeague Beach beach-dune tombolo complex is unique in that it seems to be the only part of Long Island's south shore that is currently prograding. Initially, the later Holocene dominant mode of shoreline modification was erosional, as witnessed by the prominent bluffs, now isolated from the south shore, at Hither Hills State Park and along Bluff Road. Debris, principally sand, derived from these bluffs was transported by long-shore drift, constructing a spit towards the northeast, marked by the Promised Land beach ridges, while another spit built from Hither Hills west toward Southampton.

The stratigraphy in the swale at Hither Hills Beach, where exposed, exhibits a sequence which, from the bottom upward, consists of the Montauk Till Member of the Manhasset Formation, thin beds of laminated silts with some pebbles, freshwater peat, and Holocene dune sand. Tree stumps are occasionally found rooted in the peat. One of the stumps was C-14 dated to be 5,450±115 years B.P. (sample no. I-5664). The date presumably indicates the time when the transgressing sea, and sand derived from its beach, began to influence the Ditch Plains area. Pollen extracted from the peat is principally pine and oak but with a conspicuous contribution of N.A.P., an assemblage similar to that found currently around Fresh Pond in Hither Hills State Park.

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ROAD LOG

Assembly Point: Hofstra University

Total Miles	Point to Point Milage	
0.0	0.0	Enter Montauk Peninsula and cross Shinnecock Canal connecting Great Peconic Bay (north) to Shinnecock Bay (south). Begin measured distances.
1.6	1.6	Divided highway ends, pass with care because of two-way traffic.
3.3	1.7	Southampton College to your immediate right (south).
4.0	0.7	From Southampton College to this point you are traveling through the rolling morainal knob and kettle topography of the Shinnecock Hills.
4.1	0.1	Outcrop on north side of road showing head of outwash. The moraine at this point bends sharply to the northeast.
6.2	2.1	Village of Southampton approximately 1 mile south of the road.
6.6	0.4	The trace of the Ronkonkoma Terminal Moraine can be seen to the north with the outwash plain abutting against it. The outwash is covered by thin loess in this area.
7.0	0.4	FULL STOP. Turn onto Montauk Highway, Route 27.
8.1	1.1	Entering head of Mecox Bay, Mill Creek on south.
9.4	1.3	One of the numerous Long Island duck farms can be seen on immediate left on north shore of Hayground Cove which enters directly into Mecox Bay. There is considerable controversy concerning periodic eutrophication of the water mass caused by nitrogeneous wastes from these farms entering the bay.
10.6	1.2	On north and south of road observe the southernmost extension of the Scuttlehole depression. Kellis Pond is to the south and occupies most of the depression. (See text and description of Stop 6 for details of origin.)
11.5	0.9	Village of Bridgehampton.

15.0	3.5	Active sand and gravel operation at north side of road. These pits have been dug deeply enough to intersect the water table, and present operations involve dredging methods.
17.8	2.8	Traffic light. Turn left into Village of Easthampton.
18.6	0.8	Main intersection in the center of Easthampton.
18.8	0.2	Bear to right of windmill.
20.0	1.2	Village of Amagansett.
21.8	1.8	Bluff Road entering Route 27 from south. Site of former wave cut cliff.
22.1	0.3	Leave glacial deposits and descend onto the Napeague beach complex. Note steep wave-cut bluff to immediate north. This is the central part of the Napeague tombolo. Napeague Harbor is to the north.
26.5	4.4	Observe wave-cut bluff in morainal deposits.
27.0	0.5	Observe dunes from north of the moraine. Dunes have been blown inland and over the moraine for approximately 1 mile.
27.1	0.1	Road divides. Bear left and ascend the moraine. The western boundary of Hither Hills State Park is crossed here.
31.1	4.0	Rapid descent from moraine, entering Montauk Village.
31.6	0.5	Traveling on beach deposits that have been drifted in by long-shore currents. Fort Pond to north has been isolated from the ocean by a double tombolo.
32.2	0.6	Reascend moraine. Several overlooks on the road provide beautiful ocean views on clear days.
35.2	3.0	Oyster Pond can be seen in the distance to the northeast.

36.2	1.0	Turn right into Air Force Base. Drive slowly and obey signs. In the next one mile follow these instructions: Proceed through gate; drive along winding road and go past radar tower; go straight past two right turns and through a second gate (unattended), and make sharp right turn onto a winding narrow road.
37.2	1.0	Road ends. Make right turn past sign for L.I. State Park Commission Park and dismount buses well away from the edge of the cliffs. Walk east descending to base of bluffs.

STOP 1. Montauk Air Force Station.
Here along the littoral bluffs on Long Island's southeast coast which includes the type section of the Montauk Till, we have the opportunity to examine the excruciating complexities of the island's Quaternary stratigraphy. The hoodoo topography developed on the Montauk Till provides a conspicuous marker bed which enables us to follow the till where it outcrops along the eroding bluff. However, the complicated glacial tectonics, immediately apparent in these exposures, has detached blocks of Montauk Till, and these blocks have been transported into anomalous stratigraphic positions. To our west, stratified drift beneath the Montauk Till is exposed in a large mile-wide antiform. Stratified drift including laminated silts and clay, frequently folded and in fault contact, also lie above the Montauk Till. The barely finite age obtained from a log in the lower portion of the upper stratified drift has been previously noted while a second date on disseminated wood from the upper stratified drift dates at 12,170 $\pm$ 180 years B.P. (QC-122). Discontinuous lenses of a younger till cap portions of the bluff. Also found in the upper part of the section are pockets of loess up to ten feet thick.

38.4	1.2	Return to buses and retrace way back to Route 27. Turn left and proceed westbound.
41.3	2.9	Look for sign on left reading, "Ditch Plains". Turn left onto Ditch Plains Road.

41.7 0.4 Leave paved road; travel on hard gravel road to parking area adjoining beach. Park buses and dismount. Walk west on beach to base of sea cliffs.

STOP 2. Ditch Plains.
The Montauk Till forms the base of the section exposed along the coastline. Close inspection of the till reveals pervasive deformation. The western end of our traverse displays well-developed hoodoo topography on the Montauk Till. The western portion of the section shows stratified drift and loess above the till. At the eastern end of the high bluff, thinly bedded fine sand dips towards the east and passes from view beneath the beach. This stratified deposit lies upon a persistent peat zone upon which rooted stumps are occasionally exposed. As noted previously, a radiocarbon date on one of these stumps shows it to be about 5500 years old. Excavation at the east end of our traverse (near where we enter upon the beach) discloses the following section:

Eolian sand
Peat
Laminated silt (lacustrine?)
Montauk Till

Since the peat appears to be mid-Holocene in age, the thinly bedded sand body appears to be the distal portion of a delta that was built into the Ditch Plains basin prior to the Holocene marine transgression of the area. We cannot explain why the late Holocene sand wedge was deposited. We suspect that it might have been deposited because the vegetation cover was temporarily destroyed allowing the mobilization of considerable amount of sand.

42.1 0.4 Remount buses. Return to Route 27 and turn left (westbound).

44.1 2.0 After passing through Montauk Village, Route 27 forks where Old Montauk Highway enters Route 27. Bear right and ascend moraine.

45.2	1.1	Turn right into sanitary-landfill disposal area.
45.6	0.4	Travel north on landfill access road and park buses. Dismount buses and walk to edge of largest open pit.
		<u>STOP 3. Montauk Sanitary landfill</u>. This section reveals at least 100 feet of stratified sand in the middle of the Ronkonkoma kame-moraine complex. The topographic maps of the area as well as air photos (figure 5) display a series of northeast striding ridges superimposed upon the moraine. These ridges appear to be push moraines. The deposit exhibits both folding and faulting, including several large thrust faults. The section is capped with a bouldery deposit that is probably till. The high percentage of boulders suggests the till has been washed and the boulders at least in part, represent a lag deposit. (Perhaps the term "flowtill" is appropriate here.)
46.0	0.4	Return to Route 27 and turn right (westbound).
48.0	2.0	Overlook on right side of road shows numerous beach and littoral features on north side of Montauk Peninsula. The Atlantic Ocean is to the immediate south.
49.5	1.5	Turn left onto side road and enter Hither Hills State Park.
49.7	0.2	Turn left onto Old Montauk Highway (eastbound).
49.9	0.2	Turn right into parking lot. LUNCH STOP AND REST ROOMS.
50.0	0.1	Return to Old Montauk Highway and turn left (westbound). A prominent wave cut bluff is directly to the north.
50.6	0.6	Intersection with Route 27. <u>Careful</u>; dangerous crossing. Travel west on Route 27. Magnificent dunes can be seen on both sides of the highway. They are presently stabilized by vegetation.

52.3	1.7	Make a 30° right turn off Route 27. Cross railroad tracks. Full Stop.
52.6	0.3	Napeague Harbor can been seen on the right. Beach ridges, dunes and lagoonal sediments typify this area.
53.6	1.0	FULL STOP. Turn left.
56.0	2.4	Warning - narrow bridge. Blow horn before crossing.
56.2	0.2	Return to Route 27 (westbound).
57.1	0.9	Make a 150° right turn and cross railroad tracks.
57.2	0.1	Road divides. Bear left onto Fresh Pond Road. The head of outwash is to your left (south) and the moraine is to your right (north).
58.2	1.0	Stop buses after passing rifle range. Dismount and walk into woods along dirt path.

STOP 4. Gravel pit at Amagansett.
Here is the last easternmost exposure of the Late Wisconsin drift to be seen before its termination at Bluff Road sea cliff and its reappearance 4 miles east-northeast at Hither Hills. The till at this stop has a sandier texture, fewer boulders, a lower clay content, and fewer glacial tectonic structures than the Montauk Till. The stratified drift underlying the till is postulated to be either an Early Wisconsin drift that was overridden and deformed by the Late Wisconsin advance or a Late Wisconsin proglacial outwash that was overridden by the advance. The lower stratified drift exhibits many glacial tectonic structures such as thrust faults and folds. This same unit also has preserved depositional structures such as cross bedding and graded bedding. A third unit of wind-blown sediments overlies the till.

58.4	0.2	Remount buses and proceed north. Make a left turn onto Cross Highway.
58.8	0.4	Turn left onto Abrahams Landing.
59.2	0.4	Turn left onto Alberts Landing Road.
59.6	0.4	Bear left.
60.2	0.6	Turn right and cross railroad tracks. Make a right turn onto Route 27 westbound.
63.4	3.2	Make right turn at traffic light in downtown Easthampton.
63.8	0.4	Bear left before the railroad tracks.
63.9	0.1	S-curve left.
64.0	0.1	S-curve right.
64.6	0.6	Make a right turn onto Co. Rd. 114 (Sag Harbor-Easthampton Turnpike).
64.8	0.2	Make a left turn into Easthampton Bus Co.

STOP 5. Easthampton Bus Company

This stop is included to illustrate the late-glacial loess deposit and the surficial sands that have blown in and partially covered the loess in the Easthampton area. The flat bull-dozed surface is near the top of the loess deposit. It is possible to dig down through some 62 inches of wind blown silt and enter coarse stratified sands and gravels below. The contact between the loess and the underlying glaciofluvial deposits is erosional and a lag-gravel concentrate has been developed with many wind-abraded clasts and ventifacts which were left behind during a period of aeolian deflation. Frost action (cryoturbation), probably in late glacial times, disturbed much of the section and introduced the erratic pebbles into the loess from below. After deposition of the loess and some soil formation on the loess, dune sand was blown in from the south shore and heaped into 10-foot dunes in this area. The sands are now stabilized by a soil profile and by a mature forest cover. A minor paleosoil can be seen within the dune sands. The dune sands have stripped much of the A soil horizon from the top of the loess but the B horizon is still present here.

The dune sands are traceable on topographic maps and aerial photographs to the south shore and have blown inland at least 2.2 miles (3.5 km).

The sequence of events determined from this and other similar outcrops in this area include: 1. deposition of the last glacial outwash sands and gravels 2. widespread aeolian deflation and the formation of lag-gravel concentrate and ventifacts 3. deposition of the loess on a cold barren surface devoid of vegetative cover and intense cryoturbation of the deposits. 4. indeterminant length of time during which a soil formed on top of the loess. 5. deposition of dune sand from the south shore, probably shortly after sea level reached near its present level. 6. stabilization of the dunes by soils and forest.

65.6	0.8	Exit from bus company. Turn left and go under railroad overpass. As you proceed north along Route 114 note dunal topography to the south and loess topography to the north.
66.0	0.4	Make left turn onto Stephen Hands Path. Pass a small water mill on immediate left.
67.4	1.4	Return to Route 27 and turn right (westbound).
71.3	3.9	Pass through Bridgehampton.
72.0	0.7	Slow down for blind left turn onto Snake Hollow Road just before shopping center.
72.2	0.2	Cross railroad tracks.
72.6	0.4	Make left turn onto Mitchells Lane which runs parallel to the Scuttlehole depression.
72.8	0.2	In this area, the outwash plain is blanketed with loess. The trace of the Ronkonkoma Terminal Moraine can be seen directly ahead.
73.5	0.7	Scuttlehole Road. Turn left.
73.8	0.3	Dip into the Scuttlehole depression.

74.0 0.2 Pull to side of road by "Cattle Crossing" sign. Dismount buses. Watch for traffic in both directions. Cross to south side of road overlooking Haines Pond.

STOP 6. The Scuttlehole Depression.
The Scuttlehole depression is a large topographic feature some 2.5 miles (4 kilometres) in length. It is impossible to observe the entire structure from any one point on the ground. Therefore, reference to a topographic map (Sag Harbor quadrangle) is recommended.

Our bus stop is on Scuttlehole Road just south of Shorts Pd. and just north of Haines Pd. To the north and south you can observe a topography that is strange for Long Island, reminiscent of karst topography. The elevation of the outwash plain (out of view from this point) on both sides of the depression is approximately 70 feet and the plain is amazingly level considering the nearness of the Ronkonkoma Terminal Moraine which is about 1 mile to the northeast. In this area, only glaciofluvial deposits and aeolian loess are known on the outwash plain. No till or ice-contact deposits or erratics are found on the outwash plain so the presence of glacial ice far south of the Ronkonkoma front is doubtful. The Scuttlehole depression heads near the moraine and extends southeast about 2.5 miles (4 kilometres) and consists of more than a dozen semi-isolated basins identical in size and shape with the two that can be observed here. The basins are steep-sided and flat-bottomed and are isolated from one another by shallow divides.

Several characteristics have led us to conclude that this feature is a collapse structure of thermokarst origin:

1. linearity of trend approximately 2.5 miles (4 kilometres) N25W.
2. beaded drainage system, an often observed phenomena in present-day periglacial areas.
3. size and shape of the individual basins are almost identical to present-day regions of active thermokarst.

4. lack of evidence for the existence of glacial ice in the area of the outwash plain.
5. association with small scale periglacial features such as cryoturbated loess and a single ice wedge cast of the Scuttlehole depression.

Although not conclusive, we feel the evidence merits consideration and any discussion of the interpretation would be welcomed by the authors....

75.8	1.8	Remount buses and return to Route 27 via Scuttlehole road. Turn west (right) onto Route 27.
78.1	2.3	Turn right onto North Road.
79.6	1.5	Right turn onto County Road 38 and bear right immediately. Take Majors Path going north. Note here how outwash abruptly grades into the kame and kettle topography of the moraine.
83.2	3.6	Drive slowly because of the winding road. Stop buses at Southampton Sanitary Landfill.

STOP 7. Southampton Sanitary Landfill Site. At this stop one sees a contrast in morainal morphology between here and the previous sites. Here kame and kettle topography predominates as compared to the "push" topography seen earlier. At this site one sees mostly primary sedimentary structures, although secondary structures formed by glacial tectonic activity are present. Geophysical investigations have indicated a finer till-like material at a lower level of the pit, possible equivalent to the Late Wisconsin till.

83,4	0.2	Exit landfill and turn left. Return to Route 27 via same route.
83.9	0.5	Bear left at fork in road.
86.1	2.2	Turn right (west) onto Route 27.
89.4	3.3	Pass Southampton College on left.
92.7	3.3	Pass Shinnecock Canal. Leave Montauk Peninsula. Return to Hofstra University.

NOTES

TRIP 8-A: GEOTECHNICAL CONSIDERATIONS AT SHOREHAM NUCLEAR POWER STATION

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INTRODUCTION

Long Island Lighting Company's Shoreham Nuclear Power Station is one of the largest engineering projects ever undertaken in eastern Long Island. It has required geotechnical considerations of a scope unique to nuclear-fueled electric generating facilities, and has been scrutinized closely by the general public and by various governmental regulatory agencies. This field trip will provide an opportunity to discuss the geotechnical investigations and decisions that are a part of nuclear power plant siting, design, licensing, and construction, and will include a tour of the facility itself, which is scheduled for completion in 1977.

ACKNOWLEDGEMENTS

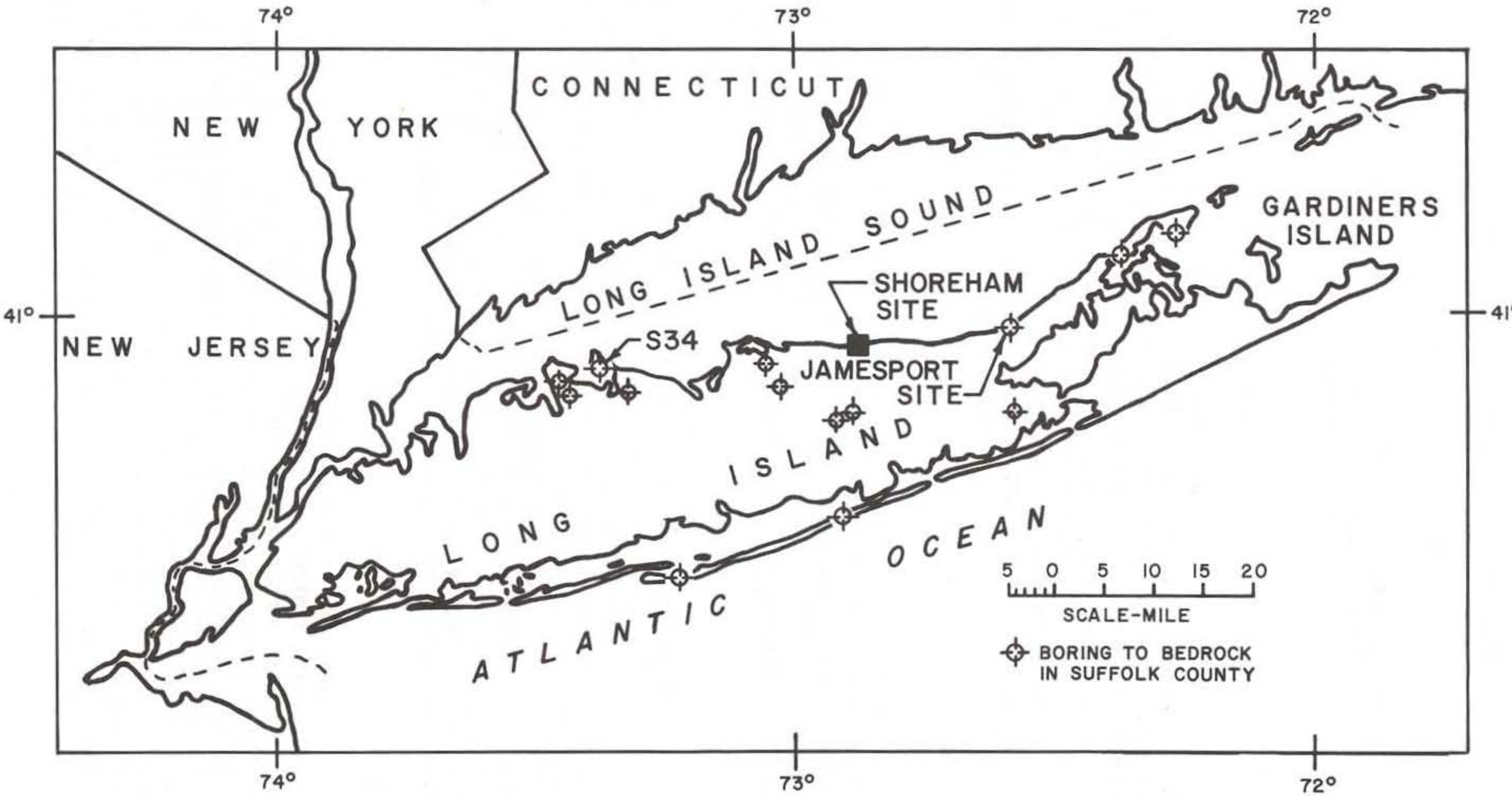
The authors wish to thank Mr. J. P. Novarro of Long Island Lighting Company for granting access to the Shoreham plant and for assistance in conducting the tour; Mr. R. J. Diecchio for tentative identification of fossils; Mr. E. F. Shorey for compilation of subsurface data; and Mr. R. P. Gillespie for assistance in preparation of the text.

GEOLOGIC SETTING

Shoreham Nuclear Power Station is located on the north shore of central Long Island, at the approximate landward edge of the Atlantic Coastal Plain (Figures 1 and 2). The crystalline rocks of the New England Piedmont slope gently seaward an estimated 1100 ft beneath the site. Overlying this deeply weathered remnant of the Fall Zone peneplain (Suter and others, 1949) is a thick sequence of unconsolidated coastal plain sediments of Upper Cretaceous to possibly Tertiary age. Long Island itself owes its existence to a somewhat linear accumulation of glacial debris unconformably overlying the coastal plain deposits. The island is separated from New England by a glacially overdeepened channel.

Bedrock

Because of its considerable depth, little is known of the basement rock beneath central and eastern Long Island. A few deep wells and test borings have penetrated bedrock in Suffolk County (Figure 1), but most of these simply recorded weathered schist and gneiss (Jensen, personal comm., 1973). Between 1948 and 1950, the U.S. Geological Survey, as part of a detailed groundwater investigation for the War Department, drilled two deep test wells into bedrock at the site of what is now Brookhaven National Laboratory, about 9 miles south of the Shoreham site. deLaguna (1963, p. A11-A12) describes the rock as a "hard, banded, granitic gneiss" with a composition of "about 50 percent plagioclase (oligoclase and andesine) feldspar, about 50 percent quartz, about 1 percent biotite, and a trace of



REFERENCE: JENSEN AND SOREN, 1971

FIGURE 1 INDEX MAP

garnet". This is capped by 15 to 30 ft of weathered rock.

At the site of Long Island Lighting Company's proposed Jamesport Nuclear Power Station, about 15 miles east of Shoreham, two bedrock borings were recently completed. There, 30 to 60 ft of saprolite and weathered rock were encountered overlying fresh rock (at 1100 ft below sea level). The rock was found to be a granitic gneiss, with foliation indistinct and occasionally lacking. It is composed of 35 to 45 percent microcline, 25 to 35 percent quartz, 20 to 30 percent sodic plagioclase, 2 percent biotite, 0.5 percent each of muscovite and garnet, and a trace of zircon.

An age of 254 ± 9 million years was determined from biotite from the Jamesport rock by Geochron Laboratories, using the K-Ar method. This is believed to be the first date ever obtained from Suffolk County basement rock, and is consistent with what is known of southern New England rocks (Zartman and others, 1970). Concentric zonation of plagioclase and possible secondary intergrowths, particularly of quartz and plagioclase, suggest that a Permian stage of metamorphic recrystallization is responsible for the K-Ar date.

It is suggested, notably by Sanders (1963) and Rodgers (1968), that the Triassic basin of southern New England may extend southward beneath the Sound and beneath Long Island. However, although aeromagnetic patterns characteristic of the Triassic basin trend south-southwestward into western Long Island (U.S. Naval Oceanographic Office, 1964-1966), no borings have been drilled to bedrock in Long Island Sound south of the apparent termination of the Triassic basin in New Haven Harbor. Bedrock borings on Long Island have encountered only crystalline rock (Jensen, personal comm., 1973; deLaguna, 1963). The Duck Island well (S34) at Northport Bay is believed by some to have recovered Triassic rock; however, this is unsubstantiated. Furthermore, three wells within a 5 mile radius of S34 recorded gneiss (Figure 1), imposing a considerable restriction on the extent of any possible Triassic rocks.

Coastal Plain Sediments

As is the case with basement rock, much less is known of the nature and extent of the deeper coastal plain deposits in Suffolk County than in western Long Island. The most thorough discussion of these units is by Suter and others (1949). Jensen and Soren (1974) have provided considerable additional geologic information for Suffolk County, particularly with reference to the configuration of the major stratigraphic interfaces.

At the Shoreham plant site it is believed that 200 ft of the Lloyd Sand Member of the Upper Cretaceous Raritan Formation overlies a deeply weathered bedrock surface at an approximate elevation of -1000 ft. The Lloyd sand is a grayish-white, fine to coarse, quartz sand and gravel. It grades locally into a clayey sand with clay intercalations. Like all the Cretaceous deposits on Long Island, the Lloyd sand increases in thickness from the northwest to the southeast and may reach 550 ft thick in southern Suffolk County.

A similar thickness of the clay member of the Raritan Formation

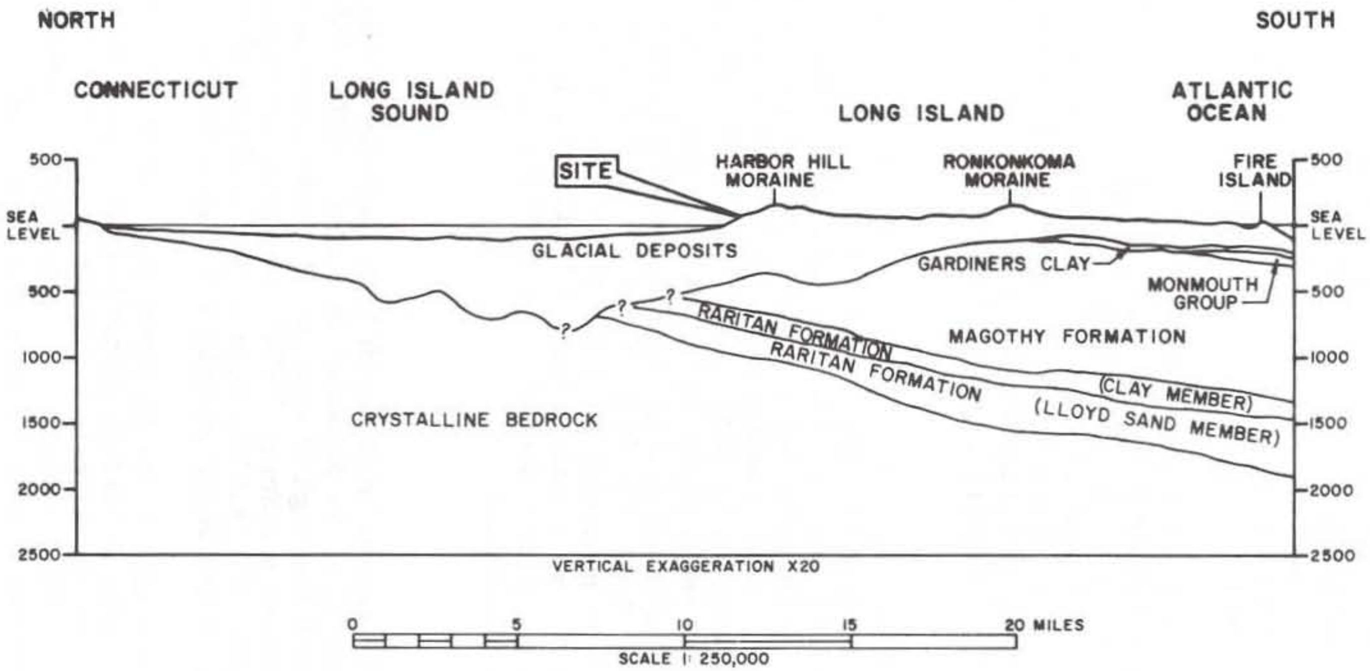


FIGURE 2 GENERALIZED GEOLOGIC SECTION THROUGH THE SHOREHAM SITE

REFERENCES:
JENSEN AND SOREN, 1974
SUTER, DELAGUNA, AND PERLMUTTER, 1949
U.S. GEOLOGICAL SURVEY, 1967

is believed to overlie the Lloyd sand. The clay member is predominantly a clay and silty clay with sandy intercalations. It is commonly gray in color, but may show multicolored banding. Its contact with the overlying Magothy Formation is considered gradational.

The major stratigraphic unit in the Upper Cretaceous of Long Island is the Magothy Formation. It is typically a fine sand with angular quartz grains and interstitial kaolin. It is commonly gray or white in color but may locally be brown, buff, yellow, red, or pink. The lower part of the formation tends to contain coarser material just above the Raritan clay member. However, Long Island Lighting Company's recent deep borings at Jamesport did not encounter typical basal Magothy Formation. The Magothy was encountered by test borings at the Shoreham site and the adjacent Shoreham West site (alternate site for the proposed Jamesport Nuclear Power Station) at elevations of -100 ft to -150 ft. This is considered to be an unusually shallow occurrence, resulting from glacial deformation. The contact between the Upper Cretaceous (Magothy) and Pleistocene deposits is an erosional unconformity.

The uppermost Cretaceous unit found on Long Island is the Monmouth Greensand. It is a dark greenish-gray, glauconitic and occasionally lignitic marine clay, silt, and clayey and silty sand. It is limited in extent to the south coastal area of Suffolk County and may reach 200 ft in thickness. It has not been encountered in any of the borings at the site.

Pleistocene Geology

Late Pleistocene glaciation is responsible not only for the physiography of Long Island, but for the very existence of the island. In Suffolk County, nearly all engineering structures, including Shoreham Nuclear Power Station, are founded in glacially derived sediments. These deposits are also the principal source of groundwater.

The Manetto Gravel was considered by Fuller (1914) to be the earliest of the Pleistocene deposits; other workers have assigned it a possible Pliocene age. It is typically a stratified, fine to coarse gravel, with well-rounded particles of quartz and occasional granite cobbles and boulders mixed with coarse, yellow sand. The unit has not been identified from borings in the site area, although it would be difficult to distinguish from glacial outwash deposits.

At the adjacent Shoreham West site, test borings encountered 20 to 50 ft of dark, grayish-green silty and clayey fine sand. Occasional clay layers; infrequent, isolated, rounded quartz pebbles; a variable mica content; and possible reworked glauconite further characterize the material. The unit unconformably overlies the Magothy Formation at elevations between -80 and -140 ft. Of particular interest are the marine and brackish water shells and shell fragments. Some of the foraminifera were tentatively identified, by genera, as Quinqueloculina (Carboniferous to Recent) and Elphidium (Eocene to Recent). We have concluded that the material is Gardiners Clay, of probable Sangamon (interglacial) age. This is consistent with the observation by Weiss (1954, p. 145) that "... any fossiliferous material of Pleistocene age overlain by glacial deposits may be called

Gardiners." Gardiners Clay was not encountered at the Shoreham plant site. Discontinuous layers of similar material in higher stratigraphic levels are believed to be of glacial or Recent origin.

At the Shoreham West site, the Gardiners Clay grades upward into a generally gray, silty, micaceous, nonfossiliferous fine sand. This is very likely what Fuller (1914) defined as Jacob Sand. At the Shoreham site and the Jamesport site (near its type locality), Jacob Sand overlies Magothy Formation. Test borings at all three sites encountered a gradation upward from Jacob Sand into typical Wisconsinan outwash sands and gravels.

All three sites are founded on the Harbor Hill Moraine, which extends nearly the length of Long Island's north shore. In the vicinity of Shoreham Nuclear Power Station, the moraine is composed principally of outwash deposits of light brown, fine to coarse, clean sand and gravel, with occasional large, erratic boulders. Thin layers of till are infrequent. The present irregular topography of the moraine is a result of the kame and kettle style of outwash accumulation.

Glacial shove and drag has caused considerable deformation of the Pleistocene and the Upper Cretaceous (Magothy) deposits. Contours drawn on several subsurface interfaces at the Shoreham West site show a pattern of asymmetric folding, with the principal stress directed from the northeast. It is this folding and possible imbricate thrusting (Kaye, 1964; Mills and Wells, 1974) which is believed responsible for the anomalously shallow occurrences of the Magothy Formation.

Recent deposits in the Shoreham site area include beach sand, dune sand (particularly capping the shore bluffs),and river and salt water marsh deposits.

Figures 3 and 4 show the pre- and post-construction geology of Shoreham Nuclear Power Station. Figure 5 is an oblique aerial view of the site during construction.

<u>Seismicity of Site Region</u>

The earthquake history of the site area has been determined by Weston Geophysical Research, Inc., for Long Island Lighting Company, by a thorough examination of technical publications and a literature search in the libraries of newspapers and other publications of Long Island, New York City, Boston, and Bridgeport, Connecticut. Historical records date back over 300 years to the first permanent Dutch settlement in the area in 1606. References to earthquakes in these records consist mainly of felt reports of earthquakes whose epicenters were located outside the eastern Long Island area. An earthquake on December 18, 1737, near New York City was the first reported earthquake whose epicenter was within the eastern New York - Long Island area. The region within 200 miles of the site has been characterized by infrequent earthquakes of low to moderate intensity and magnitude.

Seismic instrumentation was first installed in the northeastern U.S. in the early 1900's and has been gradually improved and increased. It is now capable of locating any earthquake of magnitude 4.0 (local magnitude) and most earthquakes of magnitude 3.0 within a 200 mile radius of the

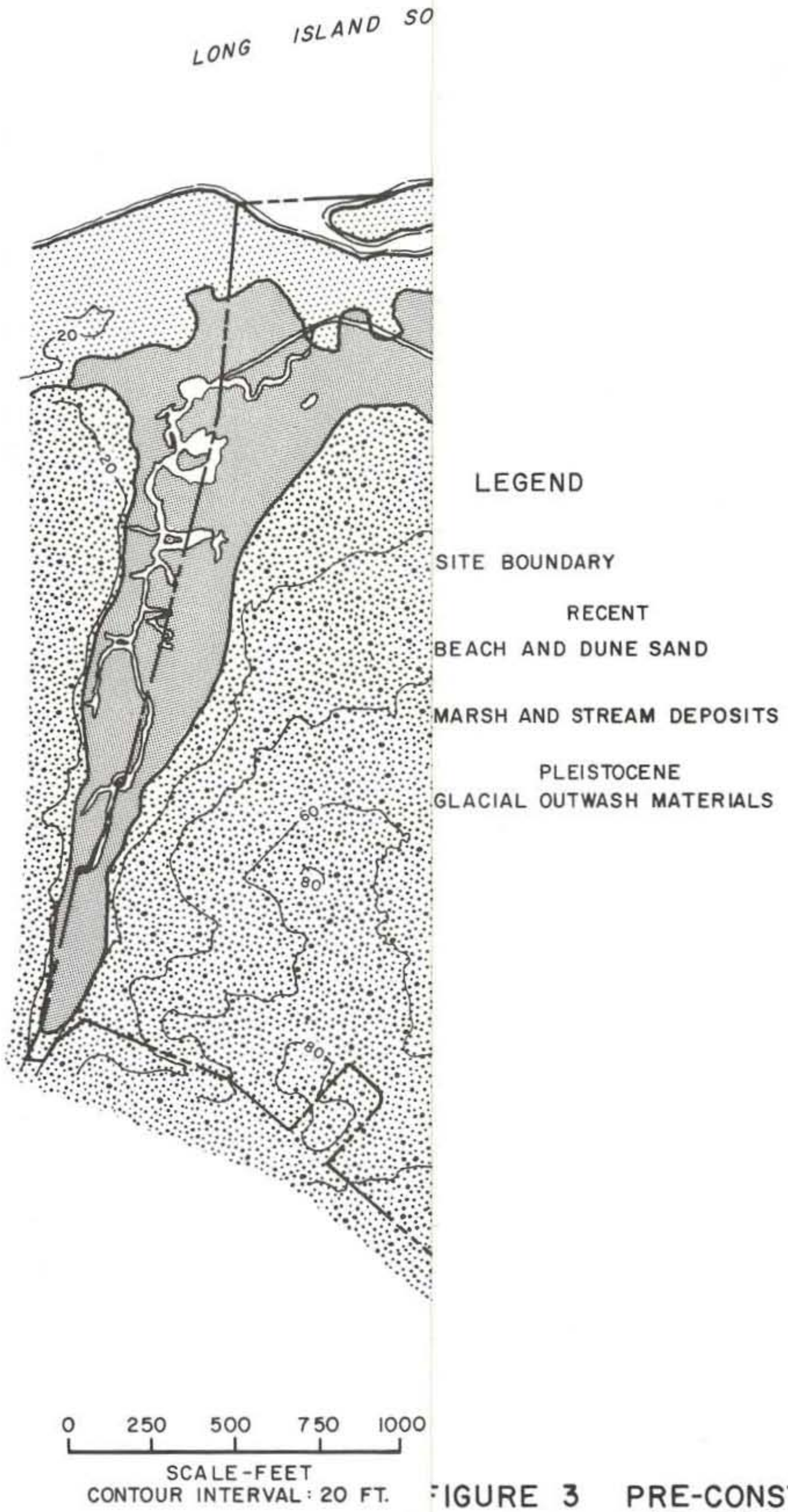
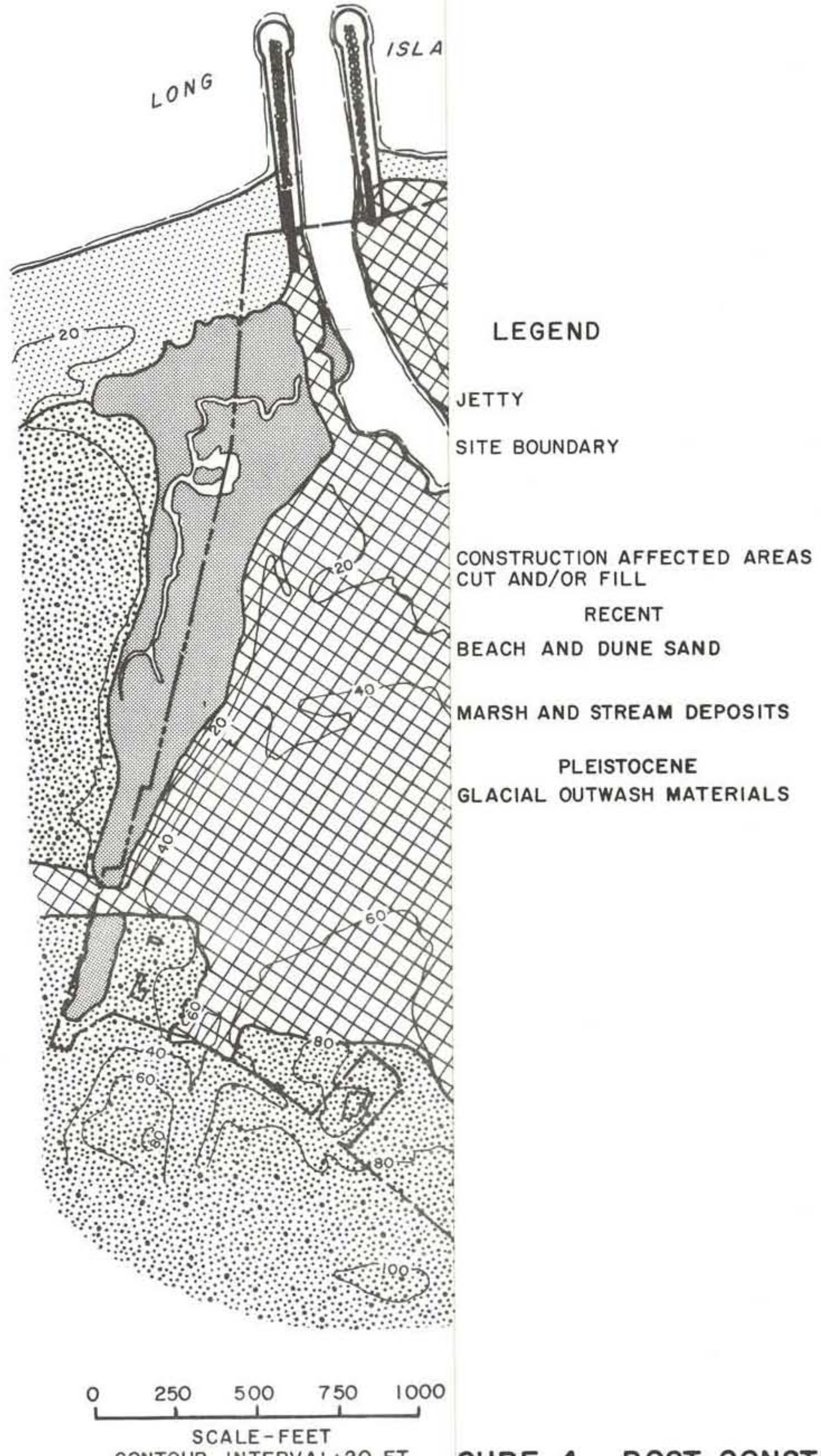


FIGURE 3 PRE-CONSTRUCTION SITE GEOLOGIC MAP



GURE 4 POST-CONSTRUCTION SITE GEOLOGIC MAP

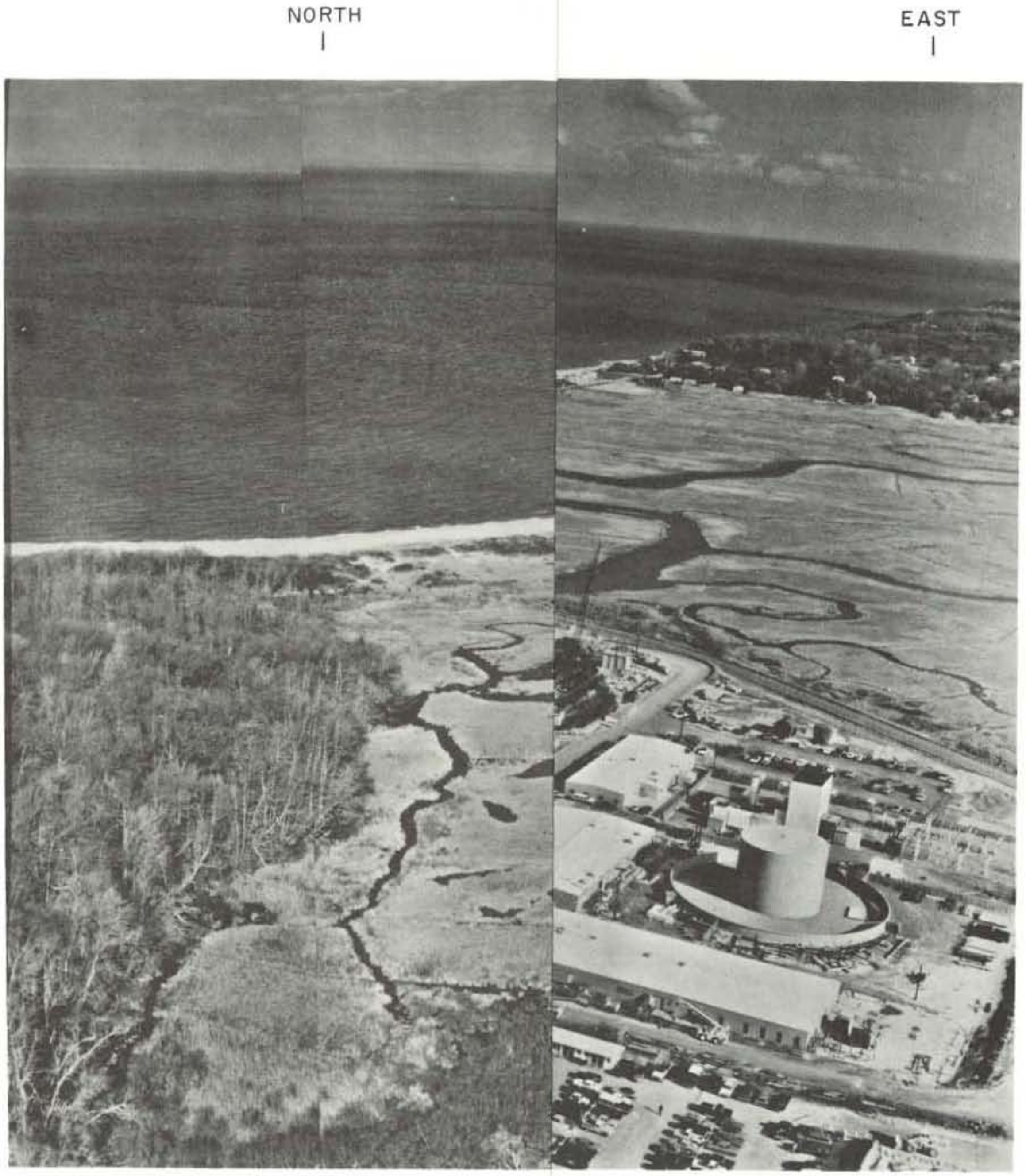


FIGURE 5 OBLIQUE VIEW OF SHOREHAM NUCLEAR POWER STATION-UNIT I

Shoreham site.

Concentrations of earthquake epicenters are located in the northern New Jersey - southeastern New York area, south central Connecticut, the Cape Ann area of Massachusetts, and the central New Hampshire region. The highest intensity for any earthquake has been assigned to the earthquake of November 18, 1755, which occurred off the coast of Massachusetts in the vicinity of Cape Ann. Outside the 200 mile area, earthquakes of epicentral intensities VIII, IX, and X (MM) have occurred along the St. Lawrence River Valley. Only two earthquakes occurring within 50 miles of the site were of sufficient intensity to be felt at the site. One occurred on May 16, 1791, in central Connecticut, and had an estimated site intensity of IV-V (MM). The other occurred on July 19, 1937, in western Long Island, with a site intensity of less than III.

NUCLEAR POWER PLANT SITING CRITERIA

Nuclear power plants are among the most complex and expensive of all engineering endeavors. Like conventional fossil-fueled systems, they consist of a number of individual components, each having its own special requirements. Some of these components, such as heat exchangers, turbines, generators, switching stations, cooling systems, and waste control systems, are common to all thermal electric generating stations. Others, such as the reactor containment vessel and the emergency core cooling system, are peculiar to nuclear-fueled facilities.

The geologic and seismic requirements for siting a nuclear power plant are really little different from any other large engineered structure whose failure could endanger man or his environment. The foundations must provide safe support for all structures and must include margins of safety against the effects of high winds and tectonic movements such as faulting.

The site itself must also be safe from the effects of flooding, unusual rises in the water table, and large sea waves or tsunamis. These requirements are valid for any type of power generating facility. The difference lies in the degree of precaution which must be exercised. Because of the nature of the nuclear fuel, criteria applied to the basic foundation design requirements are much more stringent than those applied to engineered structures of equal risk, such as large dams.

Applicable Documents

Before issuing a Construction Permit for a nuclear power plant at a given site, the U.S. Nuclear Regulatory Commission (formerly the Atomic Energy Commission) requires that the applicant submit a Preliminary Safety Analysis Report (PSAR). The form of this report is set forth in "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants". The geologic and seismic investigations required are described in 10 CFR part 100, Appendix A of the Federal Register: "Seismic and Geologic Siting Criteria for Nuclear Power Plants." Based largely on its review of the PSAR, the NRC judges whether the proposed facilities "...can be built or operated without undue risk to the health and safety of the public" (Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants; Revision 1, 1972).

Required Investigations

An applicant for a Construction Permit is required to investigate all seismic and geologic factors that may affect the design and operation of the proposed nuclear facility. A summary of the required investigations is given below. Due to the precise language used in 10 CFR part 100, Appendix A, it has been necessary to closely duplicate much of the wording of the original document.

Vibratory Ground Motion. The objective of this investigation is to obtain the necessary information to be able to describe and design for the vibratory ground motion which would occur during the severest earthquake possible in the site area, considering the regional and local geology and the past seismic history. This earthquake is called the Safe Shutdown Earthquake (SSE). A nuclear plant must be designed to be able to cease operation safely and maintain the effectiveness of the reactor cooling system after experiencing an earthquake of this magnitude.

In order to satisfy this criterion, a complete geologic and hydrologic investigation of the site must be undertaken. Local tectonic structures must be identified and evaluated with respect to their potential effects on the site. The rock and soil beneath the site must also be evaluated for their behavior during prior earthquakes as well as for their potential behavior during future earthquakes. All historically reported earthquakes which have affected or could have affected the site must be listed to include the date of occurrence, the magnitude or intensity, and a plot of the epicenter. Where past earthquakes could have caused a maximum ground acceleration of at least 0.1 g at the foundation of the proposed plant, the acceleration or intensity and duration of ground shaking at the foundations is to be estimated. Epicenters of historically reported earthquakes within 200 miles of the site must be related to geologic structures. If this cannot be done (which is the case in eastern United States), the epicenters must be correlated with tectonic provinces if within 200 miles of the site. Any faults within 200 miles of the site must be evaluated to determine if they are to be considered as "capable faults." A capable fault is defined as a fault which has experienced movement at least once in the past 35,000 years or movement of a recurring nature within the past 500,000 years, or has shown macro-seismicity which can be directly related to the fault.

Surface Faulting. This part of the investigation is concerned with determining whether and to what extent the proposed plant is to be designed for surface faulting. Any evidence of fault offset near or at the ground surface must be thoroughly investigated. Any fault greater than 1,000 ft long and within 5 miles of the site must be evaluated to determine if it is a capable fault. All earthquakes which can be associated with faults greater than 1,000 ft long within 5 miles of the site must be listed to include the date of occurrence, magnitude, and a plot of the epicenter. For capable faults greater than 1,000 ft long within 5 miles of the site, the length must be measured, its relationship to other tectonic features must be determined, and the nature, amount, and history of movement must be determined. In addition, the outer limits of the fault must be determined by mapping the fault for 10 miles along its trend in both directions from its nearest approach to the site.

Seismically Induced Floods and Water Waves. Satisfaction of this criterion includes determination of the effects which might be expected as a result of large waves or tsunamis which have occurred or might occur at the site. For sites near lakes or rivers, floods or waves caused by dam failures and landslides into lakes must also be considered.

NUCLEAR SITE SELECTION AND INVESTIGATION

Many considerations are involved in the selection of a nuclear power plant site, not the least of which are a large reliable source of coolant water, adequate available acreage, and proximity to the intended users. After a site (or sometimes several alternate sites) has been tentatively chosen, a preliminary geotechnical investigation is undertaken to determine its suitability.

A typical preliminary site investigation would consist of 10 to 15 test borings whose depths would be dictated by the dimensions and anticipated foundation elevations of the deepest plant structures and by a general (or specific) knowledge of local geologic and environmental conditions. Soil and/or rock samples would be recovered and a determination would be made of their ability to support the proposed structures under the anticipated static and possible dynamic loads. Several of the boreholes would then be converted to piezometers for monitoring groundwater table elevations. In addition, a search of the technical literature would be undertaken to reveal the general geologic and seismic history of the area to obtain basic knowledge of the site region and provide direction for further studies.

Having thus established the suitability of a site, a preliminary plant layout is decided upon. An intensive site investigation is undertaken, with particular emphasis on the proposed locations of the critical (Seismic Category I) structures. Upwards of 100 borings are frequently drilled, both on- and offshore, to provide samples for laboratory analysis and testing. A cross-hole seismic survey is made at the reactor containment location to aid in the analysis of soil or rock stability. A comprehensive study is made of regional seismicity and a detailed structural and general geologic study made of the region and particularly of a 5 mile area around the site. These investigations are frequently supplemented by various remote sensing techniques, such as high and low altitude aerial photography, ERTS (satellite) imagery, side-looking airborne radar (SLAR) imagery, and ground and aeromagnetic surveys. Highly specialized and sophisticated techniques are often required to deal with particular problems, such as dating last movement on certain faults.

The results of these various studies are used not only in the design of the plant, but are presented in the PSAR, are discussed at hearings, and become a matter of public record.

DESIGN CONSIDERATIONS

Sesimic Design

For the eastern United States, where earthquakes cannot be directly related to mapped faults, the NRC requires that a tectonic province approach be used to assign a design earthquake to a nuclear power plant site. The plant must be designed assuming 1) that the largest earthquake which has occurred within the tectonic province of the site could occur adjacent to the site or 2) that the largest earthquake in the adjacent province could occur at the nearest approach of that province to the site. That earthquake is considered which would result in the highest site intensity.

The mapped tectonic features and provinces of southern New England are widely believed to continue south-southwestward along strike beneath Long Island. Such a projection places the Shoreham site in either or both the Merrimack Synclinorium and the Bronson Hill Anticlinorium. Since the largest earthquake in this province was the intensity VII event of 1791 in East Haddam-Moodus, Connecticut (43 miles northeast of the site), the Shoreham structures were designed for an equivalent occurrence adjacent to the site. There are several relationships published (Barosh, Newman, Gutenburg and Richter, Coulter, Waldron and Devine) of ground acceleration versus earthquake intensity. These publications all indicate that 0.16 g is a reasonable, conservative estimate of the peak ground acceleration at the Shoreham site. To ensure very conservative analysis and design, a peak acceleration of 0.2 g has been chosen as the Safe Shutdown (Design Basis) Earthquake. The strong motions would result from a magnitude 6 earthquake with a focus in the lower half of the earth's crust. The duration of strong motion is estimated at 1 second at or close to the maximum horizontal ground acceleration of .2 g and 10 sec. for horizontal ground accelerations greater than .05 g.

Soil Stability

Stability analyses of soils for the support of foundations were based on detailed field investigations including in situ testing of permeability and seismic wave velocity and static and dynamic testing of soil samples to determine their physical properties. Soil moduli were based on loading tests and observation of settlements made at Brookhaven National Laboratory on soils similar in mode of deposition and character to those found at Shoreham.

Since the soils underlying the site are principally sands and gravels to a depth of several hundred feet, the major geotechnical concern was demonstrating that liquefaction would not occur under earthquake loading conditions. Liquefaction occurs when earthquake induced vibrations tend to densify loose granular soils. If the pore water cannot escape quickly enough, some or all of the overburden pressure is carried temporarily by the pore water and there is a proportional drop in shear strength. When the pore water pressure equals the confining pressure the soil temporarily liquefies. A very clear description of this phenomena has been given by Youd (1973).

The susceptibility of a soil to liquefaction is governed by grain size, relative density, and magnitude of earthquake loading. Generally speaking, silts and sands or any combination thereof may liquefy, while open gravels and clays will not. Sands with relative densities greater than 70-75 percent generally will not liquefy except under very large cyclic stresses or very high confining pressures. Naturally as the earthquake induced shear stresses increase, so does the tendency for liquefaction, all other conditions remaining equal. Unfortunately, determining absolutely the strength and relative density of sand deposits extending several hundred feet below the ground is not a simple matter. Although standard penetration resistance (SPR) and testing of undisturbed samples are two widely used means of determining the strength and relative density of sand, considerable controversy still exists concerning both methods. The SPR method consists of relating SPR blow counts to relative density based on a correlation developed by Gibbs and Holtz (1957). The undisturbed sample method consists of measuring the density of the tube sample, then remolding the sample to determine the minimum and maximum unit weight, from which the relative density is calculated. The relationships between relative density and the cyclic shear stress at which liquefaction will occur has been published by Lee and Seed (1967). In addition to these methods at the Shoreham site, remolded samples of sand were subjected to cyclic triaxial tests to confirm the stress at which liquefaction will occur. As a result of these studies it was concluded that a relatively loose zone down to elevation -12 ft would be excavated and replaced with compacted select granular fill in the vicinity of the major structures.

CONSTRUCTION CONSIDERATIONS

Soil Compaction

The soil underlying all of the structures in the general plant area, including the reactor building, turbine building, control building, and radwaste building, was overexcavated to approximately elevation -12 ft and replaced with compacted fill. The compacted backfill consisted of sand excavated from the site and recompacted in thin lifts, using vibratory equipment under carefully controlled conditions, to achieve densities of at least 95 percent of the maximum density as determined in a Modified Proctor compaction test, per ASTM D1557. This provides a pad of very dense, uniform, granular material immediately under the foundations of these structures. The thickness of the pad is 10 ft under the reactor mat and varies with the founding elevations for the other structures.

Excavation and backfill were performed in the dry, using a two stage well point system to draw the groundwater level below the bottom of the excavation. During excavation, the materials were segregated by visual inspection and stockpiled. A sufficient quantity of select granular fill, defined as clean, granular soil, containing not more than 7 percent fines passing the No. 200 sieve, was present in the excavation so the offsite fill was not needed to construct the compacted fill.

Dewatering

The average groundwater level in the general plant area is elevation 10.8 ft. In order to excavate to elevation -12 ft and construct the compacted backfill, local dewatering was necessary. This dewatering was accomplished using a two stage wellpoint dewatering system. The upper stage consisted of a closed loop header at elevation 10 ft and approximately 350 wellpoints pumped by four 2,400 gpm engine driven centrifugal-vacuum pumps. The tips of the wellpoints, including 3-foot screens, were at elevation -21 ft. The initial pumping rate was estimated to be 3,000 gpm. After ten days of pumping, the groundwater level in the excavation area stabilized at approximately elevation -6 ft, and the rate of pumping had dropped to about 2,000 gpm. Excavation proceeded as the groundwater level was drawn down. The lower stage header at elevation 0 (zero) and wellpoints with tips at elevation -24 ft were installed. Excavation continued, closely following the falling groundwater level. Artesian flow, apparently occurring through an earlier exploratory boring, Boring 201, was encountered at elevation -10 ft and was subsequently sealed. The second stage drawdown stabilized at elevation -14 ft and construction of the compacted fill was begun. Pumping of the lower stage wellpoint system was discontinued and the upper stage was returned to service after the compacted fill has been constructed to approximately elevation 0. Dewatering continued until construction of foundations of the structures had been completed, and the compacted backfill was placed to approximately elevation 10 ft.

During dewatering, samples of the groundwater were obtained from observation wells set outside the perimeter of the excavation. Chloride ion concentrations of these samples were measured to detect saltwater intrusion and possible adverse effects on neighboring wells. When saltwater intrusion was detected, a recharging system was designed and installed. This system consisted of a recharge trench located in the northeast section of the excavation area. The recharge trench was designed to receive water from the plant fresh water system for the purpose of establishing a localized hydraulic barrier against saltwater intrusion from the nearby Wading River Creek. Subsequent monitoring of chloride ion concentration indicated that the recharge trench was working effectively.

Other areas of the site requiring localized dewatering for the construction of structures included the circulating water discharge trench, circulating water intake trench, and the screenwell. Dewatering of the trenches was accomplished using a single stage of wellpoints. Dewatering of the screenwell was accomplished using submersible pumps set inside a sheetpile cofferdam.

SITE VISIT

Due to the nature of this particular field excursion, a detailed road log will not be presented here. Instead, a lecture with slides will precede a walking tour of Shoreham Nuclear Power Station.

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FORESHORE AND BACKSHORE NATURAL ENVIRONMENTS OF A BARRIER ISLAND

The tour vehicle will park in the lot at Smith Point County Park. The Fire Island National Seashore begins just west of the County Park campground. The tour will begin with a short walk down the sand trail (locally known as the "Burma Road") which runs along the center of the island.

STOP #1, Artesian Well

At the site of a former Coast Guard station will be Stop #1 to observe an artesian well, and discuss the availability of fresh water on the island, as well as the problems involved in its use.

The trip will continue through the vehicle cut in the primary dune and there will be a brief discussion on the aspects of vehicle use on the island.

STOP #2, Old Inlet Area

Proceeding onto the ocean beach, the tour will begin the 1-1/4-mile walk to the Old Inlet area. Along the way there will be a chance to observe wave action, compare the winter beach form with that of the summer, and note sand transport by wind. There will be a discussion on the formation of the barrier island and its possible future. Other topics for examination will include plant succession and stabilization of the dunes, and important marine life.

Upon reaching the Old Inlet ranger station Stop #2 will include a climb to the observation platform to observe the landforms in the immediate area. Subjects such as overwash, inlet formation, and their relationship to barrier island structure will be discussed and analyzed. The effect of man-made structures will also be discussed.

STOP #3, Salt Marsh Community

The trip will continue by following the boardwalk down to the bay to observe the vegetation of the salt marsh community. Viewing the Great South Bay from the dock the talk will center around the marine life of the bay and its economic importance to the region.

On the return trip to Smith Point the tour will once again follow the Burma Road, observing the plants of the swale and thicket zones, watching for the birds and animals which are present at the Fire Island National Seashore in November.

AN IMPORTANT NOTE: walking through loose sand is tiring. Strong hiking shoes or boots are recommended. Sneakers are inappropriate. Depending on the weather, the trip may be exposed to strong wind and salt spray. Please plan clothing and camera protection with this in mind.

TRIP B-1: LOWER PALEOZOIC METAMORPHIC STRATIGRAPHY AND STRUCTURE OF THE MAMARONECK AREA, NEW YORK

By Thomas L. Pellegrini, SUNY at Buffalo

INTRODUCTION

The rocks of southwestern Connecticut and southeastern New York can conveniently be divided into two northeast-southwest trending belts. The easterly strike belt is a metamorphosed eugeosynclinal assemblage of mixed clastic and volcanic rock (Hartland Formation and Harrison Gneiss). The Mamaroneck area is located within this belt on Long Island Sound (figure 1). The strike belt to the west is a Cambrian-Ordovician quartzite-carbonate sequence (predominantly Lowerre Quartzite and Inwood Marble) deposited on a Precambrian basement complex of the Fordham and Yonker's Gneisses. Overlying this miogeosynclinal sequence are the syntectonic and overthrust members of the Manhattan Formation (Hall, 1968a). From the Berkshire Highlands to the Manhattan Prong, these two belts meet along a sharp discontinuity known informally as Cameron's line. Cameron's line is interpreted by many (Clarke, 1958; Gates and Christensen, 1965) as a thrust fault. Locally in the Manhattan Prong, however, subsequent deformations may have obscured any local discontinuity.

METAMORPHIC STRATIGRAPHY

Hartland Formation

The Hartland Formation (Rodgers and others, 1959) represents the oldest rocks exposed in this area and is probably of Cambrian-Ordovician age. This formation is believed to be a metamorphosed assemblage of eugeosynclinal pelitic schists and graywackes. Numerous minor volcanic and intrusive rocks are also present. Recent mapping in this area indicates that three of Hall's (1968b) four subdivisions of the Hartland Formation are present. Although age relationships are uncertain here and elsewhere, the fourth and oldest member, the Amphibolite Member, may be present but not exposed. While the Carrington's Pond and White Gneiss Members can be found only in the extreme northwestern corner of the quadrangle, they are poorly exposed and will not be examined on this trip. The Schist and Granulite Member, the youngest member, comprises the bulk of the Hartland Formation in this area. Within this member numerous amphibolites have been observed. The largest of these discontinuous amphibolite units have been indicated on figure 1.

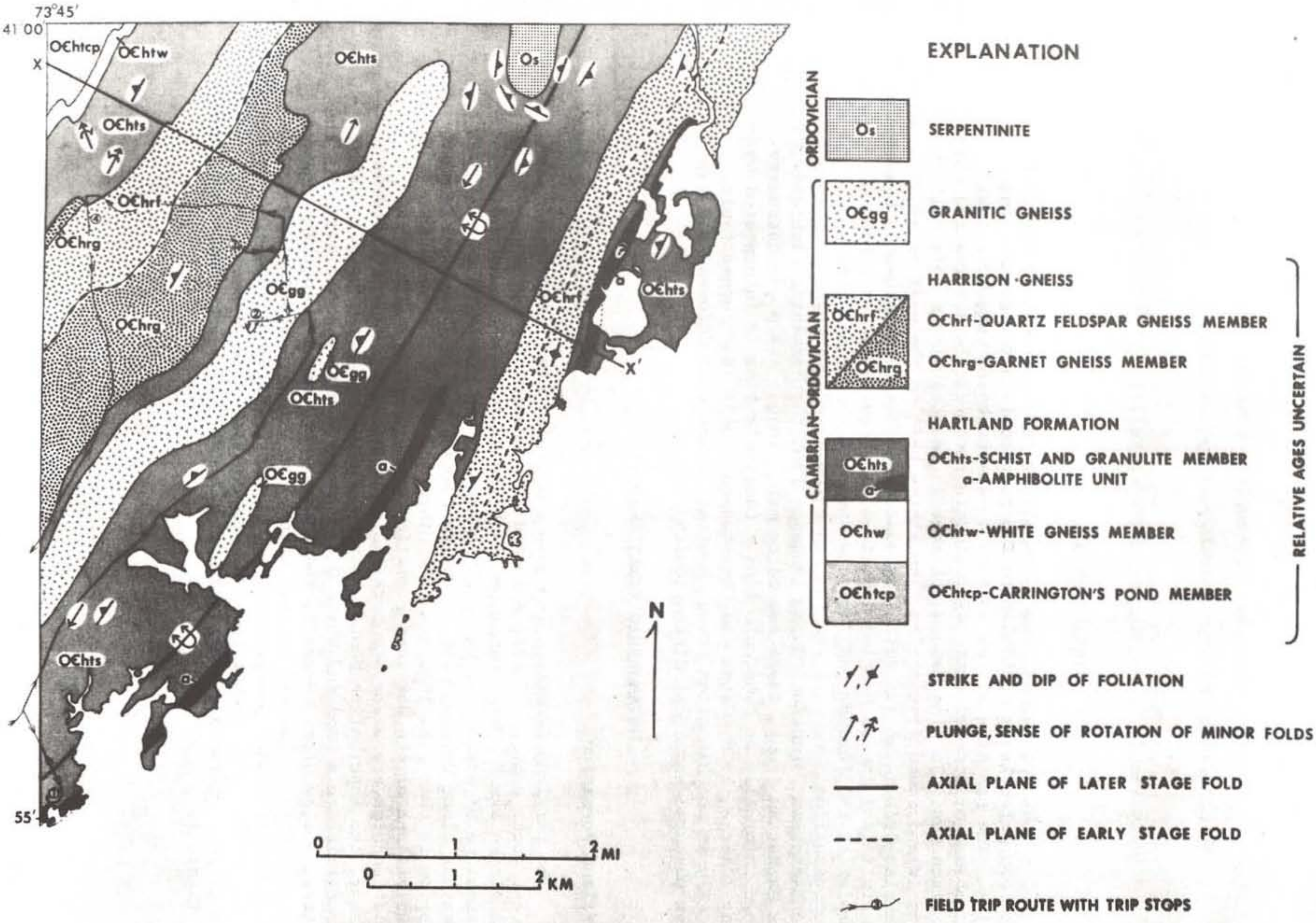

Figure 1. Geologic Map of the Mamaroneck area

These members are described briefly below in their probable order of decreasing age. In these and in all other rock descriptions, minerals are listed in order of increasing abundance.

Carrington's Pond Member: Interbedded white and gray biotite-muscovite-quartz-feldspar gneiss, rusty or brown weathering garnet-muscovite-biotite schist with local amphibolites.

White Gneiss Member: Light gray or white, medium-grained biotite-muscovite-quartz-feldspar gneiss with local garnet, light gray or white garnet-biotite-muscovite gneiss.

Schist and Granulite Member: Brown or rusty weathering, gray garnet-sillimanite-muscovite-biotite-quartz-feldspar schist and gray sillimanite-muscovite-biotite-quartz-feldspar schist with local garnet, interbedded with brownish tan weathering, gray, fine grained biotite-quartz-feldspar granulite with local garnet and coarser grained, white quartz-feldspar layers. Schist and granulite is commonly interbedded with gray, rusty weathering muscovite-biotite-quartz-feldspar gneiss or schistose gneiss. Lenses of kyanite and sillimanite are locally present. Calc-silicates interbedded with rusty weathering, sulphidic, fine grained muscovite-biotite schist are rarely present.

Amphibolite unit: Quartz-hornblende-plagioclase amphibolites with or without green calcite-diopside-epidote lenses are interbedded with the typical rocks described above.

Harrison Gneiss

Overlying the Schist and Granulite Member of the Hartland Formation is the Harrison Gneiss. In the Mamaroneck area, the Harrison Gneiss has been subdivided into the Quartz Feldspar Gneiss Member and the Garnet Gneiss Member. The Harrison Gneiss is interpreted here as metamorphosed andesitic to dacitic volcanic rock. The subdivided members of this formation are believed to have been formed contemporaneously. The Quartz Feldspar Gneiss Member is widespread throughout southeastern New York and southwestern Connecticut. Of more limited distribution is the Garnet Gneiss Member which appears only on the west limb of the major antiform (figures 1 and 2) and apparently pinches out elsewhere. Layers of the Quartz Feldspar Gneiss Member, two or three yards thick and up to a quarter of a mile in length, have been mapped within the Garnet Gneiss Member near the contact with the Hartland Formation.

The members of the Harrison Gneiss are described below.

Garnet Gneiss Member: Light gray weathering, locally rusty, medium-grained, medium gray garnet-biotite-and/or hornblende-quartz-feldspar gneiss. Poikiloblastic grains of garnet are noticeable but not abundant - often contains small prominent lenses of finer grained mafic minerals. Sphene is rare. Locally, porphyroblasts of microcline are present near the contact with the Hartland Formation in a more granitic zone.

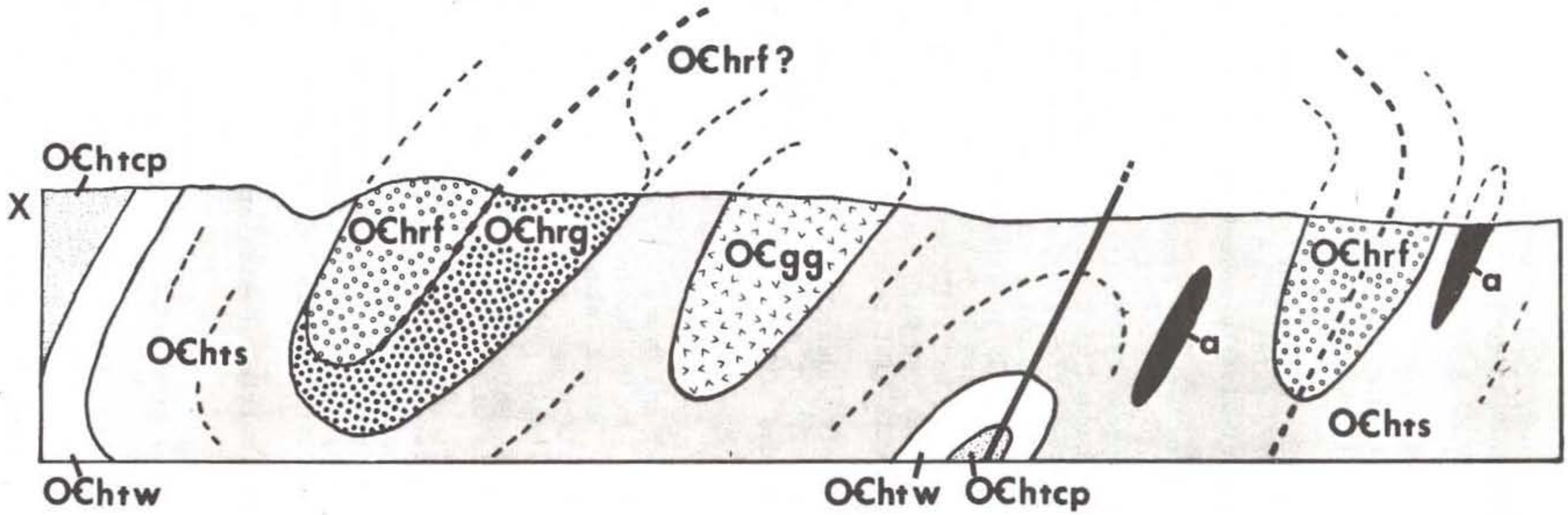

Figure 2. Generalized cross section. Refer to Figure 1 for location and symbol key. Topography exaggerated 4X.

Quartz-Feldspar Gneiss Member-Medium grained, dark gray biotite- and/or hornblende-quartz-feldspar gneiss or biotite-hornblende-feldspar gneiss with minor quartz. Sphene rare. Lenses of finer grained mafic minerals common. Easily distinguished by large irregularly shaped, coarse-grained quartz-feldspar segregations.

INTRUSIVE ROCKS

Granitic Gneiss

Numerous intrusive rocks can be found throughout the Mamaroneck area. Most of these intrusive bodies are small and not mappable at scales of 1:24,000. A large sill-like pluton and two smaller bodies of a unit informally called the Granitic Gneiss (Pellegrini, 1974, in press), however, have been indicated on figure 1. These intrusives were emplaced prior to or within the early phase of folding.

Serpentinites

Ultramafic rocks similar to those found in the Mamaroneck area have been found throughout the Appalachians in a long but narrow chain. In this area, Serpentinites have been emplaced within the Schist and Granulite Member. Since these rocks weather extremely rapidly, surface outcrops are rare and the actual contact cannot be observed. Detailed mapping in that area, however, indicated that the Serpentinite crosscuts and deforms the dominant foliation of the Schist and Granulite Member.

Although no stop is planned, there are excellent exposures of these serpentinites along the Cross Westchester Expressway. The rocks are light to medium-green weathering, fine-grained and massive often with no readily discernible lineation or foliation. When fresh, the rock is dark blackish green. Megascopic magnetite and carbonate-filled veins are common. In thin section, porphyroblasts of enstatite are commonly seen in a finer matrix of chrysotile and antigorite.

STRUCTURAL GEOLOGY

The stratigraphic units in the Mamaroneck area outline a structure resulting from at least two phases of deformation (figures 1 and 2). The dominant northeast trending bedding foliations (S_1) and related lineations (L_1) were developed during an early phase of isoclinal folding. All the units previously discussed with the exception of the Serpentinite and numerous small undeformed pegmatites were present for this early phase of folding. Metamorphism was probably in the amphibolite facies.

The early isoclinal fold is well displayed where the Schist and Granulite Member of the Hartland Formation appears continuously in contact with the Harrison Gneiss. (figures 1 and 2). On the west limb, the Garnet Gneiss Member of the Harrison Gneiss is in contact with the Schist and Granulite Member on both the east and west sides of the early-phase axial plane. This member is believed to be a continuous unit that wraps around the nose of the fold before pinching out.

In the north and northwest portions of this area, linear elements (L_1) indicate a northeasterly plunge for this early phase fold. Further to the south and southwest, the plunge reverses although locally there are horizontal, northeasterly and southwesterly plunges.

Evidence for a second major phase of folding is abundant. Minor folds, plunging in various directions and often showing opposite senses of rotation, folded lineations, and refolded isoclinal folds are relatively common. The westerly dipping limbs of the later stage antiformal fold are clearly shown by the Harrison Gneiss in the east and west portions of figures 1 and 2. The nose of this fold is clearly outlined by the Harrison-Hartland contact further north (Hall, 1968b). The axial plane of this isoclinal fold trends northeast and dips steeply to the west. Minor folds and boudin lines (L_2) generally plunge slightly west of north or north. Locally the plunge may be to the south, particularly in the central part of the area, and occasionally almost vertical. Further south near New Rochelle, the axial plane becomes vertical and still further south it dips to the east. Minor folds resulting from this deformation are usually easily recognizable since they refold the S_1 foliation about the L_2 axes.

Evidence for a third phase has also been observed. In large outcrops, large gentle warps are present in the foliation planes; the axes of which plunge steeply to the northwest. This possible third phase appears to have had no profound effect on the major structures previously described.

SPECULATIONS ON THE AGE OF DEFORMATION

Isotopic ages in southeastern New York and southwestern Connecticut suggest that at least three metamorphic events effected this region since the Precambrian (Long, 1961; Long and Kulp, 1962; Clark and Kulp, 1968). The dates obtained for these events are 480 to 460 m.y., 360 m.y. and 255 m.y. ago.. These ages correspond to the Taconic, Acadian and Alleghenian orogenies. The first event is believed to be the most intense while the 360 m.y. event was only a mild reheating. The youngest event becomes progressively more predominant eastward into Connecticut. In and near the Mamaroneck area, isotopic ages for these units range from 379 to 285 m.y. The emplacement of the Serpentinite may provide a basis for speculation on the age of the deformational phases and of the rocks themselves. Studies of orogenic zones (Hess, 1955; Coleman, 1971; Dewey and Bird, 1971) suggest that such emplacement occurred in the initial phases of orogeny shortly after the establishment of a subduction zone. The Serpentinite in the Mamaroneck area can be found exposed near the axial surface of the later-phase anticlinal fold. There they plunge northward in accord with that structure. These rocks were then emplaced prior to or within that phase of folding. Since they also appear to crosscut and deform the bedding foliation of the early phase fold, they must be younger than this phase.

The time of emplacement of similar ultramafic rocks throughout the northern Appalachians is generally accepted to have been during the Ordovician (Doll, 1961; Dewey and Bird, 1971; Zen, 1972). It is probable then that the rocks of the Mamaroneck area were intensely deformed during the Ordovician Taconic Orogeny. The Acadian thermal event (360 m.y.) may be recorded in the numerous small undeformed pegmatitic intrusions seen throughout this area (Clark and Kulp, 1968, p. 886). It is therefore apparent that the rocks of this area were not as severely deformed during the Devonian as they were in earlier periods, and that the earlier deformation consisted of at least two and probably more distinct pulses.

REGIONAL CORRELATIONS

Correlations of the various units in the Mamaroneck area are tentative. Regional considerations suggest that the Hartland Formation may correlate in whole or in part with the Lower Cambrian through Middle Ordovician Hoosac, Rowe and Moretown Formations of western Massachusetts (Hatch and others, 1966; Hatch, 1967). In the Glenville area, Hall (1968, p. 4) suggests that the youngest member of the Hartland Formation, the Schist and Granulite Member, does correlate with the lithologically similar Moretown Formation. If these correlations are valid, the Harrison Gneiss would be in the correct stratigraphic position to correlate with the volcanic Hawley Formation of western Massachusetts (Hatch, 1967). Although a detailed stratigraphic sequence has been established in areas of western Connecticut, the lack of outcrops permits only generalized correlation with this region. In southcentral Connecticut, Hall (1968b, p. 4) suggests that the Beardsley Gneiss Member of the Prospect Gneiss (Crowley, 1968) is a correlative of the Harrison Gneiss (in this paper, the Quartz Feldspar Gneiss Member) of the Glenville area. The Garnet Gneiss Member may also correlate with the Pumpkin Ground Member of that same formation and the Granitic Gneiss appears to be lithologically similar to the intrusive Ansonia Gneiss (Fritts, 1965). It is unclear, however, as to which units correlate with the Hartland Formation of this area.

The Harrison Gneiss has previously (Merrill and Magnus, 1904) been correlated with the Ravenswood Granodiorite at the westernmost end of Long Island. This interesting correlation may indicate that the proposed thrust fault (Cameron's line) between the eugeosynclinal and the miogeosynclinal sequences may extend through the East River. There the Hartland Formation which probably underlies Long Island, would be in contact with the miogeosynclinal Inwood Marble.

ACKNOWLEDGEMENTS

I would like to express my thanks to the following for allowing access to the exposures viewed on this trip: Larchmont Manor Park Society, Town of Harrison, and the Michael Harmony Corporation. I would also like to thank Leo M. Hall of the University of Massachusetts for first introducing me to the geology of this area and Leslie Sirkin of Adelphi University for his support.

ROAD LOG

Cumulative Miles	Miles from last point	Description
0.0	0.0	The road log begins at the toll booths at the north end of the Throgs Neck Bridge. After paying toll, bear to the right to take the New England Thruway (I-95) north.
8.6	8.6	Exit I-95 at North Avenue-Cedar Street (exit 8-last exit before toll). Turn right (south) off exit ramp.
8.9	.3	Turn left (east) onto North Avenue.
9.2	.3	Turn left (north) onto Main Street (US 1).
9.9	.7	The Granitic Gneiss outcrops on the west side of the road.
11.2	2.0	Turn right (east) onto Larchmont Avenue.
11.5	.3	After entering the Mamroneck Quadrangle, continue down Larchmont Avenue through the axial region of the later stage fold. After the road bends to the right, Larchmont Avenue becomes Park Avenue.
12.0	.5	Turn right onto Prospect Avenue and park for STOP 1 at the Larchmont Manor Park.

STOP 1. Larchmont Manor Park. NO HAMMERING PLEASE! Enter the park along the paved path at the intersection of Prospect and Park Avenues. Proceed southeast (left) towards a small shelter on a promontory on Long Island Sound. The rocks here have been assigned to an amphibolite unit of the Schist and Granulite Member of the Hartland Formation. As the path continues before the clubhouse, it crosses a broad fold in interbedded schists and granulites which formed during the later stage of folding.

Generally, however, the minor folds related to this episode of folding are tight isoclinal folds. The parallel lithologic layering seen throughout this member is believed to be primary in origin. Although metasomatism may have accentuated this layering in the original S_o plane, these gross compositional differences are considered bedding, reflecting a sedimentary or volcanic origin. The early stage of isoclinal folding produced a foliation (S_1) generally parallel to the S_o. The later stage of folding refolded this early foliation. The S_2 foliation produced clearly crosscuts the S_1 here.

Continue down the path towards the shelter past a glacially grooved and striated amphibolite. The numerous interbedded amphibolites to the east of the shelter occupy a persistent stratigraphic position and are believed to be of volcanic origin. Similar rocks have been described at Pelham Bay to the south (Seyfert and Leveson, 1968). Greenish calc-silicate lenses composed primarily of epidote and diopside with calcite are common here and often prominent in the crestal regions of folds. The numerous northerly plunging folds are related to the later stage of deformation. The variation in the angle and direction of plunge of the L_2 axes may be due to an additional deformation, or it may be the reflection of the development of L_2 on a curvilinear surface. Crosscutting, undeformed pegmatites can be seen throughout the park. These pegmatites probably correspond to the Acadian thermal event.

Across the inlet northeast of the shelter, the interbedded schists and granulites are typical of the rocks of the Schist and Granulite Member although to the north schist may be more abundant. The rhythmic interlayering of these rocks may represent graded bedding.

Return along same path and board the bus. Proceed down Prospect Avenue and turn right (north) onto Magnolia Avenue.

12.2 .2 Turn left (west) onto Larchmont Avenue.

12.9 .7 Right turn (north) onto Boston Post Road (US 1).

14.0 1.1 The outcrops on the west side of the road near the playing fields behind the Administrative Offices of the Mamaroneck School District contain amphibolites very similar to those seen at STOP 1. Here, however, they are apparently a small isolated lens.

15.3 1.0 Bear to the left (west) at the fork for Harrison Avenue (Route 127) and proceed north towards Harrison.

16.7 1.4 After crossing the bridge over the railroad tracks, turn left (west) onto Calvert Street across the contact of the Granitic Gneiss and the Schist and Granulite Member. Continue down Calvert Street past Nelson Avenue.

17.1 .4 Park on Calvert Street in front of Pettijohn Park for STOP 2.

STOP 2. Pettijohn Park.
These outcrops of Granitic Gneiss lie near the center of this sill-like pluton. Typically this rock is a brown or brownish tan weathering, light bluish gray, fine to medium-grained, biotite-muscovite-quartz-feldspar gneiss. Microcline is the dominant feldspar; garnet is rare and occurs as small scattered grains. Biotite, although relatively sparse, gives the rock a distinct foliation which here trends northeast in accord with the major structures. The more typical fine-to-medium-grained gneiss at this exposure is commonly associated elsewhere with a white, foliated and lineated pegmatite. Although the contacts between the two types of rock tend to be sharp, the lineations and foliations pass without interruption into the more typical granitic gneiss. The pegmatites are therefore mapped as part of this unit.

Smaller bodies of this rock have been mapped throughout this area and the larger ones have been indicated on figure 1. Some crosscutting dikes have been observed within the Harrison Gneiss, however, the other bodies are all concordant. Although the smaller bodies tend to have sharp contacts, a zone of migmatite occurs along the contacts of this large body.

From the park continue west on Calvert Street. Go around the block by making a left (south) onto Adelphi Street, left (east) onto Rugby Street and left (north) again at Avondale Street. You should now be back at Pettijohn Park. Turn right onto Calvert Street.

17.6 .5 Turn left (north) onto Nelson Avenue.

18.1 .5 Cross the bridge over the New England Thruway and make a left (west) turn onto Crystal Street. Proceed down Crystal Street across the west contact of the Granitic Gneiss with the Schist and Granulite Member.

18.5 .3 At the end of Crystal Street, enter the Town of Harrison Veterans Memorial Park while crossing the contact of the Hartland Formation with the Garnet Gneiss Member of the Harrison Gneiss. Park in the unpaved parking area for STOP 3.

STOP 3. Veteran's Memorial Park.
Scattered throughout the park are excellent exposures of the Garnet Gneiss Member of the Harrison Gneiss. These exposures are on the west limb of the later-stage antiform. This member apparently pinches out further north and is not present on the east limb of the same fold (figure 1). The flat glaciated outcrops within and around the parking area expose a distinctly porphyroblastic zone within this member. The rock is more granitic than most of this member and the porphyroblasts are microcline commonly exhibiting Carlsbad twinning. This zone parallels the contact of this member with the Schist and Granulite Member of the Hartland Formation for at least two miles and appears as a distinct unit or units within the Garnet Gneiss Member. Intensely deformed metasedimentary layers are also present in these outcrops.

From the restrooms at the southern end of the parking area, proceed southwest (bearing 250°) across the recently filled valley to a dirt road and then up the east valley wall. PROCEED WITH CAUTION OVER THE CONSTRUCTION DEBRIS FILL! Total distance to the top of the ridge from the restrooms is about one thousand feet. These exposures contain some of the evidence for the volcanic origin of the Harrison Gneiss. The contact of both members of the Harrison Gneiss with the Schist and Granulite Member is always conformably interlayered with that member. As shown here, thin distinct metasedimentary layers, often only an inch or two thick, can be traced for tens of feet without interruption through the Harrison Gneiss. This interbedded contact can be up to 150 feet thick. The interlayering is suggestive of alternating sedimentary and possibly pyroclastic deposition rather than an intrusive or tectonic mechanism. The Prospect Gneiss, a possible western Connecticut correlative, has a similar contact. Crowley (1968, p. 39) believes that the Prospect Gneiss is a metamorphosed volcanic sequence. The Ravenswood Gneiss to the south also has an interbedded contact although Blank (1973, p. 656) considers it to be sedimentary.

Additional exposures of the contact, although quite deformed, can be seen west of the playing fields adjacent to the entrance to the park. The Schist and Granulite Member is exposed in the stream flowing by the nearby Louis M. Klein Middle School. As can be easily seen at this stop, topographic differences usually facilitate the location of the contact.

Return down Crystal Street to Nelson Avenue.

18.9	.4	Turn left (north) onto Nelson Avenue.
19.1	.2	Turn left (west) onto Union Avenue.
19.3	.2	Recross the contact of the Schist and Granulite Member with the Garnet Gneiss Member.
19.9	.6	Cross the axial plane of the early stage fold and the contact of the Garnet Gneiss Member of the Harrison Gneiss with the Quartz Feldspar Gneiss Member. Here the two members of the Harrison Gneiss have been folded against each other (figures 1 and 2).
20.3	.4	The outcrops in front of the Harrison High School are of the Quartz Feldspar Gneiss Member.
20.7	.4	After crossing the west contact of the Harrison Gneiss with the Schist and Granulite Member, turn left (south) onto Mamaroneck Avenue.
20.9	.2	Turn left (east) into the parking lot and park at the southern end of these continuous exposures for STOP 4.

STOP 4. Parking lot cuts off Mamaroneck Avenue. NO CLIMBING ON THE ROCKS PLEASE! These extensive cuts are in the Quartz Feldspar Gneiss Member of the Harrison Gneiss. Large irregularly shaped segregations of quartz and feldspar and the lack of megascopic garnet easily distinguish this member from the Garnet Gneiss Member. Although biotite commonly exceeds hornblende in both members, the great abundance of biotite here accounts for their somewhat slabby appearance. Present throughout both members and evident in these outcrops are small lenses or streaks of fine-grained hornblende, biotite and feldspar, usually measuring a few inches by a foot or more. Similar lenses have been interpreted as relict volcanic bombs in the Prospect Gneiss (Crowley, 1968, p. 39) and in the high grade metavolcanics of the Southern Appalachians (Tobisch and Glover, 1971, p. 2212).

At the north end of these cuts and along Union Avenue, the contact with the Schist and Granulite Member is exposed. Here the Hartland Formation, on the limb of a small fold (figure 1), contains rusty weathering, sulphidic looking schists. The contact of this member of the Harrison Gneiss with the continuous but folded contact of the Schist and Granulite Member is also interbedded.

Most of the exposures across the Mamaroneck River in the northern part of Saxon Woods Park are of the Quartz Feldspar Gneiss Member. To the southwest, near the Hutchinson River Parkway, the Garnet Gneiss Member is exposed. There it apparently wraps around the nose of the refolded early stage fold (figures 1 and 2) but pinches out before reaching this location.

Exit the parking lot by turning left (south) onto Mamaroneck Avenue.

21.4	.5	Recross the folded contact of the Quartz Feldspar Gneiss and Garnet Gneiss Members.
21.7	.3	Enter the southbound entrance ramp of the New England Thruway (I-95) passing exposures of the Garnet Gneiss Member and return to the Throgs Neck Bridge.

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NOTES

GEOLOGICAL ASPECTS OF STATEN ISLAND, NEW YORK

By A. Ohan, A. Kureshy and E. Kaarsberg

Staten Island Community College
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INTRODUCTION

The purpose of this Staten Island field trip is to illustrate some of the major aspects of the island's geology. As shown in Figure 1, the geology of this area can be subdivided into four main units as follows:

1. A lower Paleozoic serpentine body that is exposed in the north central part of the island and which displays a northeast-southwest trend.

2. The late Triassic aged Stockton Formation of the Newark Group which overlays the serpentinite unconformably on the northwest. Its beds dip to the northwest and are generally arkosic in character. The southern extension of the Palisades diabasic sill is intrusive into the Stockton Formation.

3. The late Cretaceous aged Raritan Formation, which overlays the Triassic aged unit unconformably, is part of the Coastal Plain sedimentary deposits that outcrop on the southern and eastern part of Staten Island. It dips gently to the southeast and lithologically is composed of sand and clay interbeds.

4. Pleistocene deposits unconformably overlaying the older units almost everywhere on the island.

Figure 1 also shows the location of the four field trip stops that will be made and their relationship to the above mentioned geological units. Also shown are the locations of two geological cross-sections that will be discussed in this field trip. No stop will be made at a Triassic aged sedimentary outcrop.

GEOLOGY OF THE STATEN ISLAND SERPENTINITE

(By A. Ohan)

General Information

The Staten Island Serpentinite is a NE-SW trending oval shaped body located in the northeast portion of Staten Island and has an outcrop dimension of approximately 20 square miles. This ultramafic mass displays a sheared, conformable contact with metamorphic rocks of the lower Paleozoic New York City Group and is unconformably overlain by younger Triassic and Cretaceous sediments along the northwest and southeast borders, respectively.

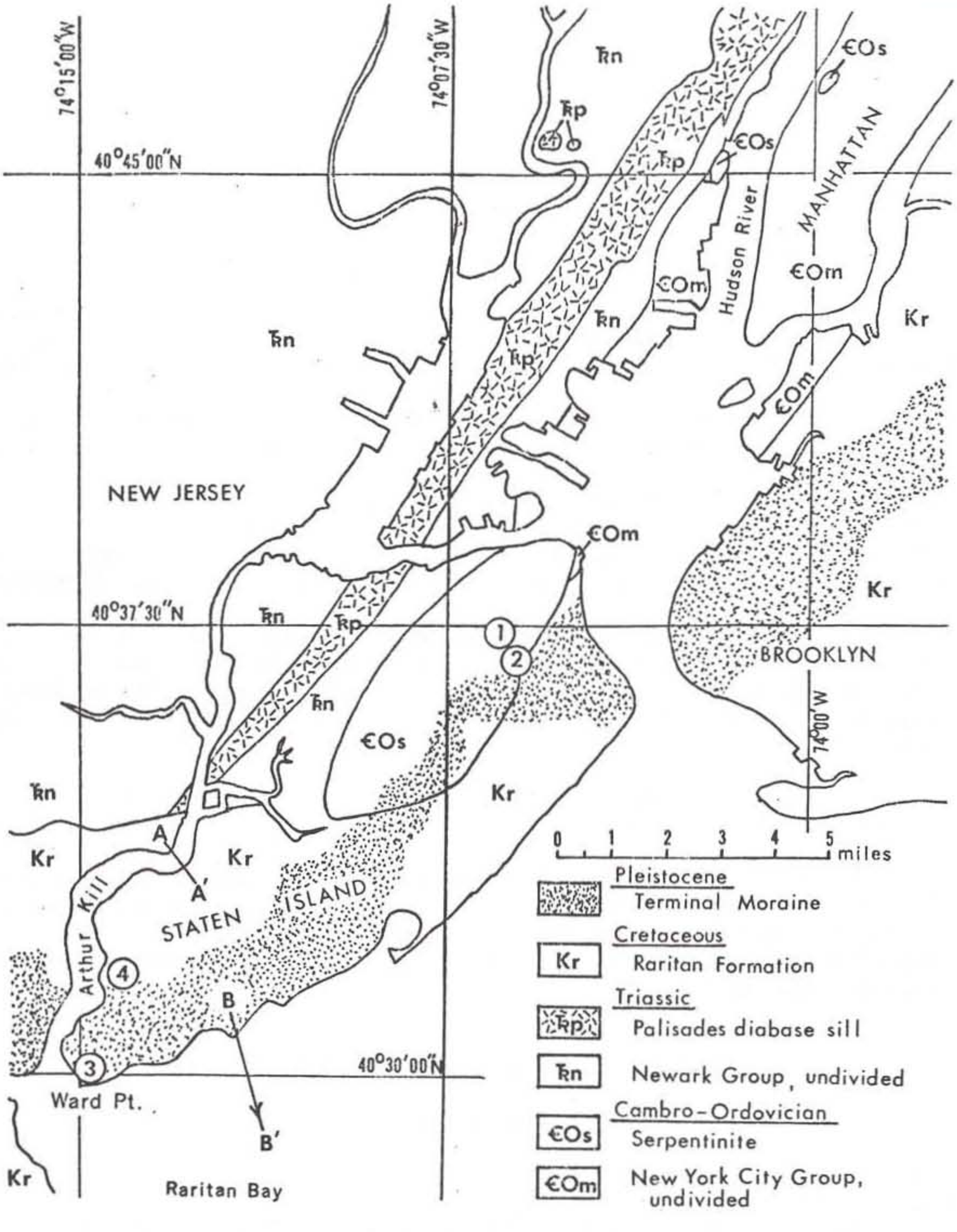


FIGURE 1 — REGIONAL GEOLOGY OF STATEN ISLAND
(Modified after Miller, 1970)

The long dimension of the Serpentinite is parallel to the structural trend of the New York City Group which evolved during the Ordovician Taconian Orogeny. As a result of extensive overlying Pleistocene deposits as well as urbanization, outcrops are few in number. Topographically, the Serpentinite is a ridge former, reaching an elevation of 413 feet above sea level.

Historical Summary of Investigations

The principal petrologic study of the Staten Island Serpentinite was accomplished by J. Behm (1954). His conclusions are outlined as follows:

1. The original ultramafic body was a harzburgite-type peridotite composed of olivine, orthopyroxene with accessory picotite.

2. As a result of serpentinization, the above minerals were altered to antigorite, bastite (serpentinized orthopyroxene), serpophite (glassy serpentine), chrysotile, talc, anthophyllite and magnetite.

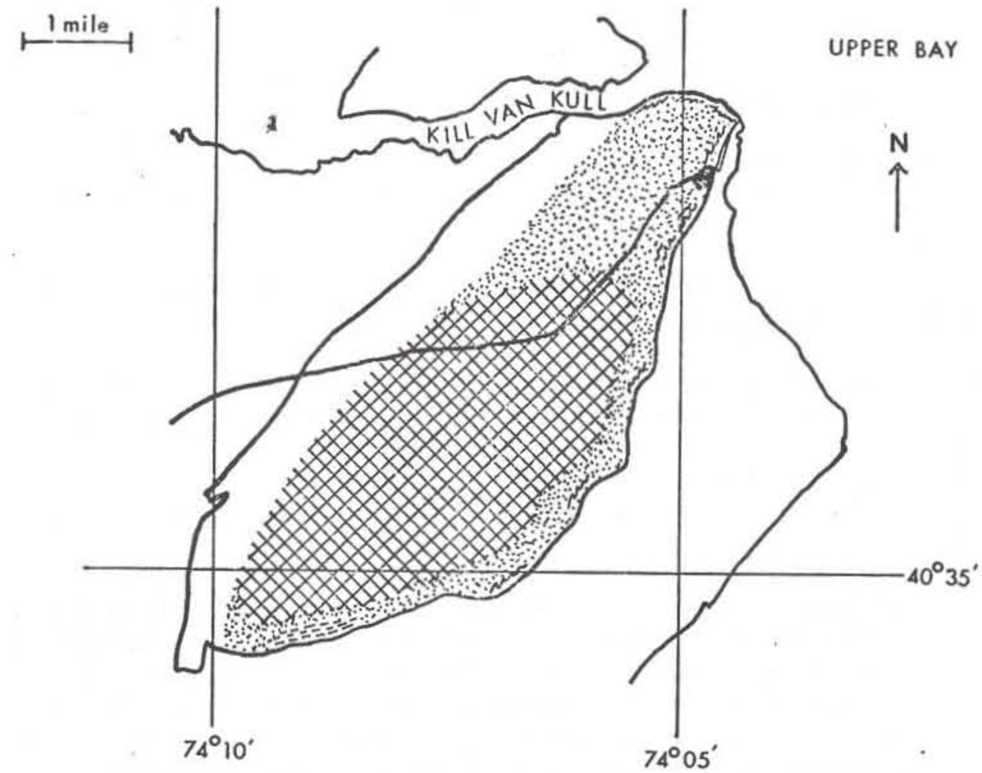
3. Two major zones exist in the Serpentinite as shown in Figure 2. These are:

A Central Zone termed a massive porphyritic serpentinized peridotite, composed essentially of porphyritic enstatite-bastite and olivine in a matrix of antigorite, serpophite and olivine. Magnetite, picotite, anthophyllite, talc and chrysotile occur as accessory minerals. The rock is foliated with antigorite representing the essential foliation-producing mineral. The degree of serpentinization varies from one exposure to another.

A Border Zone termed a massive talcose serpentinized peridotite. This zone shows a more extensive degree of serpentinization when compared with the Central Zone and is characterized by a distinctive increase in talc, anthophyllite and magnetite. Talc and anthophyllite schists exist in a number of localities. In the northeast part of this zone, a dunite mass is present showing minor amounts of serpentinization. Throughout this zone, shearing is pronounced and veins of silica and carbonates are common.

Wasserman (1956) conducted a magnetic survey of the Serpentinite and recognized the presence of a high magnetic intensity area which corresponded with Behm's eastern Border Zone and a low intensity magnetic area which corresponded with his Central Zone (see Figure 3). Although several interpretations of the magnetic data are possible, Wasserman suggests that near vertical contacts and higher concentrations of magnetite within the eastern Border Zone are the controlling parameters. He concludes from the study of the magnetic patterns of the serpentinite body "that it might have the shape of a rectangular prism of limited cross sectional dimensions extending downward indefinitely."

The structural aspects of the Serpentinite were studied by Miller (1970), who recognized the presence of an affinity between the fault system and the tectonic axis of this body. He noted that the existing longitudinal, transverse and diagonal faults were extensively sheared, with near vertical



VARIATION IN TEXTURE IN STATEN ISLAND SERPENTINITE

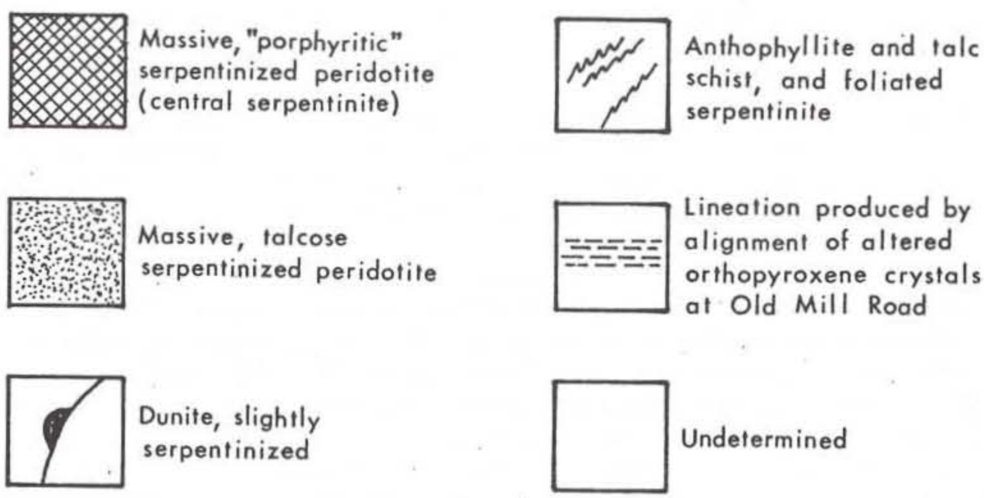
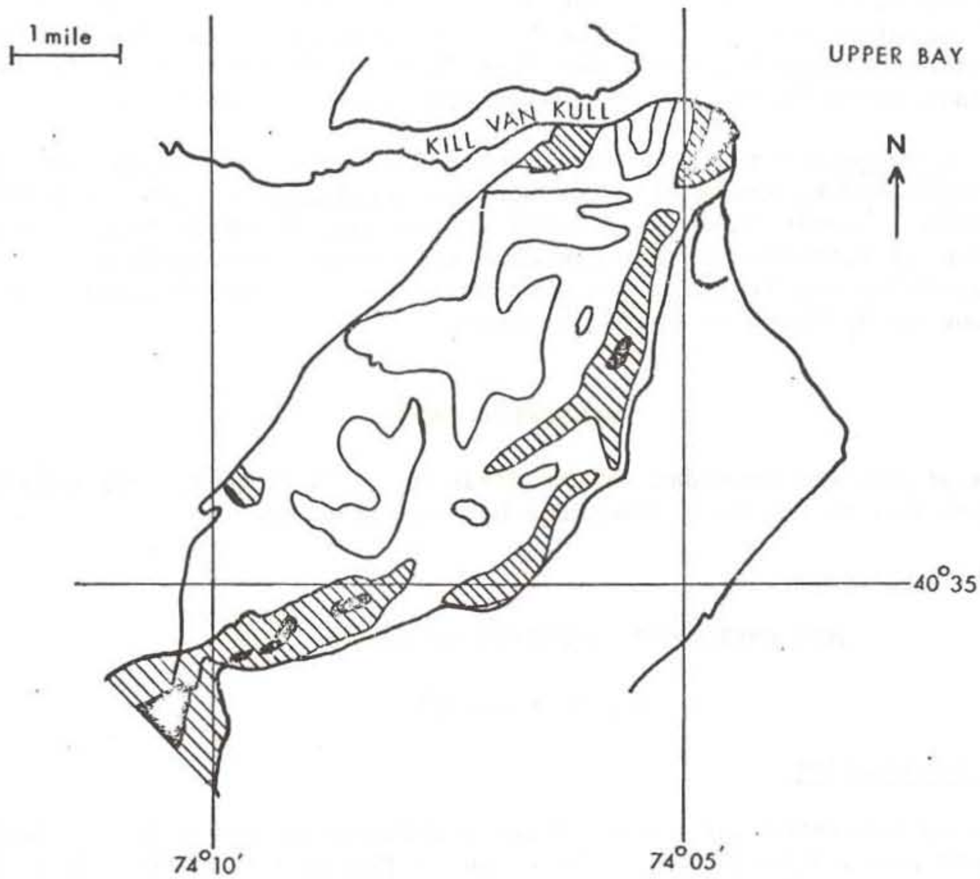


FIGURE 2 — FACIES MAP OF STATEN ISLAND SERPENTINITE (after Behm, 1954)



CONTOURS OF VERTICAL MAGNETIC INTENSITY
contour interval -500 gammas

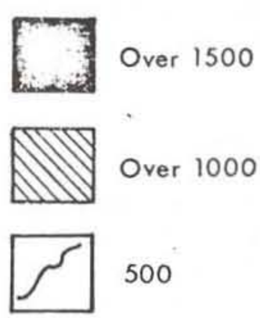


FIGURE 3 — MAGNETIC INTENSITY MAP
(after Wasserman, 1956)

dips and fault movements that were essentially in a vertical direction. At a number of localities graben-like structures developed (e.g. Silver Lake) and the accumulations of Pleistocene and Recent sediments within these topographic lows may have controlled the low magnetic intensities found to be characteristic of the Central Zone of the Serpentinite body. Miller concludes that since the Serpentinite body is topographically higher than the more resistant lower Paleozoic New York City Group and also the Mesozoic sedimentary rocks it must be intrusive into the Mesozoic rocks.

It is suggested that the topographic expression of the Serpentinite may be explained by graben-like structures resulting through reactiviation of a number of early Paleozoic faults during late Triassic time. This conclusion is supported by the presence of a fault breccia with fragments of Serpentinite and Triassic sedimentary rocks in close proximity with a fault zone (Stop No. 2 at Spring Street).

ACKNOWLEDGEMENTS

Assistance was provided in the field by S. Okulewicz. Appreciation is also expressed to Dr. K. E. Lowe for his critical review.

LATE CRETACEOUS DEPOSITS OF STATEN ISLAND

(By A. Kureshy)

General Information

The consolidated and unconsolidated sedimentary sequences of Staten Island are comparatively thin. As shown in Figure 1 they consist of the Triassic aged Stockton Formation of the Newark Group in the northwestern part of the island and the Cretaceous aged Raritan Formation in the eastern and southern part where it overlies the Stockton. Throughout the area nearly all these strata are covered by either morainal or stratified drift of Pleistocene age. Both the upper and the lower boundaries of the Triassic and Cretaceous sequences are marked by pronounced unconformities.

Lithology of the Raritan Formation

The Raritan Formation is composed chiefly of sand and clay. Light colored sands are interbedded with dark variegated silty clays which show considerable variation in texture, composition and thickness. A thick bedded sequence of micaceous silt and clay containing a large amount of lignite and some sulphide minerals are also present. The sandy beds are extensively cross-stratified. In some places a different facies of the Raritan occurs which consists largely of thick intervals of light colored and massive to thick bedded variegated shale of red, white and light-green silty clay.

Nowhere on the island is a complete sequence of the members of the Raritan Formation exposed. However, Lovegreen (1974) reported the following stratigraphic succession in the Raritan from bore hole logs obtained along an E-W geological section extending from Perth Amboy, N.J. to Charleston, S.I. across the Arthur Kill:

(a) Gray consolidated varved clay
(b) Gray sand
(c) Gray and Red consolidated clay
(d) White sand
(e) Gray consolidated clay
(f) Red consolidated clay

This section is close to Stop No. 4 where the relationship of stratified and unstratified glacial deposits to older and younger sedimentary deposits can be seen in an exposure. The contacts and general interpretation of the bore hole data (Lovegreen, 1974) are recognized as only tentative.

Depositional Environments

The Atlantic Coastal Plain Sediments to which the Raritan Formation belongs consist of sediments deposited in a wide variety of continental, transitional and marine environments. The deposits of the Raritan are extensively cross-stratified which is characteristic of a non-marine origin. On the basis of its lithology and sedimentary structure, the Raritan deposits have been interpreted by Allen (1965) and by Owen et al. (1968), as having been deposited in a sub-aerial deltaic plain. However, a second view about their origin was proposed by Broughton (1966) which is that these deposits are partly marine and partly non-marine with much of the non-marine sediments being deposited in fluviatile or swampy lowland and estuarine environments along the coast.

Age and Fauna of the Raritan Formation

Since Broughton (1966) proposed that the Raritan Formation is composed of partly marine, partly non-marine Cretaceous deposits, corresponding kinds of fossil remains are required to establish these identities. In this connection the author examined samples of various local members of the Raritan Formation for such evidence. The washed residue of these deposit samples however proved to be barren, no macro or microfossils being recorded.

According to Hollick (1967) the Upper Cretaceous age of the Raritan Formation is delineated by characteristic fossils of plant leaves such as the following: *Liriodendropsis* simplex Newb., *Laurusplutonia* sp., *Thinufeldia* sp., *Sapindus* morrisoni Lesq., and *Moriconia cyclotoxon* Deb.

Occurrences

The Raritan Formation Cretaceous deposits apparently extend up to the southern border of the serpentinite ridge. Further to the west they apparently extend as far north as the Fresh Kills marshes. They are especially abundant in the morainal accumulations at Tottenville, Princess Bay and Arrochar. No strata of Cretaceous age have been found in the morainal deposits to the north and west of the serpentinite ridge. In the south much of the morainal material represents fragments which have been eroded from the Cretaceous deposits south of the serpentinite ridge and transported there by the advancing glacier or by streams from the melting glaciers.

Correlation of the Raritan Formation

The correlation of the Staten Island Cretaceous strata with those of other localities outside the island is difficult on account of the erosion and the disturbance to which they were subjected during the glacial epoch. Theoretically, according to Hollick (1967), if the Raritan Formation of New Jersey extended to Staten Island, then the lower members of this formation, represented by those at Woodridge, Perth and Amboy, would strike the western shore of Staten Island in the vicinity of Tottenville. The upper members of the Raritan in New Jersey, represented by the southern shore from Tottenville to Arrochar and a marl member, represented at Cliffwood, N.J., would be found in the vicinity of the Narrows. The correlation of the Raritan Formation of New Jersey with that of Staten Island is consequently quite arbitrary and it is not helped by the absence of any exposure on the island showing a complete sequence of this formation.

GLACIAL FEATURES AND DEPOSITS OF STATEN ISLAND AND ADJOINING AREAS

(By E. Kaarsberg)

Age and Distribution

Staten Island is covered almost entirely by glacial deposits, the most prominent of which is a terminal moraine extending along the south-east shore of the island from Long Island in the east to New Jersey in the west as shown in Figure 4. This moraine marks the most southerly advance along the Atlantic coastline of the last great continental ice sheet, the Wisconsinan, which Carbon 14 dating indicates began its retreat between 17,000 and 18,000 years ago (Bryson and Wendland, 1967 and Prest, 1969). An excellent cross sectional exposure of this moraine and in places nearby some of the associated stratified outwash material can be seen at the south end of the island at Stop No. 3. According to Prest's map the first recessional moraine along the Hudson River is found about 170 miles to the north of Staten Island and has a Carbon 14 date of 14,000 years B.P. However, other investigators find evidence of five or more other recessional moraine in the Wallkill Valley west of and parallel to the Hudson River in this same distance interval to the north.

Striations and groove patterns in the bedrock in the New York City area indicate, as also shown in Figure 4, that the movement of the ice was from north to south across Staten Island.

Some indication of a minor Wisconsin substage retreat and advance has also been found by Sanders (1975) in the Princess Bay area of Staten Island.

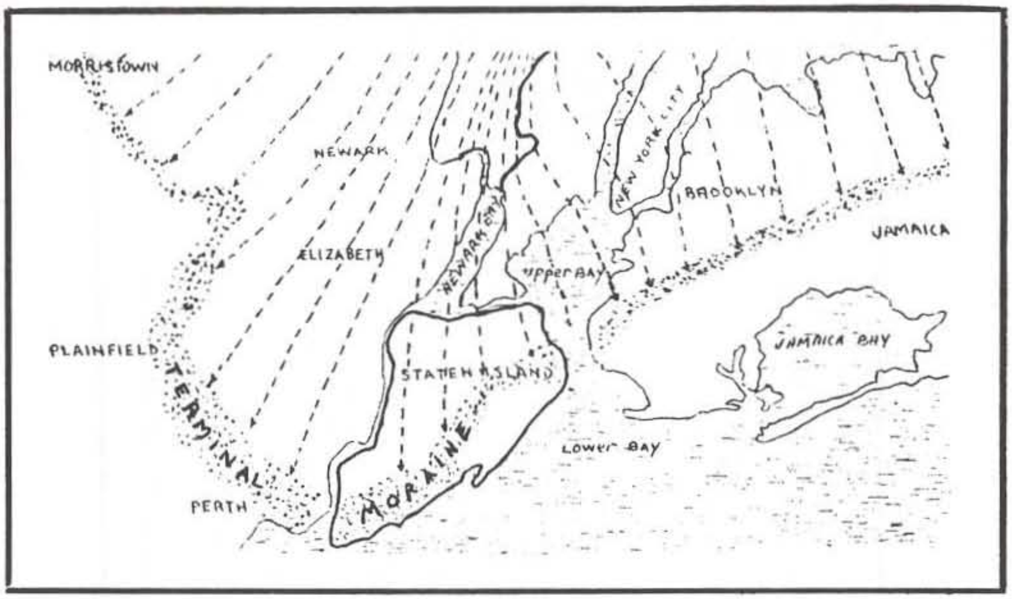


Figure 4. Sketch map of New York City and vicinity, showing position of the terminal moraine and the directions of the ice movement (indicated by arrows) during the last or Wisconsin Glaciation. (After Reeds, 1930 and the United States Geological Survey.)

At the peak of and during the early stages of retreat of the Wisconsin Ice sheet great quantities of sedimentary material were deposited on extensive outwash plains that then extended many miles off-shore eastward and which are now submerged. This was established by early investigators of off-shore seafloor deposits. From more recent investigations (Flint, 1971) it has been estimated that the lowest possible position of relative sea level during the peak of the Wisconsin ice age was about -100 meters. This would place the Atlantic shoreline at that time at about 50 miles east of its present position along the New York-New Jersey coast. The results of off-shore geological investigations of this kind, that are considered to be the most reliable and consequently the most discussed, are based on Carbon 14 dated fossil organisms of a kind that lived in very shallow littoral environments and that were collected from localities at which they are believed to have lived at known depths beneath the present sea level. With these it has been possible to construct Time-Depth Curves such as the one shown in Figure 5 of sea level changes associated with the retreat of the Wisconsin Ice Sheet.

Stratigraphic Relationships

Figure 6 is a generalized geological cross section between Seguine Point on Staten Island and Conaskonk, New Jersey (see line A-A' on map in Figure 1) prepared, by MacClintock and Richards (1936), from test hole borings that were made in 1930-31 for a proposed bridge between these two points. At Bore Hole No. 1 on Staten Island the glacial drift is gravelly and bouldery. Below this and extending far out under Raritan Bay is a deposit of reddish brown sand and gravel containing shell fragments in a few places which MacClintock and Richards identify as the Cape May Formation,

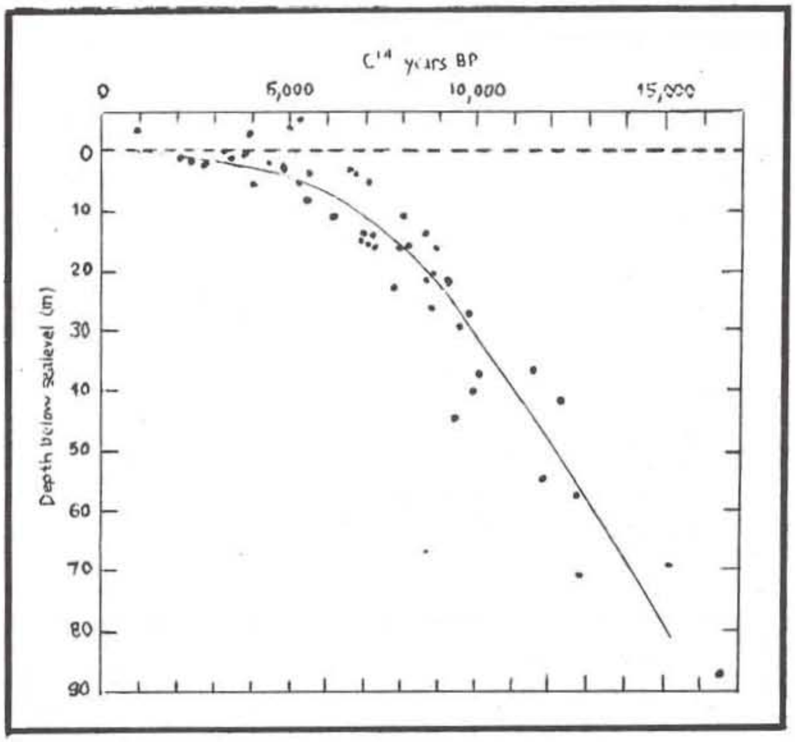


Figure 5. Submergence curve based on nearly 50 C_{14}-dated samples of organisms taken from growth positions judged to have been close to sea level. Samples are from various depths along or off several coasts thought to have been "relatively stable." C_{14} ages are plotted against depths. Curve reflects progressive submergence, believed to be chiefly eustatic. (After Shepard, 1963b.)

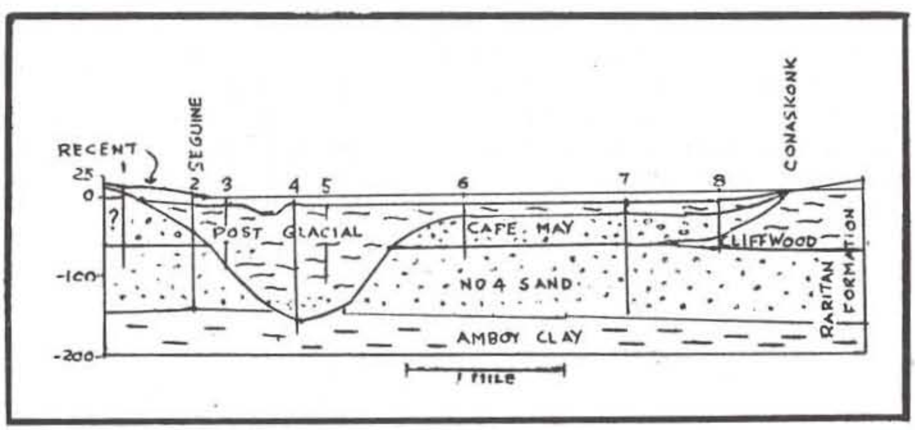


Figure 6. Generalized cross-section from Seguine Point, Staten Island, to Conaskonk Point, New Jersey, based on borings, as numbered, made by the Port of New York Authority. (After MacClintock and Richards, 1936.)

laid down during the Wisconsin glacial age. This depositional layer since that time was evidently deeply trenched as shown by the Raritan River to a depth of 170 feet into the underlying Raritan Formation (Cretaceous). This trench or channel was subsequently filled as shown with post-glacial material. Borings on the Staten Island shore, at locations No. 1 and 2, show a thin deposit of sand on top of the post-glacial "channel fill." This is interpreted to be beach material and post-glacial wash from the moraine to the north.

Figure 7 shows a northwest-southeast geological section from Carteret, New Jersey to Rossville, Staten Island, across Arthur Kill prepared by Lovegreen (1974) from bore hole logs (see Line B-B' on map in Figure 1). This section is the closest one that could be found to Stop No. 4. It is one of several Lovegreen prepared for the Staten Island and adjoining areas which show the relationships of the stratified and unstratified glacial deposits to the older and younger non-glacial deposits with which they are associated. The exposure at Stop No. 4 shows the contact between the Pleistocene glacial and the underlying Cretaceous deposits very clearly.

As indicated by the dashed boundary lines and the question marks on this geological cross section, the interpretation of the hole data presented by Lovegreen is regarded as being only tentative, a number of other interpretations being possible.

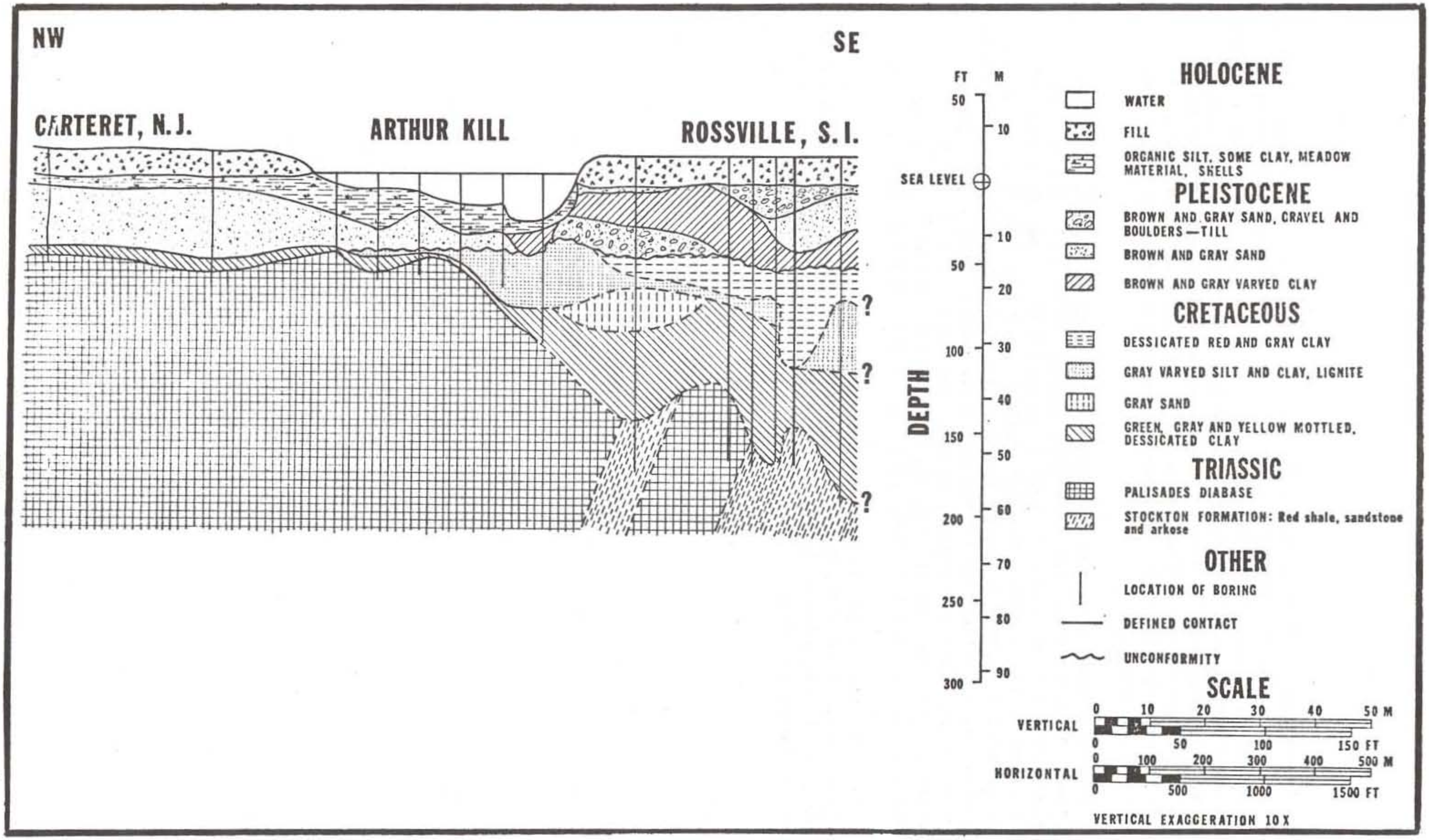


Figure 7. Geological cross section from Carteret, N.J. to Rossville, S.I. across Arthur Kill based on bore-hole logs (Interpretation after Lovegreen, 1974).

ROAD LOG

Cumulative Miles	Miles from last point	Description
0.0	0.0	Road log begins at the Verrazano-Narrows Bridge on Staten Island Expressway (Interstate 278) and goes west.
0.7	0.7	Exit from I-278 at Clove Road exit and follow Narrows Road, parallel to the expressway, to Richmond Road where the Narrows Road becomes Little Clove Road, which also parallels the expressway. Continue on Little Clove Road to Renwick Avenue.
2.0	1.3	Turn left onto Renwick Avenue, passing under the expressway, and reaching Milford Drive.
2.1	0.1	Turn right onto Milford Drive. This is a Dead End street and is used as an off campus parking lot at Staten Island Community College. Drive to the end of the street and park. Walk up the embankment there to an access road and turn left on the abandoned access road to the outcrop at I-278 and Slossen Avenue.

STOP NO. 1 - Serpentinite Outcrop

This outcrop represents the largest continuous exposure of the Central Zone Serpentinite on Staten Island. The rock is a foliated serpentinized peridotite. The dominant mineral is antigorite which has replaced in varying degrees the original olivine and enstatite. The minor constituents are magnetite, brucite, picotite (chrome spinel), picrolite (sheared antigorite) and graphite. Numerous veins are filled with talc, chrysotile or carbonates. Note:

1. The foliation has been deformed into small folds displaying axial planes which are almost vertical and trending in a general northeast-southwest direction.

2. A number of folds are cut by an axial plane oriented slip cleavage.

3. Several small, high angle, northeast-southwest trending faults and associated fault zones.

Return to bus. Follow Milford Drive back to Richmond Road (second traffic light).

3.4	1.3	Turn right on Richmond Road and continue on to Spring Street (first traffic light).
3.8	0.4	Turn right on Spring Street. Bear right at Y intersection and continue to outcrop ahead on right.

STOP NO. 2 - Serpentinite Outcrop**

This exposure is located within the Border Zone of the Serpentinite body and is in close proximity to the near vertical Spring Street Fault. The rock is essentially fine grained, foliated and extensively sheared. The principal mineral is antigorite with small amounts of magnetite and brucite. Some porphyritic serpentinite is present with phenocrysts of olivine and magnetite in a matrix of antigorite. Talc, hydromagnesite, aragonite and artinite exist in veins or along shear planes. Note:

1. Topographic expression of the northeast-southwest trending Spring Street Fault Zone.

2. Small folds with axial planes oriented in a northeast-southwest direction.

3. Fault breccia with fragments of serpentinite and Triassic sedimentary rocks.

4. Near-source glacial erratics with fragments of serpentinite, Triassic sedimentary rocks and gneisses (possibly fanglomerates?).

** This outcrop is in the locality for a housing development and may be eliminated in the near future. If this occurs an alternative exposure will be visited.

4.7	0.4	Return to bus. Turn right on Richmond Road. This road follows the almost vertical contact of the Serpentinite body and outcrops of this rock can be seen on the right in many places. Continue on Richmond Road to New Dorp Lane (Gulf Station on left).
7.2	2.5	Turn left on New Dorp Lane and continue on to Hylan Boulevard.
7.9	0.7	Turn right onto Hylan Boulevard and continue to the end of this thoroughfare.
14.5	6.6	Seguine Avenue which leads to Princess Bay and Seguine Point on the left.

14.9	0.4	Woodvale Avenue. Open areas here begin to show hummocky terrain with poorly developed drainage so typical of glaciated areas to the north.
17.7	2.8	<u>STOP NO. 3</u> - Terminal Moraine Glacial Deposit

Along the beach at the south end of Hylan Boulevard a Wisconsin aged terminal moraine has been clearly exposed by beach erosion. It shows the typical unsorted nature of this kind of glacial deposit with large boulders intermingled with finer rock debris. On the beach itself these boulders are left stranded after wave action and near-shore currents have removed the finer material. The great variety of composition that these boulders show bespeaks the great variety and far flung distribution of their source areas. For example the dark diabase boulders probably came from the Palisades Sill structure only a few miles to the north whereas many sedimentary boulders found on Staten Island often contain marine fossils which indicate that they probably came from rock exposures in east-central New York or northwest New Jersey.

In places further along the beach remnants of stratified glacial outwash deposits may be found.

Return to bus. Continue on back north on Hylan Boulevard to Page Avenue (first traffic light).

19.1	1.4	Turn left on Page Avenue and proceed along this road through the first traffic light at Amboy Road and across Mill Creek Bridge to Richmond Valley Road.
20.1	1.0	Turn left on Richmond Valley Road and continue to Arthur Kill Road.
20.3	0.2	Turn right on Arthur Kill Road and continue along this road underneath the Outerbridge Crossing to area of quarry operations.
21.0	0.7	<u>STOP NO. 4</u> - Raritan Formation Outcrop

The outcrops in the quarries in this area represent largest continuous exposures of Cretaceous sedimentary deposits found on Staten Island. Two members of the Raritan Formation belonging to the Gray consolidated clays and the Red consolidated clays are represented at these exposures. The Gray colored clay deposits are characterized by the presence of lignite fragments and pyrite. The Red colored clays apparently do not contain any of these materials. These deposits are also characterized by various sedimentary structures of which cross stratification in the sands is one. Samples of these deposits were processed for the study of any microfossil fauna, but none were recorded. Neither were any plant fossil remains found.

Return to bus. Continue on Arthur Kill Road to Richmond Avenue.

25.6	4.6	Turn left onto Richmond Avenue and continue north to expressway (I-278).
30.4	4.8	Turn right onto expressway. Continue east toward Verrazano Narrows Bridge.
33.0	2.6	Staten Island Community College on right.
36.1	3.1	Entrance to Verrazano-Narrows Bridge.

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NOTES

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.

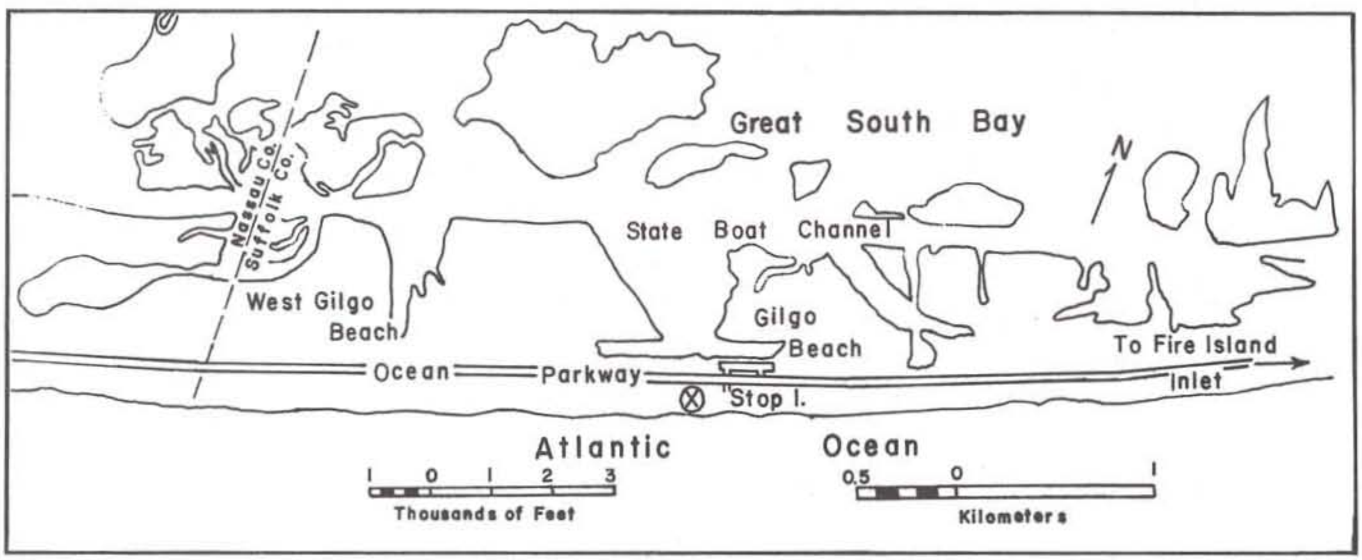

Figure 1. Location map of Stop #1 on the Jones-Captree Beach barrier island.

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).

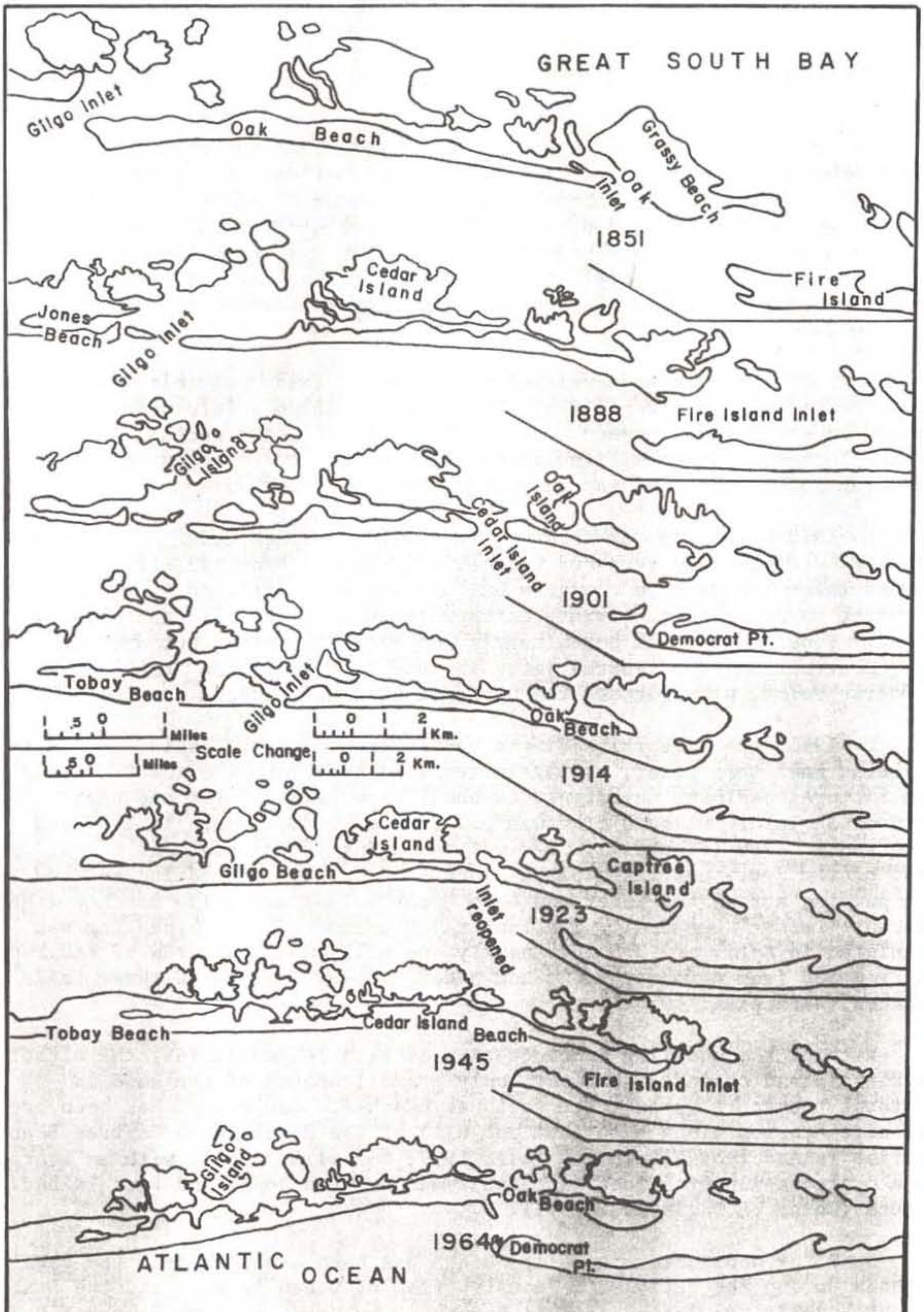

Figure 2. Historical map of Gilgo Beach-Democrat Point and their adjacent features (1851-1964). See text for explanation. (Data taken from Coast & Geodetic Survey Maps and Topographic Maps.)

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).

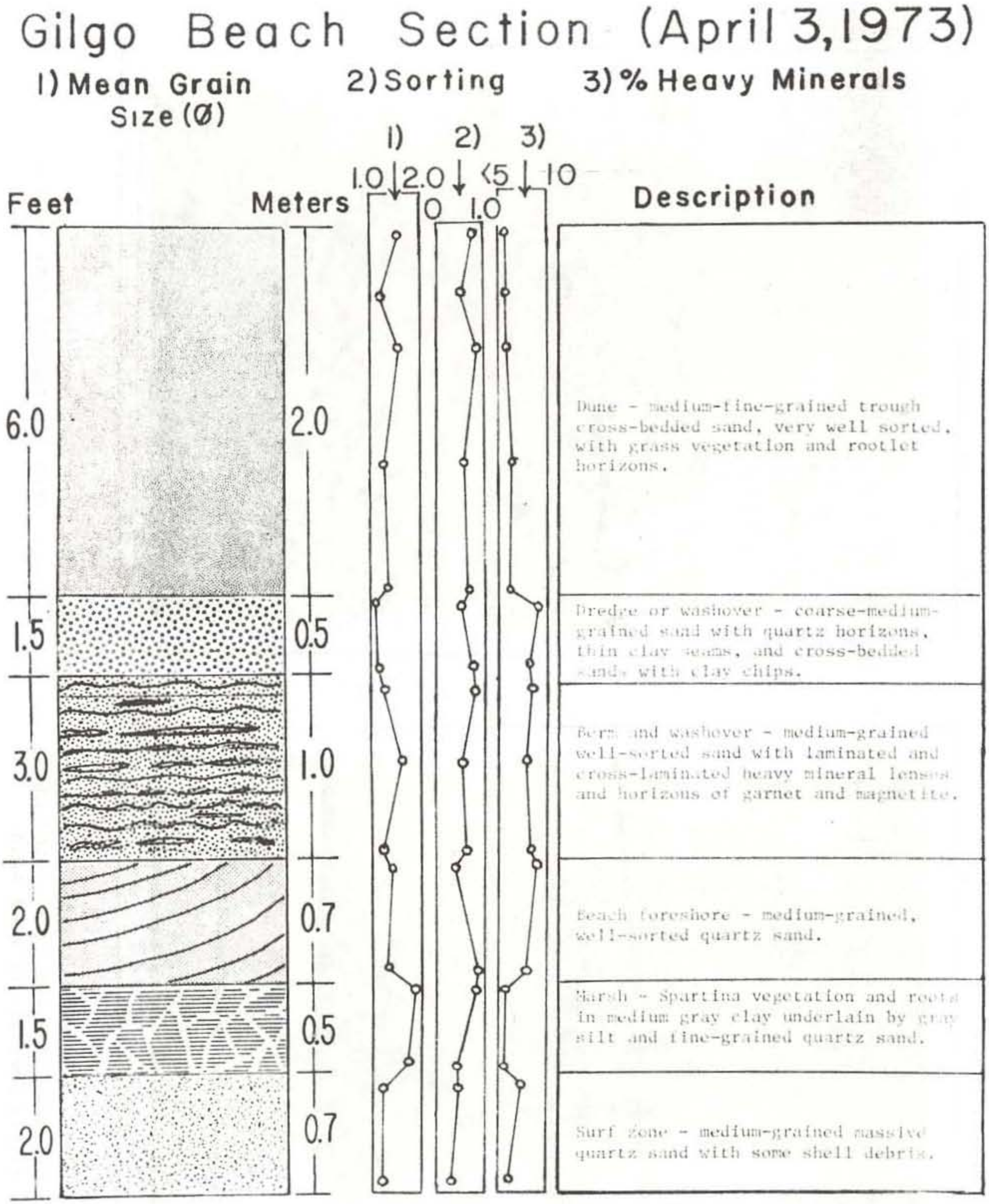

Figure 4. Vertical section of exposed dune ridge at Gilgo Beach (April, 1973). Columnar graph indicates changes in: 1) size distribution of medium sand (1Ø=0.50 mm.-2Ø=0.25 mm.); 2) sorting (0=very well-1=moderately well; 3) concentration of H. M. (beach and dredge material 5-10%; marsh and dunes 5%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

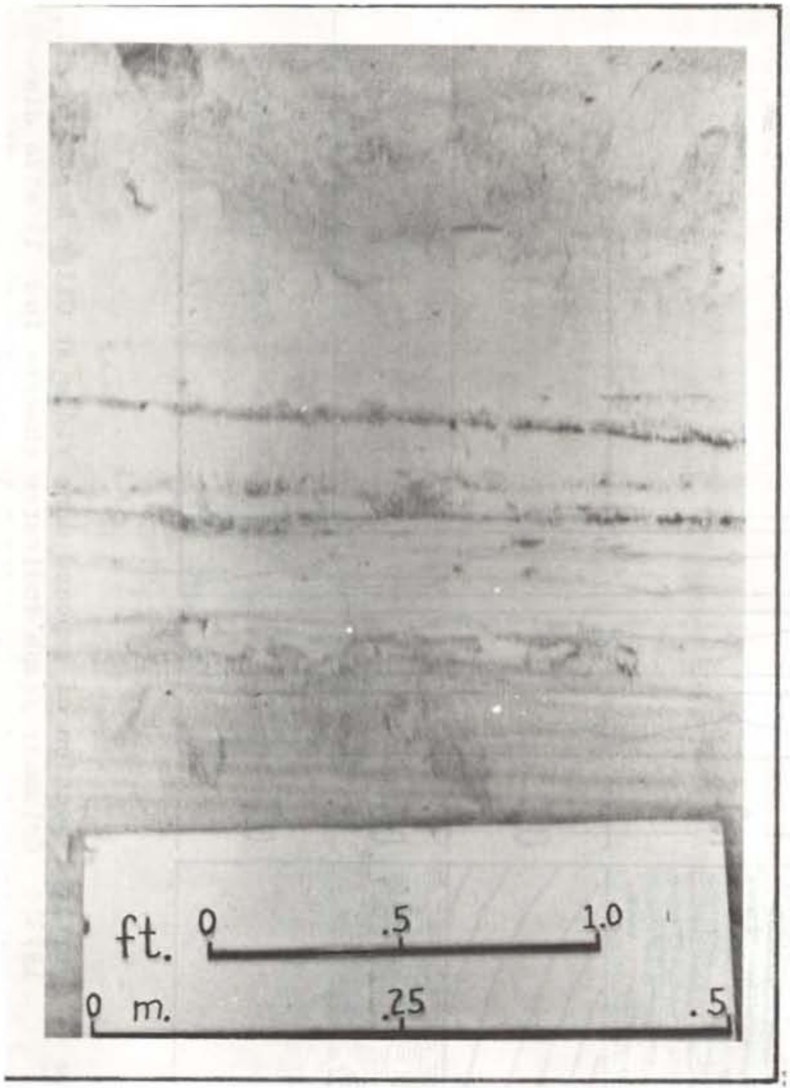

Figure 5A. Berm and overwash deposits with seams of marsh clay and disoriented clay chips; overlain by dune sands.

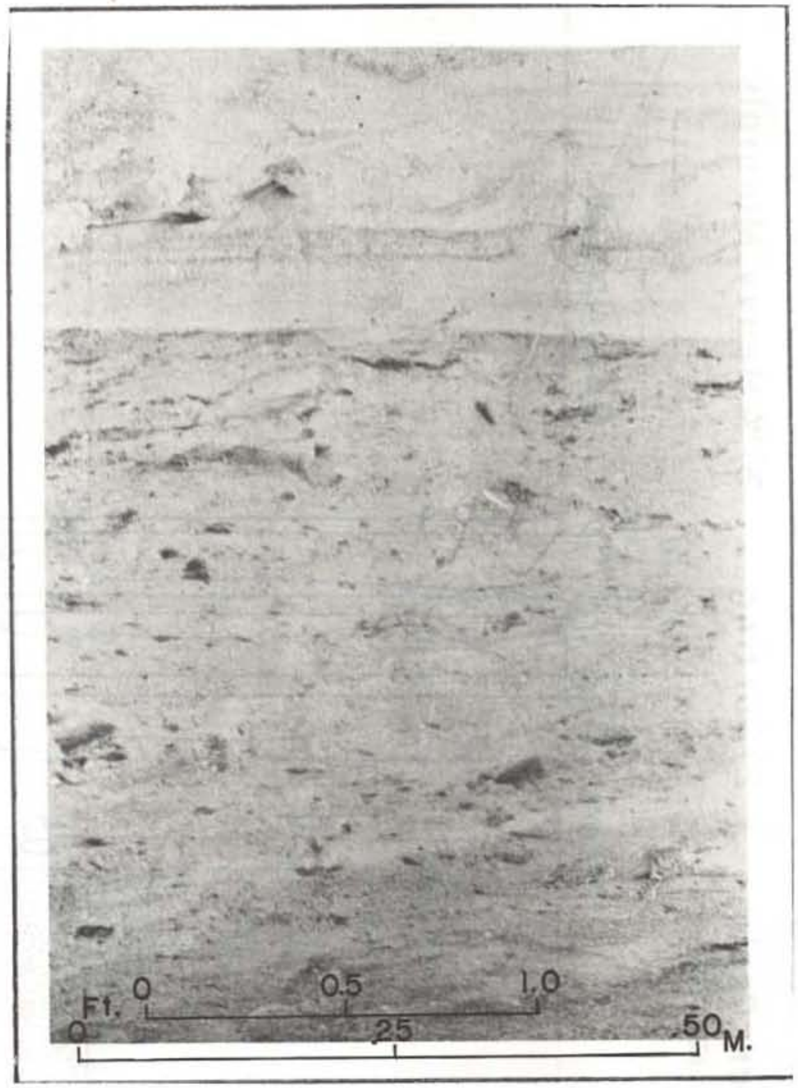

Figure 5B. Overwash and dredge (?) deposits beneath dune sands.

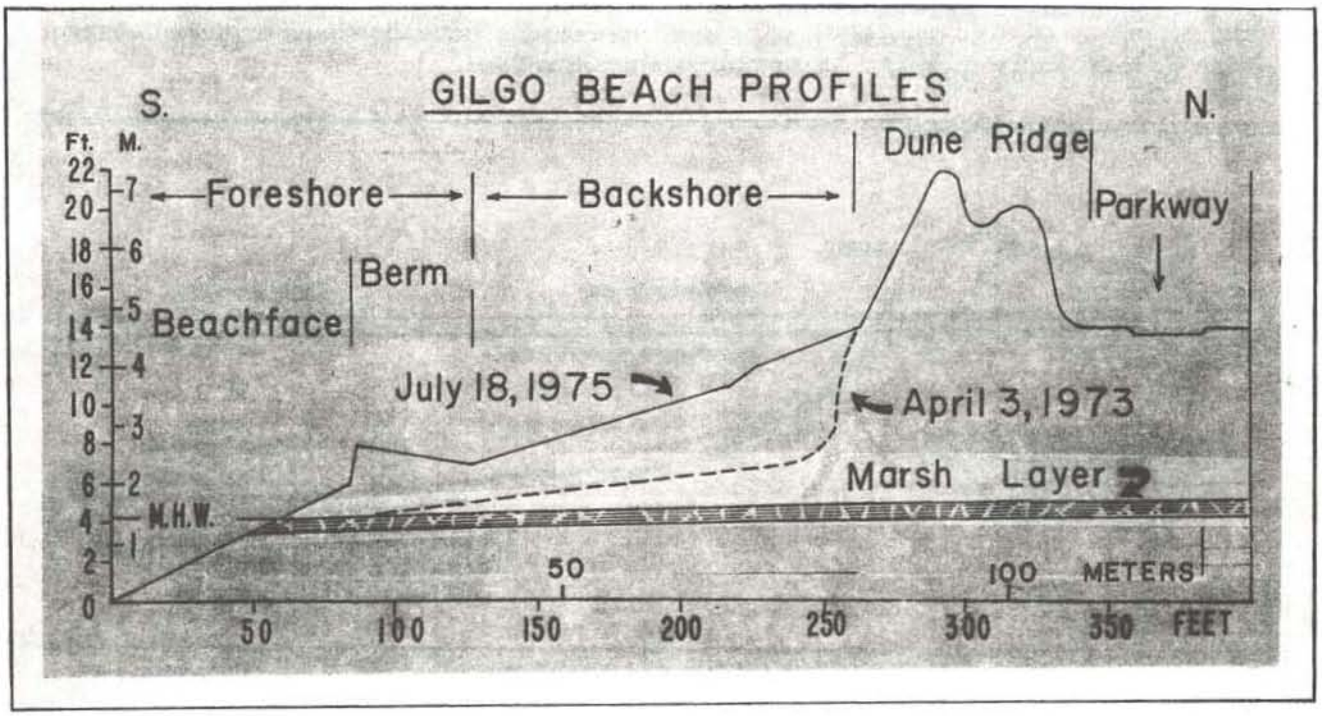

Figure 6. Gilgo Beach cross-profile indicating losses and gains of dredged beach sand and position of marsh layer.

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.

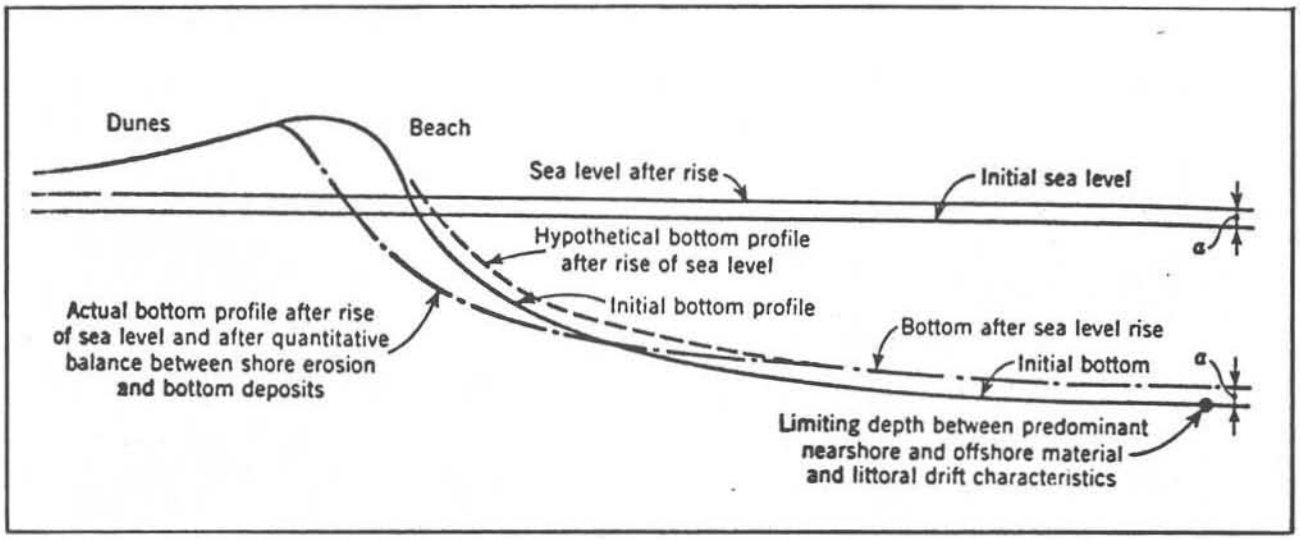

Figure 7. Hypothetical and actual offshore and beach profiles (after Bruun, 1962) indicating the influence of a rising sea on the Long Island coastline.

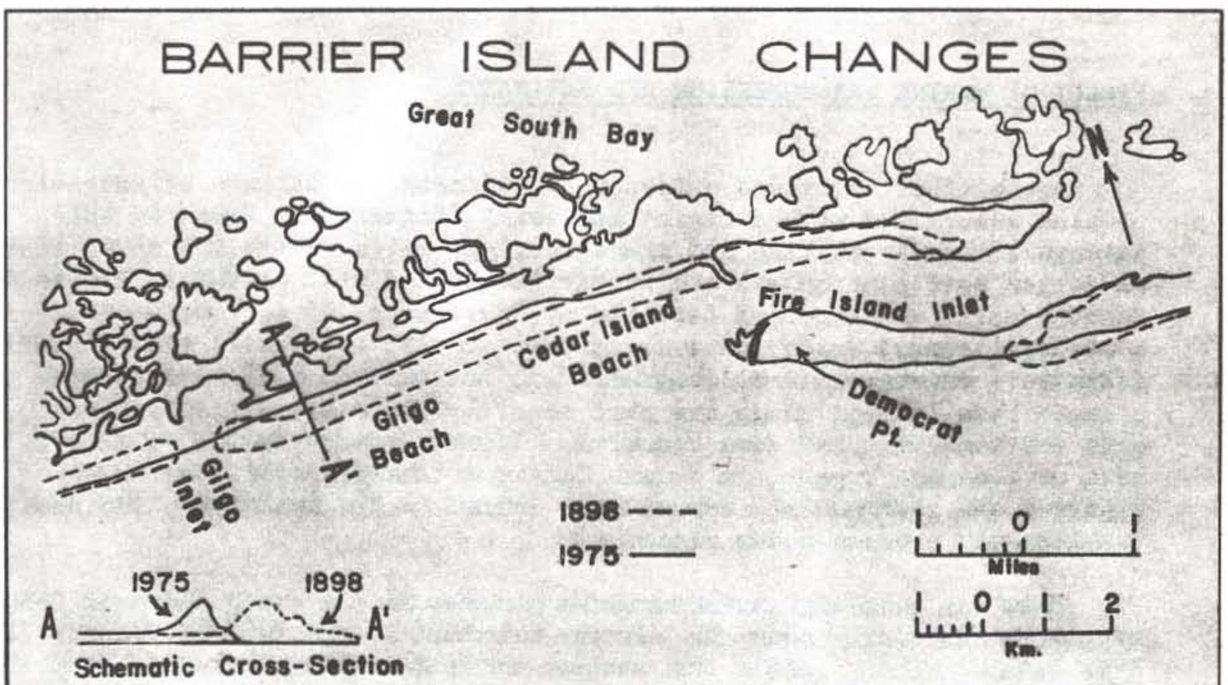

Figure 8. Overlay of 1898 and 1972 Coast and Geodetic Survey Maps at same scale to indicate effects of erosion and ravinement (see also Taney, 1961).

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).

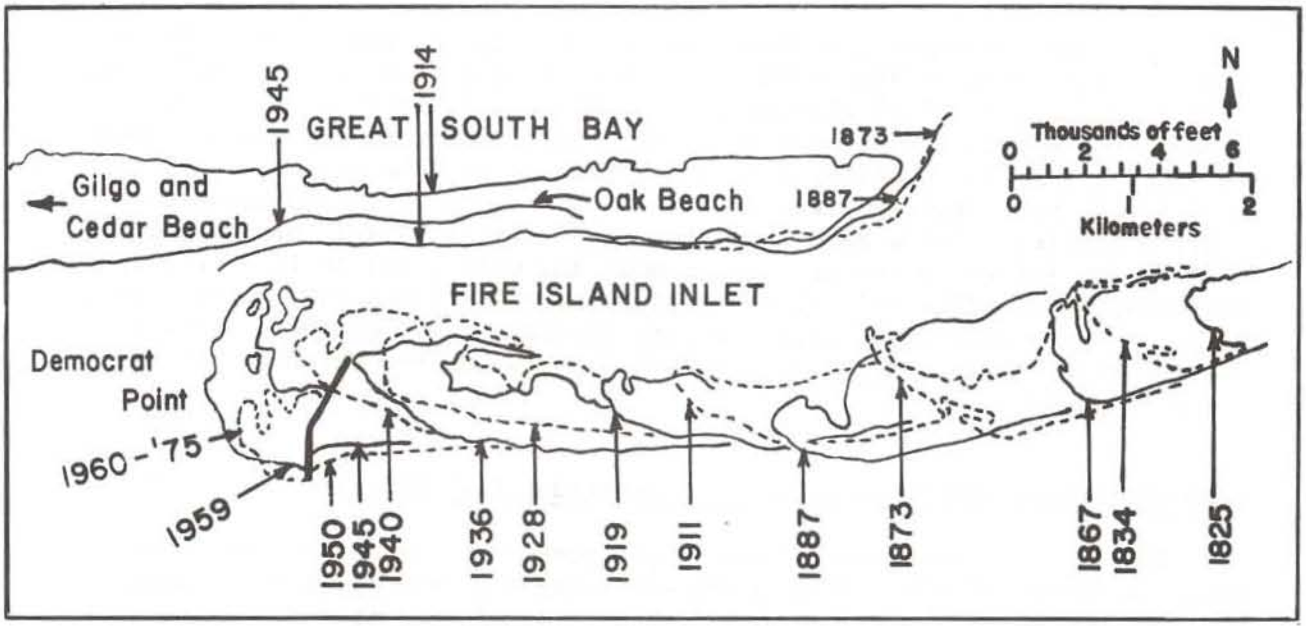

Figure 9. Historical changes in the growth of Democrat Point and erosion of Oak Beach along Fire Island Inlet.

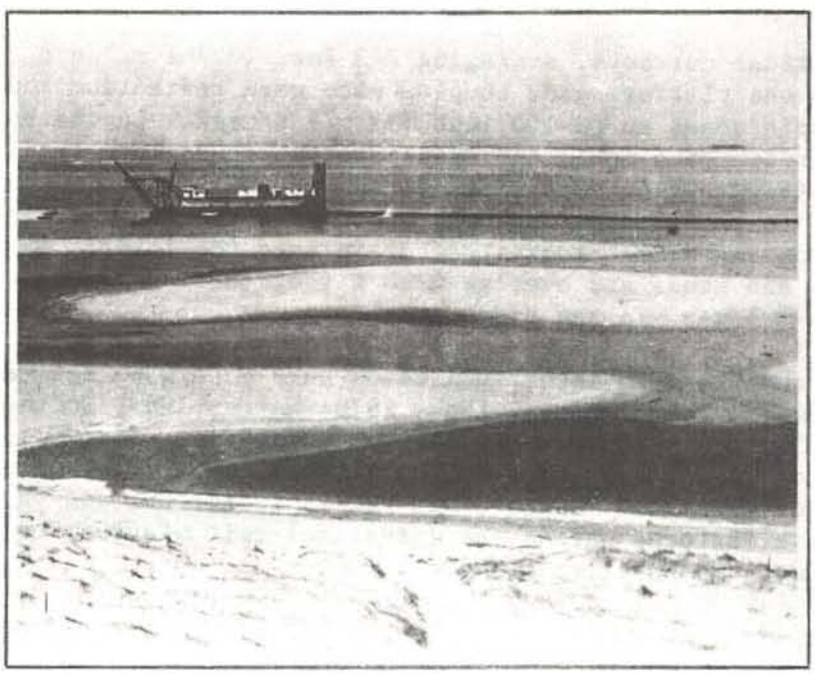

Figure 10. Dredging and sand bypass by hydraulic pumping - looking north (February, 1972).

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.

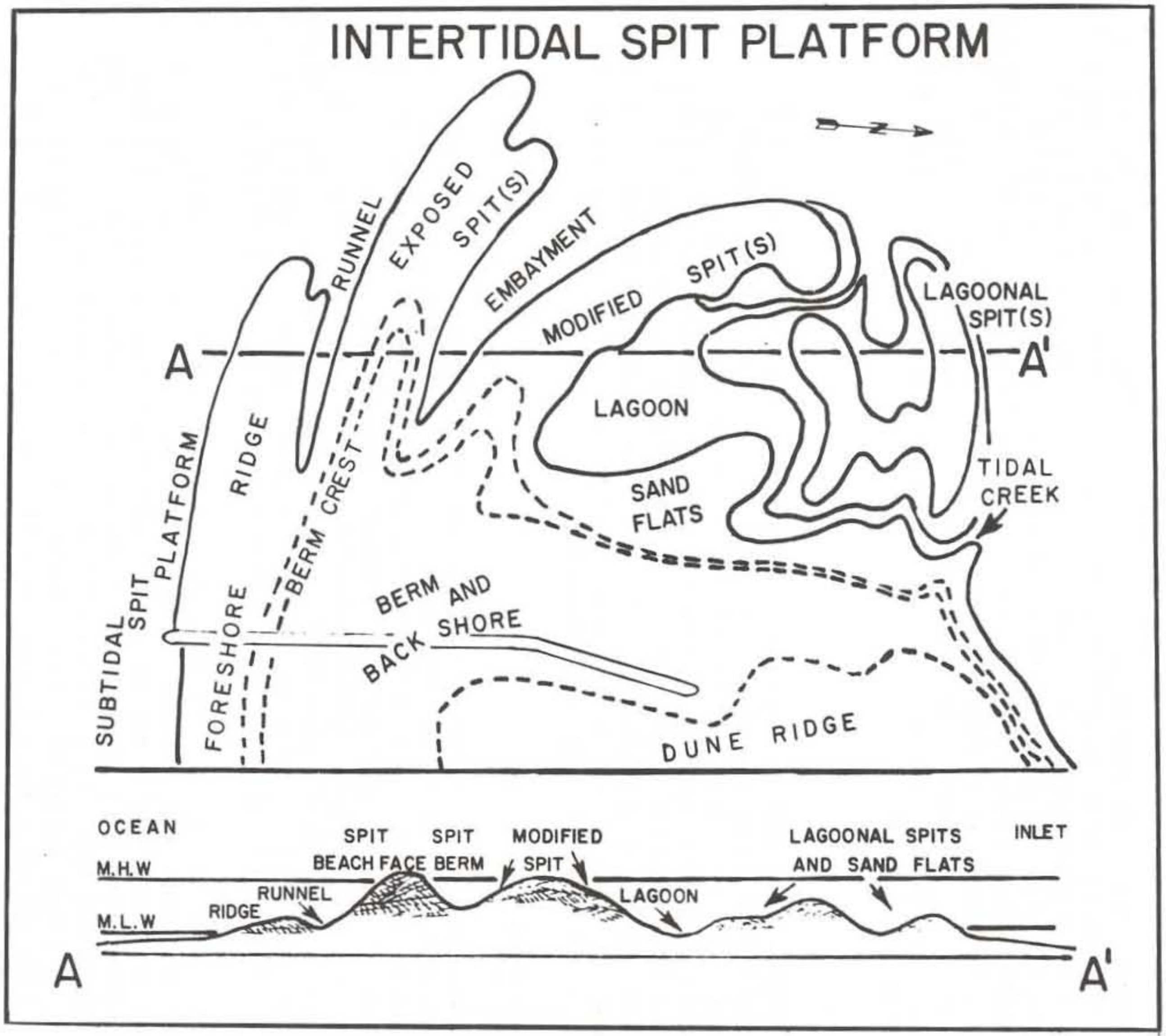

Figure 11. Features and environments associated with the intertidal spit platform.

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°.

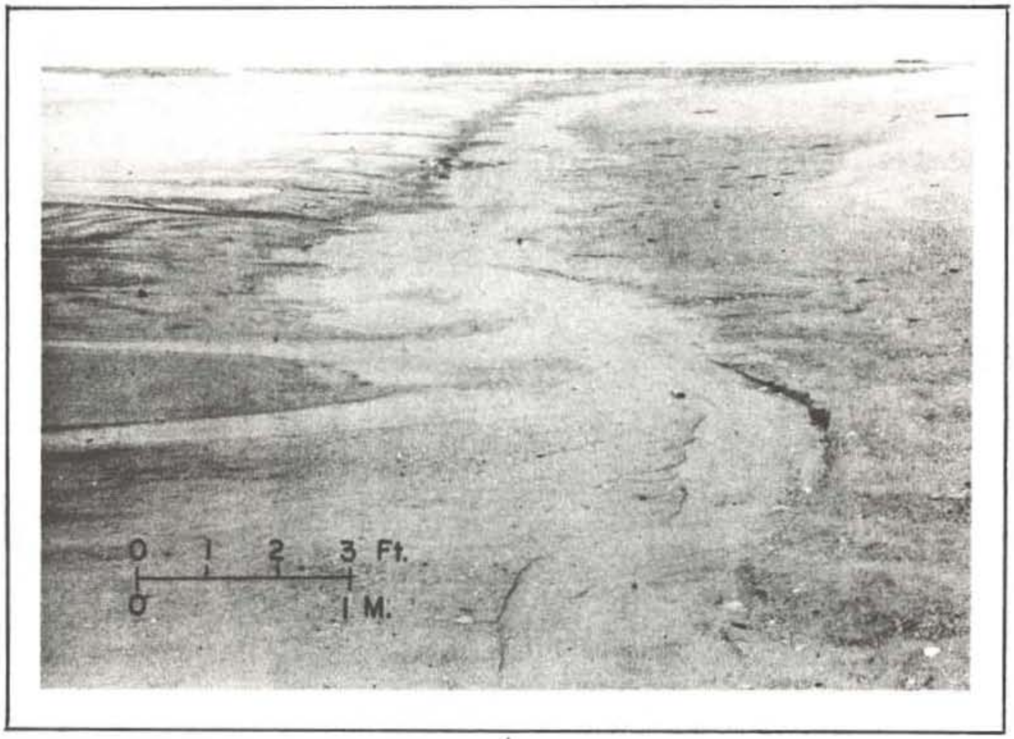

Figure 12. Ridge accretion (left) toward foreshore of exposed spit (right). View is toward west. (November, 1971.)

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

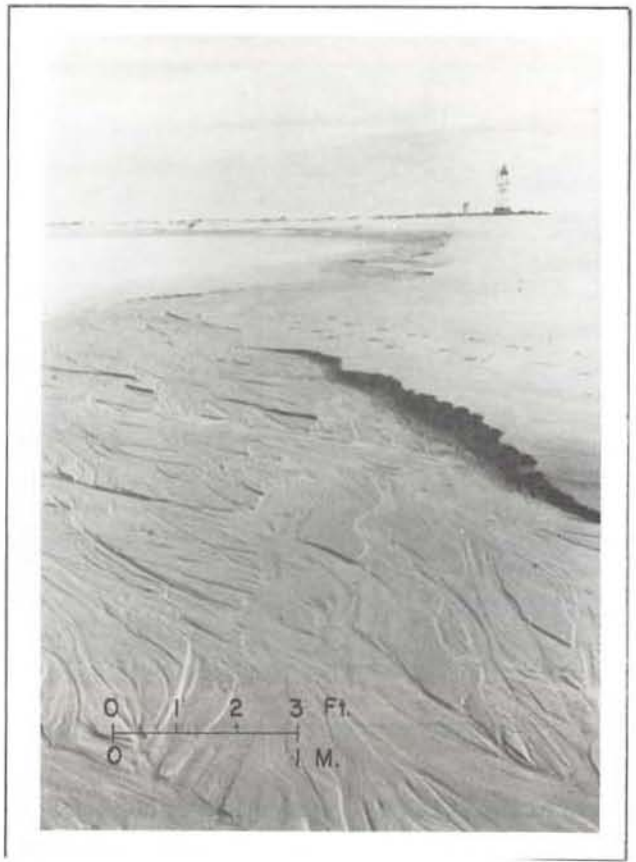

Figure 14. Tidal drainage between accreting ridge (right) and beach foreshore (left) creating a new berm, exposed spit, and beach foreshore. View is toward east. (January, 1973.)

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.)

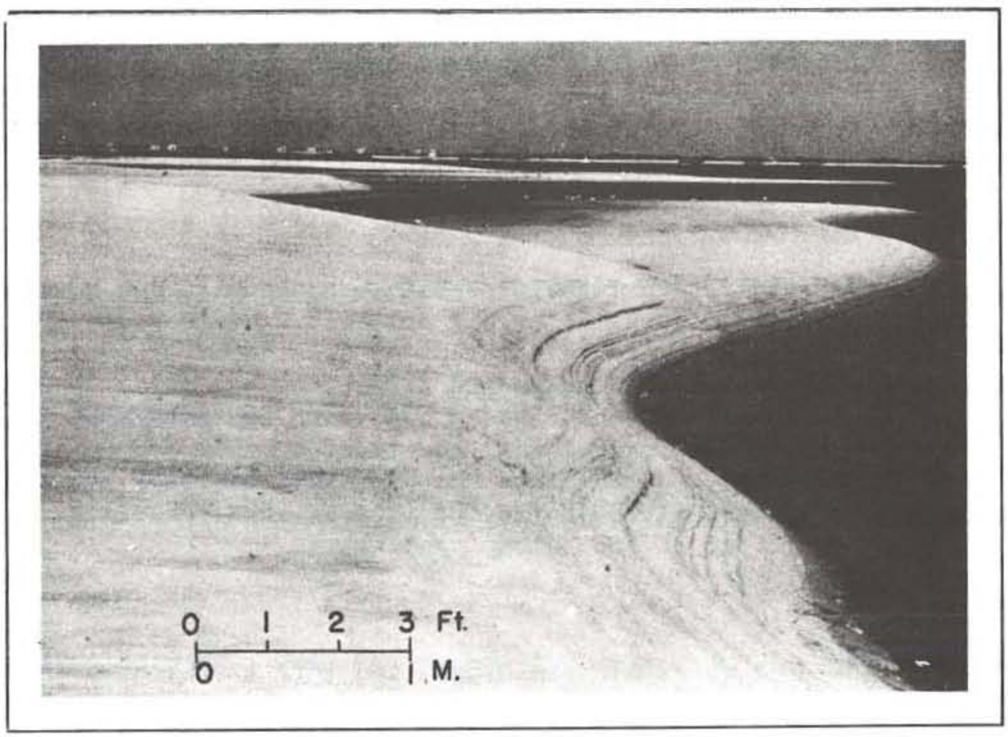

Figure 18. Late stage of bay development as overlapping washover lobes constrict embayment near inlet to form a lagoon. View is to northwest. (October, 1971.)

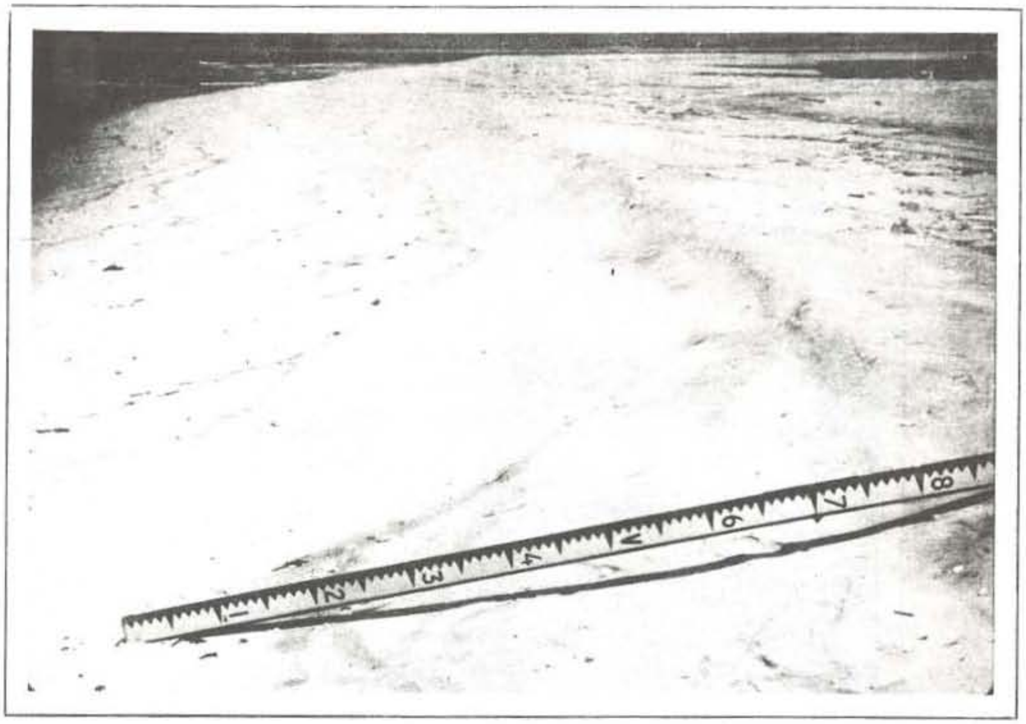

Figure 19. Concave beach foreshore and berm of modified spit - lagoon at upper right. View is to northwest. (June, 1973.)

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

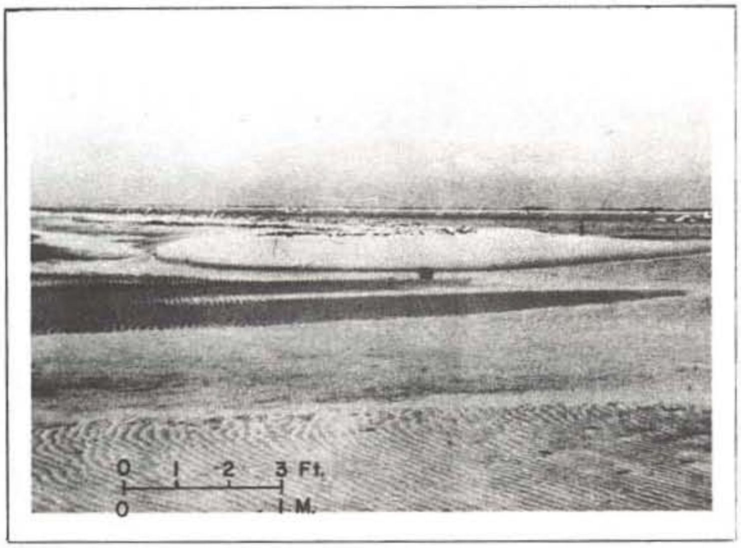

Figure 20. Recurved spit or hook at inlet edge of modified spit and embayment. View is to northwest. (September, 1972.)

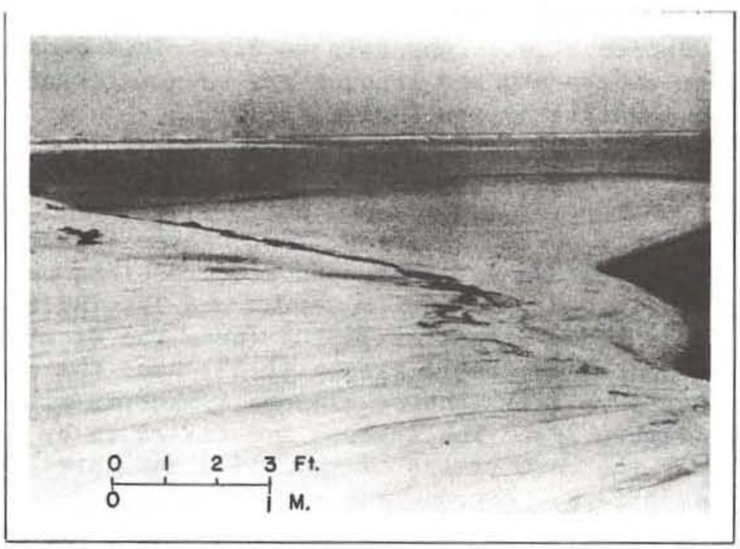

Figure 21. Overlapping washover deposits along backshore of modified spit. View is toward north. (September, 1971.)

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).

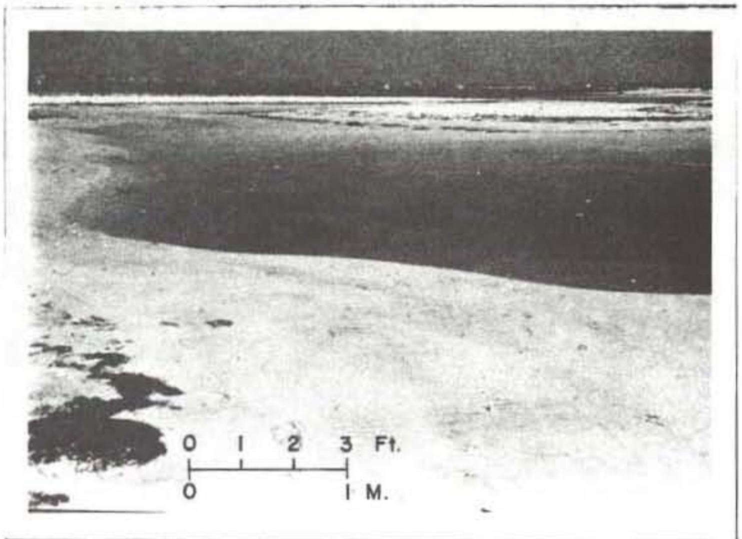

Figure 23. Development of lagoonal spits on the sand flats near the inlet. View (from modified spit) is to the north. (July, 1972.)

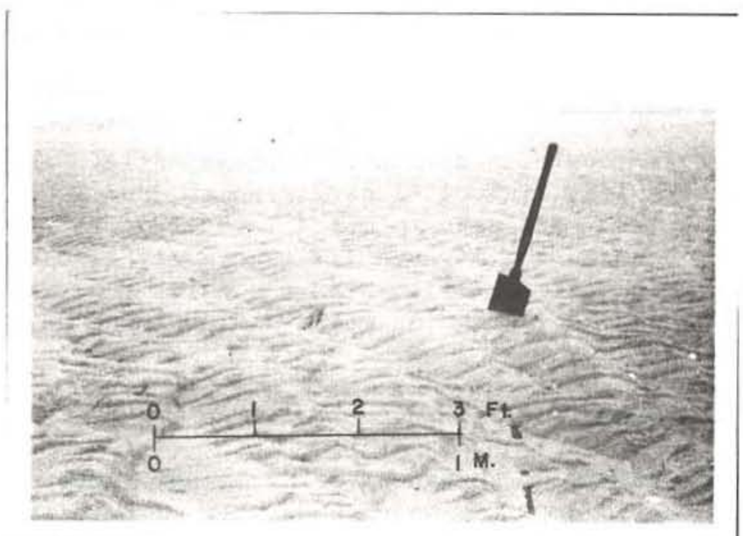

Figure 24. Superimposed ripples to form "ladderback" pattern during ebb tidal drainage on the sandflats. View is toward south. (September, 1973.)

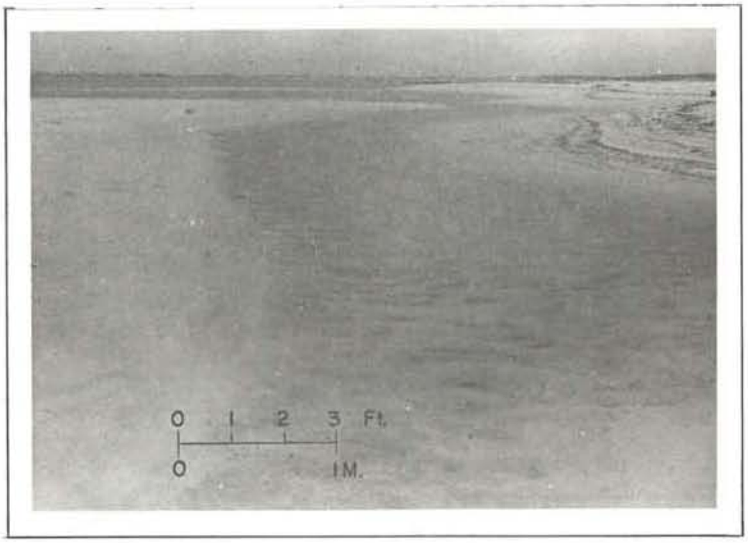

Figure 25. Tidal drainage creek between modified (left) and lagoonal spits (right). View is toward north. (May, 1973.)

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

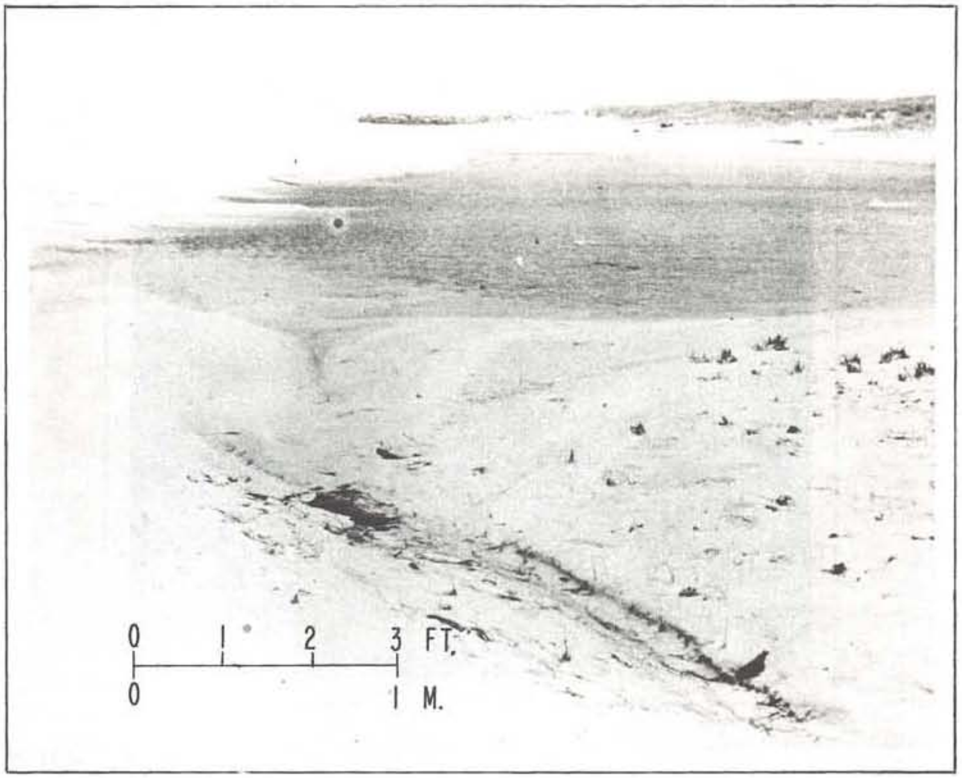

Figure 27. Development of beach grass on dunes near sandflats and beach of inlet. View is to northeast. (June, 1972).

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

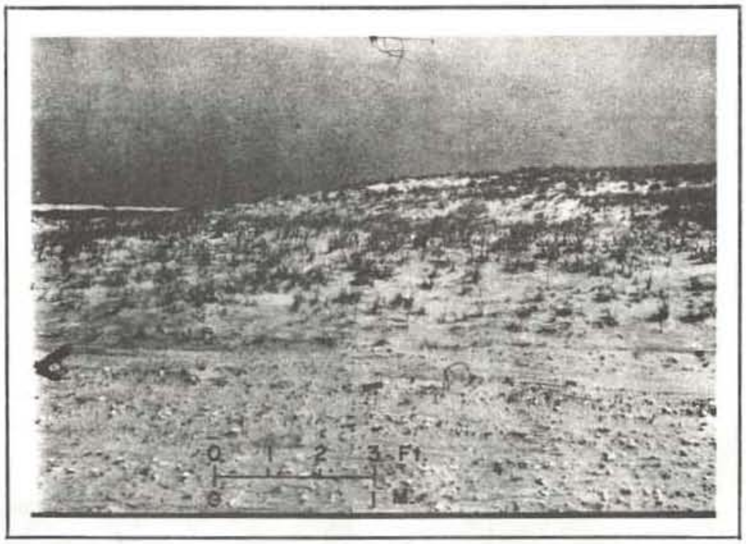

Figure 28. Lag concentrations of shell debris and coarse sand near base of dune ridge. View is toward east. (June, 1973.)

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

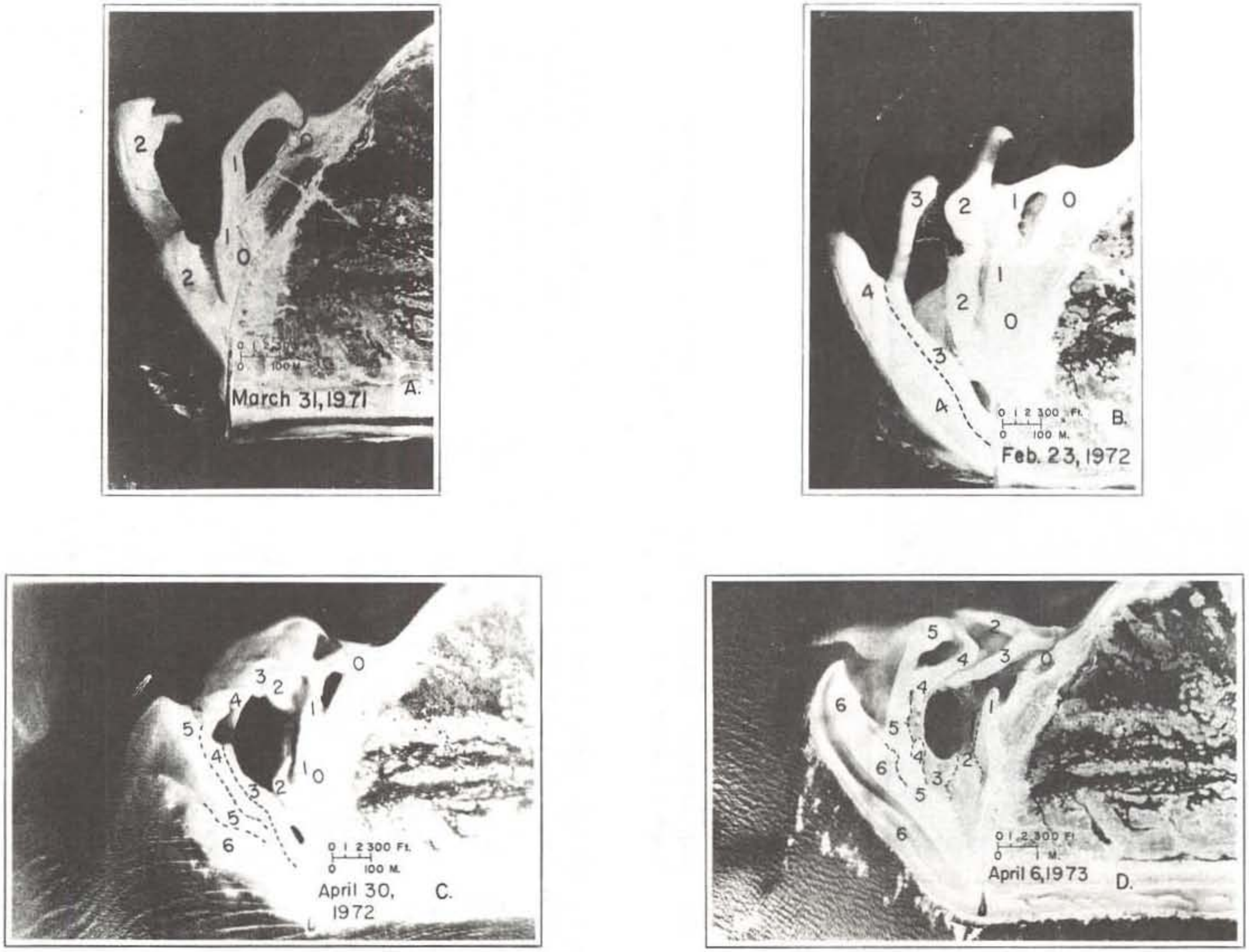

Figure 29 (A-D). Progressive development of intertidal spit platform features at Democrat Point - 1971 to 1973. Numbers reflect the order of spit development.

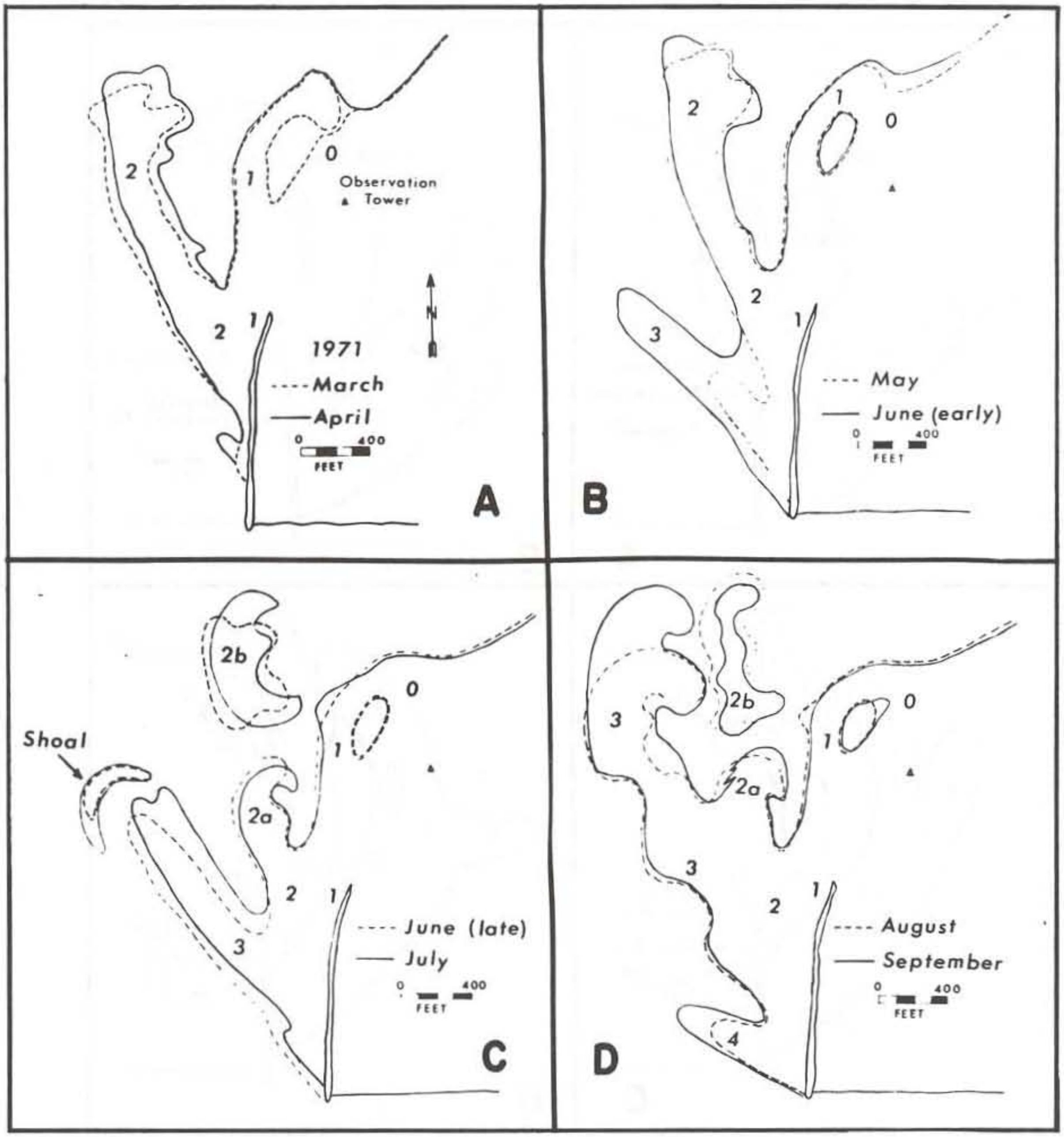

Figure 30 (A-D). Monthly pattern of spit accretion and refraction (March-September, 1971). See Text for more detailed explanation.

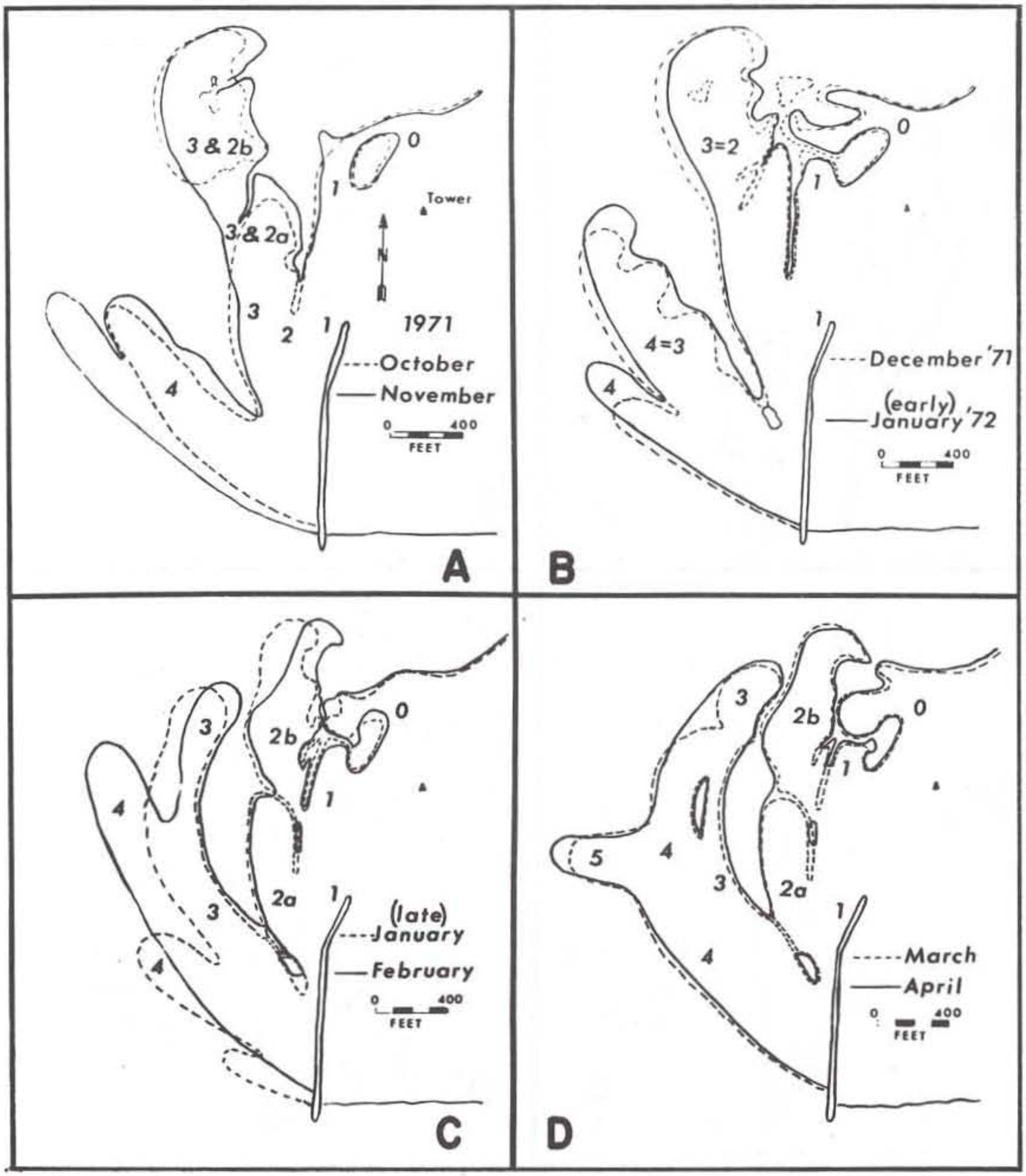

Figure 31 (A–D). Monthly pattern of spit accretion and refraction (October, 1971–April, 1972). See Text for more detailed explanation.

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

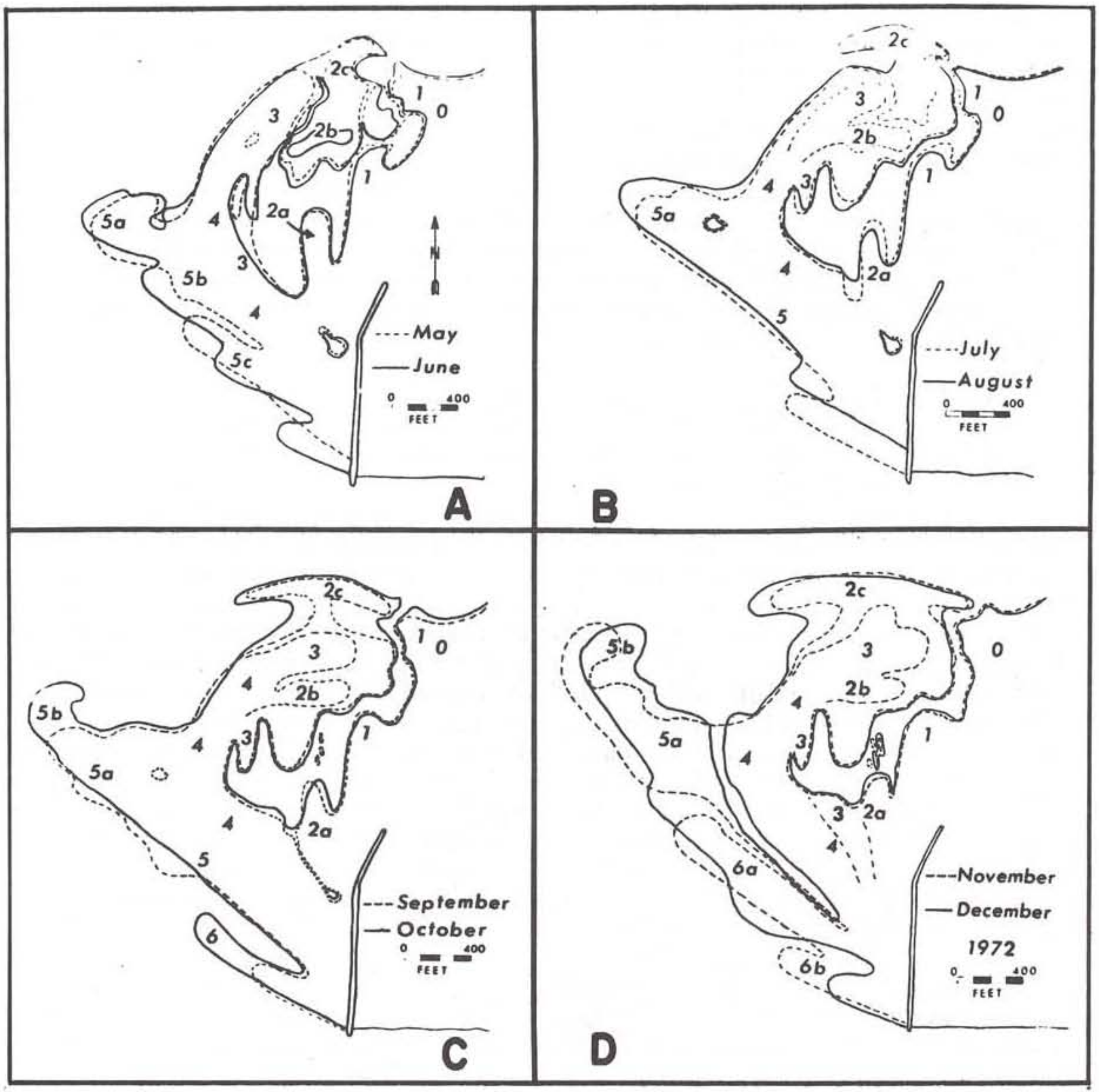

Figure 32 (A-D). Monthly pattern of spit accretion and refraction (May-December, 1972). See Text for more detailed explanation.

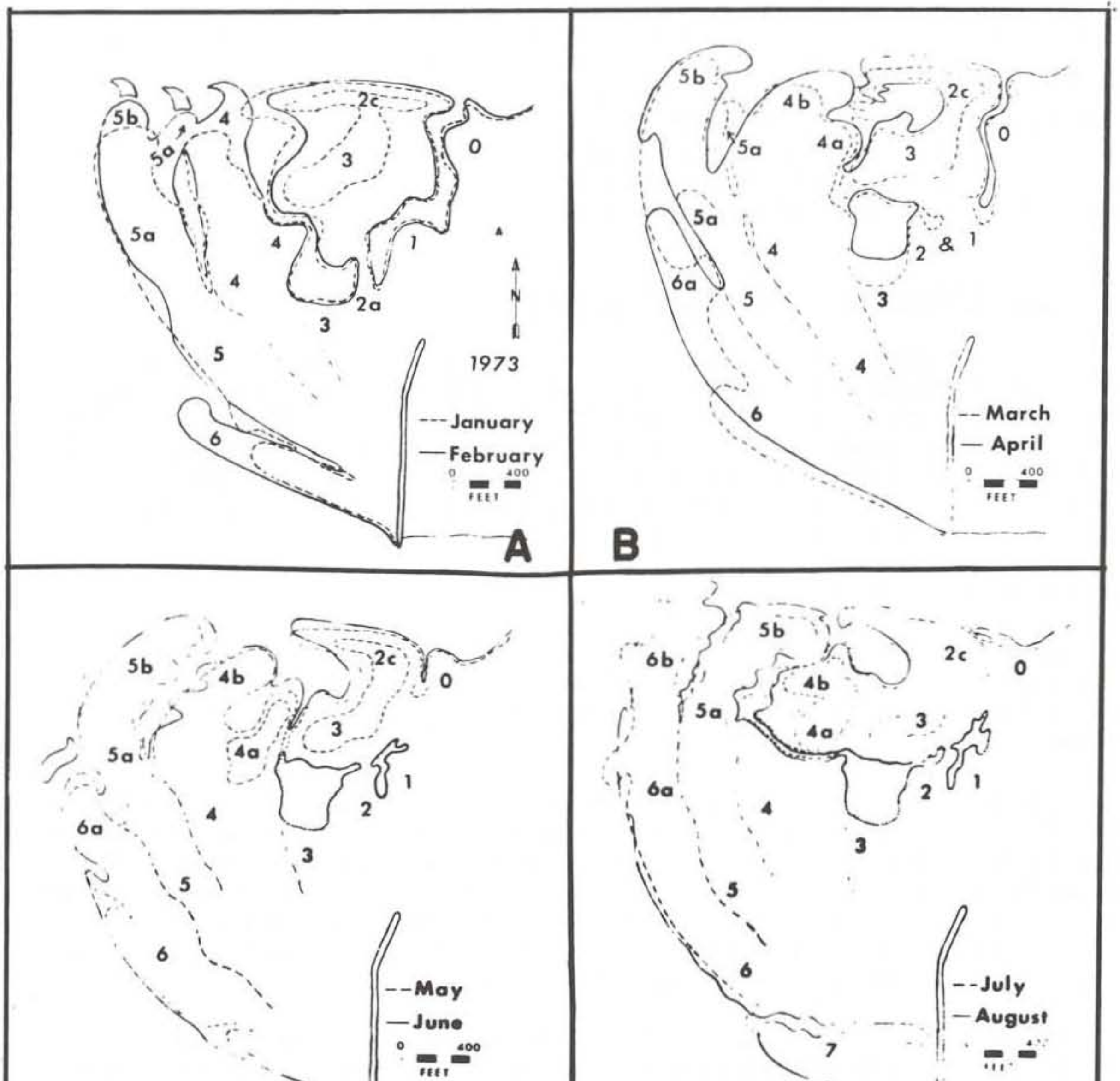

Figure 33 (A-D). Monthly pattern of spit accretion and refraction (January-August, 1973). See Text for more detailed explanation.

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.

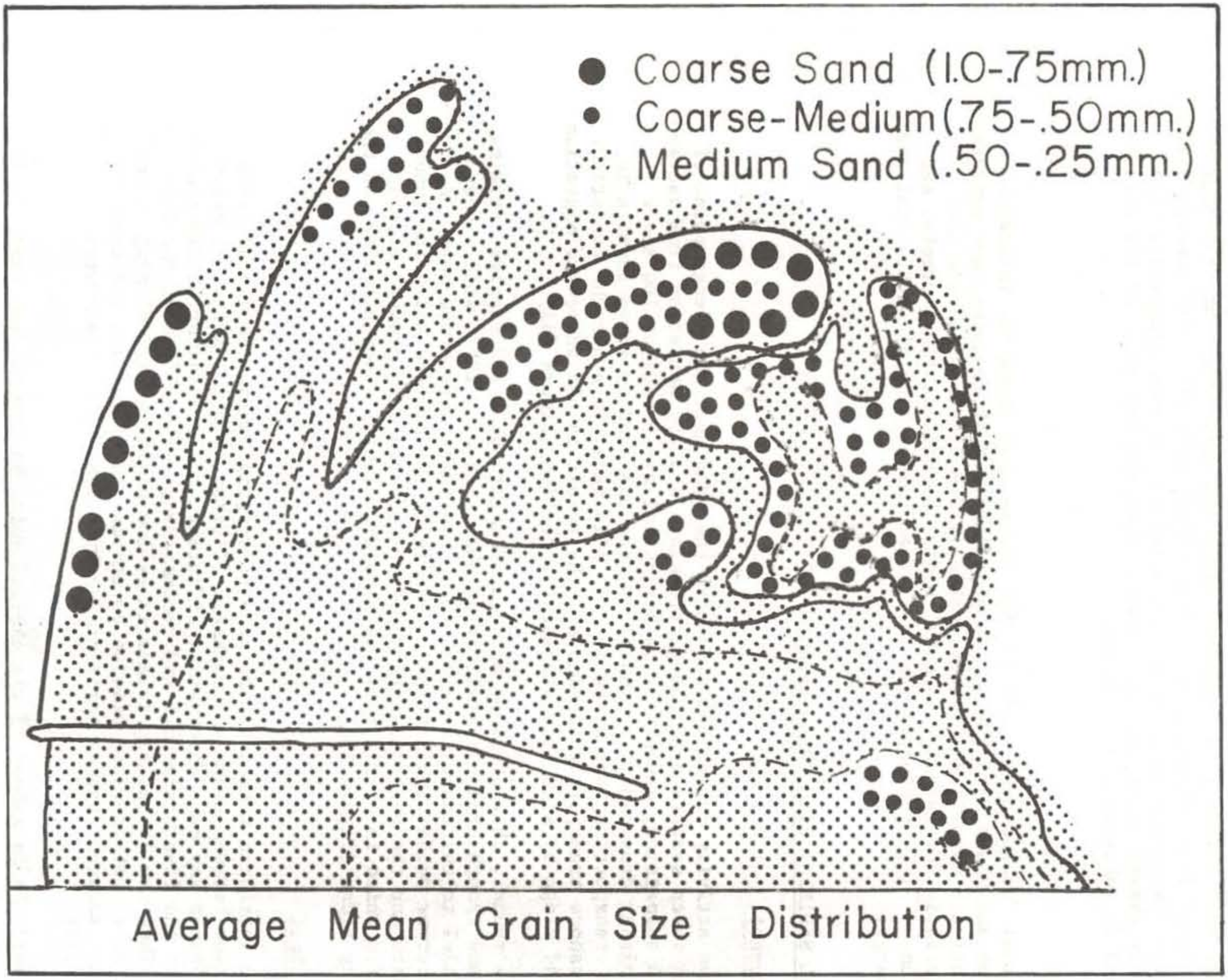

Figure 34. Variations in mean grain size for different intertidal spit platform environments averaged over a two year period.

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

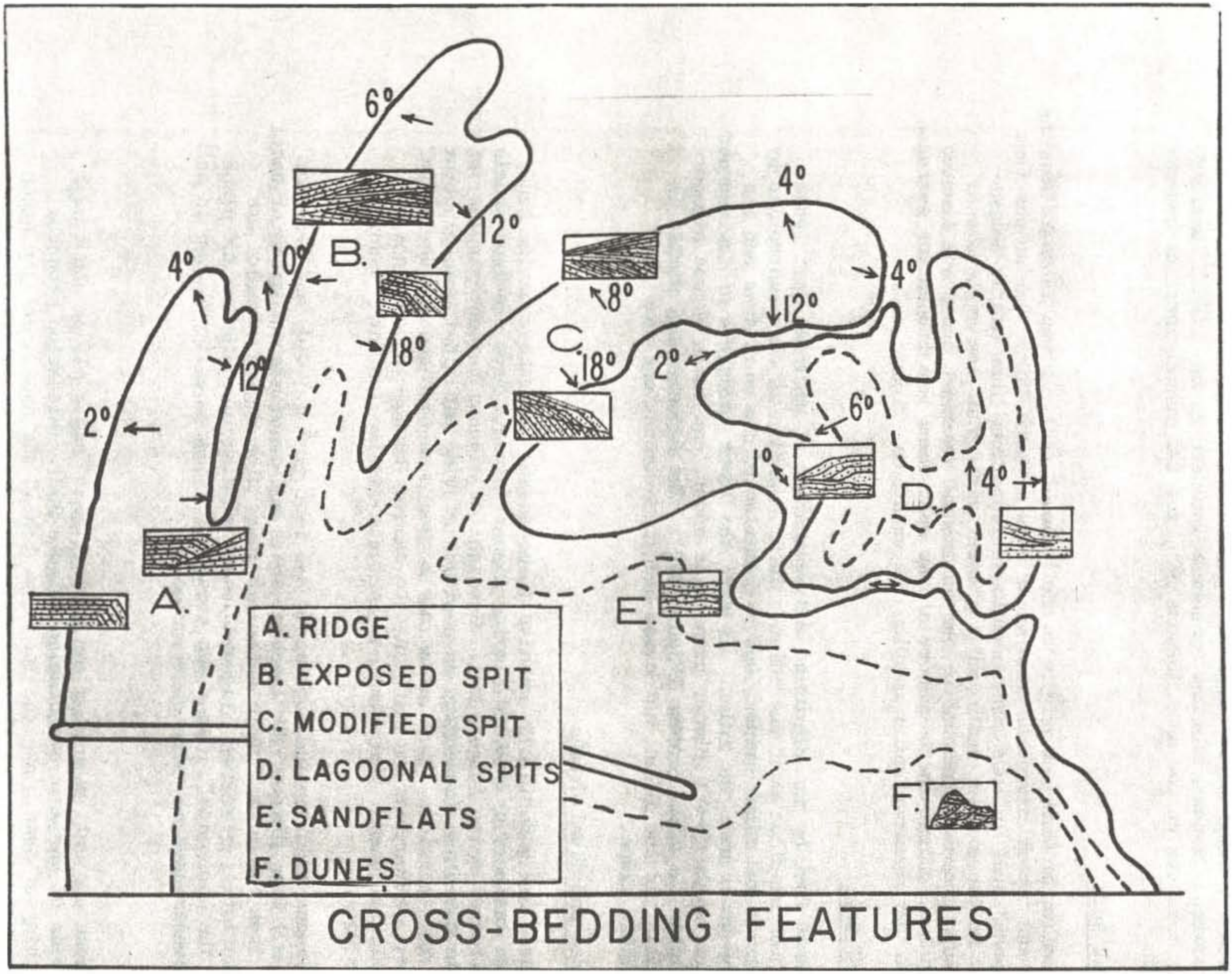

Figure 35. Foreshore and backshore cross-bedding features on the intertidal spit platform. See Text for explanation.

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.

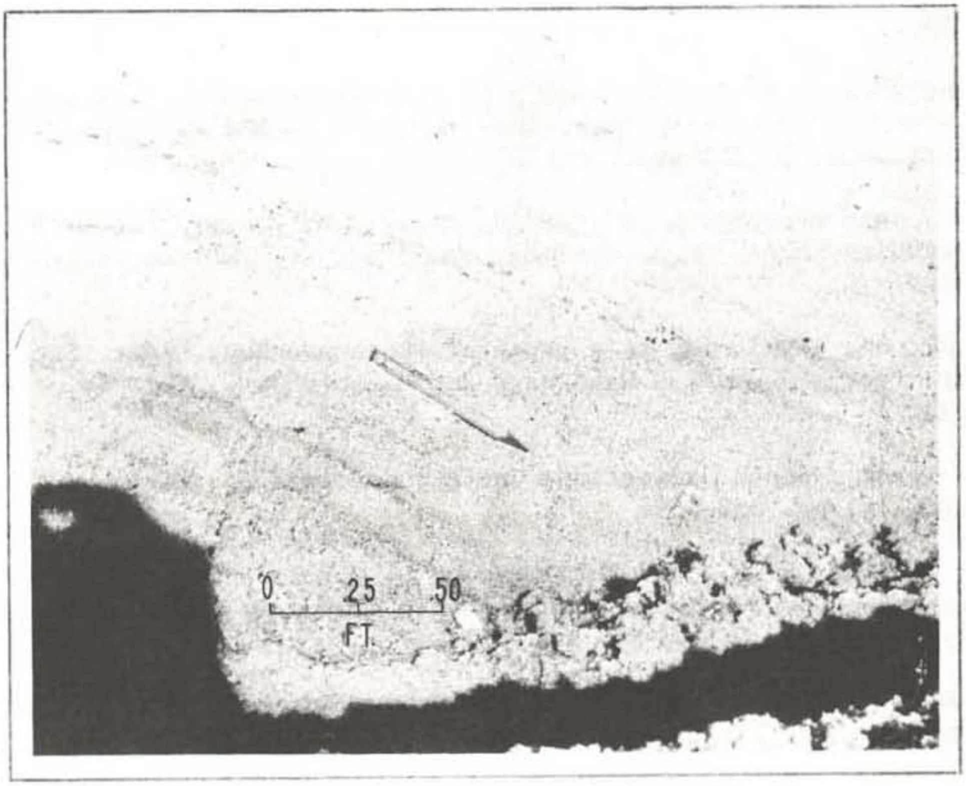

Figure 36. Steep, landward dipping planar foresets on backshore of exposed spit.

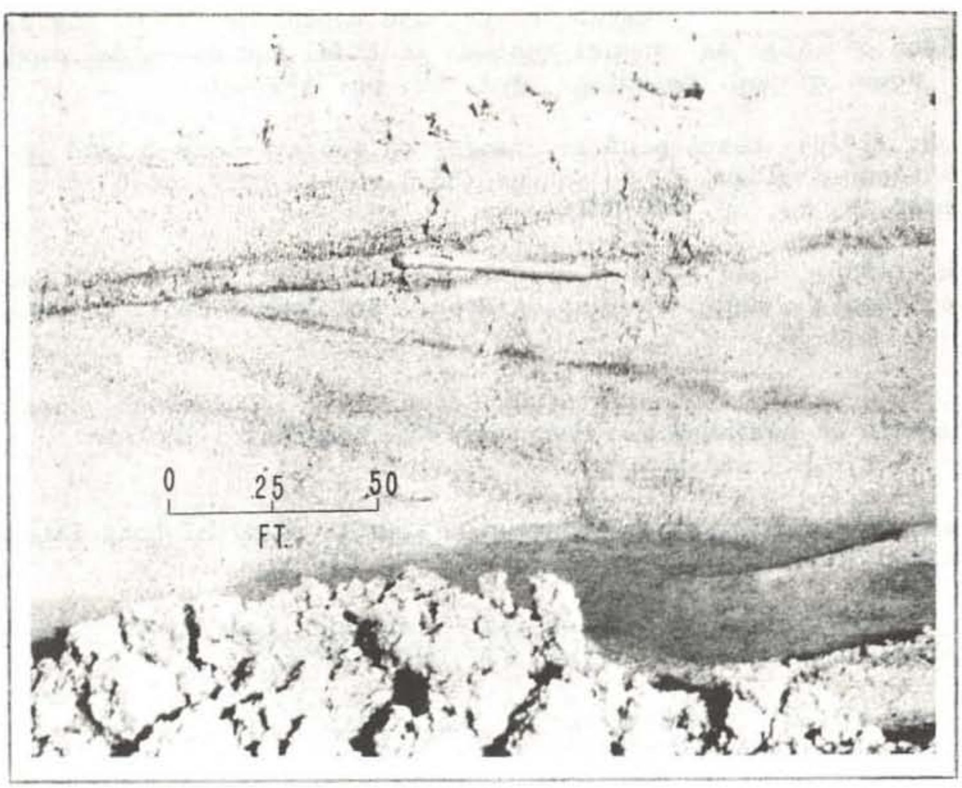

Figure 37. Gentle, landward-sloping planar foresets overlain by tidal washover deposits of the sandflats.

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APPENDIX A

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

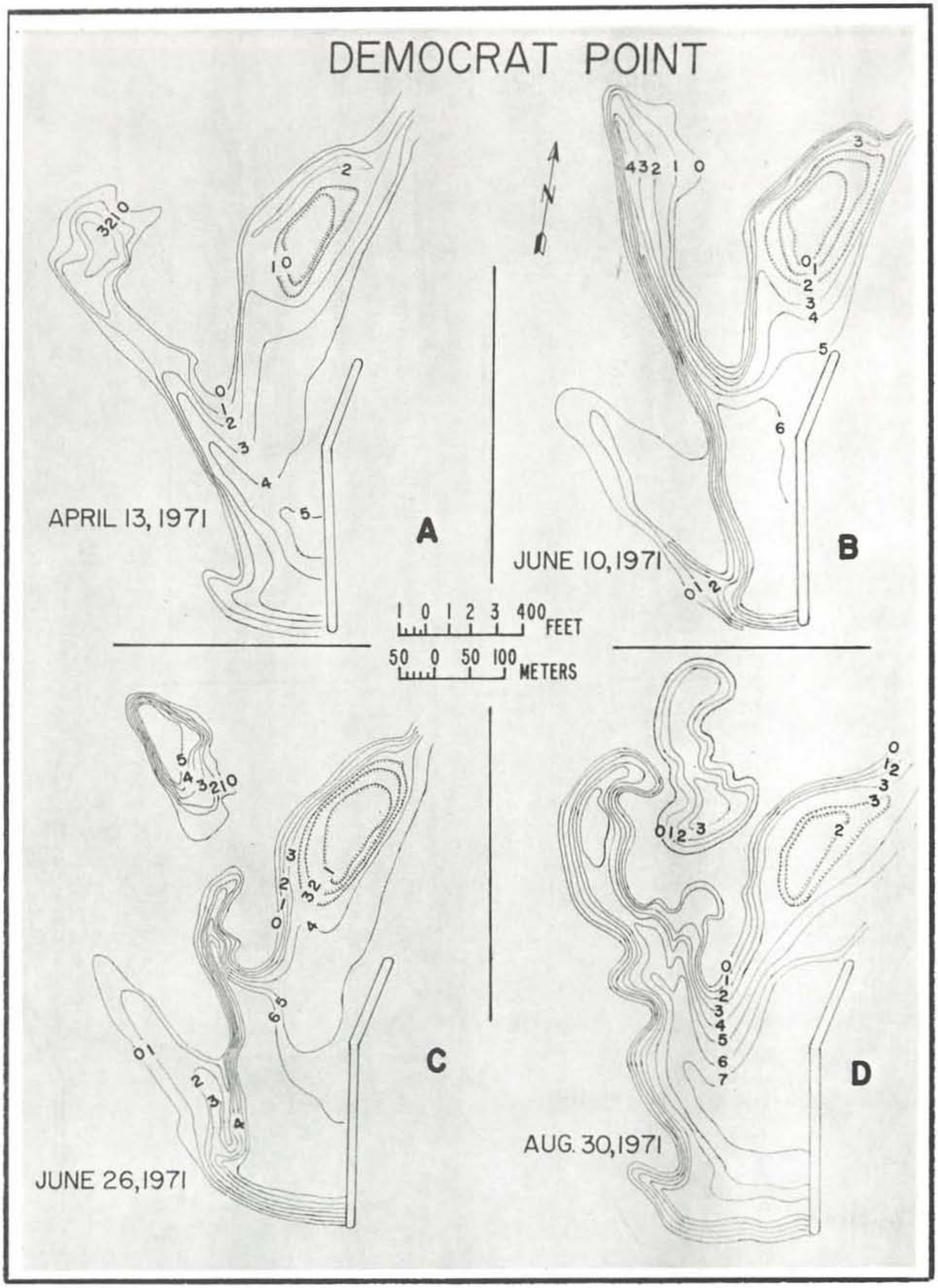
DEMOCRAT POINT
APRIL 13, 1971
A
JUNE 10, 1971
B
JUNE 26, 1971
C
AUG. 30, 1971
D
1 0 1 2 3 400 FEET
50 0 50 100 METERS
N

Figure A-1.

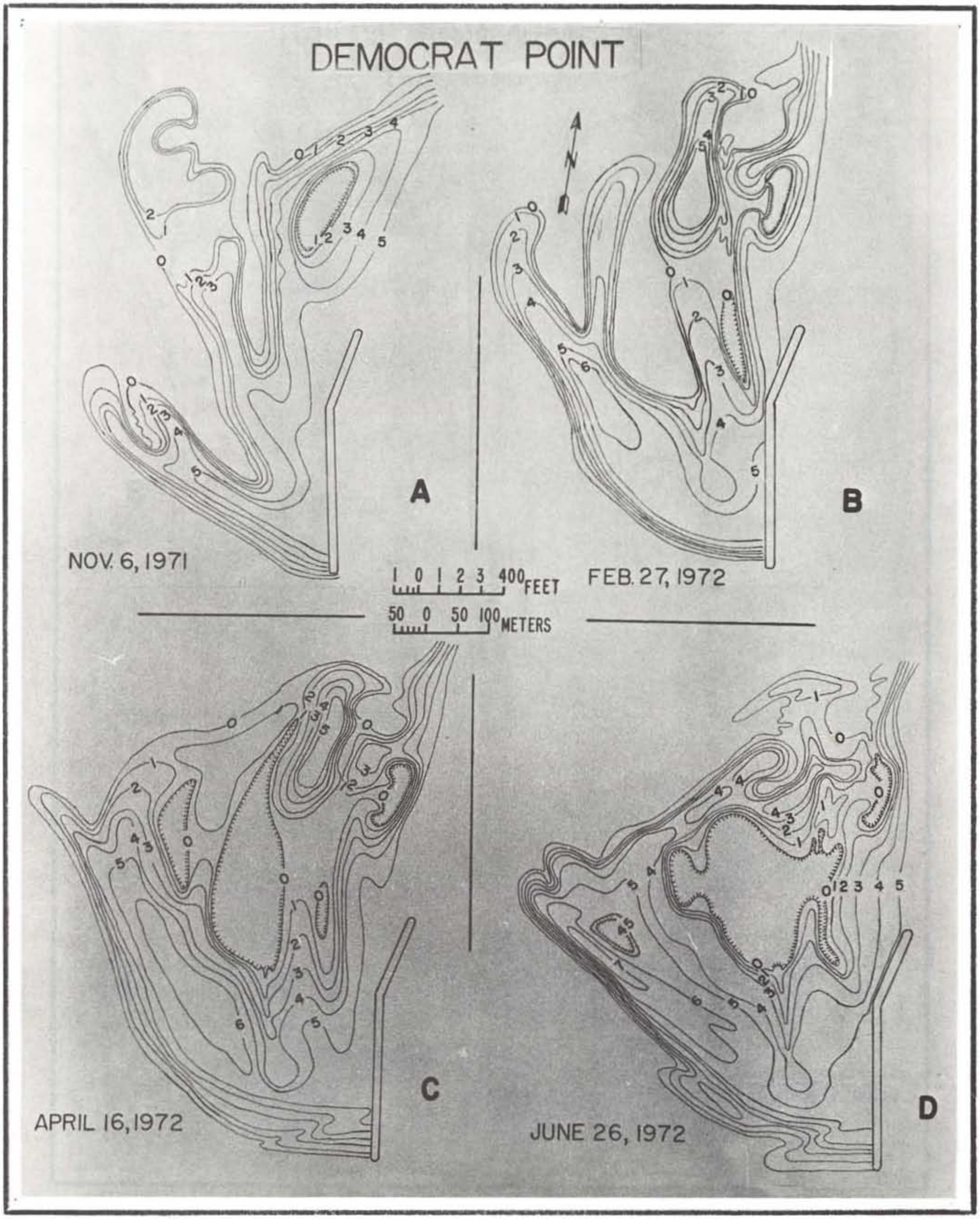
DEMOCRAT POINT
A
NOV. 6, 1971
B
FEB. 27, 1972
1 0 1 2 3 400 FEET
50 0 50 100 METERS
C
APRIL 16, 1972
D
JUNE 26, 1972

Figure A-2

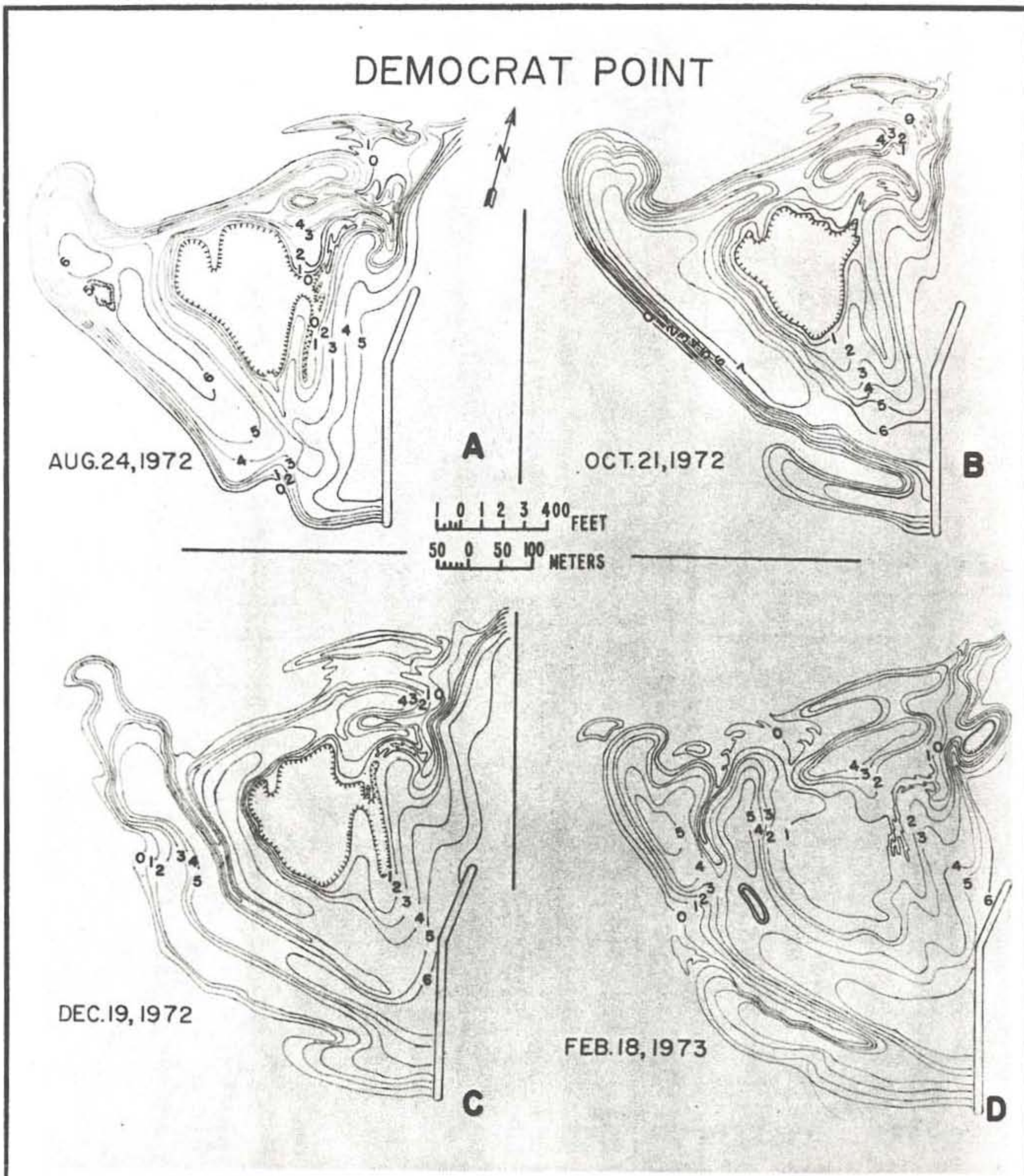
DEMOCRAT POINT
AUG.24,1972
A
OCT.21,1972
B
0 1 2 3 400 FEET
50 0 50 100 METERS
DEC.19, 1972
C
FEB.18, 1973
D

Figure A-3.

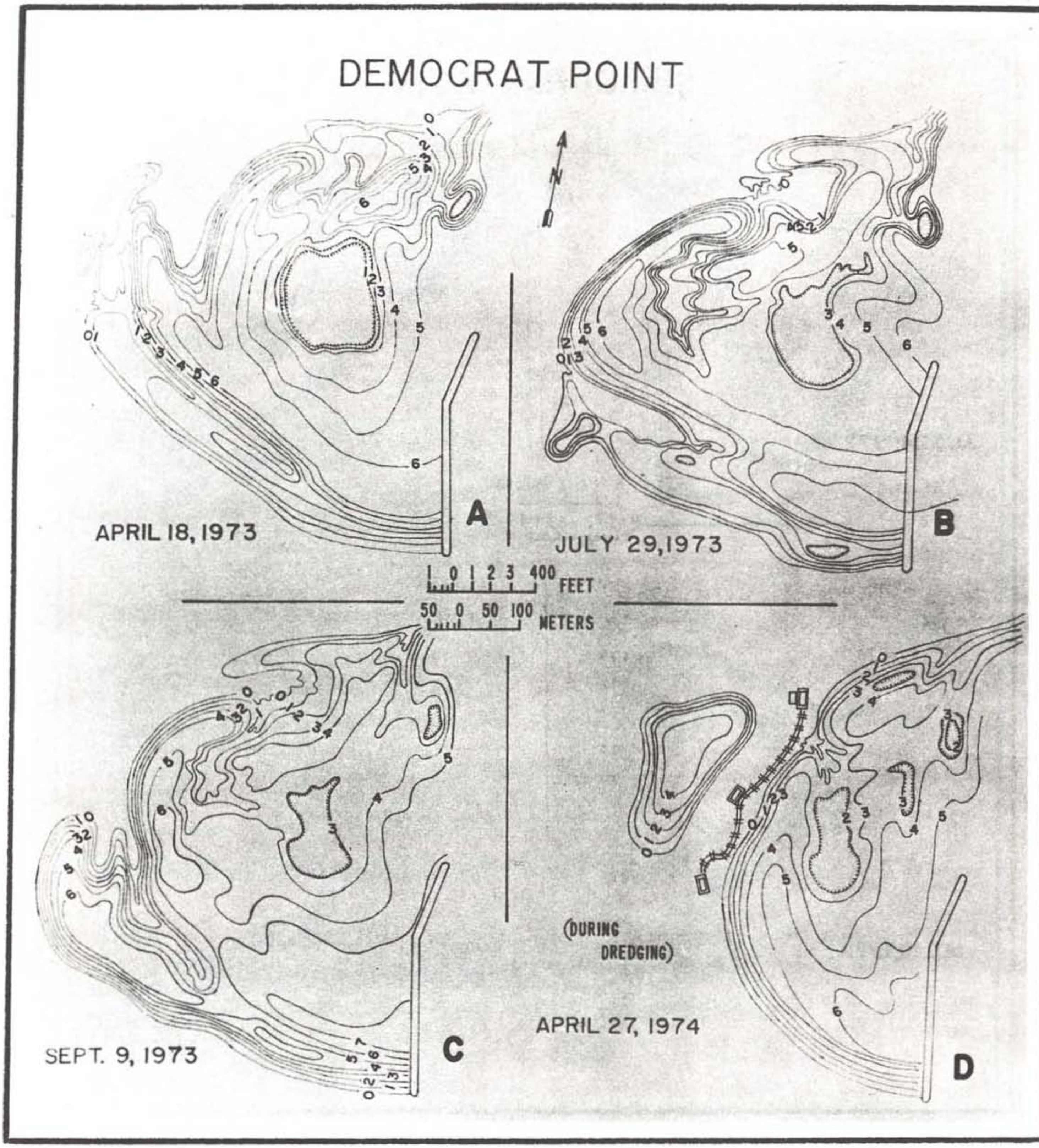
DEMOCRAT POINT
A
APRIL 18, 1973
B
JULY 29, 1973
0 1 2 3 400 FEET
50 0 50 100 METERS
C
SEPT. 9, 1973
(DURING DREDGING)
APRIL 27, 1974
D

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

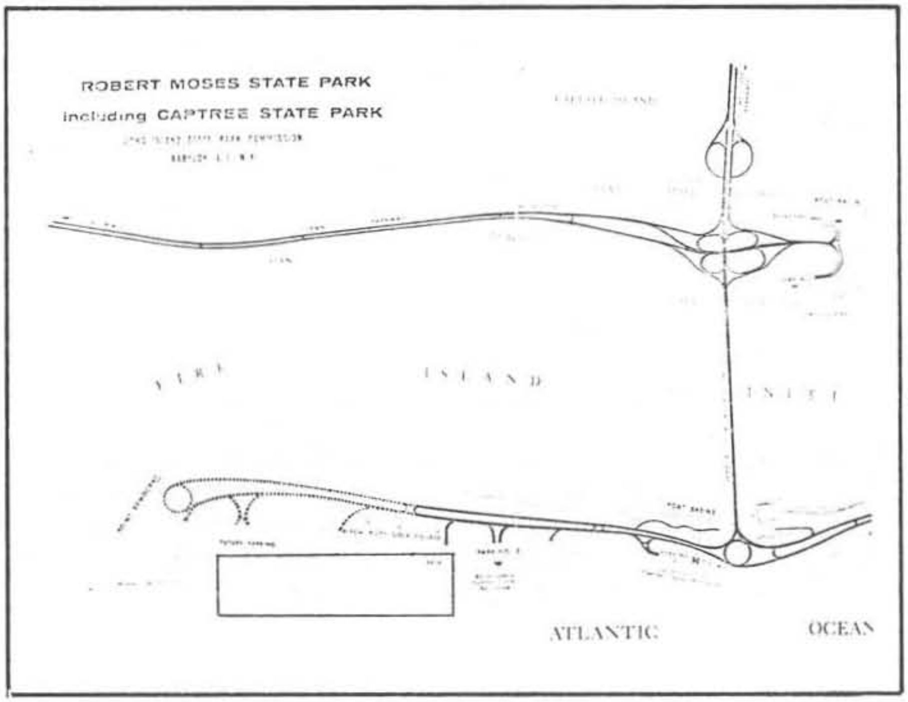

Figure 1. Stop 3 - Location of the study area.

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 Direction	Speed*	(B) December 1 Direction	Speed	(C) December 2 Direction	Speed	(D) December 3 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.)

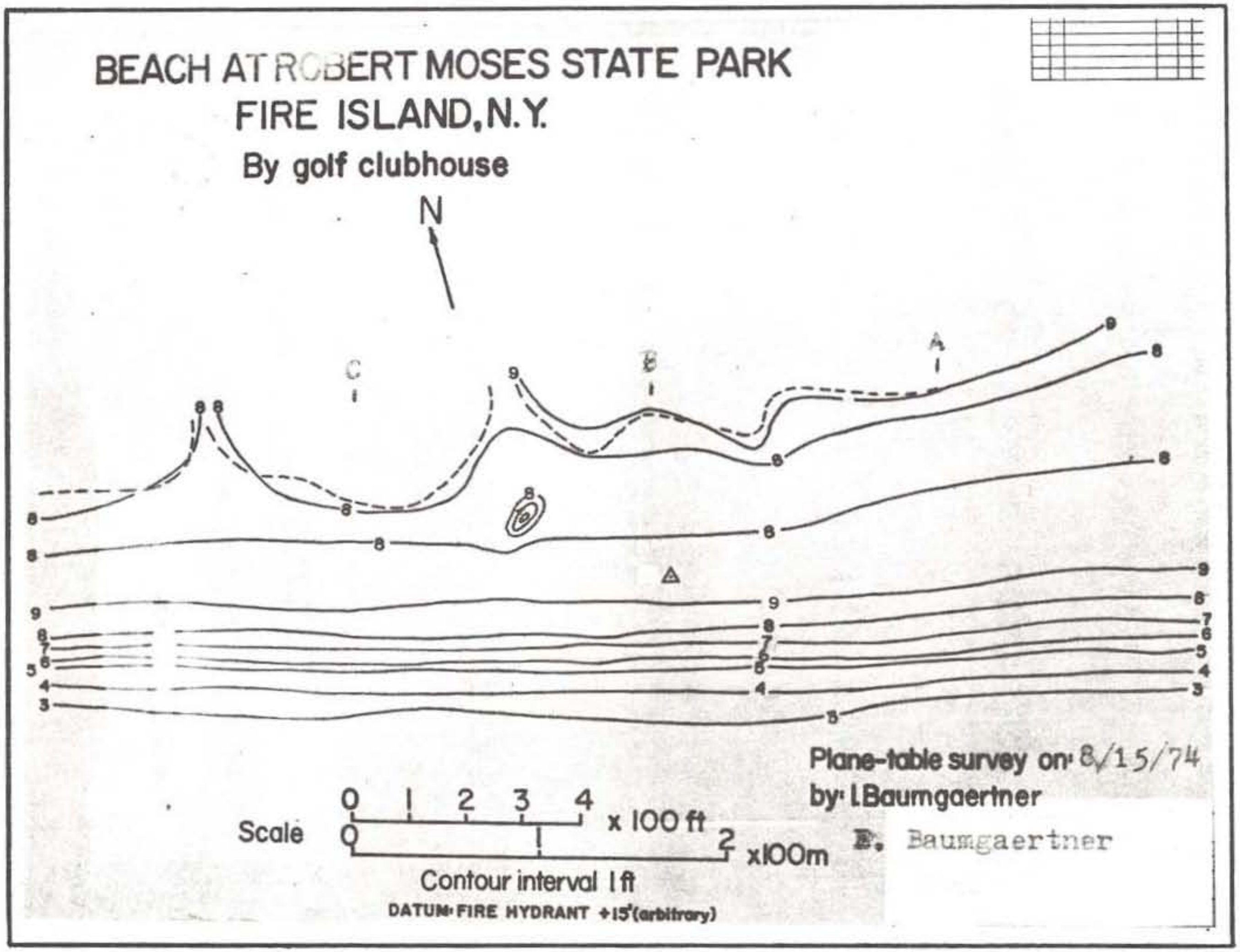

Figure 2. Pre-storm topographic map of the monitored section at Robert Moses State Park, Fire Island.

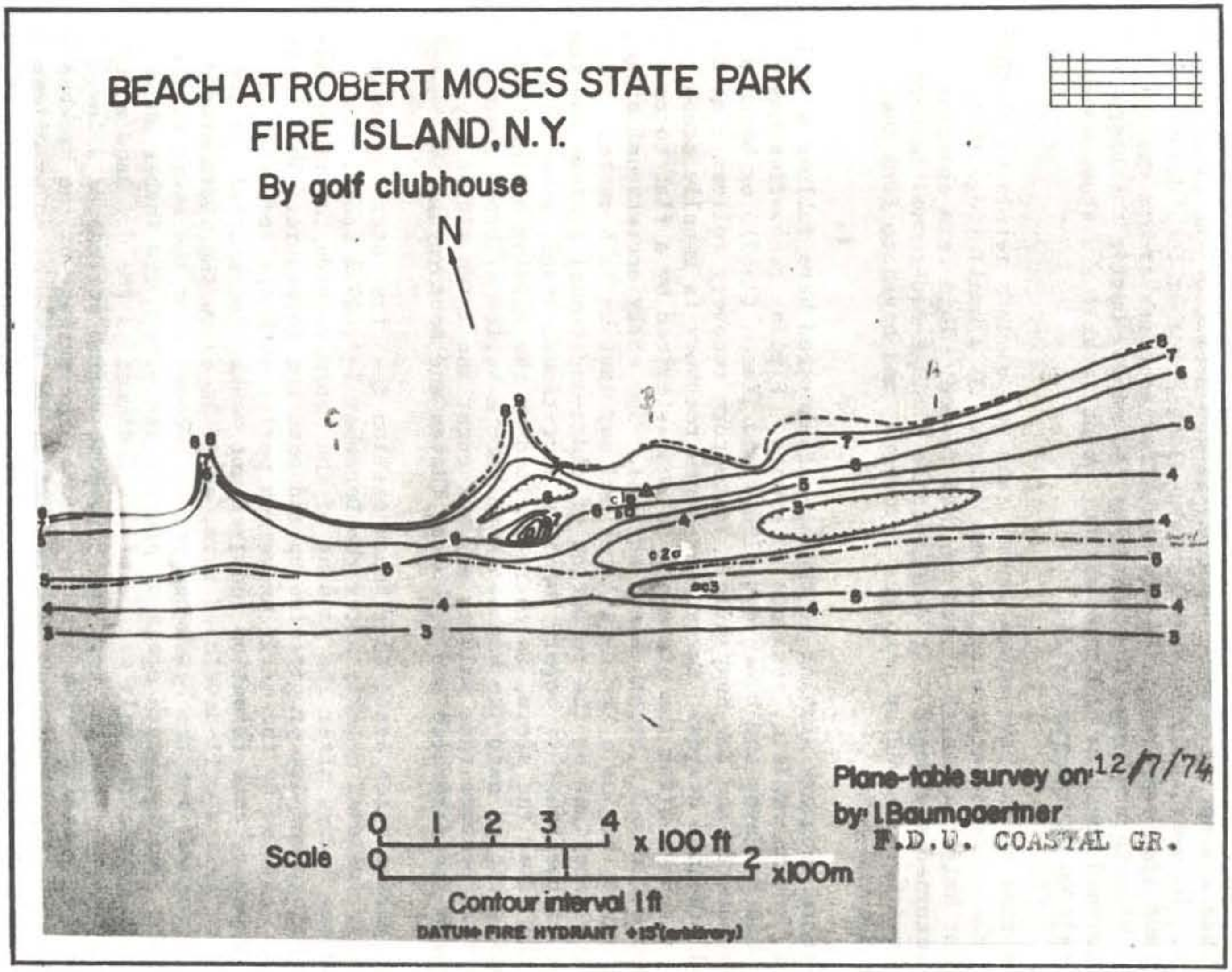

Figure 3. Topographic map of the monitored section at Robert Moses State Park, Fire Island on December 7, 1974.

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),

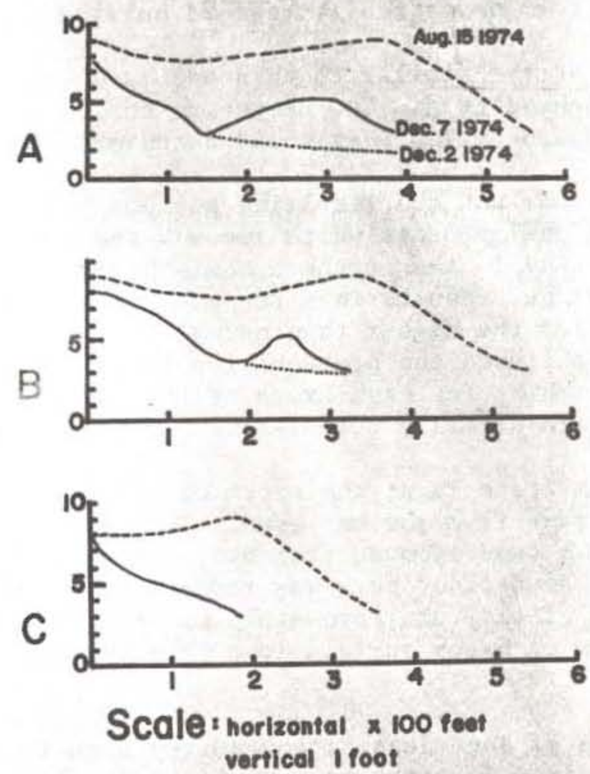

Figure 4. Beach profiles from the map area before (----), during (····), to immediately after the storm and 5 days after the storm (____). NOTE: Had it not been for our presence on the beach immediately after the storm, the profiles taken from the topographic maps (post-storm profile) would have given 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 h/L_d 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 <u>very</u> 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 <u>parallel</u> 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).

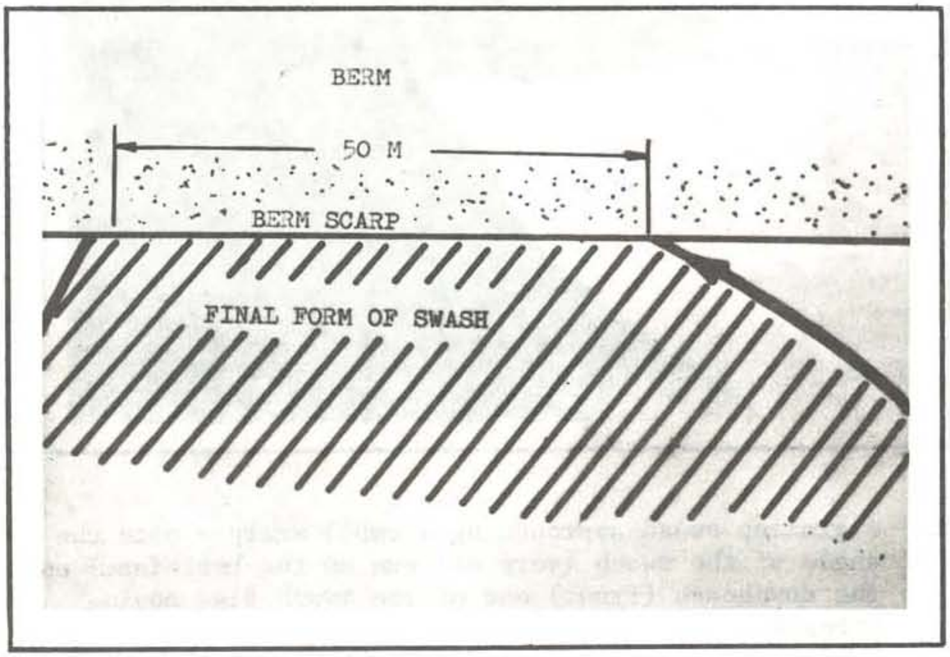

Figure 5. A newly formed miniature scarp forces subsequent swashes to move along the scarp and to erode the berm edge.

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

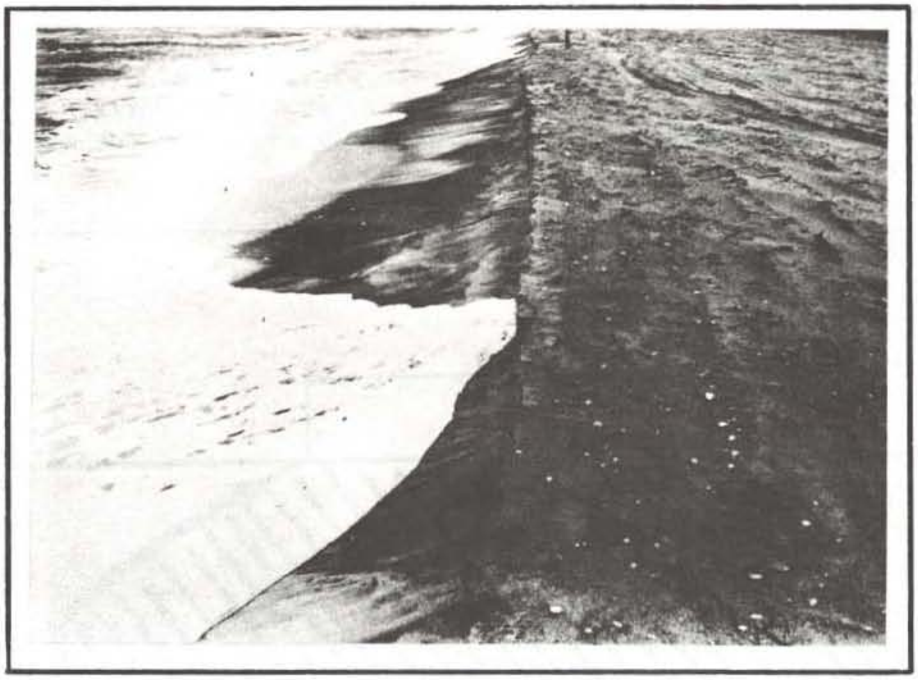

Figure 6. A grazing swash approaching a small scarp - note the angle of the swash (very oblique up the beachface) and the downbeach (front) end of the swash also moving upbeach.

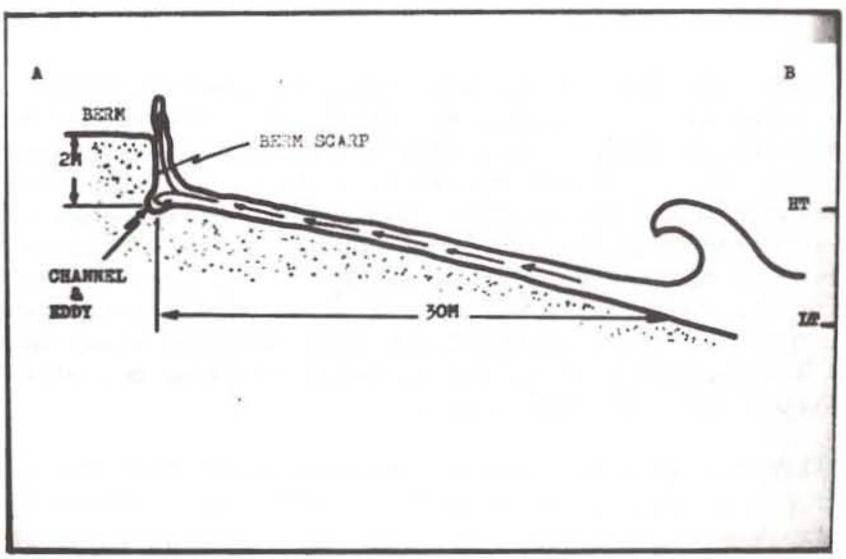

Figure 7. Details of the upbeach movement of the grazing swash at the base of the growing scarp.

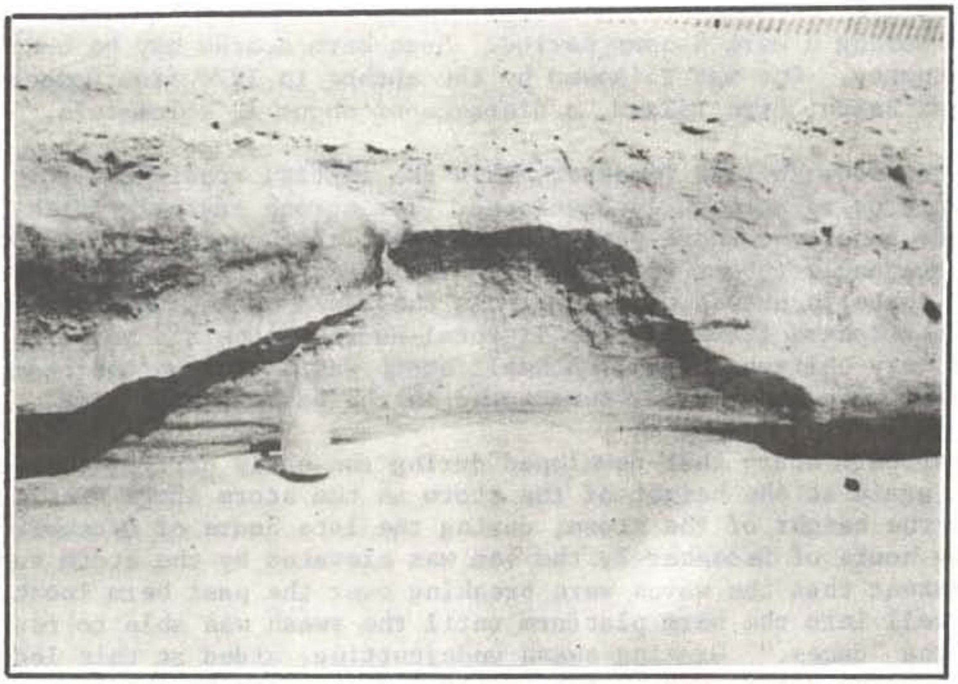

Figure 8. Small cave-in exposes the horizontal layers in the face of a scarp. Note the half-circle shaped channel undercut at the base of the scarp by the grazing swash. The height of the bottle is about 30cm (12 in.) and the height of the scarp, inactive by this time, was about 1 meter.

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-north-easterly 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.

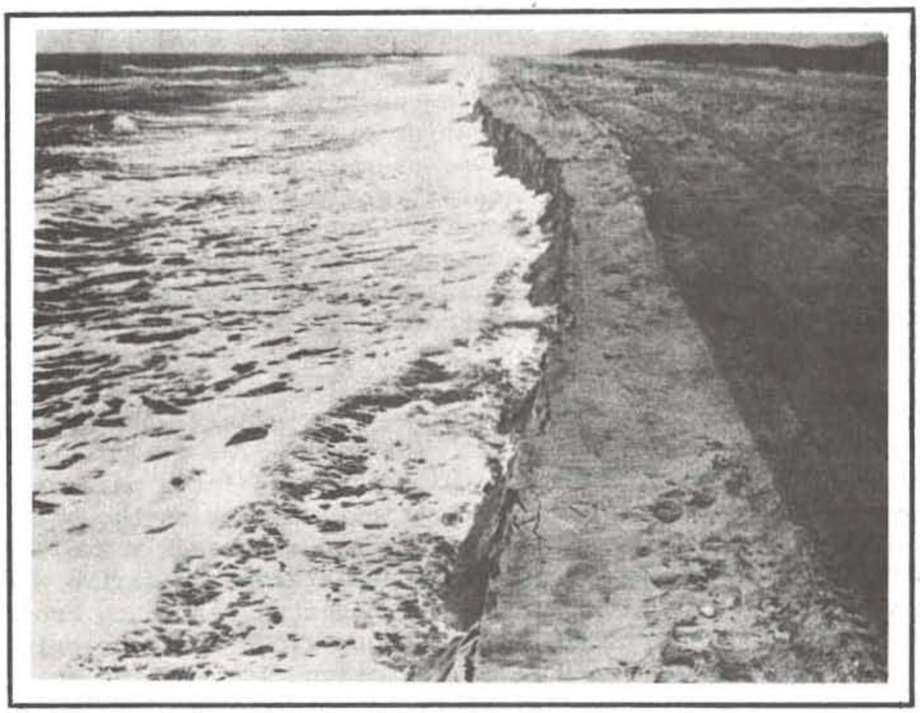

Figure 10. A berm scarp is still being undercut on 26 September, 1975. E to NE winds by this time declined to only 10 mph, but at high tide the scarp still continued to grow. On the photograph the scarp is about 1m high. Note the thin crevasses in the berm surface indicating soon-to-follow slumping.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

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NOTES

Jamaica Bay: A Case Study of Geo-environmental Stress

by

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INTRODUCTION

Jamaica Bay is the westernmost of the estuarine marshes which lie behind a system of barrier beaches along the south shore of Long Island (Figure 1). Horseshoe shaped, the bay is encircled by a gently sloping glacial outwash plain along its northern perimeter and by the elongate Rockaway barrier beach to the south. Human activities have fundamentally changed the surface character of the region and disrupted the natural geologic processes. The purpose of this paper is to examine the historic relationship between the natural geological environment and human activities.

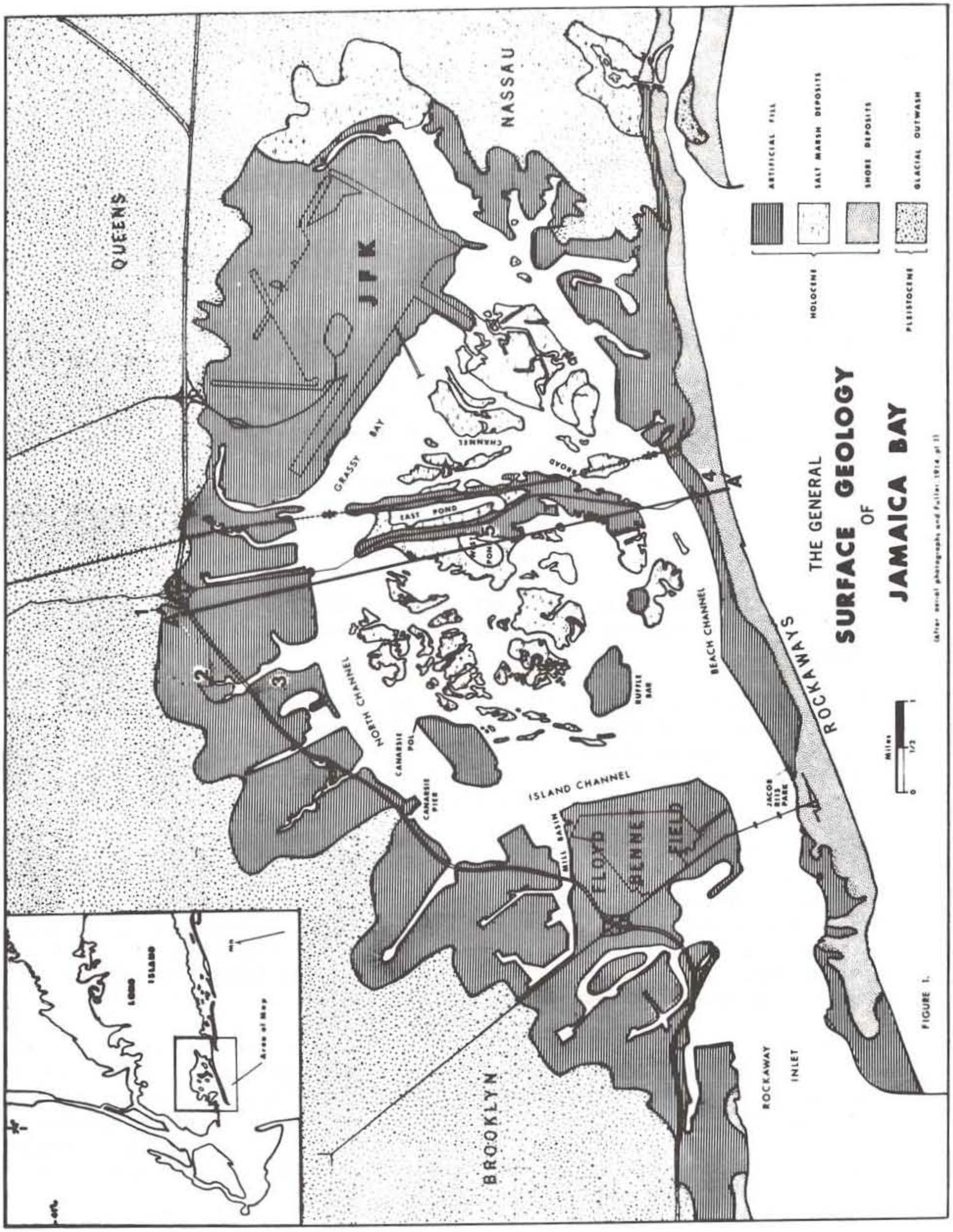
SUBSURFACE GEOLOGY

Although the field trip can visit only the surface of the Jamaica Bay area, the subsurface geology plays a significant role in the recent geo-environment.

The subsurface geology of the Jamaica Bay region is known almost entirely from well logs. A blanket of Late Wisconsinan glacial outwash, itself obscured by modern shore and urban deposits, conceals an unconsolidated sedimentary wedge overlying the erosionally sculpted, southeastward dipping crystalline basement complex of the New York City series.

The basement surface beneath western Long Island is deeply weathered and exhibits relief locally up to 300 feet (Newman, 1966). It strikes approximately northeast-southwest with a dip of about 80 feet per mile and is about 1,100 feet below sea level at Far Rockaway (Sutter, deLaguna and Perlmutter, 1949). Flint (1963) considered this bedrock floor to be a continuous, southward subsurface extension of the facetlike surface in coastal Connecticut known as the "Fall Zone."

Lying unconformably on bedrock in ascending order are: two terrestrially derived formations of Late Cretaceous age, the Raritan Formation, and the Magothy Formation-Matawan Group undifferentiated (Perlmutter and Todd, 1965, p. 9); the Pleistocene pre-Wisconsinan Jameco Gravel and Gardiners Clay; a series of Wisconsinan glacial and interglacial deposits (Rampino, 1973); Holocene shore, bay and salt marsh sediments; and artifical fill deposits.



THE GENERAL SURFACE GEOLOGY OF JAMAICA BAY

FIGURE 1.

These stratigraphic units contain the four distinct aquifers described by Cohen, Franke, and Foxworthy (1968, p. 18). These include in ascending order, the Lloyd aquifer (the Lloyd aquifer is equivalent to the Lloyd sand, the lower member of the Raritan Formation), the Magothy aquifer, the Jameco aquifer, and the upper glacial aquifer. Although these predominately sand or gravel or gravel aquifers are generally hydrologically separated from one another by clay or clay-rich sand, they are locally contiguous due to non-deposition, removal by erosion, or facies changes (Sutter, deLaguna and Perlmutter, 1949).

SURFICIAL GEOLOGY

The natural surface geology of Jamaica Bay includes all of the land surface exposed above low tide. Three major sediments: 1) glacial outwash, 2) salt marsh deposits, and 3) beach and dune deposits characterize the area's major depositional environments.

Sloping gently upward away from the northern bay perimeters, the outwash plain is composed of stratified sands and gravels which Fuller (1914, p. 127; pl. 1) variously placed within his Manhasset Formation, described as "outwash from ice along Harbor Hill moraine with outcrops of the Manhasset Formation", or left undifferentiated. More recently Mills and Wells (1974), and Sirkin (1971) have described this outwash as being a glacial meltwater deposit of upper Wisconsinan (Woodfordian) age.

To the south, the narrow eleven mile long Rockaway Peninsula is one of the barrier beaches which separate most of the south shore of Long Island from the Atlantic Ocean. Sand derived from the prevailing westerly drift of the littoral current (Fuller, 1914; Taney, 1961) has added successive recurved beach ridges at the distal tip of the barrier (Johnson, 1919). These have probably doubled the length of the Rockaways within historic time (Bassett, 1967, p. 3). In an 1878 report to the U. S. Army Corps of Engineers, Lt. Col. John Newton calculated westward inlet migration at the rate of 220 feet per year; a figure which is close to Johnson's (1919, p. 416) figure of 200 feet per year for the period 1889-1912. Taney (1961, p. 46) estimated the annual littoral transport rate at Rockaway Inlet to be 450,000 cubic yards.

The upland marshes of Jamaica Bay are presumed to have begun developing in the intertidal zone along the western margins of the outwash plain some 3-4,000 years ago in a pattern analogous to that described by Redfield (1972) in his study of the Great Marshes of Barnstable Harbor, Massachusetts. Two grasses dominate the flora of the marsh: _Spartina alterniflora_, a coarse tough plant, lives within those portions of the marsh flooded twice daily by the tides, while _Spartina patens_, once prized by settlers as salt hay, thrives in the less frequently flooded margins of the marsh. By trapping and binding sediment they cause salt peat to accrete upward and maintain the living marsh in a position in equilibrium with rising sea level (Bloom and Stuiver, 1963; Redfield, 1972, p. 209).

Ground Water Utilization

Exploitation of the four aquifers which underlie Jamaica Bay largely enabled the urban development that has so severely altered the nature of the area.

Utilization of ground water in the Jamaica Bay region began in 1636 when Dutch settlers found the area reminiscent of their native Holland and established Long Island's first settlement in the Flatlands section of "Brookland" (Brooklyn). Shallow dug wells and the numerous natural springs, streams, and ponds were ample sources of freshwater for their domestic and agrarian needs.

Large scale public water use began in the mid 1800's paralleling the increase in population associated with eastward urban growth. By 1880 over-development of the shallow aquifers in western Kings County initiated large scale removal of water from the larger and untapped ground water reservoir in Queens County for public supply uses in Brooklyn (Soren, 1971). Continually increasing water usage finally outstripped natural recharge capabilities. This resulted from two major causes: 1) decreased recharge due to extensive impervious paved surfaces, and 2) the increased development of sewers. Pavements reduced the effective recharge surface area while sewers prevented recycling by piping fresh water into the bay. By 1908 there were about 800 miles of common sewer lines. In Kings County alone this figure grew to 1,700 miles by 1972 (Kimmel, 1972).

By 1947 all public supply pumping had to be stopped. The depressed water table had caused most fresh water streams entering the bay to shrink or disappear and induced massive salt water intrusion of aquifers near the shore. Perlmutter, Geraghty, and Upson (1959) calculated that in southeastern Queens County, the water table had declined by as much as 20 feet between 1903 and 1959. They speculated that increased withdrawals in central Queens were the cause of as much as two miles of landward encroachment.

Significant changes occurred following the cessation of pumping. In 1972 Kimmel observed that water levels in Kings County were nearly the same as they were before intensive urban development. This, despite the fact that impermeable surfaces had been placed on over 90% of the recharge area. Citing abnormally high nitrate concentrations observed in the upper glacial and Jameco aquifers, he suggested that leakage of contaminated fresh water from the dense area-wide network of sanitary and storm sewers was responsible for the unexpected recovery.

Due to easy access to the upper aquifers, the Lloyd was rarely tapped and, the few private wells that currently draw from the Lloyd aquifer generally produce uncontaminated water (Julian Soren, personal communication).

CULTURAL SURFACE GEOLOGY

Man's influence on the surficial geological environment has been profound. The consequences of his actions on each habitat are described below.

The Beach and Dune Environment

The presence of man upon the Rockaway barrier island is apparent even from a distance. Multi-story buildings form a crowded silhouette that suggests how completely the island has been modified. The bay side has been bulkheaded and backfilled to create valuable real-estate, while the ocean shore has been stabilized by the emplacement of over 100 groins. In addition, the once extensive dune fields (Fuller, 1914, p. 181) have been leveled to create a platform for residential housing.

The effects these alterations may have on the barrier as it reacts to the continuing rise of sea level and periodic intense storms are not known. Certainly the processes of oceanic overwash (Dolan, 1972) and landward migration (Sanders and Kumar, 1975) have been halted. The island that was once a flexible wave form in equilibrium with oceanic energies (McCormick, 1972) is now rigid and unyielding.

Storms are an important part of the inventory of geologic process which act on the Rockaway barrier beach. In their natural condition, the low resistance that barrier beaches present to storm surges enables them to survive the severe perturbations of tropical and extratropical storms (Dolan, 1972, p. 277). The Long Island area experiences a storm which causes moderate damage, on the average, about once every two years. Severe storms occur about three times every century. Fortunately, the track of a major hurricane has not crossed Jamaica Bay since 1893 (Davies, Axelrod, and O'Conner, 1973).

In 1960 and 1962, two severe storms accompanied by high winds and tides, struck the New York area. Flooding was extensive in Jamaica Bay and the Rockaways were severely eroded. In 1965 the U. S. Army Corps of Engineers revealed plans for a dike and sea wall 18 feet above the mean high water (eight feet above the 10 foot elevation of the beach) to run along the Rockaway Peninsula for six miles before crossing over in the vicinity of Riis Park to join up with a 4,530 foot long hurricane barrier. This was to have straddled Rockaway Inlet to connect with a dike 1.2 miles long on the Brooklyn shore. A six hundred foot opening in the center of the barrier was designed to close at the time of high water. Legislative delays, rising high costs (53 million dollars in 1965), and public concern for shore access and water quality (construction by the gates would increase residence time of water in Jamaica Bay) defeated the plan.

The Bay-Salt Marsh Environment

A salt marsh is a natural storm buffer. By intercepting wave shock and absorbing water, marshland is capable of mitigating the effects of storm surge. Johnson (1969) calculated that one acre of marsh is capable of holding 300,000 gallons of water through its sponge-like peat and grass composition.

In 1907 Jamaica Bay was 24,640 acres in extent. Of this, 16,170 acres was marsh. However during the first seventy years of this century at least 125 million cubic yards of marsh and bay bottom was dredged from Jamaica Bay. By 1970 dredging and filling had reduced the bay to only 13,000 acres of which only 4,000 were marshland. Dredging also increased the original average water depth from 3 to 16 feet. Dredging and filling are in part responsible for the contaminated condition of bay waters. By decreasing tidal flushing action, these operations have impounded the water pollution caused by storm overflow, street runoff, and the outfall from sewage treatment plants. Dredging accounts for 70% of the present volume of the bay. Coupled with decreased tidal flow caused by the filling of marshes, this equates to a higher residence time for pollutants entering the estuary. Contemporary turnover rates of about 35 days are more than triple Jamaica Bay's original retention time of 10 or 11 days.

Although a concert of other causes have contributed over the years to high water-pollution levels in Jamaica Bay, many of these effects are short lived (e.g., oil spills) or technically correctable (e.g., sewage disposal). However, the destruction of bay bottom and salt marsh environments are almost totally irreversable actions. It is difficult to imagine how the amount of material necessary to restore Jamaica Bay's bottom could be obtained (Grassy Bay is now over 50 feet deep in places). The high marsh is essentially a non-renewable resource (Redfield, 1972) and even under controlled conditions Spartina alterniflora is difficult to regenerate (Terry, Udell, and Zarudsky, 1974). Taken in the complete context of the ecologic, economic, educational, and esthetic benefits provided by marshes (Teal, 1969), the destruction of 75% of Jamaica Bay's marshes amounts to a questionable final choice in land use and resource utilization.

HISTORY OF LAND USE

Interpretation of a modern surface geology map of Jamaica Bay (Figure 1) is best made in the context of a historical as well as geological narrative. In addition to geological processes which have shaped the modern sediments of beach, bay, and marsh; patterns of population growth, evolving technology, geographic proximity to the urban hub, and planning influenced by political and economic considerations must be examined.

Such patterns are apparent in the below listed chronology*:

Land Use in Jamaica Bay: An Historical Outline

1636 Flatlands, the first settlement on Long Island is established by Dutch colonists; the Hudde and Gerritsen Grant is obtained from the Canarsie Indians securing ownership of most of the western bay.

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* Compiled from many sources. Those not listed in the bibliography include newspaper clippings and other sources from the reference section of the Queensboro Central Library in Jamaica and the vertical files of the Environmental Information Service Library, S.U.N.Y. Stony Brook.

1650 English obtain the area from Peter Stuyvesant and name it "Jamaica" after the Jameco Indians.

1651 Flatbush is settled.

1655 Governor Nicholl confirms a patent for marshes bordering Jamaica Town "to extend southeast to the Rockaway Swampe."

1656 A patent is issued granting ownership of valuable salt hay meadows to "indwellers and inhabitants of the Canarsie meadows lying east of The Indian Planting Ground."

1850 Development of large tourist industries along the ocean beaches, and fishing industries within the bay.

1877 The Long Island Rail Road testle to the Rockaways is built.

1880 Queens County begins the large scale pumping and export of ground water to Kings County.

1898 To protect the ocean beachfront a pneumatic lift system, serving a summer colony of 29,000, goes into operation at Far Rockaway. The ejectors lift sewage over the barrier island and discharge it into Jamaica Bay.

1903 New York City takes title to the Jamaica Town colonial patents. The area includes some 7,000 acres and 12 miles of waterfront in and around Grassy Bay.

1906 Harry Chase Bearly publishes an influential pamphlet urging large scale commercial development and conversion of Jamaica Bay into a major deep water port.

The Jamaica Bay Improvement Commission is appointed.

1910 An act is passed by the State Legislature ceding all land under water in Jamaica Bay to the City of New York.

New York City and the Federal Government enter into a cooperative agreement to develop Jamaica Bay via deep-channel dredging.

1913 Purchase of Brooklyn's Marine Park is authorized by Mayor Mit hel.

The main channel from Barren Island to Mill Basin is dredged to a width of 500 feet and a depth of 18 feet.

1921 Completion of the Mill Basin Pier, the first commercial pier in Jamaica Bay. It is 1,200 feet long and made of concrete.

All shellfish beds are closed.

1922 Deputy Dock Commissioner Henry A. Meyer proposes extensive further development in Jamaica Bay.

1923 The Jacob Riis State Park shore is fitted with groins and a bulkhead.

Cross Bay Boulevard is completed.

1925 Jacob Riis Park is opened.

1927 Groins and a bulkhead are constructed between Fort Tilden and Rockaway Point.

Groins and beach fill are emplaced east of Jacob Riis State Park.

1930 An act passed by the State Legislature permits the City of New York to lease lands fronting Jamaica Bay for commercial purposes.

Robert Moses proposes that the world's largest waterfront park be created in Jamaica Bay.

1931 Floyd Bennett Field, New York City's first municipal airport, is created by filling 1,320 acres on Barren Island.

1933 A jetty is constructed at Rockaway Point.

1936 Sanitation Commissioner William F. Carey proposes that the marsh islands in the center of the bay be converted into a garbage dump. City Park Commissioner Robert Moses fights the plan and wins.

Copies of a resolution sponsored by 90 Jamaica Bay civic associations urging completion of a circumferential highway along the eastern and northern shores of Jamaica Bay is forwarded to Commissioner Moses.

1937 A court ruling against private claims based on the Hudde and Gerritsen Grant gives New York City clear title to 1,774 acres, including Floyd Bennett Field.

1938 Expanded facilities, including parking for 9,000 cars, are completed at Jacob Riis Park.

The Marine Parkway Bridge is opened.

Robert Moses' recommendations for large scale park and recreational use of City-owned bay property are accepted; Jamaica Bay becomes a New York City park. The plans include six beaches, ball fields, a golf course, a marina, and a wildlife refuge.

The Belt Parkway is completed.

Cross Bay Boulevard is widened to 8 lanes.

A dredging permit is authorized for 60 million cubic yards of fill for creation of Idlewild (John F. Kennedy) Airport.

1941 Canarsie Pier is completed.

1942 Floyd Bennett Field is converted to a Naval Air Station.

1946 Grassy Bay is dredged to a depth of 50 feet and 4,900 acres of tidal marsh are filled as part of the construction of Idlewild Airport.

1947 All public supply pumping of ground water is stopped in Kings and Queens Counties.

1948 Idlewild Airport is opened.

1950 Part of the Long Island Rail Road's wooden trestle burns and the railroad elects to abandon the spur.

The New York City Transit Authority decides to run a subway to Far Rockaway and replace the trestle along Broad Channel with a viaduct built from bay-bottom sand.

Robert Moses grants permission to dredge to the Transit Authority in return for construction of dikes for two fresh water ponds for a wildlife refuge. The dikes require six million cubic yards of fill.

1953 Diking of the ponds is completed and the Jamaica Bay Wildlife Refuge is established.

Herbert Johnson is placed in charge of the refuge and initiates a planting program which stabilizes the sand dikes and attracts wildlife.

1956 Digested sludge from the Hendrix Creek Sewage Treatment Plant is mixed with sand and applied to Carnarsie Pol to create, after planting, a "wildlife cafeteria." Canarsie Pol becomes the largest island in the bay.

1958 4.3 million cubic yards of sand is dredged to form the Easterly Runway extension at John F. Kennedy Airport ("JFK").

1962 11.5 million cubic yards of sand is dredged to form the Westerly Runway extension at JFK.

For seven months while repairs are made on the South Ozone Park Sewage Treatment Plant, raw sewage is dumped into Bergen Basin. Gases generated by the sewage blackens paint on homes nearby.

1964 Bergen Basin is dredged to remove decomposing sewage.

1969 The Port of New York Authority commissions a study of the environmental effects of the construction of two large runways at JFK.

1971 The two volume multi-disciplinary study "Jamaica Bay and Kennedy Airport" is released. It recommends against airport expansion.

1974 The National Park Service takes over large areas in the bay to create the Jamaica Bay Unit of the Gateway National Park.

DISCUSSION

Several generalizations regarding land use and resource utilization emerge from an examination of this historical sequence of events. The period of 1636-1850 was characterized by a non-disruptive or "passive" relationship with the geo-environment in which human activity was, for the most part, in harmony with natural geological processes. During this time man lacked either the technology, economic incentive, or need to overtly alter the bay area. The period from 1850-1900 was "transitional" in the sense that previous land uses were being abandoned as an ever increasing population placed new demands upon the resources of the bay. During the period of 1900 to the present man has interacted in an "intensive" fashion with the bay area geo-environment.

As used here, "intensive" refers to interaction with the environment such that man himself becomes a geologic agent, i.e., a force effecting or facilitating geological-scale changes. By moving, removing, adding to or otherwise changing earth materials, man has altered the character of the sedimentary record. More importantly perhaps, in a time frame measured on the scale of human life and values, by modifying Jamaica Bay's interdependent biologic and geologic processes without a full awareness of or regard for the long term environmental implications, man has brought about changes which have eliminated important land use alternatives.

The intensive-use years were especially destructive primarily because of the manner in which human impact was involved. Conflicting political jurisdictions, interests, and sources of funding led to a haphazard development pattern during the first part of this century. When several powerful regional authorities were unified in 1934 under the aegis of New York City Park Commissioner Robert Moses (Caro, 1974, p. 362), they were totally without environmental accountability. In one stroke Moses' Circumferential (Belt) Parkway simultaneously blocked recreational access to most of the shoreline, made the automobile the most important form of area transportation, initiated large scale landfilling along the flanks of the parkway, and cut off much of the natural flow of fresh water into the bay.

The great Jamaica Bay Park which Moses proposed to compliment the boulevard and parkway skeleton, was never built because polluted bay water made construction of a multi-million dollar bathing-beach park unfeasible. As a result, the major part of the central bay remained relatively undisturbed.

In effect, the preservation of the last natural part of the bay was made possible by the fouling of surrounding areas; an irony that should be appreciated by those who scorn Jamaica Bay's polluted waters while enjoying her relatively unspoiled marshes.

CONCLUSIONS

The geologic character of Jamaica Bay is the result of both natural events and human activities. The historical development of the Jamaica Bay geo-environment provides a model useful in predicting effects of, and (where appropriate), seeking alternatives for man-induced changes in similar settings.

Intentions to modify any analogous coastal region should be carried out within the context of modern planning methods that include periodic reassessment and a comprehensive understanding of regional geologic processes.

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ROAD LOG

Assembly Point: Hofstra University

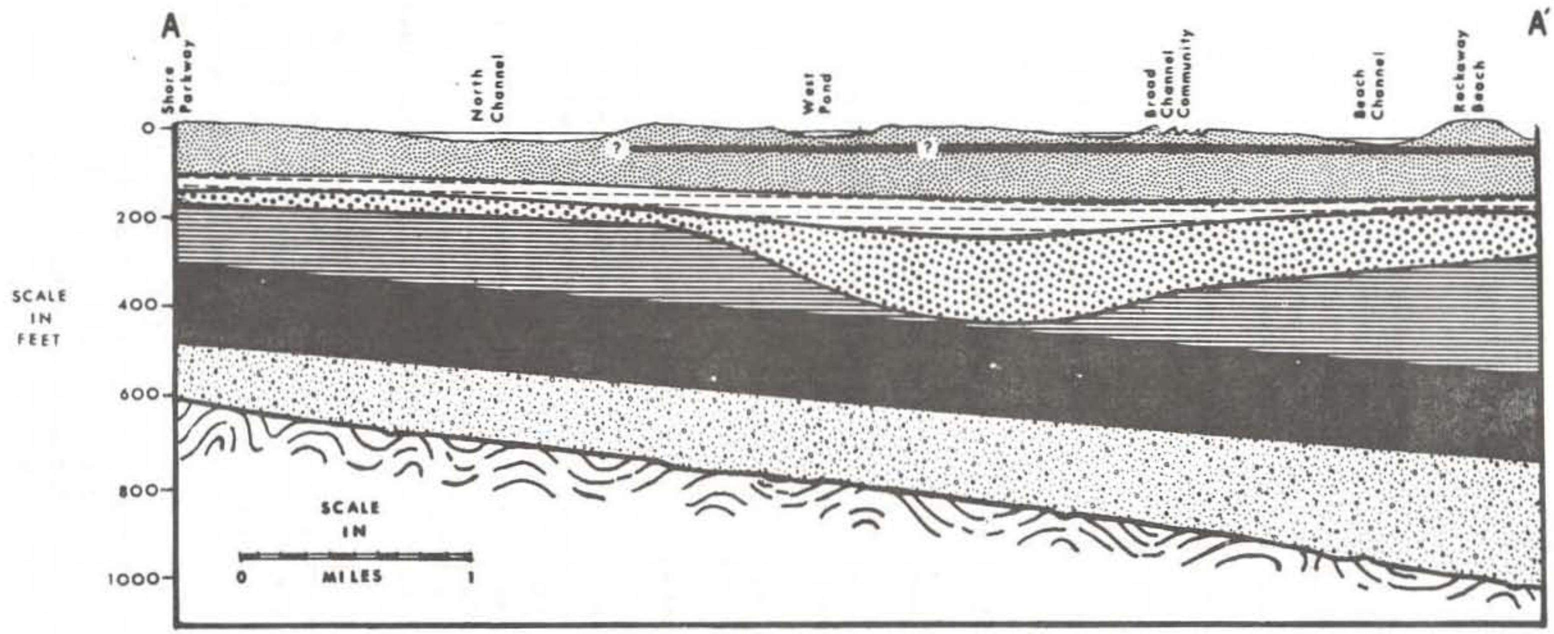
Departure Time: 8:30 A.M.

Trip Leaders: Steven Englebright, S.U.N.Y. at Stony Brook.
Julian Kane, Hofstra University

Cumulative Miles	Miles from last point	Description
0.0	0.0	Leave Hofstra University (Begin mileage under foot bridge) proceeding west on Rt. 24.
0.9	0.9	Turn left (south) onto Peninsula Boulevard.
6.1	5.2	Turn right (west) onto Merrick Road.
9.5	3.4	Turn left (south) onto Brookville Boulevard.
10.0	0.5	Turn right (west) onto North Conduit Avenue and continue on it until intersecting the Cross Bay Boulevard.
15.7	5.7	Make a right turn (north) onto the Cross Bay Boulevard and get into the left turn lane (quickly!).
15.9	0.2	Turn left onto 149th Avenue. Go one block to the corner of 149th Avenue and Redding Street.

STOP 1. This street corner is approximately on the boundary of what was, at the turn of the century, the shore of Jamaica Bay. Stretching out before you to the south was one of the great salt marshes of the northeast. Its 16,000 acres were penetrated by shallow meandering channels bordered by smooth chord grass, *Spartina alterniflora*. A broad belt of high marsh, the outer edge of which was approximately where we stand, was covered by *Spartina patens.* Notice that today you cannot even see the bay from here. The urban development that is apparent everywhere in this vicinity is typical of almost all of the former upland margins of Jamaica Bay.

Notice also figures 1 and 2 of the field guide.



A Generalized Geologic Cross Section of

Jamaica Bay

along Cross Bay Boulevard

Geological section information from SOREN, United States Geological Survey (oral communication, September 1975) and from well data on file at Mineola, New York. Data is provisional and subject to revision.

Explanation:

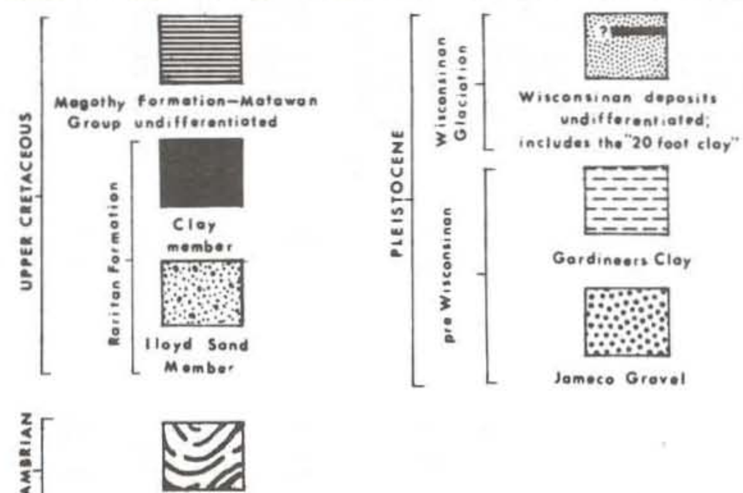


FIGURE 2.

Figure 1 shows where our field stops are located. The trip will take us across the Cross Bay Boulevard in a roughly north-south transect of the bay.

The geologic cross-section (figure 2) was drawn to closely parallel our path today. During the trip you may find it interesting to periodically consult the cross-section and compare changes in surface and sub-surface features along our route.

16.0	0.1	Proceed straight (west) on 149th Avenue to the stop sign. Turn right (west) onto North Conduit Avenue.
16.3	0.3	Bear left (careful changing lanes!) and turn onto Linden Boulevard.
16.9	0.6	Turn left (south) onto Drew Street.
17.0	0.1	A right turn onto Loring Avenue.
17.1	0.1	Go left onto Forbell Street and proceed south to the end of the street.
17.3	0.2	STOP 2. The building on your left is the South Shore Incinerator.

In 1960 there were 2.5 million people living in New York within 5 miles of Jamaica Bay. The solid waste this large population produces is a serious disposal problem. By burning solid refuse, its volume can be reduced by as much as 90% and make its ultimate disposal considerably more efficient. As urban growth took place around the bay, solid refuse was used as landfill. This plant is built on filled marshland.

The South Shore Incinerator receives solid wastes from western Queens and most of Brooklyn. Collection trucks dump material into a waiting bin until it can be placed directly into one of four furnaces. The refuse is its own fuel unless it has rained, in which case oil is sometimes added to keep the furnace hot. The standard temperature is 1500-1600°F and the plant is kept operative 24 hours per day, Monday through Saturday. (On Sunday the furnaces are cleaned which explains the quiet, inactive atmosphere here today.) After incineration the residue is carted to a landfill. Before boarding the bus again, examine some of the ash (refuse) where it is piled outside the south end of the plant. After burial in a sanitary landfill these ashes will cause groundwater percolating through the fill to become highly acidic. Because of leaching, sanitary landfill sites, especially those immediately adjacent to the bay can be expected to be a continuous pollution source.

17.5	0.3	Return via Forbell Street to the intersection with Loring Avenue.
17.6	0.1	Turn left onto Loring Avenue; go one block west, then turn right and proceed north to Linden Boulevard.
17.7	0.1	Turn left (west) and proceed along Linden Boulevard.
18.3	0.6	Turn left (south) onto Fountain Avenue. Go straight to the end of the road.
19.4	1.1	STOP 3. As New York City grew around Jamaica Bay, it used the bay waters for disposal of liquid waste and the fringing marshlands for the disposal of solid waste. We are at the Fountain Avenue landfill. Some six thousand tons of solid refuse are brought here each day. There are two kinds of solid waste disposal sites: 1) a sanitary landfill consists of refuse which is sprayed with a germ-ocide and periodically covered with a sand or earth cover; and 2) a garbage dump, which is simply an open disposal site. Before 1933 the City dumped most of its solid waste into the ocean, but it was forced to stop this practice after a Supreme Court ruling specifically prohibited it. Partly as a result of this, the deposit of solid wastes around the periphery of the bay increased in the 1930's just as sewage treatment programs were getting under way. Between 1938 and 1971, 10 million cubic yards of sand was dredged from the bay for sanitary land-fills along the north shore of Jamaica Bay. In 1965, Brooklyn and Queens each produced 1.7 million tons of solid waste of which 947,000 tons were deposited in Queens, much of it on the Jamaica Bay marshes. This 300 acre landfill was begun in November of 1961. It is scheduled to operate until 1985 at which time it will become a park.

Return to Linden Boulevard.

20.5	1.1	Turn right (east) on Linden Boulevard.
21.7	1.2	Get onto South Conduit Avenue.
22.2	0.5	Turn right (south) onto the Cross Bay Boulevard.
27.3	5.1	Pay 50¢ toll. Follow signs for "Shore Front Parkway."
30.0	2.7	Turn left (east) along the Shore Front Parkway. Stay in the right lane.
30.4	0.4	Pull over behind the traffic island. Park bus.

STOP 4. Walk up the stairs and go to the ocean side of the boardwalk. Sand trapped in artificially maintained inlets further west has been denied to the Rockaway barrier beach and portions of it have become so severely sand starved as to require artificial beach nourishment. By 1974 the berm in this area was completely gone, erosion of the boardwalk was occurring, and in places the shore parkway was threatened. The wide beach we see today is the result of a current ten million dollar beach restoration project begun in April and administered by the Army Corps of Engineers. By the time this project, the first of three between Jones and Rockaway inlets, is completed in November, 4,950,000 cubic yards of sand will have been placed along the shore between 110th and 45th Streets. The sand is obtained by dredging from a huge accumulation known as the "East Bank" some two miles off of Breezy Point. There it is loaded onto barges which transport it to a "booster" dredge-pump on the bay side of Rockaway Beach. Mixed with water it is then pumped under pressure through steel pipes across the barrier to the ocean side. Sand placement is progressing, steplike fashion in an updrift, i.e., easterly direction. By early September, under the influence of the prevailing westerly drift the area was acting as a feeder for the beaches further west.

Proceed out from behind the traffic island, cross over to the right westbound lane of the Shore Front Parkway. Drive west to B94th Street.

30.9	0.5	Turn right onto B94th Street.
31.1	0.2	Enter the approach ramp for the Cross Bay Boulevard.

31.9 0.8 Pay the 50¢ toll.

Proceed through Broad Channel community. Look for a Texaco station on the right at the north end of town; your next turn will be the first break in the traffic islands beyond the gas stations. Get in the left lane.

33.6 1.7 Make a U-turn into the right, southbound lane.

33.7 0.1 STOP 5. We are in a National Park. Please read and obey the posted rules and regulations.

Despite its natural look, this too is a man-made environment. Dikes around the two fresh ponds have been landscaped with abundant varied vegetation to attract wildfowl. Besides being a major nesting area, the Jamaica Bay Wildlife Preserve lies on the Atlantic Flyway. Over 300 species of birds have been seen here.

However, our main purpose in stopping here is to collect, not objects, but rather ideas, concepts, and impressions. This is a place of contrasts. Evidences of both positive and negative human interactions with nature are apparent everywhere; on the horizon and under your feet.

The guide for this part of the trip is yourself. Be sure to "synchronize watches" with everyone else before leaving the bus. Your challenge is to discover, observe, and reflect upon what you have seen today, as well as what you are about to explore. Stay on the trails and be sure to return by the appointed time.

Return to Hofstra University basically retracing our earlier route via: Cross Bay Boulevard, South Conduit Avenue, Brookville Boulevard, Merrick Road, Peninsula Boulevard and Rt. 24. Total Mileage: 53.8 miles.

NOTES

Trip B-5

WISCONSINAN GLACIAL STRATIGRAPHY AND STRUCTURE OF NORTHWESTERN LONG ISLAND

Les Sirkin, Adelphi University
Herb Mills, Museum Supervisor,
Nassau County Department of Parks

Introduction

The most detailed report on the geology of Long Island is that of Fuller (1914). In this work, Fuller developed a detailed stratigraphy which incorporated the Pleistocene sediments of Long Island into the classical stratigraphy of 4 glacials and interglacials recognized in the midwest. Fuller's work, built on such preceding studies as Woodworth (1901) and others, contains many excellent stratigraphic sections, but it is restricted to the "state of the art" for that time. More recent contributions such as Fleming (1935), MacClintock and Richards (1936), deLaguna and Perlmutter (1949), Swarzinski (1963), Donner (1964), and Sirkin (1967, 1968, 1971, 1972, and 1975, and Sirkin and Stuckenrath, 1975) began to revise the stratigraphic interpretations, mainly in limiting the number of glaciations to mapable drift sheets. With the aid of palynology and radiometric dating, recent authors have been able to place the rock units into a more refined time scale.

Pollen analysis has shown that at least two cold episodes, corresponding to glacials, and possibly three warm intervals, an interglacial (?), and interstadial, and the postglacial, have taken place here (Sirkin, 1967, 1971, 1968, 1972, and 1975, and Sirkin and Stuckenrath, 1975). Additional information about glacial deformation has provided a better understanding of the complications observed in the stratigraphy (Mills and Wells, 1974). The recent discovery of interstadial deposits has also brought about a change in the interpretation of the stratigraphy of only a few years ago in which the trend seemed to be toward monoglaciation (Sirkin, 1968, and Connally and Sirkin, 1973). Prior to this discovery much of the confusion was centered around the incorporation of morainal terminology with stratigraphic units. This fostered a sort of morphostratigraphy in which drifts were named and associated with moraines. The observation that the moraines were constructed of superposed drifts (Sirkin, 1968) and the introduction of the new data (Sirkin, 1975, and Sirkin and Stuckenrath, 1975) has made it possible to distinguish between geomorphology and stratigraphy.

Stratigraphy

Pre-Pleistocene. Metamorphic rock of early Paleozoic age forms the basement on which this portion of the Atlantic Coastal Plain-Continental Shelf is constructed. The metamorphics are probably part of the Cambro-Ordovician eugeosynclinal facies known as the Hartland Gneiss (Hall, 1968, Pellegrini, 1974) or the Hutchinson River Group (Seyfert and Leveson, 1969). The basement is overlain by a sequence of deltaic and marine clay, sand, and gravel of Cretaceous age. Pollen analysis has shown that much of the nearly 603m (2000') of sediments beneath the south shore of Long Island is upper Cretaceous including the Raritan, Magothy, and Magothy-Matawan (undifferentiated) Formations (Sirkin, 1974a). The older, Raritan Formation (lower, upper Cretaceous) comprises a smaller segment of the record than previously believed, and the lower Cretaceous does not appear in the Long Island section. Sediments containing Monmouth age (youngest Cretaceous) foraminifera were also obtained in a south shore well by Perlmutter and Todd (1965). The main water bearing stratum, the Lloyd Sand, may include thick sands deposited during both Raritan and Magothy time and separated occasionally by thin clay lenses.

As yet, Tertiary sediments have not been identified in Long Island, although the sediments filling the deep buried valleys in central and eastern Long Island (Jensen and Soren, 1974) may be pre-Pleistocene. In the north shore of the Island, the Cretaceous sections exposed in the bluffs and sand pits have been identified as Raritan in age (Sirkin,1974a). Most of these outcrops are believed to be ice shoved, but whether they have been stacked over Magothy sediments has not yet been determined. The "stacked" Raritan is characterized by tan and orange colored sand, red and gray clay, white sand and gravel with a clay binder, and occasional lenses of lignite. There are also abundant concretions, ranging from iron oxide nodules surrounding lignite or plant debris, pipes and paint pots of probable ground water origin, and marcasite and pyrite nodules.

According to most authors, Pleistocene deposits may exceed 60m (200') in thickness. The glacial deposits consist mainly of till and outwash, in some areas occurring as local coarse gravels, and at least two estuarine or maine clay units. Many authors from Fuller on, believed that the presence of two moraines signified two glaciations late in the Pleistocene, and that sediments of earlier glaciations occurred beneath the surface or were exposed as surficial gravels. The contacts between these units were thought to be erosion surfaces and therefore evidence of interglacials. Alternatively,as late as 1973, Connally and Sirkin tied the moraines and encompassing drift to one major glaciation and minor readvances.

An equally simplistic model for the stratigraphy and geomorphology of Long Island, proposed by Sirkin and Stuckenrath (1975) is based first on the presence of two superposed drift sheets both with separable and mapable characteristics,and an interstadial, estuarine sequence defined by radiocarbon ages and pollen analysis. Secondly, the model is based on the concept of a lobate glacial margin in which ice flow and deposition was controlled by regional land forms such as the Hudson Valley, central Connecticut, and the Narragansett Bay regions (Connally and Sirkin, 1973, Sirkin 1975). Thus, a model emerges in which two drift sheets were deposited by different lobes of glaciers related to two separate glaciations.

In western Long Island the drifts are superposed and consist mainly of tills separated by outwash. Till fabrics on the lower till (the Montauk Till equivalent) show a preferred northeasterly orientation (Sirkin, 1975), while the upper till (the Roslyn Till of Sirkin, 1971) has a northwesterly orientation. In central Long Island, the lower drift has not as yet been observed south of the Harbor Hill Moraine, and the upper drift of outwash, till, and lacustrine sediments often directly overlies the Cretaceous in north shore cliffs. The upper drift also occurs as the kame-like deposits of the Ronkonkoma Moraine which overlie a thick outwash section. The lower drift emerges again in the south fluke of the Island and is best observed in the type section at Montauk Point (Newman and others, 1968). There, till fabrics and clast provenance point to a northeasterly source area in Rhode Island and eastern Massachusetts, and the drift represents deposition by the Narragansett Lobe of the early Wisconsinan glacier (Sirkin, 1975).

The long arc of the Harbor Hill Moraine in central and eastern Long Island consists mainly of till and outwash of the upper drift sheet, and outlines the shape of the late Pleistocene, Connecticut Lobe. Interlobate moraines are probably located where the north-south trending hills appear to separate or break up the east-west linear trend of the moraines. This occurs most noticably in the Dix Hills-Manetto Hills-Half Hollow Hills areas. Manetto Hills is the type locality of the Manetto Gravel which Fuller (1914) placed in an early Pleistocene glaciation. Rather than an early Pleistocene outwash, this gravel is probably a head of outwash, well weathered due to superglacial exposure, of late Wisconsinan age. Other probable interlobate moraines may exist in the Eatons Neck and Shelter Island areas.

Thus, the massive Harbor Hill Moraine in western Long Island is composed of two superposed drift sheets. The older drift in northwestern Long Island was derived from a Connecticut Lobe of the early Wisconsinan glacier (Fig. 1). The younger drift is an overlapping deposit from the Hudson Valley Lobe (Connally and Sirkin, 1973) that deposited the Ronkonkoma and Harbor Hill end moraines. In western and central Long Island, the Ronkonkoma Moraine, once believed to be a linear correlative of the Vineyard and Nantucket Moraines of the offshore islands of Massachusetts, is an end moraine composed of late Wisconsinan drift deposited mainly by the Connecticut Lobe of the late Wisconsinan glacier. This ice advanced over the Cretaceous cuesta and the older drift. To the west the Ronkonkoma is an end moraine of the Hudson Valley Lobe separated from its eastern portion by interlobate moraines located in the Dix Hills-Manetto Hills-Half Hollow Hills areas. Perhaps the lack of continuity of the older drift across Long Island may be attributed to the cutting of through valleys by meltwater from the Connecticut Lobe, which may not have reached Long Island in early Wisconsinan time.

The model may be tested more realistically with the available stratigraphic data (Fig. 2). The lower or early Wisconsinan drift is overlain by the late Wisconsinan drift which may be correlated with the Woodfordian of the midwest (Frye and others, 1968). The early Wisconsinan drift is also older than 43,800 years B.P., the greatest age of interstadial beds in western Long Island (Sirkin and Stuckenrath, 1975). Both drifts are composed of till and outwash. The early Wisconsinan till is known as the Montauk Till at Montauk Point and the Montauk equivalent (or Montauk ?) in western Long Island. Lack of deep weathering on the lower drift, in fact weathering on the Montauk Till is rarely observed in the field, limits placing this drift in pre-Wisconsinan time. The composition of the Montauk Till and its presumed equivalents to the west varies from the darker gray colors derived from the dark metamorphic parent rock of Rhode Island and eastern Massachusetts, as seen in the mid gray color of the Montauk Till at Montauk Point, to a light gray or brown on western Long Island. The till on western Long Island owes its color to lighter colored granite and metamorphic rock of southern New England and New York. Other facies of the Montauk Till include the threefold sequence in Block Island, described by Kaye (1960) and

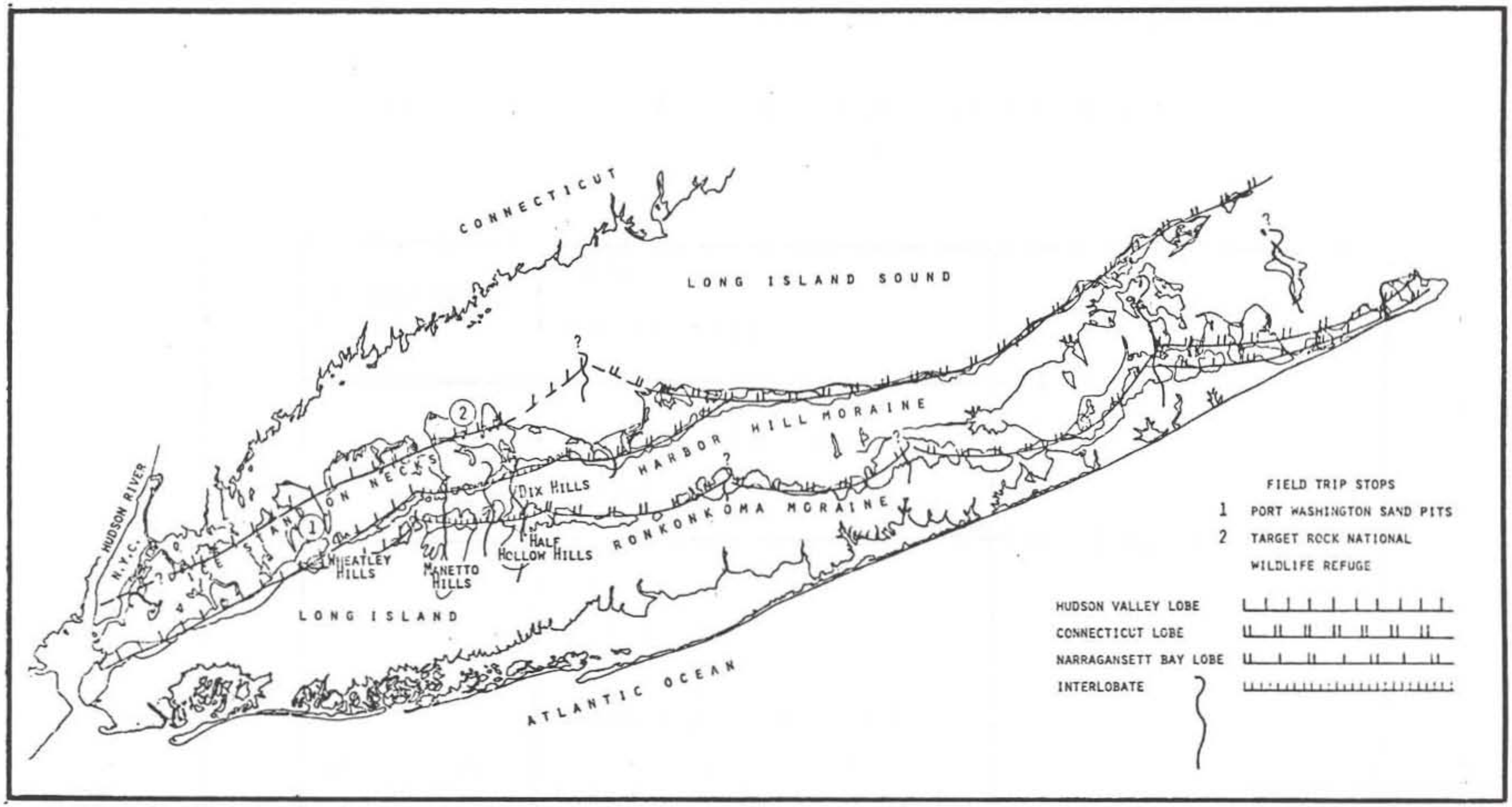


Fig. 1 Terminal moraines and lobate model of Wisconsinan glacial margins on Long Island. Narragansett Bay lobe is early-Wisconsinan; all others represent late-Wisconsinan ice stands. Probable and possible interlobate positions are also shown. (Harbor Hill and Ronkonkoma moraines after Fuller, 1914).

Stage	Substage	Stratigraphic Units	Ages
Wisconsinan	Late Wisconsinan	Surface deposits, Kames, etc. Proglacial lake beds, gravel Roslyn Till Outwash	18,000 yrs. B.P.
			ca 24,000 yrs. B.P.
	Mid Wisconsinan	Oyster Reefs, Clay Fresh and salt marsh peat	
			43,800 yrs. B.P.
	Early Wisconsinan	Montauk Till Outwash	

Figure 2. Glacial stratigraphy - Long Island

Sirkin (1975a), and the thin bedded flow till-gravel sequence at Port Washington. Characteristic of the Montauk (?) Till in the superposed sequences at Port Washington is its tendency to erode in deep gullies and hoodoo structures (Fig. 3B & 3D).

If a Pleistocene unit older that the early Wisconsinan drift exists, it would be the Gardiners Clay and associated Jacob Sand. These units, known from the type section in Gardiners Island, contain marine invertebrate fossils comparable to warmer latitudes according to MacClintock and Richards (1936) and Gustavson (1974, personal communication), and pollen representative of temperate forests bounded by pollen of boreal forests (Donner, 1964). Many believe the Gardiners to be Sangamonian in age and to represent an interglacial unit deposited prior to the early Wisconsinan glaciation and deposition of the Montauk Drift. Alternatively, the Gardiners may be part of the mid-Wisconsinan interstadial and mark the high stand of the sea at that time rather than during the Sangamonian. The major difficulties in accurately locating the Gardiners in time are the absence of radiometric ages for this unit, some confusion as to what is Gardiners in other places than Gardiners Island (Upson, 1964), discrepancies in the faunas in the Gardiners Island section and elsewhere (Gustavson, 1974, personal communication), and the existence of other Pleistocene clays or Holocene clays found in drill cores and cliff sections in Long Island. Certain clays exposed in cliffs are now proven to be interstadial clays, deposited during the high stand of the sea in mid-Wisconsinan time. For example, organic-rich clay found in cores off Fire Island contains pollen indicative of temperate vegetation. This unit has been dated at 28,000 years B.P. (Dietrich, 1974, personal communication). Thus, the Gardiners remains an unsolved problem awaiting radiometric dating and faunal analysis, which was proposed by Gustavson (personal communication, 1974).

The discovery of mid-Wisconsinan sediments stacked in the drift north of the Harbor Hill Moraine at Port Washington has provided the key to the age of the drift sheets and to the Pleistocene history of Long Island (Sirkin, 1975). The interstadial sediments consist of several layers of peat, clay, and oyster (<u>Crassostrea virginica</u>) reefs which were picked up by the advancing late Wisconsinan glacier as it crossed what is now the westernmost part of Long Island Sound. These beds were recumbently folded, thrusted, and emplaced in the late Wisconsinan outwash (Figs. 3,4). The beds range in age from greater than 43,800 to about 23,000 years B.P. (Sirkin and Stuckenrath, 1975). The older, fresh and salt water peats contain pollen of boreal vegetation, and tundra herbs, as well as spruce wood. Warming began around 31,000 years

B.P. and was accompanied by the high stand of the sea and the development of the oyster reefs. Foraminifera in the reef sediments are similar to those found in Long Island Sound today. The pollen record points to a temperate, deciduous forest in this region during the interstadial. The opening of this part of the Sound to the ocean may have been through deep channels cutting across Long Island southward into the Hudson estuary, south of its present mouth, and perhaps not eastward through a sound as it is today, although eastward drainage may have occupied a less imposing river valley. The warm episode lasted until around 29,000 years B.P. Pollen of much colder types of vegetation, mainly plants associated with the northern needleleaf forest, enter the record after this. Thus, a maximum age as well as environments, are established for this region just prior to the advance of the late Wisconsinan glacier.

This advance which probably began well before 24,000 years B.P. in more northerly regions was accompanied in the Long Island region by the deterioration of climate prior to glacial deposition. By the time the ice reached Long Island, the shoreline was near the margin of the continental shelf and vegetation had receded well to the south of the island. Radiocarbon dated sediments from the Delmarva Peninsula contain pollen of spruce forests and some tundra herbs during this time (Sirkin, 1974b). The ice advancing toward Long Island deposited outwash over Cretaceous hills and early Wisconsinan drift. This ice was capable of folding and thrusting large blocks of Cretaceous, outwash, and Montauk Till and forming overthickened sections of these sediments according to Mills and Wells (1974). The interstadial deposits were also involved in this deformation (see Deformation section and Fig. 4).

The Roslyn Till which caps this sequence has the appearance of lodgement till in most sections. In its upper portions it contains thrust planes which may mark its deposition at the ice margin as ablation till, or north of the terminus as ground moraine of the waning glacier. Facies of the late Wisconsinan till include the Roslyn (a clay till), thin flow tills seen in some outwash sections, a very sandy till capping the Ronkonkoma Moraine in western and central Long Island, and a clay till facies capping the early Wisconsinan drift in eastern Long Island and Block Island. During the late Wisconsinan, tundra vegetation persisted south of the glacial margin and boreal forests generally to the south of the tundra as seen in the pollen record in sections from near Sandy Hook, New Jersey, the Delaware River Valley, and the Delmarva Peninsula (Sirkin and others, 1970, Sirkin, 1974b).

Deformation

Over the years, several investigators (Fuller, 1914; Sirkin, 1968; Mills and Wells, 1974; and others) have described various structures in unconsolidated sediments resulting from ice-shove deformation on Long Island. These vary from minor overturned folds in near-surface outwash sands and gravels to major (up to 50m (150') thick by 300m (1000') long) thrust blocks of Cretaceous sediments.

Through detailed investigations of many of these structures on western Long Island (Manhasset Neck) it has been shown that the major deformational event occurred in the late-Wisconsinan, prior to the deposition of the Roslyn Till. In this region all units older than this till, including the Cretaceous, early-Wisconsinan drift, mid-Wisconsinan interstadial beds, and late-Wisconsinan outwash have been deformed rather extensively at one site or another. In contrast, the Roslyn Till at the surface maintains a relatively horizontal attitude truncating the structures in the underlying deformed beds. There is no evidence that the early Wisconsinan glaciation was a major deforming force. The advance outwash of this ice generally has an undeformed contact with the overlying Montauk (?) Till. Furthermore, no older Cretaceous sediments are found incorporated in this drift. During resession this ice produced no major deposits.

Sirkin and Stuckenrath (1975) have identified mid-Wisconsinan marine and fresh water deposits stacked in a deformed cliff section in Port Washington (see Interstadial and Part 1, Stop 3, sections). These sediments formed north of the Cretaceous cuesta in northern Long Island and indicate a significant ice front retreat and warming during the mid-Wisconsinan interstadial.

A model for the deformational sequence is suggested. As the ice front advanced in late Wisconsinan time it entered Long Island Sound and the north shore bay valleys depositing thick advance outwash and building up the Necks areas (MacClintock and Richards, 1936). The development of deep permafrost in this outwash and in the interstadial beds, early Wisconsinan drift, and Cretaceous sediment occurred at this time. The build up of ice in the lowland north of the cuesta pushed the glacial margin further south. Advancing ice picked up the interstadial beds, and meeting resistance at the northerly facing Cretaceous cuesta, sheared off long wedges of frozen sediment. These intact clasts were carried a mile or more to the south (Mills and Wells, 1974).

Movement of the ice with these massive blocks deformed the late-Wisconsinan advance outwash and underlying early-Wisconsinan drift. The mid-Wisconsinan beds were recumbently folded into the outwash. North of this section, larger Cretaceous blocks were stacked one behind the other with blunt northerly ends and long tapering tips pointing south (Fig. 4). As the ice continued to advance, it overrode and beveled all of the deformed sediments and deposited lodgement till (Roslyn Till) on the surface. Some minor structures related to later ice stands and fluctuations during deglaciation have also been observed and can be seen on this field trip at Target Rock (see Part 2, Field Excursions).

Deglaciation

The surface of the Harbor Hill Moraine in western Long Island includes numerous kames and possible lineations of surface deposits denoting minor glacial stillstands during glacial recession (Sirkin, 1967, 1968, 1971, and 1975; Newman and Pike, 1975). The retreat of the ice from Long Island was not uniform and surficial deposition, lineation of deposits, and erosional features supply some of the details of the glacial recession. Sirkin (1968) and Connally and Sirkin (1973) describe an ice stand across the northernmost parts of western Long Island necks (Fig. 1). This stand may be the Hudson Valley Lobe equivalent of the Connecticut Lobe, Harbor Hill Moraine on northeastern Long Island. The retreat of the ice was sequential with stillstands somewhat as marked in Fig.1. It has been suggested that minor readvances of the ice from its "Necks" stillstand partially excavated the bays. These valleys are U-shaped and are (or once were) occupied by north flowing streams that head in the proximal slope of the Harbor Hill Moraine. A few of the valleys may have occupied older through channels of pre-Wisconsinan drainage. The readvance in the valleys is marked by kames deposited against the valley walls on the proximal slopes but well up the valleys. As the ice receded to the "Necks" position, meltwater cut east- west channels at different elevations across the necks or incised channels from the bays into the necks. At this time drainage was probably blocked by ice masses and numerous proglacial lakes developed. Fine sediments, including cross-bedded deltaic sands, and varved lake clays and silts, attest to this event. Glacial recession probably began well before 18,000 years B.P., and the island was ice free about that time. The rate of deglaciation curve described in Connally and Sirkin (1973) gives an idea of the extensive downwasting of the ice that must have occurred before more accelerated northward glacial recession began around 15,000 years B.P. Much of the Long Island Sound Valley was probably excavated by meltwater in this 2,000 to 3,000 year interval.

The proglacial lake stages have not been dated and pollen has not been recovered from the sediments. Presumably pollen would include the tundra herbs and shrubs, as it does in the lake beds (varves?) in Block Island. That minor readvances occurred during recession is also seen in the Target Rock section where a gravel, which in some exposures is till-like, is thrust over a basal till (Fig. 5). Fluvial or glacio-fluvial sands overlying the till are deformed with thrusts and convolutions. A kame caps similar deposits on Eatons Neck eastward across the bay from Target Rock. The recession of the ice across the Sound area left remanents of small moraines that trend northeastward into Connecticut (Flint, 1974, Newman and Pike, 1975). There is also some indication of recession in the pollen record in western Long Island. The Flower Hill Bog near the proximal slope of the Harbor Hill Moraine contained a much longer pre-forest record than that in the bog at Kings Point Park which is located very near the "Necks" stand (Sirkin, 1967). In central Long Island bogs on the Harbor Hill and Ronkonkoma Moraines and on the Manetto Gravel surfaces all record late and postglacial vegetation and environments; none of these records extend into the interstadial (Sirkin, 1971). The pollen record for this region is summarized in Sirkin,(1968 and 1971).

The field trips accompanying this brief review of more recent concepts of the geology of Long Island are designed to present the evidence supporting the models of glaciation, stratigraphy, deformation, and deglaciation. The stops will allow participants to consider the evidence and the models, and test the inferences.

Field Excursions Part 1

Port Washington Sand Pits

Road Log Trip B-5 (Sunday, Nov. 2)

A.M. trip - Port Washington Sand Pits

From Hofstra take Hempstead Turnpike west to Clinton Rd. (Approx. 1.5 mi.). Turn right (north) (Clinton becomes Glen Cove Rd.) and follow (approx. 6 mi.) to Rt. 25A (Northern Blvd.) intersection. Turn left and proceed west across Roslyn viaduct to light at top of hill (2 mi.). Turn left at this light then left again at next light (100 ft.) (Old Northern Blvd.). Proceed down hill to triangle in road, come to stop sign (do not bear right) and make left hand turn onto West Shore Rd. Proceed north about 1 mile; stop 1 is opposite prominent partially excavated sand hill. (Total mileage approx. 10.5).

The large sand mines that extend for two and one-half miles from Roslyn to the Beacon Hill area of Port Washington along the west shore of Hempstead Harbor provide the best opportunity for observing glacial stratigraphy and ice-shove deformation on Long Island. The stops described for this field trip log were chosen as illustrative of the magnitude and variety of Wisconsinan events on western Long Island.

Stop 1-A. Remanent area, known as Billy Goat Hill (Fig. 3A). This location has an apparently undisturbed 2 till - 2 outwash sequence (outwash-till-outwash-till). There is a 5-6m layer of tan gravelly sand at the base of the cliff, which rests on clayey Cretaceous sands not far below the surface. A compact gray-brown till of fairly uniform thickness (about 2m) overlies the outwash. Abundant cobble and small boulder sized erratics can be seen in this till, and at one point a prominent boulder lag occurs at the top of the till. If this lower outwash and till are attributed to the early Wisconsinan glaciation, the till would be the Montauk Till equivalent on western Long Island. Above this till is another thick (8-10m) outwash similar to the lower outwash, except with more prominent oxidization zones due probably to ground water movement. A second till, well cemented and of variable thickness (2-4m) overlies the upper outwash. The upper outwash and till represent late-Wisconsinan drift commonly observed in western Long Island.

In both cycles outwash and lodgement till were deposited. The lag boulder zone on the Montauk (?) Till may represent a mid-Wisconsinan erosion interval. Large boulders resting on the Roslyn Till (Sirkin, 1971) and numerous kames and minor kame-like moraines on the Necks north of the Harbor Hill terminal moraine are products of late Wisconsinan deglaciation.

It might be noted that Fuller (1914) placed the top of his Manhasset Formation (of Illinoian age in his time scale) above the upper outwash (his Hempstead Gravel). As will be seen at later stops, an angular unconformity often occurs at this horizon due to late-Wisconsinan deformation. No significant depositional hiatus can be justified between the upper till and outwash.

Proceeding to Stop 1-B notice the persistent thickness and elevation of Montauk (?) Till. The late-Wisconsinan drift has been largely removed at several points by the sand mining. Other features of note are the well formed and sorted talus cones, mud cracks, and quicksand (BEWARE) if conditions are right.

Stop 1-B. 1/4 mile west of Stop 1-A (Fig. 3B). The Montauk (?) Till is dramatically thicker at this location due to ice-shove deformation associated with the late-Wisconsinan advance. A light reddish iron stain marks a folded thrust plane indicating that the relatively, thin, undisturbed lower till of Stop 1-A has been increased in thickness due to folding, faulting and probable flow. Dramatic changes in the thickness and position of the Montauk (?) Till have been described by Mills and Wells (1974) and can be seen at Stop 2 of this trip.

The thick till at Stop 1-B is well cemented, contains many cobble and boulder-sized erratics,and exhibits the sharp ridge and pinnacle "hoodoos" also seen in the Montauk Till at Montauk Point. A till fabric in this till revealed a northeasterly source direction. When traced along the outcrop to the west, this till again thins and assumes an apparently undisturbed horizontal altitude. Above the disturbed section of Montauk (?) Till, there is an unusually thin deposit of late-Wisconsinan drift capped by about 2 meters of loess. A gravelly zone in the Roslyn Till may indicate a local flow till or outwash. To the west, the upper outwash thickens and the section looks much as it does at Stop 1-A. Across the landfill site, a lighter area in the cliffs marks the site of an ice transported clay lens of probably mid-Wisconsinan age. This localized deformation is typical of the glacial stratigraphy north of the terminal moraine.

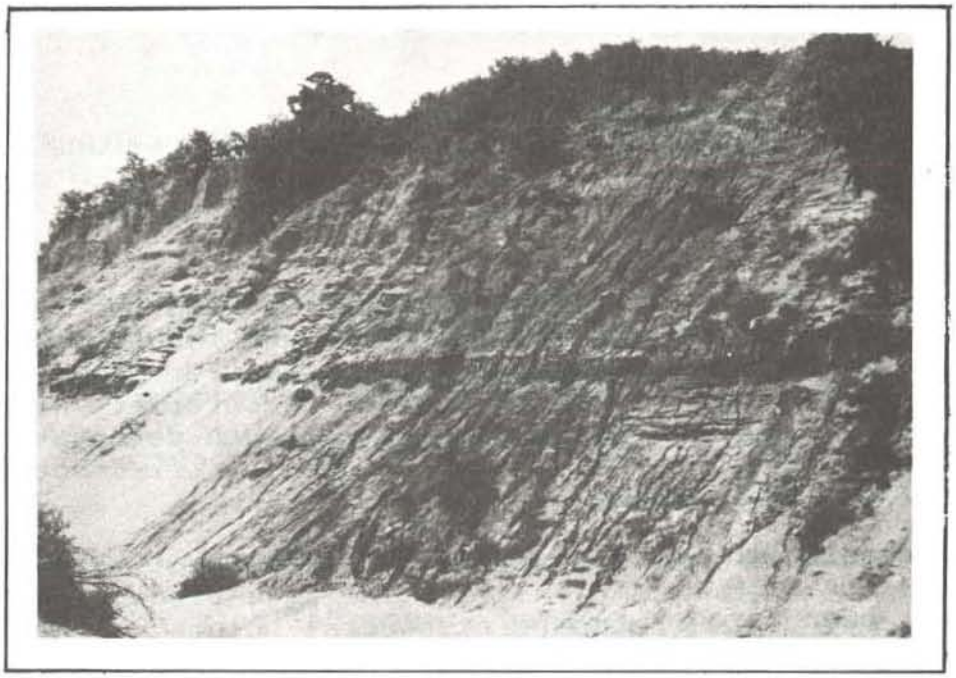


Figure 3A. Port Washington, Stop 1A - Early Wisconsinan outwash at cliff base is covered by Montauk (?) Till (dark band) with lag boulder zone at right. Late-Wisconsinan outwash with Roslyn Till at the surface complete this section.

Figure 3B. P.W., Stop 1B - Montauk (?) Till overthickened by ice-shove deformation. Note fault plane dipping from left to right near center of picture, also "hoo-doo" erosion of till.

Stop 2-A. North end of sand pits (Fig. 3C). This section described by Sirkin (1968) and redefined by Mills and Wells (1974) exhibits several meters of gravelly outwash at the base, a large thrust block of ice-shoved Cretaceous sands, clays and gravels, and unusually thick, bouldery layer of Roslyn till. The Cretaceous thrust block, one of several (Fig. 4), is about 15 meters thick with a gravelly zone of rotted quartz pebbles near the top. The basal thrust plane is marked by a thin purplish clay and occasional small folds. There is also a less obvious thrust plane within the Cretaceous which is noticed by an offset in the gravel zone. The brown silt that covers the cliffs just south of Stop 2-A is sediment from an old settling pond that was placed on the cliff to slow the erosion.

Proceeding to Stop 2-B, note another section similar to 2-A except with an incredible number of large boulders eroding from the Roslyn Till.

Stop 2-B. about 500 meters south of 2-A (Fig. 3 D). A prominent erosion pinnacle of thick Montauk (?) Till with ice-shoved Cretaceous draped over the top is the highlight of this stop. The till dips steeply and pinches out less than 100m to the north. To the south, it dips below thick talus and reappears at a lower elevation in the bluffs. The till then enters a large, almost 50m high fold, swelling in thickness in the synclines and pinching out over the crest of the anticline (Fig. 4). Rising at a steep angle on the south limb of the fold, the till is truncated by the flat lying Roslyn Till at the surface.

The Cretaceous thrust block draped over the till pinnacle thickens rapidly just to the south and then tapers to a long wedge and pinches out above the large fold. The northerly, butt end of another Cretaceous thrust block is in contact with the steeply rising Montauk (?) till on the south limb of the fold. Thick, deformed outwash units (early-Wisconsinan below and late-Wisconsinan above the Montauk (?) Till) complete the deposits seen in this section, except that presumably in place Cretaceous beds are exposed in the lower elevations of the mining pits.

Other features of note in this vicinity include: a spectacular boulder field with erratics collected from source areas as far away as the southern Adirondacks; numerous Cretaceous iron-oxide and pyrite concretions; a deformed Cretaceous clay and lignite, containing pollen of Raritan age (Sirkin, 1974a);many crystalline quartz ventifact cobbles located on the Cretaceous surface suggesting strong periglacial winds (Mills and Wells, 1974); and a cobble filled stream channel cut into the Cretaceous thrust block beneath the Roslyn Till, just to the left of the Montauk (?) Till pinnacle.

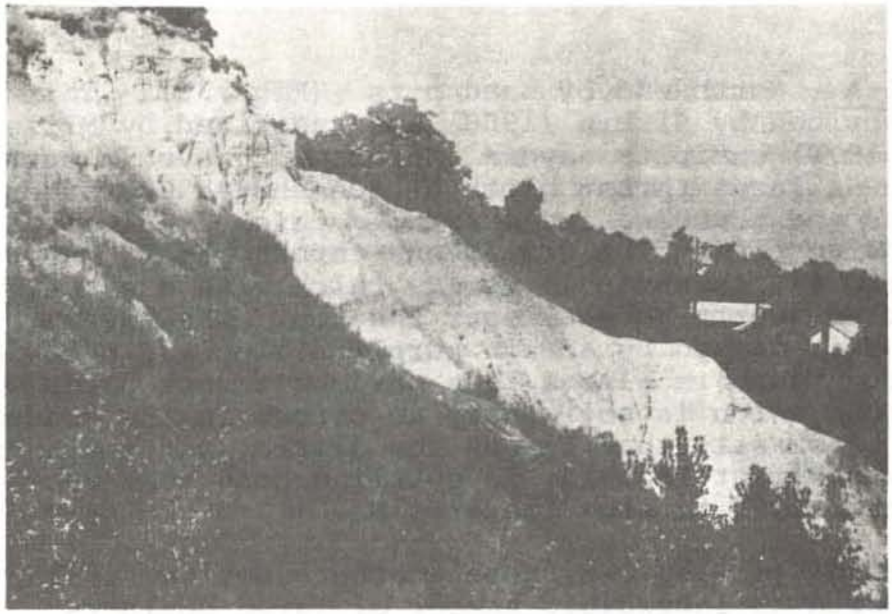


Figure 3C. P.W., Stop 2A - Late-Wisconsinan outwash at lower right corner is covered by about 15 meters of ice-shoved Cretaceous sand, clay, and pebbles. Thick (7-9m), bouldery Roslyn Till forms the resistant surface layer (upper left corner).

Figure 3D. P.W., Stop 2B - Large, eroded pinnacle of resistant Montauk (?) Till at right is partially covered by ice-shoved Cretaceous sediments seen as light area in cliff (center & left). Horizontal Roslyn Till (5m) caps the section.

Stop 3. Approximate mid-point of the sand pits, along the west wall, northwest of Stop 1. The section of peat, clay and oyster reef stacked in the late Wisconsinan drift has provided important new information on the late Pleistocene stratigraphy of Long Island. The dark layers in the cliff (Fig. 3E) are peat and clay layers. The structure of the section is similar to those already observed to the north. The beds have been recumbently folded and somewhat thrusted. The axes of the folds are nearly horizontal, and the peat and clay beds are often over-thickened (doubled) or telescoped into greater thicknesses. The two main shell bearing horizons on the north side of the section represent the same unit with the underlying sequence overturned. Both have been folded into small synclines and are overthickened along the axes of the fold. They consist mainly of peat, marine clay, oyster reef, and thin interbedded till and outwash. A series of over 20 radiocarbon ages have been determined by Bob Stuckenrath of the Smithsonian Radiation Biology Laboratory. The dates represent a sampling of all of the units and of different materials from each layer including peat, shell and wood. The ages range from > 43,800 to 23,000 years B.P. and with the pollen data have made it possible to reconstruct the sequence of environments and vegetation during the mid-Wisconsinan interstadial and high stand of the sea. The brown peats lower in the section represent fresh and salt marsh deposits formed over 35,000 years ago in the western end of what is now Long Island Sound. These peats contain pollen of pine, spruce, birch, alder and nonarboreal pollen (NAP). These pollen spectra suggest boreal vegetation, like the northern needleleaf forest or taiga in northern Canada, and cold climatic conditions at the end of the early Wisconsinan glaciation. The shell beds, dated around 31,000 years B.P., contain pollen of pine, hickory, black gum, oak, birch, and minor hemlock and NAP. This assemblage indicates a much warmer climatic regime and a regional forest composed of pine, oak, and hickory. The black gum suggests a coastal setting. These sediments also contain foraminifera similar to those of the Sound today. Overall, the climate and vegetation are similar to the modern climate and vegetation in this area. Evidence of cooling is seen in the pollen from the peats and clays dated at 28,150 years B.P., found above the shell zones. These sediments contain pine, alder, birch, hemlock, oak, and NAP; the indicators of warm temperate conditions have dropped out of the record or are only minor elements. Within the next few hundred years rather cold climate developed in this region as seen in the pollen record. Pollen of pine, birch, spruce, and alder suggest a return to boreal forests and cold, moist conditions by 27,900 years B.P. This evidence heralds the onset of the late Wisconsinan glaciation. The last radiocarbon date in this sequence, an age of about 23,000 on spruce wood may be the maximum age for the arrival of the late Wisconsinan glacier on Long Island, and for the deformation of the interstadial and subsequent deposits.

Stop 4. Northerly facing bluffs at south end of pits (Fig. 3F). Although only 1 mile south of Stop 1, the section here appears markedly different. Instead of the two distinct tills of Billy Goat Hill, the Montauk (?) Till is represented by a series of thin tills interbedded with thin layers of orange, oxidized outwash. The Roslyn Till at the surface is much less pronounced here and in places may be absent completely. Fuller (1914) noted lateral changes in the Montauk (?) Till, and Mills and Wells (1974) found an orange outwash phase of this till at the north end of the sand pits. Facing the main section of slopes and looking eastward, the Montauk (?) shows a facies change from the thin interbedded till and outwash to a single thicker till with outwash above and below. Since this outcrop is located at the foot of the proximal slope of the Harbor Hill terminal moraine, we may be observing lateral facies changes associated with glacial deposition.

At the low outcrop near West Shore Road, a thin bedded deposit probably of lacustrine origin covers the Montauk (?) Till. The late-Wisconsinan drift is very thin with no till, and the section is capped with loess.

Part 2

Late Pleistocene Geology of Long Island

Evidence for deglaciation in the coastal bluffs at Target Rock National Wildlife Refuge, Lloyd Neck, N.Y.

Road Log Trip B-5 (Sunday, Nov. 2)

Optional P.M. trip - Target Rock National Wildlife Refuge

Drive south from last stop on West Shore Rd. pass under Roslyn viaduct and make first right turn onto Mott St. Drive up hill and bear around to right onto 25A east-bound. Stay on 25A for about 14 miles passing through the Village of Cold Spring Harbor. About 1 mile beyond the shopping district turn left onto West Neck Road.

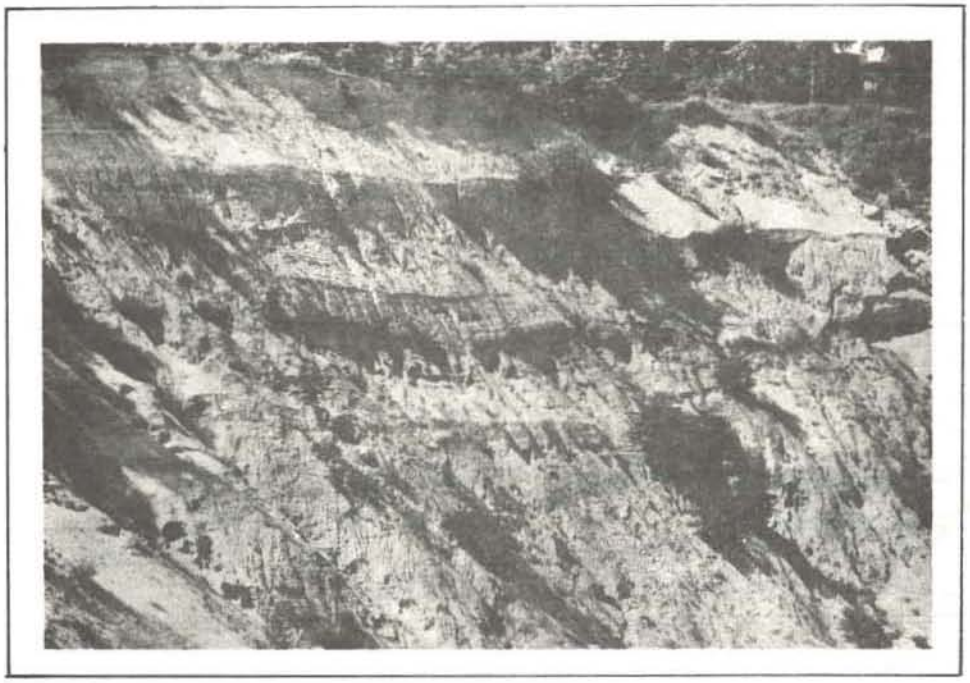


Figure 3E. P.W., Stop 3 - Three darker bands in cliff are recumbently folded, ice-thrusted layers of mid-Wisconsinan (interstadial) peat and clay. Middle layer is overturned, and folded outwash is noticeable above this layer. Oyster reef shells (indistinguishable) occur in middle and upper bands at extreme right of photo.

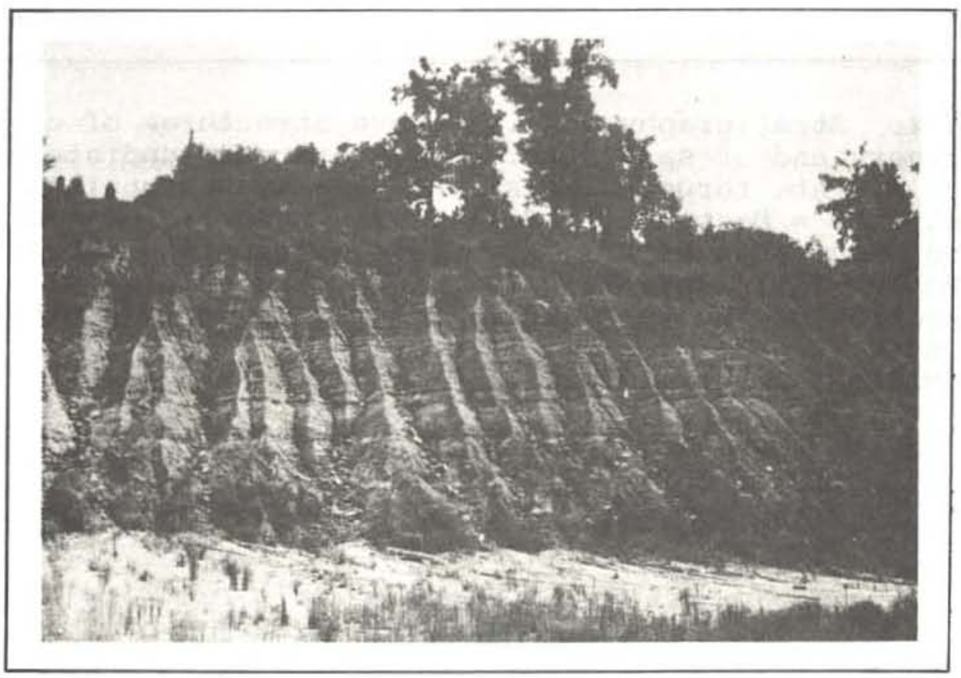


Figure 3F. P.W., Stop 4 - Eroded cliff on proximal slope of Harbor Hill terminal moraine showing the sequence of thin interbedded tills and outwash believed to be a facies of the Montauk (?) Till.

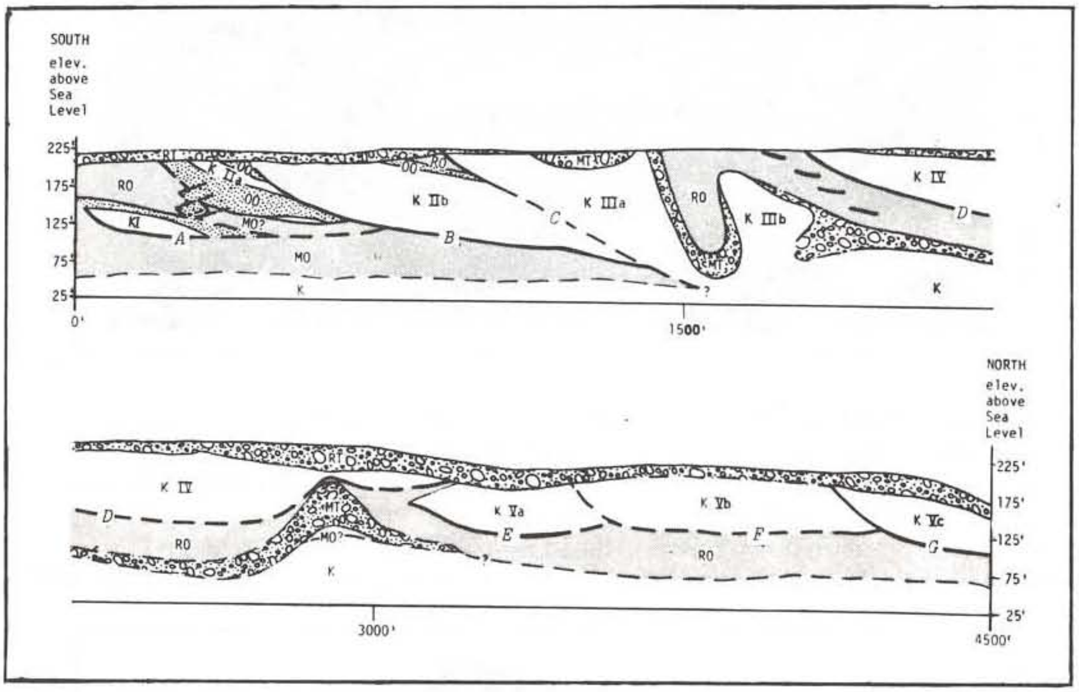


Figure 4. Stratigraphy and ice-shove structures of cliffs at northern end of sand pits. K = Cretaceous undisturbed; KI etc. = Cret. thrust blocks; MO = early-Wisconsinan outwash; MT = Montauk (?) Till (early Wisc.); OO = oxidized outwash phase of MT; RO = late-Wisconsinan outwash; RT = Roslyn Till (late-Wisc.). Field trip stop 2A at intersection of faults F and G; Stop 2B to left (south) of 3000' mark.
(From Mills & Wells, 1974).

(at St. Patrick's Church). Stay on West Neck Rd. to dead end on Lloyd's Neck (about 6 mi.). Entrance to Target Rock National Wildlife Refuge is at end of road. (total mileage approx. 20).

An interesting sequence of glacial and proglacial deposits may be observed in the one-half mile of northeasterly facing bluffs exposed along the eastern shore of Lloyd Neck.

The Neck itself seems to be separated from the mainland by a pronounced east-west channel, Lloyd Harbor. This channel probably formed as a drainage channel marginal to the ice during the "Ice stand on the Necks" (Sirkin, 1968, Connally and Sirkin, 1973).

Smaller east-west topographic lows may be drainage channels while topographic highs may represent ice marginal positions, both contributing to a sort of washboard effect. This is a prime location to study depositional and erosional features associated with the final sequence in the deglaciation of Long Island. This part of the excursion begins at the stairway to the beach and proceeds northwesterly along the shoreline of Huntington Bay.

Stop 1. About 100m northwest of the stairway. The cliff section reveals a sequence of outwash, till, outwash, and loess. At the base, from the level of the beach upward are approximately 5m of glacial outwash composed of stratified sand and gravel. A compact, brown till (a sandy loam with abundant cobbles and boulders) about 1m thick overlies the outwash. Above the till another unit of stratified sand and gravel (outwash?) forms a lens pinching out to the southeast and thickening to about 2m to the northwest. The height of the cliff diminishes southward as this unit pinches out. The section is capped by about 1m of loess. On the beach there is an abundance of cobbles and boulders. Diabase and purple-red puddingstone conglomerate erratics, along with till fabrics and other rock compositions suggest a northwesterly source area for the till. The diabase may be derived from the Palisades and the puddingstone from lower or middle Paleozoic conglomerates such as the Green Pond Conglomerate found near the New York-New Jersey border northwest of the Palisades.

Between Stops 1 and 2, cobbles begin to appear in the loess and the stratified unit above the till thickens and then thins until the loess is nearly resting on the till.

Stop 2. (Fig. 5A). At the actively slumped section in the topographic high in the bluffs. The increased elevation of the bluffs in due to the thickening to about 8m of the fine grained bedded sediments above the till. These stratified layers exhibit small scale cross bedding and bedding rippled by translational waves overturned to the southeast. This unit is characterized by clay, silt, and fine sand at the base which is somewhat obscured by slumping. It coarsens upward into fine and medium sized sand. Overall this unit probably represents sedimentation in a proglacial lake that formed between the ice just to the north and the upland to the south. Eastward across the bay in Eatons Neck, a well defined, horizontal band is visible in the bluffs. This dark layer also consists of proglacial lake sediment that overlies Cretaceous sand, but at a somewhat higher elevation than the lake beds at Lloyd Neck. The proglacial lake deposits are seen as evidence of the "Necks" stillstand during the recession of the late Wisconsinan glacier. A marked increase in cobbles in the loess layer and a thin stone layer on the stratified sands also appears in this section. Between Stops 2 and 3 the elevation of the bluffs decreases and the lake sequence becomes thinner. Also, the dark silty base of the lake deposits becomes visible and minor deformational features begin to appear in the overlying sediments. The surface unit has coarsened and also shows evidence of deformation, mainly small thrusts displaced southward. At one point a sizable granitic boulder in this unit has been rotated to the southeast. This evidence suggests southeastward movement of ice that overrode and deformed this section. On the beach a number of predominantly dark colored erratics of mafic composition have been eroded from the till. Some of these rocks resemble the Harrison Gneiss found to the north and northwest in southern Westchester and Connecticut.

Stop 3. This stop is separated into two parts, 3A and 3B. Stop 3A (Fig. 5B) is in the low cliff where well exposed lake silts may be observed. Here the basal unit of interbedded, fine grained silts and sands are well exposed. These beds are somewhat disturbed and have small folds that are overturned to the southeast, and represent additional evidence of minor glacial deformation due to overriding by the ice.

Stop 3B is just to the northwest of Stop 3A. The lake beds pinch out between these stops and the coarsened cobble unit rests directly on the compact (lodgement?) till. The rapidly changing nature of the upper unit is apparently the result of changing levels of energy of nearby ice and meltwater from the ice. It may have been emplaced as a till or ground moraine or as a head of outwash. Alternatively, this layer could be a colluvium or a lag deposit developed after the ice receded. Thus this unit seems to exhibit a combination of glacial, glacio-fluvial, or postglacial erosional characteristics. Clearly, deposition occurred near

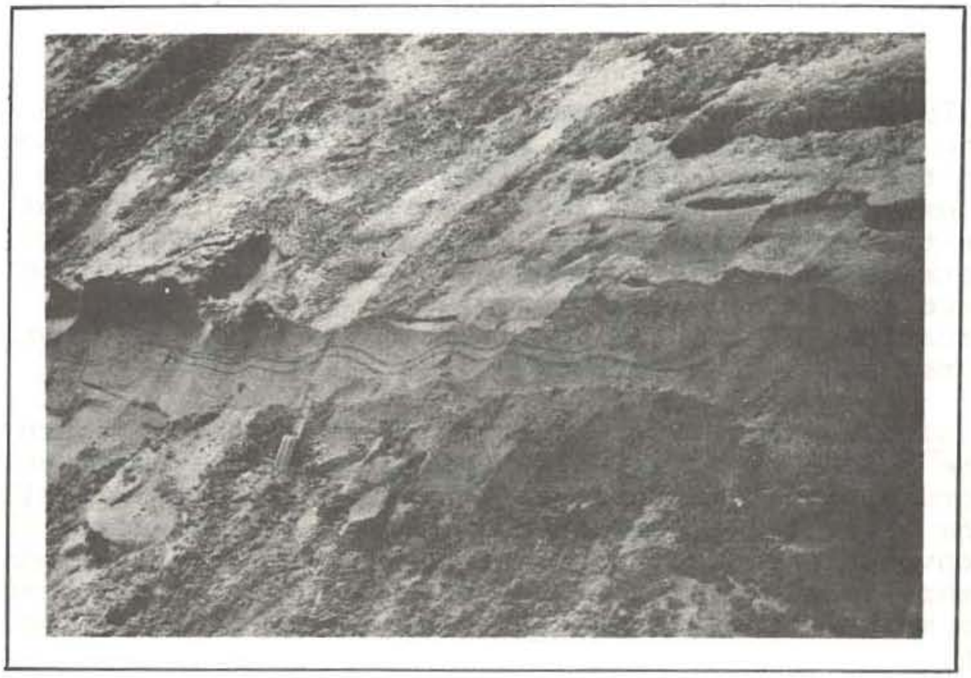


Figure 5A. Target Rock, Stop 2 - Small translational ripples, overturned to southeast, in fine proglacial lake sands.

Figure 5B. T.R., Stop 3A - Thinly interbedded silts and fine sands form the basal unit of the proglaical lake deposit seen below the shovel. Slight disturbance of these beds (due to glacial overriding?) occurs at the contact with the cobbly upper unit (see text).

the glacial margin and some glacial overriding is indicated in the minor deformational features. When the ice stood along the northern edge of Lloyd Neck, tongues of ice may have extended southward into Huntington Bay. Till was deposited at the ice front, and outwash, colluvium and lacustrine sediments accumulated on the upland south of the ice and in and around proglacial lakes. Minor fluctuations of the ice resulted in the minor deformational features and in the sorting of the gravel layer.

Stop 4. (Fig. 5C). The low cliff at the northern point of the beach. The till-like character of the upper unit is more apparent in this section where it rests directly on the lower till. Pronounced thrusts and complex folds or convolutions occur along the contact between the beds. The more felsic nature of the erratics seen on the beach is in marked contrast to the rocks on the beach to the south.

This upper till is of limited extent and seems to grade southward into proglacial deposits. It was probably deposited during the "Necks" stillstand, with a different source area than the underlying till. While correlation with other local tills has not been resolved, the lower till at Lloyd Neck may be the equivalent of the upper or late Wisconsinan till (the Roslyn Till) in Port Washington. The differing source areas between the two (possible) late Wisconsinan tills may be due to their interlobate position and the stacking of Hudson Valley and Connecticut lobe deposits as the ice front fluctuated.

The following sequence of events is postulated for deglaciation in this region.

1. Late Wisconsinan ice downwasted, thinned and gradually receded northward from the terminal moraine.

2. As the ice receded minor lineations of surficial deposits and meltwater channels developed, marking ice marginal positions.

3. When the ice reached the northern margin of the necks, a major stillstand occurred. Meltwater cut east-west drainage channels such as Lloyd Harbor.

4. Ice tongues expanded into and excavated U-shaped valleys where the bays are today. Kames on the proximal slope of the Harbor Hill moraine mark the southward extent of this readvance.

5. As the ice receded, proglacial sediments, outwash and

Figure 5C. T.R., Stop 4 - Contact between upper and lower tills shows complex convoluations caused by the emplacement of the localized upper till during the "Ice stand on the Necks". Lower till is lighter in color but contains more dark erratics, it is also more indurated.

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colluvium were deposited. Lacustrine sediments accumulated in proglacial lakes dammed between the ice and the upland. Minor fluctuation of the ice deformed these sediments but on a much smaller scale than the deformation observed at Port Washington which was related to the main advance of the Late Wisconsinan glacier.

6. Recession of the ice from the "Necks" position formed other minor lineations observed in the position of small islands of glacial deposits in the Sound and minor moraines in Westchester and Connecticut.

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