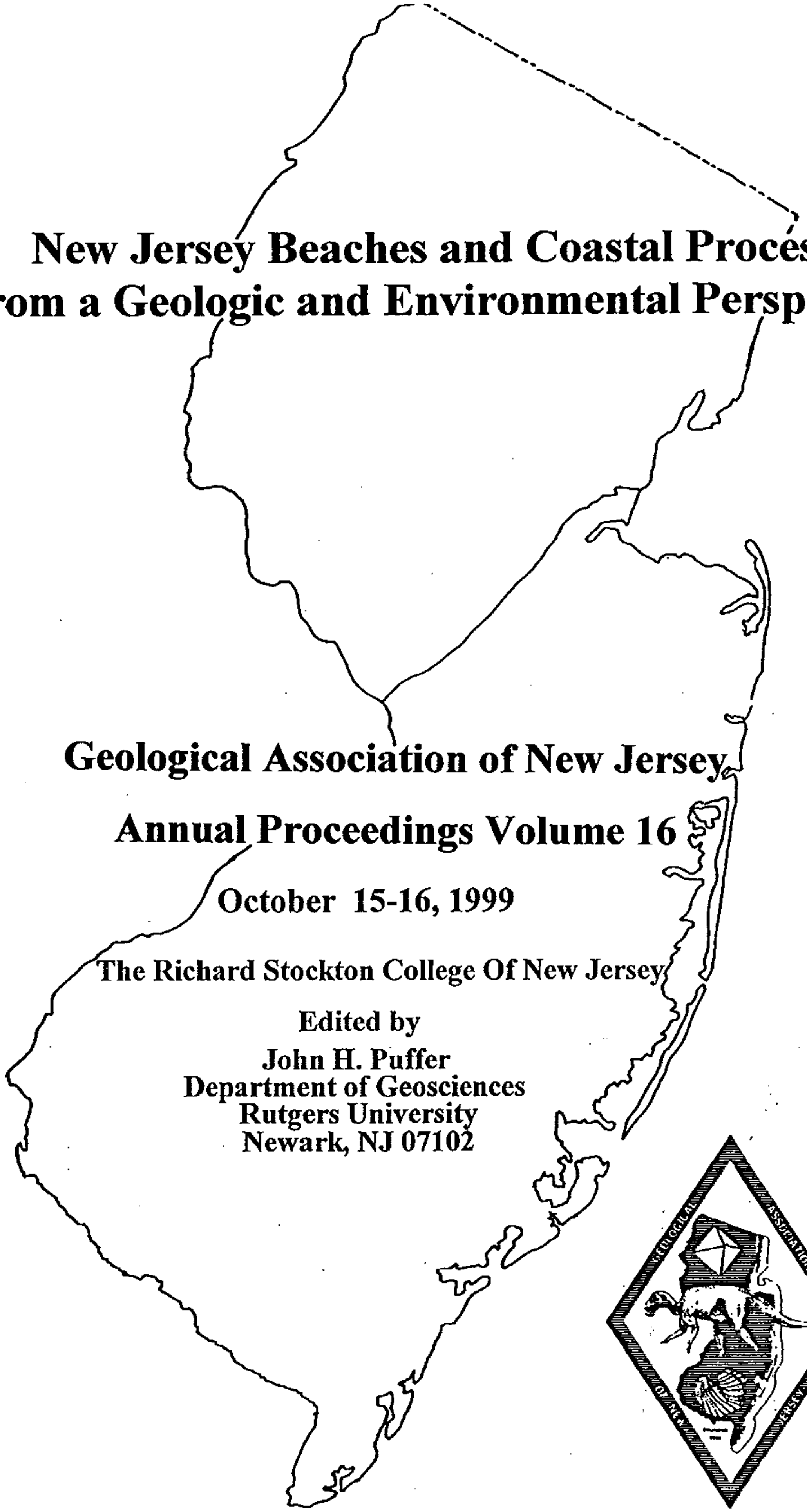

New Jersey Beaches and Coastal Processes from a Geologic and Environmental Perspectives

Geological Association of New Jersey

Annual Proceedings Volume 16

October 15-16, 1999

The Richard Stockton College Of New Jersey

Edited by

John H. Puffer
Department of Geosciences
Rutgers University
Newark, NJ 07102

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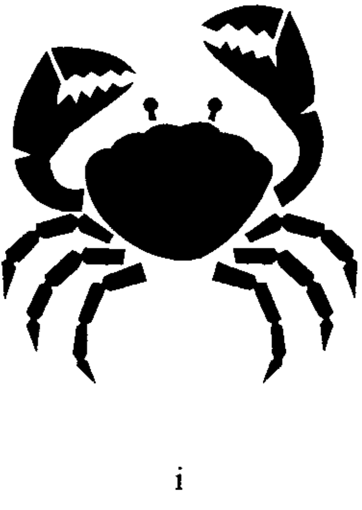

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NEW JERSEY BEACHES AND COASTAL PROCESSES FROM GEOLOGIC AND ENVIRONMENTAL PROSPECTIVES

Schedule of Events

Friday Oct. 15, 1999

Registration (Townsend Life Center, Richard Stockton College)................12:30-7:00pm

Opening Remarks..1:00pm
John H. Puffer, GANJ President; and Fredric Goldstein, President Elect.

Magnetite Spherules as a Measure of the Influx of Particulate Air Pollution into the Beaches of New Jersey..1:20pm
John H. Puffer, Rutgers Univ., Newark, New Jersey

Rates of Longshore Transports on the Atlantic Ocean Shore of New Jersey...........1:40pm
Cyril Galvin, Coastal Engineering, Springfield Virginia

Holocene Sea Level Fluctuations along the New Jersey Shore..............................2:00pm
N.L. Caruso, and Michelle Goman, Rutgers Univ., New Brunswick, New Jersey

Geologic Framework of the New Jersey Inner Shelf: Results from Resource-Based Seismic and Vibracore Studies.............................2:20pm
Jane Uptegrove, Jeffery S. Waldner, David W. Hall, Benjamin J. Lubchansky,
NJ Geological Survey, Trenton, New Jersey
Robert E. Sheridan, and Gail M. Ashley, Rutgers Univ. New Brunswick, New Jersey

Coffee Break..2:40pm

Hurricane Hazards in New Jersey...3:00pm
Nick Coch, Queens College, Flushing, New York

Remote Sensing as a Tool for Monitoring New Jersey Coastal Water Quality........3:20pm
Sima Bagheri, New Jersey Institute of Technology, Newark, New Jersey,
C. Zetlin J. Howard Lab, Highlands, New Jersey

Coastal Management Projects in Cape May County, NJ..................................3:40pm
Stewart Farrell, Richard Stockton College, Pomona, New Jersey

The Effects of Development on the Dune System of a Barrier Island Community...4:00pm
Mary Jo Hall, Stacy Aron, Danielle Lake, Rider Univ., Lawrenceville, New Jersey,
Sue Halsey, NJ Department of Environmental Protection, Trenton, New Jersey

Fossiliferous Concretions from New York Bight Beaches:
Implications for Late Pleistocene and Holocene Coastal Environments
around Sandy Hook and Western Long Island...4:20pm
Philip Stoffer, US Geological Survey, Menlo Park, California
P. Messina, San Jose State University, San Jose, California
J. A. Chamberlain, Jr., Brooklyn College, Brooklyn, New York

Observations of Beach Cusps on a Sandy Estuarine Beach,
Delaware Bay, New Jersey..4:40pm
Nancy L. Jackson, New Jersey Institute of Tech., Newark, New Jersey,
Karl F. Nordstrom, Rutgers Univ., New Brunswick, New Jersey

Teachers Workshop: (Room B-126)
Sand, Sun, and Science: Enhancing K-12 Science Education
By Incorporating Inquiry Based Marine Science into the Curriculum...............5:15pm
Bill Slattery, Wright State Univ., Dayton, Ohio
Claire Antonucci, NJ Marine Sciences Consortium, Highlands, New Jersey
Martin Becker, The College of New Jersey, Ewing, New Jersey

Socal Hour..6:30pm
At *Gourmet Italian Cuisine*, Pitney & Jimmie Leeds Road, 609-748-2400

Annual Dinner Meeting and Keynote Address:
The Hurricane Record in the Mid-Atlantic Region: Implications for the
NY-NJ Metropolitan Area..7:00pm
Nick Coch, Queens College, Flushing, New York

Saturday, October 16, 1999

FIELD TRIP:
New Jersey Beaches & Coastal Processes from Geologic
& Environmental Prospectives (The Beaches of Cape May County)
(from The Townsend Life Center, Stockton College)........................ 8:00am-5:00pm
Lead by Stewart Farrell, Richard Stockton College, Pamona, New Jersey

GEOLOGICAL ASSOCIATION OF NEW JERSEY

Field Guides & Proceedings of Annual Meetings

First Annual Meeting - 1984
Puffer, John H., ed., 9184, *Igneous Rocks of the Newark Basin: Petrology, Mineralogy, and Ore deposits, and Guide to Field Trip.*

Second Annual Meeting - 1985
Talkington, Raymond W., and Epstein, Claude M., eds., 1985, *Geological Investigations of the Coastal Plain of Southern New Jersey: Part 1 - Field Guide; Part 2A - Hydrology and Coastal Plain; Part 2B - Paleontologic Investigations (The set, Parts 1, 2A, 2B, priced as one volume).*

Third Annual Meeting - 1986
Husch, Jonathan, M. and Goldstein, Fredric R., eds., 1986, *Geology of the New Jersey Highlands and Radon in New Jersey.*

Fourth Annual Meeting - 1987
Gallagher, William B., ed., 1987, *Paleontology and Stratigraphy of the Lower Paleozoic Deposits of the Delaware Water Gap area.*

Fifth Annual Meeting - 1988
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Brown, James O., and Kroll, Richard L., eds., 1990, *Aspects of Groundwater in New Jersey.*

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Crawford, Maria L., and Crawford, William A., eds., 1991, *Evolution and Assembly of the Pennsylvania - Delaware Piedmont.*

Ninth Annual Meeting - 1992
Ashley, Gail M., and Halsey, Susan D., eds., 1992, *Environmental Geology of the Raritan River Basin.*

Tenth Annual Meeting - 1993
Puffer, John H., ed., 1993, *Geologic Traverse Across the Precambrian Rocks of the New Jersey Highlands.*

Eleventh Annual Meeting - 1994
Benimoff, Alan I., ed., 1994, Geology of Staten Island, New York.

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Thirteenth Annual Meeting - 1996
Dalton, Richard F. and Brown, Lames O., eds., 1996, *Karst Geology of New Jersey and Vicinity.*

Fourteenth Annual Meeting - 1997
Benimoff, Alan I. and Puffer, John H., 1997, *The Economic Geology of Northern New Jersey.*

Fifteenth Annual Meeting – 1998
Puffer, John H., ed., 1998, *The Economic Geology of Central New Jersey*

Sixteenth Annual Meeting-1999
Puffer, John H., ed., 1999, *New Jersey Beaches and Coastal Processes from Geologic and Environmental Prospectives*

FOREWORD

This year's (1999) GANJ meeting takes on topics that involve considerable controversy and current interest. This conference proceedings volume examines New Jersey beaches from geologic and environmental prospectives. Beach erosion, flooding, protection, restoration, and pollution are difficult issues with no clear solution, and need to be carefully studied. Each of the leading experts that are researching New Jersey beaches were invited to participate and the response has been exceptional. We have assembled an all-star group that will make this year's conference a major event.

The Star-Ledger of New Jersey has recently reported on several beach related items of current interest that are addressed in detail by GANJ- 99. For example, the July 16, 1999 issue includes a report by Andrew Gannon indicating that the water quality along New Jersey's beaches has improved for a fourth year in a row while most of the rest of this countries beaches have suffered a dramatic decline. However, his report also indicates that the New Jersey Dept. of Environmental Protection considers 85 percent of New Jersey's inland waterways too polluted for fishing or swimming; so there is still a lot more work to be done.

A recent series of Star-Ledger reports have described ongoing New Jersey beach erosion and flooding problems and the likelihood that the problems will get much worse. It is becoming increasingly clear that global warming may accelerate sea level flooding through a combination of ice melting and thermal expansion, and may increase storm damage to beaches as the energy level of the atmosphere increases. Our response to these problems is obviously critical. Legislation is currently pending in New Jersey that would increase annual funding for beach replenishment projects from $15 million to $25 million. Although the $15 million annual budget has been in effect since 1962, the need for more beach replenishment only seems to increase. Perhaps the shore communities should raise the money by doubling their "public" beach access fees. Or, if innovative geologic solutions were accepted, the need for ongoing replenishment may be diminished. Conference participants will hopefully actively discuss these and other controversies.

John H. Puffer, GANJ President

NEW JERSEY BEACHES AND COASTAL PROCESSES FROM GEOLOGIC AND ENVIRONMENTAL PROSPECTIVES

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Philip W. Stoffer[1] Paula Messina[2] and J.A. Chamberland, Jr[3].

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2. Dept. of Geology and Program in Science Education, San Jose State Univ., San Jose, CA 95192-0102
3. Department of Geology, Brooklyn College, Brooklyn, NY 11210

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Bill Slattery[1], Claire Antonucci[2], and Martin Becker[3]

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2. New Jersey Marine Sciences Consortium, Manager of Education, Building #22, Fort Hancock, Highlands, New Jersey 07732
3. The College of New Jersey, Dept. of Physics, Ewing, New Jersey 08628

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Stewart C. Farrell
Richard Stockton Coastal Research Center, Stockton College, Pomona, NJ 08240
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OBSERVATIONS OF BEACH CUSPS ON A SANDY ESTUARINE BEACH, DELAWARE BAY, NEW JERSEY

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Institute of Marine and Coastal Sciences, Rutgers University
New Brunswick, New Jersey 08903-0231

ABSTRACT

Beach cusps formed on 2 occasions during a 28-day field deployment conducted 11 October to 9 November 1990 on a coarse-sand estuarine beach in Delaware Bay. The first cusps were superimposed on a swash bar, representing post storm recovery. They were created during 3.0 m s^{-1} obliquely onshore winds that generated significant wave heights of 0.16 m and periods of 2.7 s. The spacing of the cusps ranged from 2.7 to 4.9 m. The second set of cusps had wave lengths that ranged from 2.8 to 4.0 m and formed on a deposit at mid-foreshore that occurred during storm conditions (9.3 m s^{-1} onshore winds and wave heights of 0.32 m and periods of 3.6 s). The foreshore slope in the region where cusps formed was the same on the two days ($\tan \beta = 0.13$). Results of this investigation reveal that beach cusps form under conditions (near-normal incident waves, steep reflective foreshore) that are similar to those found in exposed ocean environments but they are smaller and last over short time durations (one tidal cycle). Cusp development at the location of sediment deposition suggests that sufficient topographic variation existed to enhance scour on the bayward side of the deposits, alter swash uprush and backwash on the foreshore and modify sediment transport patterns.

INTRODUCTION

Beach cusps are three-dimensional, rhythmic sedimentary forms located on the beach foreshore in the region reworked by swash processes. Beach cusps have been observed in exposed ocean (Holland and Holman 1996) and fetch-limited environments (Komar 1973) and under depositional (Komar 1971) and erosional (Smith and Dolan 1960) processes. They typically form where incident waves approach normal to the shoreline and where a large percent of incident wave energy is not dissipated in the surf zone but is reflected off the foreshore (Wright and Short 1984). Beach cusps have been observed on beaches composed of sediments ranging from fine sand to cobble (Russell and McIntire 1965; Nolan et al. 1999; Sherman et al. 1993) but are frequently associated with low wave energies and coarse-grained sediments (Masselink et al. 1997).

Cusps are rare on sandy beaches on unconfined estuarine shoreline segments, although they are occasionally observed high on the upper foreshore where breaking waves and swash remain in a similar position for a relatively long time. Cusps are more frequently encountered in small embayments created by headlands or shore-perpendicular structures, where resonance contributes to formation of standing wave energy, and in the lower reaches of estuaries, where there is interaction between local estuarine waves and ocean swell (Nordstrom 1992).

Uncertainty remains over which mechanisms cause the development of cusps and account for their longshore spacing. Reported spacing of beach cusps range from 0.01 to 57 m (Komar 1998). The two hypotheses most often tested to explain the generation and subsequent spacing of beach cusps are the edge wave and self-organization hypotheses. The edge wave hypothesis accounts for the alongshore spacing of beach cusps as a result of the generation of a standing edge wave producing a systematic longshore variation in swash height. Swash oscillations associated with incident waves and motions associated with standing edge waves produce longshore variations in swash height that account for cusp development (Guza and Inman 1975). Cusp horns occur at edge wave nodes and cusp embayments occur at edge wave antinodes. Sub-harmonic edge waves (mode $n = 0$) are generally the most frequently excited edge wave type. The spacing of beach cusps (λ) due to the presence of a subharmonic edge wave is:

$$\lambda = (g/\pi)\, T^2 \tan \beta$$

where T is the incident wave period and $\tan \beta$ is the beach slope.

The self-organization hypothesis (Werner and Fink 1993) explains beach cusp formation as the interaction of fluid flows in the swash zone and beach morphology that can enhance topographic variations on the beachface. The presence of small depressions in the beachface can increase water flow in the swash lense to these areas, leading to further erosion. The spacing of beach cusps according to the self-organization hypothesis is:

$$\lambda = f S$$

where f is between 1 and 3 for simulated cusps and S is the swash excursion length (defined as the distance between the upper and lower limit of the swash front).

Field observations have found the ratio of cusp spacing to swash excursion length is 1.5 (Dean and Maurmeyer 1981).

The purpose of this paper is to characterize cusp formation on an estuarine beach in Delaware Bay by identifying beach state and wave-current conditions under which cusps form from data gathered during a 28-day field deployment in 1990.

FIELD SITE

The field site is a coarse sand beach on an estuarine barrier located in the southern portion of Delaware Bay (Figure 1). Tides are semi-diurnal, with a mean range of 1.6 m and a spring range of 1.9 m (NOAA 1992). Dominant winds are from the northwest and blow onshore across a 48 km fetch. The beach foreshore is planar with an average slope of 6°. The broad low tide terrace has an average slope of $< 0.5°$. The site, located along a shoreline reach approximately 4 km in length in the updrift direction, is not sediment starved.

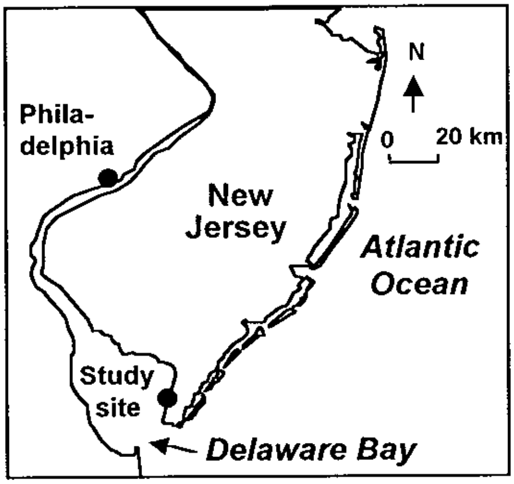

Figure 1. Locator map.

METHODOLOGY

The field investigation occurred from 11 October to 9 November 1990. Wind speed and direction were recorded at an elevation of 1, 2, 4, and 6 m above the dune crest (Figure 2). Wave data were gathered with pressure transducers deployed, in a triangular array, 26 and 36 m from a baseline located along the crest of the dune (Figure 2). Cross-shore and longshore current velocity data were gathered with electromagnetic current meters located on the foreshore 17 and 26 m from the baseline. Data were recorded at 2 Hz for durations of 17.1 minutes at high water. Significant wave heights were calculated as four times the standard deviation of the wave record (CERC 1984). Wave periods were determined from the peak frequency of the spectral estimates from the pressure transducer located 36 m from the baseline. Location of the breakers at high water was derived from the solitary wave breaker criterion ($\gamma_b = H_b/h_b$) where H_b is the wave height at breaking and h_b is the water depth. Values of H_b and h_b were determined from pressure transducer data using the procedure outlined in CERC (1984) based on Goda (1970). A value of $\gamma_b = 1.2$ was used based on previously published field data from the site (Jackson and Nordstrom 1993).

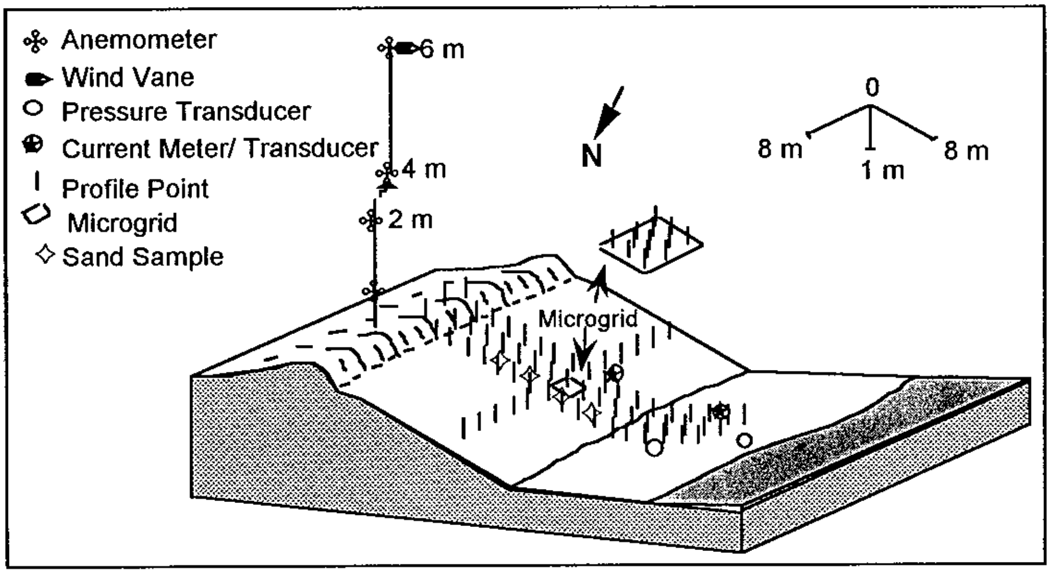

Figure 2. Field design.

Beach surface elevation was measured along three parallel lines 2 m apart and extending from the baseline to a distance 34 m bayward (Figure 2). An additional line of rods 10 m from the baseline extended alongshore at 2 m intervals. Surface sediment samples were gathered at four locations across the foreshore during low water prior to wave and current monitoring. Samples were sieved at 0.5 ϕ intervals and analyzed for grain size and sorting using the procedure outlined in Folk (1974).

RESULTS

Beach change at the field site is associated with breaking waves of up to 0.80 m in height generated by strong onshore winds that occur during the passage of cold fronts. Sediment is removed from the upper foreshore and deposited low on the foreshore during these conditions (Figure 3). Recovery of the profile occurs during the following tidal cycle with migration of a bar (< 0.10 m in height) in the swash zone during the rising tide. Surface sediments on the foreshore following storms are finer than during non-storm conditions (Nordstrom and Jackson 1993). Mean grain size of sediments in the region where cusp development occurred is 0.41 mm during storms and 0.50 mm during non-storm conditions.

Cusps formed during two tidal cycles over the 28-day field investigation. The slope of the foreshore in the region where cusps formed was similar on both occurrences (tan β = 0.13). The first occurrence was associated with beach recovery following a storm. Strong onshore winds ranging from 6.7 to 14.2 m s^{-1} during 18-19 October generated waves with an offshore significant height of 0.26 to 0.50 m and period of 3.4 to 3.8 s (Jackson 1995). These waves produced erosion on the upper foreshore and deposition on the lower foreshore.

During post-storm recovery on 20 October, winds from the north with an average speed of 3.0 m s^{-1} generated incident waves with an offshore significant height of 0.16 m and a period of 2.7 s (Jackson 1995). A low amplitude swash bar formed low on the profile and migrated up the foreshore in the swash zone during the rising tide. The swash bar was eventually deposited between 9 and 15 m from

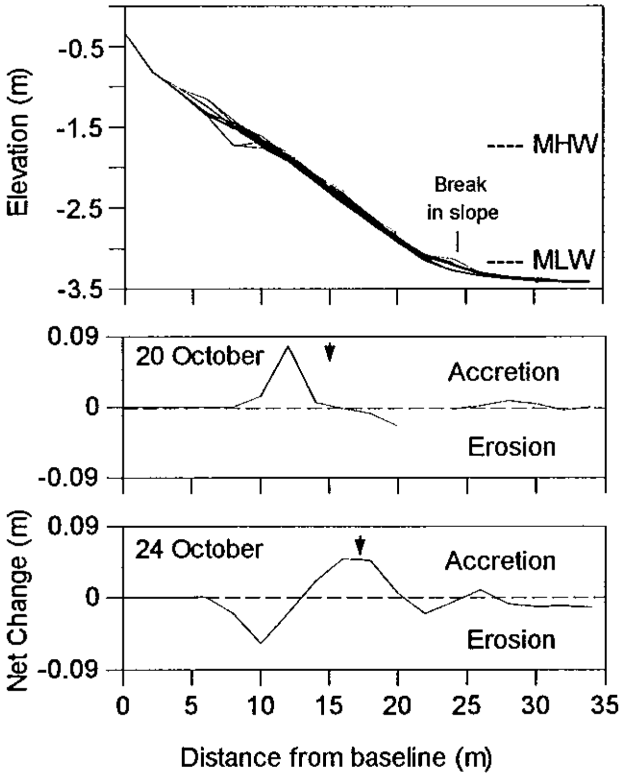

Figure 3. Daily profiles for the 28 day field investigation and net change elevation during beach recovery (20 October) and after a storm (24 October). Arrows indicate location of wave breaking at high water.

the baseline (Figure 3). Cusps developed on the swash bar 11 m from the baseline and were superimposed rather than cut into this feature. The cusps trended northwest-southeast with an average spacing of 3.3 m and a range of 2.7 to 4.9 m (Figure 4). The cusps were eliminated during the following tidal cycle.

The second time cusps occurred was on 24 October. Onshore winds, with a mean speed of 9.27 m s^{-1} generated waves that approached near normal to the shoreline, with an offshore significant wave height of 0.32 m and period of 3.6 s (Jackson 1995). There was erosion across the upper profile and deposition lower on the profile as a result of these strong onshore winds (Figure 3). Shore-normal cusps formed 16 m from the baseline on this depositional feature. The wavelengths of the cusps ranged from 2.8 to 4.0 m (Figure 4). The cusps were superimposed on the foreshore and eliminated during the following tidal cycle.

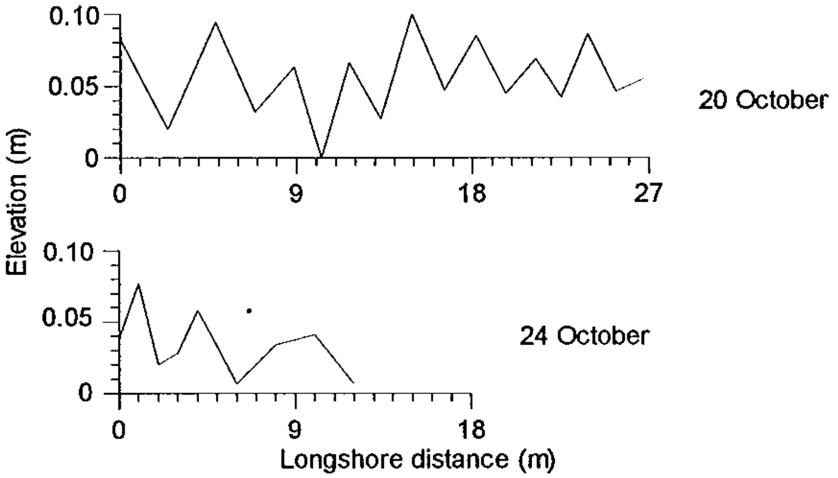

Figure 4. Longshore cusp morphology measured at mid-cusp position.

Swash excursion distance was not measured as part of this field deployment but was measured as part of a later field investigation at the same site that examined swash and beach water table interactions (Jackson et al. 1999). For conditions similar to those monitored during the events reported in this paper, the swash excursion distance is 2.0 m during low wave energy conditions such as on 20 October and 5.0 m during high wave energy conditions that occurred on 24 October. Using these excursion values to estimate cusp spacing based on the self-organization hypothesis, and $f = 1.5$, results in a calculated cusp spacing of 3.4 m on 20 October and 8.5 m on 24 October (Table 1). The calculated value on 20

October is within the range of observed values but the calculated value on 24 October is greater than observed values.

Table 1. Observed cusp spacing and calculated lengths (in meters) based on self-organization and subharmonic edge wave hypotheses.

Date	Observed	Self-organization	Subharmonic edge wave
20 October	2.7 - 4.9	3.4	3.0
24 October	2.8 - 4.0	8.5	5.3

Calculation of cusp spacing, based on the subharmonic edge wave hypothesis yields similar results. Calculated values are 3.0 m on 20 October and 5.3 m on 24 October (Table 1). The calculated value on 20 October is within the range of observed values and is close to the calculated average. The value derived for conditions on 24 October is higher than the range of observed values but closer to observed than the value obtained from the self-organization hypothesis.

If the subharmonic edge wave hypothesis is a factor in cusp development energy at half the incident wave frequency should be present in the spectral estimates (i.e. 0.19 Hz on 20 October and 0.14 Hz on 24 October based on peak frequency of the incident wave). Identification of the incident wave frequency is important because cusp spacing is dependent on the square of the incident wave period. The spectral estimates reveal broad-banded energy associated with the incident wave (Figure 5). Estimation of the edge wave frequency from the observed range of cusp spacing would result in a frequency range of 0.14 to 0.19 Hz on 20 October and 0.16 to 0.19 Hz on 24 October but there is no evidence of statistically significant energy within these frequency ranges on either day.

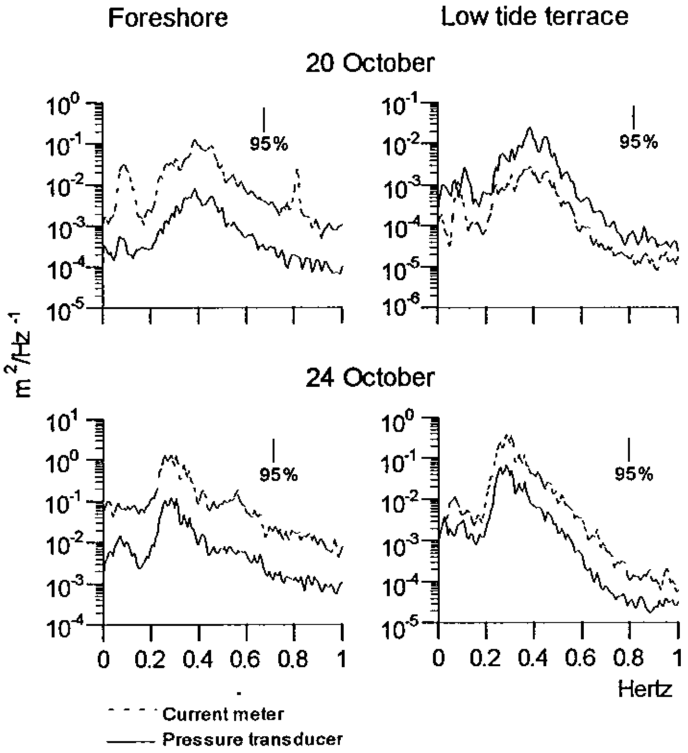

Figure 5. Spectral estimates from pressure transducer and cross-shore velocity records gathered at high water on 20 October and 24 October.

FINDINGS

Results of this investigation reveal that beach cusps form under conditions (near-normal incident waves, steep reflective foreshore) that are similar to those found in exposed ocean environments but they are smaller and last over short time durations (one tidal cycle). Beach cusps are frequently found on reflective beaches where the Iribarren number, or surf similarity parameter, (ξ) is > 1. Masselink et al. (1997) found the surf similarity parameter to be a useful indicator of the likelihood for cusp formation or destruction with $\xi < 1.2$ resulting in the planing off of cusps and $\xi > 1.2$ resulting in enhanced cusp morphology. The value of ξ for the two days when cusps formed at the field site is 1.3 on 20 October and 1.0 on 24 October. The cusps on 20 October were more pronounced than the cusps that formed on 24 October.

Cusps have been observed under both erosional and depositional conditions (e.g. Smith and Dolan 1960; Komar 1971). Cusps at the field site also occurred during erosional and depositional events, but the location of cusp development on the foreshore was in association with a depositional feature. This finding suggests that local morphological variations played a role in their development. The small amplitude swash bar on 20 October, as well as the sediment accumulation at mid-foreshore during the storm on 24 October, could provide sufficient topographic variation to enhance scour on the bayward side of the deposits. The interaction between local morphology and swash processes could alter swash uprush and backwash on the foreshore and modify sediment transport patterns.

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MAGNETITE SPHERULES AS A MEASURE OF THE INFLUX OF PARTICULATE AIR POLUTION INTO THE BEACHES OF NEW JERSEY

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ABSTRACT

Spherical particles composed of magnetite are generated in a variety of industrial furnaces together with other fly-ash particles and enter the air supply through smokestacks. Fall-out of magnetite spherules and other air-born particulates is washed into the surface drainage system of New Jersey and into the beaches. Most air-born particulate material is degraded and its identity is lost after fall-out. However, magnetite spherules retain their unique and easily recognizable identity and are readily separated from samples of beach sand.

Many of the spherules are vesicular and some have densities less than one. Some spherule fall-out onto ocean water, therefore, floats and is added to beach sand to the extent it is washed onto beaches. Most spherules, however, enter the beach system via rivers. Abrasion and chemical alteration to limonite during long-shore drift rapidly degrades the magnetite spherules and their abundance decreases down shore from the mouths of the rivers that carry them to the beaches.

INTRODUCTION

There are two major sources of magnetite spherules; an extraterrestrial source and an industrial particulate emission. They have been widely recognized as ablation particles from meteorites and as cosmic dust and most of the early descriptions were published assuming that all magnetite spherules were extraterrestrial. Clearly magnetite spherules sampled from Paleozoic salt deposits (Mutch, 1966) and deep, pre-industrial-age, ice cores (El Gorsey and Fechtic, 1968; Langway, 1962) are good examples of the extraterrestrial type. The chemical composition of such spherules is highly varied but is characteristically enriched in cobalt, chrome, and nickel resembling the chemistry of iron meteorites.

One of the first descriptions of magnetite spherules from industrial emissions was published by Puffer (1974) who compared the spherule content of Miocene (Kirkwood Formation) coastal plain sands from New Jersey (very rare) with the content in recent river sediments and beach sands along the New Jersey coast (very common, Table 1). The spherules were also compared with particulates collected in a high-volume-air-sampler stationed on the roof of Boyden Hall on the Rutgers Newark

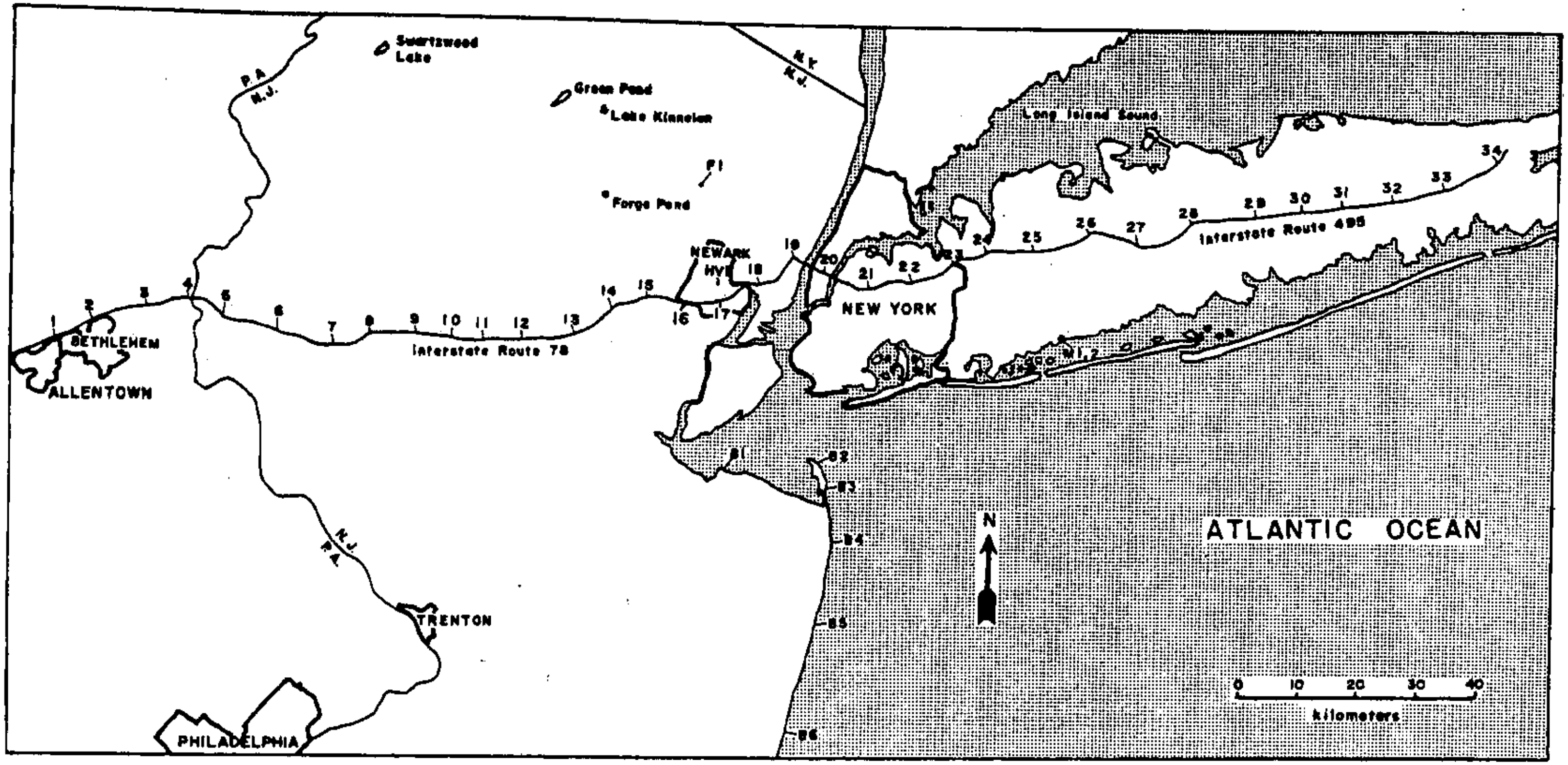

FIG. 1.—Locations of samples of sediment analyzed for magnetic spherule content within the greater New York City area.

After Puffer and others (1980).

campus (abundant) and with spherules collected from the stack scrubber of a scrap iron foundry located in Little Falls, New Jersey. Magnetite spherules are a major component of the foundry dust and were also found to be abundant in surface sediment and soil collected near the blast iron furnaces and steel mills of Bethlehem, Pennsylvania (Table 2 after Puffer and others, 1979).

Samples collected by Puffer and others (1979) along interstate highway I-78 east of Bethlehem, through New York City, and along I-495 out to the east end of Long Island were also examined for magnetite spherule content (Figure 1). As expected, the spherule content decreased with distance from the steel mills but increased in the industrial areas of New York City, then decreased again east of New York City (Table 2).

SAMPLE COLLECTION TECHNIQUE

Extraction of magnetite spherules from unlithified detrital sediment is generally very simple. However, particle sizes much less than fine-grained sand are more difficult to work with than sand sizes, and poorly sorted sediment is more difficult to work with than well-sorted sediment. Beach sand is particularly simple to process and a demonstration will be conducted at the lunch stop.

If a series of samples are to be taken along shore in order to determine any north-south variations it is important to maintain a consistent depositional environment on a beach profile such as the crest of a berm (masters thesis). However, due to recent beach restoration activity it is no longer meaningful to consider depositional environments along the New Jersey beaches. Some sand has been dredged and pumped onto the beach; elsewhere it is the product of natural depositional processes.

About one pound of sand should be collected from each sample site and weighed to the nearest gram. The sand should be spread out onto a clean disposable paper that is large enough so that a layer of sands less than one mm thick is exposed. A strong magnet shielded from the sand with clean weighing paper is then passed over the sand, within one cm, without touching the sand. The magnetic fraction is then be further concentrated with heavy liquids (bromoform SG = 2.85) and weighed. If a large quantity of magnetic detritus is separated, a weighed split should be placed in a watch glass and examined under reflected light. Magnetite spherules are then counted and hand picked. The spherules are easily recognized (Figure 2) and readily distinguished from all other magnetic detritus.

Separations from fine peletic detritus or organic enriched sediments involve centrifuging in bromoform.

LAKE, MARSH, AND OCEAN FLOOR SEDIMENTS:

Table 3 presents spherule content and size data of several samples of lake, marsh, and ocean floor sediment analyzed by Puffer and others (1980).

Table 1.
Abundance, Size, and Chemical Composition of Magnetite Spherules from Northeastern New Jersey

	Location	No. per gram of sample	diameter range µm	diameter mean µm	No. analyzed	Fe	Mn	Cr	Ti	Ni
							weight percent			
SCRAP IRON FOUNDRY, STACK SCRUBBER										
Fi	Little Falls	918	3-1010	70	2000	71.2	0.84	0.18	0.16	0.07
HIGH VOLUME AIR SAMPLER										
Hvl	Rutgers Univ. Campus, Newark	8000	3-35	15	.		—	—	—	—
STREET SWEEPINGS										
S1	University Ave., Newark	9	10-300	60	2000	70.7	0.52	0.29	0.20	0.00
S2	Market Street, Paterson	13	20-300	70	.	—	—	—	—	—
S3	Springfield Ave., Irvington	6	30-200	50		—	—	—	—	—
S4	Springfield Ave., Summit	5	20-250	110	—	—	—	—	—	—
S5	Springfield Ave., Berkeley Hts.	3	30-300	70	—	—	—	—	—	—
SANDS OF KIRKWOOD FORMATION										
K8	Prospertown (5 cm from surface)	6.52	5-250	20	5000	69.8	0.25	0.00	0.00	0.00
PASSAIC RIVER SUSPENDED SEDIMENT										
P1a	Berkeley Heights	4	10-70	20	—	—	—	—	—	—
P2a	Newark	12	10-65	20	—	—	—	—	—	—
PASSAIC RIVER BED SEDIMENT										
P1b	Berkeley Heights	0.10	20-210	70	—	—	—	—	—	—
P2b	Newark	0.21	20-200	80	4500	69.5	0.39	0.14	0.08	0.00
BEACH SAND										
B1	Union Beach	0.62	10-800	150	4000	70.1	0.70	0.39	0.39	0.00
B2	Sandy Hook	0.25	20-550	120	—	—	—	—	—	—
B3	Sandy Hook	0.28	10-600	115	2000	69.2	0.81	0.19	0.47	0.00
B4	Monmouth Beach	0.15	20-550	190	—	—	—	—	—	—
B5	Asbury Park	0.15	40-600	180	—	—	—	—	—	—
B6	Point Pleasant Beach	0.11	20-650	140	—	—	—	—	—	—
B7	Briginteen	0.10	10-650	140	2000	69.3	0.74	0.79	0.39	0.00
B8	Atlantic City	0.19	10-800	150	4000	69.9	0.69	0.41	0.50	0.00

*Spherules were analyzed by means of X-ray fluorescence techniques using National Bureau of Standards steels: Ni26-Cr15#348 and Basic electric #65d as standards.

After Puffer (1974)

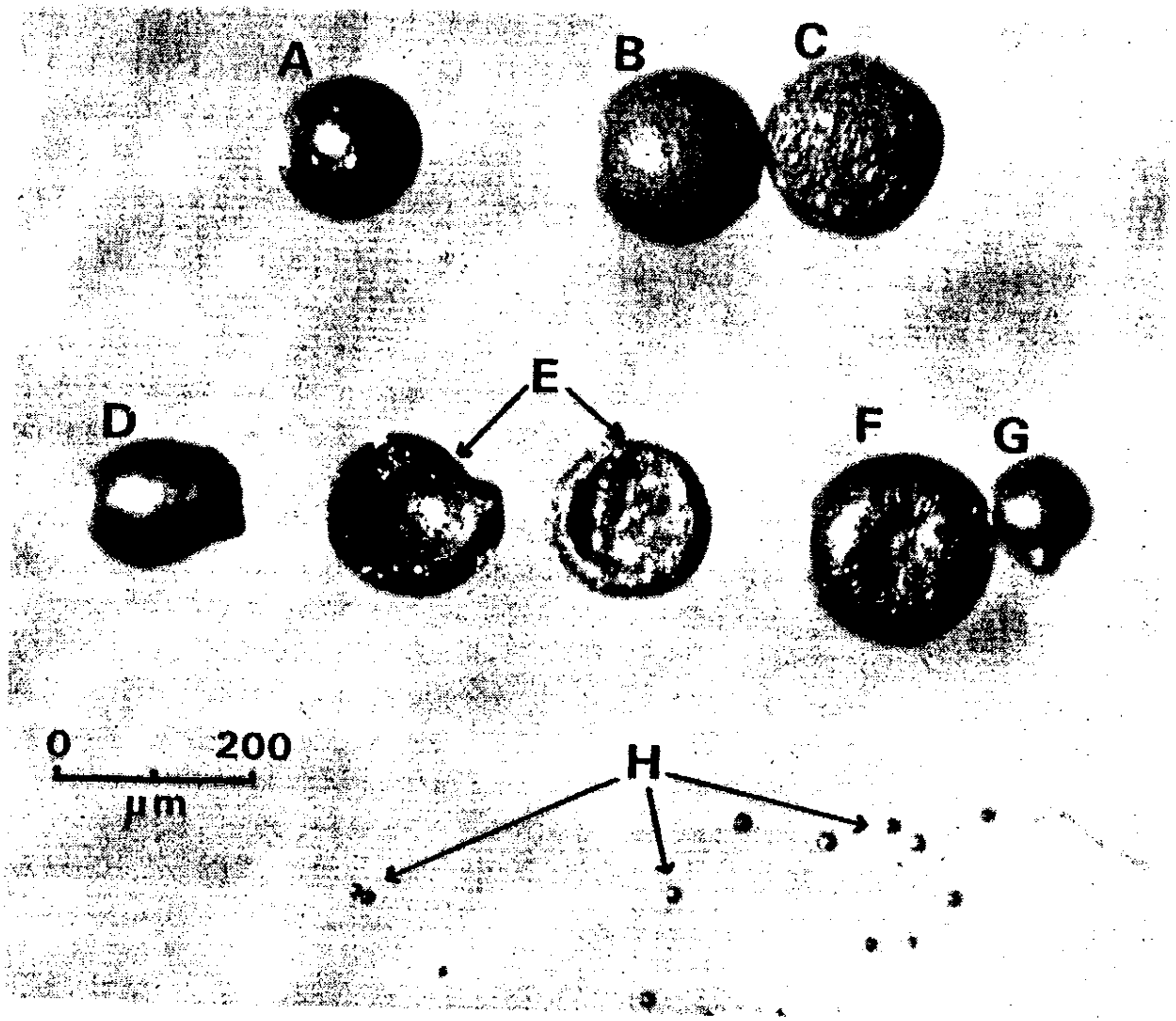

Fig. 2: Magnetite spherules from New Jersey beaches: A. perfectly smooth spherule typical of about 70 percent of most samples, B. a frosted variety typical of about 25 percent of most samples, C. a deeply pitted and corroded variety typical of about 5 percent of most samples, D. a spherule ruptured by expanded gases, E. broken spherules revealing centrally located gas vesicles, F. button shaped spherule, G. composite spherule consisting of two spherules fused together, H. magnetite spherules from sands of Kirkwood Formation sampled near the surface.

After Puffer (1974)

Lake-Bottom Sediments - Table 3 indicates that concentrations of magnetite spherules from sediments sampled at the floor of four lakes located in northern New Jersey decrease with depth throughout the upper few centimeters of sediment. Concentrations drop off sharply becoming rare to absent at a level just above a palynolologically determined biostratigraphic contact (Russell, 1979) between sediment deposited before and after the area was inhabited by settlers of European derivation. Lake bottom sediment cores were sampled at 1-cm intervals for pollen analysis. Approximately 300 or more pollen grains were identified and counted as several grains were identified and counted as several levels. A large increase in Ambrosia (ragweed) pollen in the upper levels of cores is generally attributed to the beginning of European agriculture in the northeastern United States.

The average concentrations of magnetite spherules in seven samples of lake-bottom sediment deposited below the base of the Ambrosia-bearing sediment (8.1 spherules per gram, sharply contrasts with the average of six samples from four lakes deposited after the area was settled (382 spherules per gram).

The median size of the spherules differs among the four lakes indicating that local environments of deposition control their size. However, there is no consistent vertical change in spherule size within any of the cores. The degree of weathering (corrosion) of the spherules is also not related to depth. The ratio of spherules that are highly polished to those that are deeply pitted is approximately four to one throughout each of the cores.

Marsh Sediments – Cores of sediment from two salt marshes located along the margin of Great South Bay in Southern Long Island were collected with 6.4-cm diameter plastic tubes. Tube cores were advanced with blows of a sledgehammer. Cores were withdrawn from the marsh sediment using a manual jack, and later split longitudinally and sampled in the laboratory.

Table 3 indicates that concentrations of magnetite spherules at both Long Island marsh locations decrease with depth throughout the upper few centimeters of sediment. At both locations, the spherules become rare to absent just above the level interpreted on the basis of C-14 data (Rampino, 1978) as having been deposited about 110 years ago. This would correspond to the culmination of the Industrial Revolution that occurred between 1790 and 1860 (Morison, 1965) and to the most rapid settlement of the New York City area. Between 1790 and 1860 the population of New York City increased from about 33,000 to about 1,000,000 people.

Ocean Floor Sediments – Cores of ocean floor sediment from 8 North Atlantic locations were examined for their spherule content (Puffer and others, 1980). At the top of the 8 cores the magnetite spherule content ranges from 0 to 14.5 per gram of sediment and averages 2.81. In contrast, a range of 0 to 1.38 and an average of 0.24 spherules per gram occur in 13 portions of cores sampled at or exceeding 10 cm below the core tops. The cores chosen are believed to be undisturbed and where possible trigger-weights (gravity) cores were used for the core-top sample to insure that we were actually sampling the sea bed surface. Sediment deposited at depths below about 10 cm predates the industrial revolution on the basis of very low (1 cm/100 year) deposition rates typical of ocean floor sedimentation. The spherule concentration range in the sediment below 10 cm (0 to 1.38) approximately agrees with the 0.2 to 2 range found by Levant and Mellis (1955) throughout the 5 to 300 cm level of deep sea Core 72. Although spherule concentrations vary with rates and environments of deposition, our 0 to 1.38 spherule per gram range resembles that found in Permian and Silurian salt (0.03 to 0.77 spherules per gram) sampled in underground mines (Mutch, 1966).

New Jersey Beach Sand – Magnetite Spherules were found in samples of beach sand collected along the coast of New Jersey at several locations. The beach sands were found to contain up to 6 spherules per gram. Spherules were found in the sand at depths down to two meters below the surface but are most abundant in the uppermost cm of sand. They are also highly concentrated wherever the sands are black due to iron/titanium oxide and garnet enrichment. Spherules were found in each sample of beach sand. They were found to be most common at Union Beach, where an average of 0.6 spherules per gram of sand were found, and are least common at Point Pleasant Beach, where only 0.11 per gram were found. The beach sand spherules range in diameter form 10 to about 800 um and average about 135 um. The size of the spherules correlates directly with the size of the host sediment. Spherules recovered from beach sand are typically fine sand size particles whereas spherules recovered from marsh, lake, and deep-ocean floor samples are typically silt to clay size.

INTERPRETATION

The ease of identification and recovery of magnetite spherules from sediments facilitates their use as indicators of probable post-settlement age. The use of magnetite spherules as a post-settlement indicator is, however, restricted to sediments deposited near industrialized areas, such as New York City and Philadelphia, which must serve as the principal source of the spherules. Their use is also restricted to sedimentary environments within the chemical stability field of magnetite. The occurrence of detrital non-spherical magnetite below layers of sediment containing spherules is good evidence that this restriction was met in each of our sample sites. In addition, spherules of an industrial source must be sufficiently abundant to render any extraterrestrial spherules statistically insignificant. Throughout the New Jersey area the base of the post-settlement layer is interpreted as the base of the narrow interval where spherule concentrations sharply decrease. Spherules occurring below this level are of probable extraterrestrial or volcanic origin unless there is evidence of bioturbation or any other process that may have displaced spherules of an industrial origin and carried them to deeper levels. To the extent that beachs have been restored with sand dredged from offshore, any interpretations pertaining to source or deposition rate are particularly difficult.

Table 2 – Distribution of magnetic spherules from smoke stack, city air supply, beach sand, and along an east-west highway through New York City (Figure 1), from Puffer and others (1980).

Sample	Location	Spherules per gram	Diameter range (μm)	Diameter mean (μm)
Scrap Iron Foundry, Stack Scrubber				
F1	Little Falls, New Jersey	1200	3–1010	70
High Volume Air Sampler				
HV1	Rutgers Univ., Newark, N.J.	13000	1–35	15
Beach Sand				
B1	Union Beach, N.J.	0.62	10–8000	150
B2	Sandy Hook (north), N.J.	0.25	20–550	120
B3	Sandy Hook (south), N.J.	0.28	10–600	115
B4	Monmouth Beach, N.J.	0.15	20–550	190
B5	Asbury Park, N.J.	0.15	40–600	180
B6	Point Pleasant Beach, N.J.	0.11	20–650	140
Highway Surface				
1	Whitehall, Pa.	20	16–230	49
2	Bethlehem, Pa.	345	20–310	70
3	Hectown, Pa.	23	16–215	35
4	Easton, Pa.	28	12–70	41
5	I-78 at Alpha, N.J.	51	8–107	25
6	I-78 near Bloombury, N.J.	9.1	8–62	33
7	I-78 Pattenburg exit	35	16–78	25
8	I-78 Annadale, N.J.	5.8	8–62	30
9	I-78 Patterstown, N.J.	4.5	8–62	21
10	I-78 1 km west of Lamington exit	4.8	8–49	20
11	I-78 at I-287 interchange	0.00	—	—
12	I-78 1.5 km west of King George Rd.	0.32	4–20	12
13	I-78 Watchung, N.J.	0.27	12–37	20
14	New providence, N.J.	0.00	—	—
15	I-78 Millburn, N.J.	3.0	12–40	25
16	I-78 1 km west of Garden State Pkwy.	25	8–40	25
17	I-78 at Newark Airport	25	8–40	20
18	Harrison, N.J.	38	12–205	60
19	Secaucus, N.J.	17	12–144	45
20	42nd street at 1st Ave., Manhattan, N.Y.	86	8–168	55
21	I-495 near Maurice Ave.	54	4–53	21
22	I-495 exit 23	7.8	8–82	30
23	I-495 exit 31	21	8–58	33
24	I-495 exit 37	5.4	12–49	20
25	I-495 2 km west of exit 40	6.4	12–66	35
26	I-495 exit 45	7.0	12–82	33
27	I-495 Bayless Rd. under-pass	4.6	8–83	21
28	I-495 exit 52	5.8	16–62	40
29	I-495 2 km west of Sagtilos Pkwy.	1.4	20–62	40
30	I-495 Smithtown exit	1.0	8–40	21
31	I-495 exit 63	2.8	8–33	20
32	I-495 exit 66	0.70	8–20	12
33	I-495 1 km west of Wading River Rd.	0.36	8–25	12
34	I-495 5 km east of exit 70	0.04	8–17	13
35	I-495 exit 73	0.18	8–107	20

Table 3 – Vertical distribution of magnetic spherules in sediments (after Puffer and others, 1980).

Sample	Location		Sediment Depth (cm)	Spherules per gram	Diameter range (μm)	Diameter mean (μm)
Lake Sediments						
773	Green Pond, New Jersey		5.5	240	6–30	12
			20	187	6–30	10
		Ambrosia increase* →	43	—	—	—
			46	0	—	—
776	Lake Kinnelon, New Jersey		1	526	6–40	15
		Ambrosia increase →	13	—	—	—
			15	0	—	—
			20	0	—	—
771	Forge Pond, New Jersey		1	750	6–40	17
			23	190	6–40	17
			46	400	14–70	33
		Ambrosia increase →	54	—	—	—
			58	40	10–60	20
778	Swartzwood Lake, New Jersey	*Ambrosia* increase →	15	—	—	—
			29	2	10–16	13
			34.5	12	5–25	12
			46	3	7–18	10
Marsh Sediments						
M1	Seaford Harbor, New York (north)		1	46	8–60	20
			9	171	7–75	18
			14	67	8–192	19
			16	19	6–45	20
			19	0.9	10–55	20
			60	0.3	—	25
			82	0	—	—
			150	0	—	—
		1015 ± 100 years B.P. →	170	0	—	—
M2	Seaford Harbor, New York (south)		1	300	5–50	16
			7.5	110	5–45	15
			14	0.1	—	75
			17	9.0	7–55	20
			20	3.0	5–40	15
			23	0.2	—	18
			32	0	—	—
			48	0	—	—
		300 ± 85 years B.P. →	90	0	—	—

Sample	Latitude	Longitude	Water Depth (m)	Topo.	Sediment Depth (cm)	Spherules per gram	Diameter range (μm)	Diameter mean (μm)
Atlantic Ocean-Floor Sediments								
V18-357	15°08′N	80°14′W	1818	slope	0	1.13	10–30	15
					18	0.0	—	—
					34	0.0	—	—
V22-233	34°40.5′N	57°05.5′W	2178	plain	0	2.50	40–80	60
					10	0.25	45–90	60
					20	0.0	—	—
					40	0.23	30–60	50
					80	0.53	30–120	50
V27-110	56°53.6′N	18°29.6′W	1264	ridge	0	0.0	—	—
					10	0.0	—	—
					20	1.35	20–40	30
					30	0.78	20–30	25
V26-176	36°02.8′N	72°23′W	3942	plain	0	1.9	10–140	20
					10	0.0	—	—
					22	0.0	—	—
V23-7	41°57′N	61°24′W	4212	plain	0	0.62	10–20	13
V23-1	39°44′N	70°21′W	1997	slope	0	1.82	7–11	10
V4-1	38°53′N	70°55′W	2807	canyon	30	0.0	—	—
					180	0.0	—	—
V28-14	64°47′N	29°34′W	1855	slope	0	14.5	10–45	15
Pacific Ocean Floor Sediments (after Laevastu and Mellis, 1955)								
72	7°38′S	152°53′W	5000	plain	5	2	—	—
					5–300	0.2–2	10–230	44

*The depth at which *Ambrosia* (ragweed) pollen sharply decreased is indicated for each lake sediment core. Ragweed is a reliable marker for the beginning of European settlement (Russell, 1979).

Table 4 – Chemical composition of magnetite spherules from the northern New Jersey area after Puffer and others (1980).

Description	Location	Number analyzed	Fe	Cr	Ti	Ni
Spherule concentrates (weight percent)*						
Smoke stack filtrate	Scrap iron foundry, Little Falls, New Jersey (F1)	2000	71	0.2	0.2	0.1
Beach sand	Union Beach, New Jersey (B1)	4000	70	0.0	0.1	0.0
*Individual spherules** (average weight percent)*						
Air filtrate	Rutgers Univ. campus, Newark, New Jersey (HV1)	8	70	0.1	0.0	0.0
Marsh core 1 (1 cm depth)	Seaford Harbor, New York (north)	10	68	0.0	0.0	0.0
Marsh core 1 (19 cm depth)	Seaford harbor, New York (north)	2	73	0.0	0.0	0.0
Marsh core 2 (1 cm depth)	Seaford harbor, New York (south)	10	69	0.0	0.0	0.1
Marsh core 2 (14 cm depth)	Seaford harbor, New York (south)	1	70	0.0	0.0	0.0

*Hand picked concentrates estimated to be at least 99.5 percent pure, ground to a powder and analyzed by means of x ray fluorescence techniques using National Bureau of Standards steels Ni 26-Cr15 # 348 and Basic electric # 365 as standards.

**Analyzed by means of electron microprobe techniques using National Bureau of Standards steels Ni 26-Cr15 # 348 as standards.

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RATES OF LONGSHORE TRANSPORTS ON THE ATLANTIC OCEAN SHORE OF NEW JERSEY

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DEFINITIONS AND CONTROLLING VARIABLES

Longshore Transport. When waves come on the beach, they steepen and break. In breaking and moving across the surf zone, the waves stir up the sand, putting the sand temporarily in motion. Usually, the wave crest makes a slight angle to the shore, which creates a longshore current. This current carries with it whatever sand has been set in motion by the breaking process. The cumulative effect of this sand transport, parallel to shore, in the surf zone, is *longshore transport.* (The term 'littoral drift' is commonly used as a synonym for longshore transport, but 'longshore transport' is the more accurate term.)

The above definition presumes that there is sand available in the surf zone for the waves to stir up. Often, this is not true. Sand may have been eroded away, leaving rock; or the beach and nearshore water may have been frozen; or seaweed may effectively shield the sand from wave turbulence. For these and other reasons, it is necessary to distinguish between the *actual* longshore transport rate at a site and the *potential* longshore transport rate. The actual rate at a site may be lower than the potential transport rate at that site. The potential transport rate forms an upper limit to the actual transport rate at any site.

Variables. From the above discussion, it is evident that the sand and waves determine longshore transport at any site. First of all, sand has to be there, and sand is defined by size, so we expect that sand size would be an important variable. Strangely enough, the effect of sand size on longshore transport rate is not clear, except that, in a general way, most, but not all, investigators expect that finer sand will be transported more quickly. In a general way, the sand size distribution of New Jersey beaches south of Barnegat Inlet conforms to that expectation, going from coarse to very fine, from Long Beach Island to Wildwood, in the downdrift direction.

Next, we expect sand to somehow affect the beach profile, with coarser sands making steeper beaches; finer sands making flatter beaches. On the foreshore of the beach, the slope is well defined by the sand size; further seaward, sand size fairly well predicts slope, but with less certainty. Theoretically, the longshore transport rate should increase as slope increases, all other factors being equal.

Given the sand and profile of the shore, the longshore transport is determined by the waves. Wave height affects longshore transport rate because the waves stir up sand when they break. Waves break when they reach water where the depth approximately equals the wave height. Bigger waves break further offshore, which means that the surf zone is wider, so more sand can be put into motion. Thus, breaker height, H_b, is important.

To a first approximation, the slope of the profile under the surf zone is planar, so the surf zone, to a first approximation, is a triangular wedge of water. The area of this triangluar wedge increases as the breaker gets bigger and breaks further offshore. By the geometry of triangles, the area of the surf zone increases as the square of the breaker depth at the seaward edge of that triangle. Because breaker height approximately equals depth, *the surf zone area is approximately proportional to the breaker height squared.* This height-squared vs area relation means that if breaker height is doubled, the area of surf zone available to carry sand is four times larger.

But breaker height only determines the amount of sand stirred up in the breaking process. Breaker height *does not,* in itself, determine the quantity of sand moved alongshore; that is, breaker height does not determine the longshore transport rate. It is necessary to have a longshore current flowing at the time the sand is stirred up for longshore transport to occur.

The strength of the longshore current is determined almost entirely by the angle between the wave crest at breaking and the shoreline. Let us call this angle, θ, and use the subscript $_b$ to indicate that we mean the angle between the breaking wave crest and the shoreline. Because of the process known as *refraction,* wave crests tend to become more parallel to the shoreline the nearer they get to the shore. As a result, θ_b almost always is a very small angle, typically averaging around 8° under ordinary wave conditions, somewhat larger during storms (Galvin, 1973).

The remaining wave variable, the time between arrival of successive wave crests, or the wave period, T, has less direct influence on longshore transport. It does appear that longshore current velocity increases as T increases, all other factors being equal, which implies that longshore transport should increase as T increases. However, all things do not usually remain equal as T increases. In particular, as T increases, waves tend to refract more, which reduces θ_b, the most important variable in determining longshore transport rate.

Angle of the Shoreline. Above, we define θ_b to be the angle between the breaking wave crest and the shoreline. This is the angle in the horizontal plane, such as would be shown on a good vertical air photo taken above the surf zone, measured between the general trend particular location and time within that segment. In particular, the large curvature at the shore ~~of~~ 'drumstick' barrier islands is smoothed out by this averaging. of the wave crest where the wave starts to break, and the general trend of the shoreline just landward at tht breaker spot.

Usually, oceanographers and coastal engineers concern themselves with changes in the wave leg of that angle, but the shoreline leg changes as well. Table 1 lists the direction of segments of the New Jersey shoreline measured from a small scale (1:500,000) map. These shoreline segments are at least several miles long, and thus the angles in Table 1 may not represent the shoreline direction at any particular location and time within that segment. In particular, the large curvature at the shore of 'drumstick' barrier islands is smoothed out by this averaging.

Table 1. **REGIONAL STRIKES OF NEW JERSEY SHORELINE SEGMENTS**

No.	Segment	Strike of Segment	θ_0 (degrees)	Sin$2\theta_0$ (–)
1.	Base of Sandy Hook to Sea Bright	N6.6°W	-6.6°	-0.206
2.	Long Branch to Deal	N10.5°E	10.5°	0.324
3.	Belmar to Manasquan	N12.6°E	12.6°	0.386
4.	Seaside Heights plus or minus	N7.6°E	7.6°	0.236
5.	Island Beach to Barnegat Inlet	N5.5°E	5.5°	0.172
6.	Long Beach Island	N24.8°E	24.8°	0.703
7.	Brigantine Inlet - Brigantine	N38.6°E	38.6°	0.937
8.	Absecon Island (Ventor – Margate)	N61.9°E	61.9°	0.931
9.	Pecks Beach (Ocean City to Corson's Inlet)	N45.0°E	45.0°	1.000
10.	Ludlam Island (Strathmere to Townsends Inlet)	N32.4°E	32.4°	0.851
11.	Stone Harbor to Hereford Inlet	N32.4°E	32.4°	0.851
12.	The Wildwoods	N40.7°E	40.7°	0.958
13.	Cape May	N62.8°E	62.8°	0.920

• Data from USGS map of New Jersey, 1:500,000 scale, 1978 edition. Information measured by protractor, averaging a shoreline segment at least five miles long. Data are segment averages and cannot be relied on for specific sites within segments.

θ_0 is the angle between a wave crest in deep water aligned in N-S direction, traveling due west, and the Segment shoreline. Sin$2\theta_0$ gives an idea of the variation in longshore transport for such a westward-traveling wave, due only to change in shoreline orientation.

•

The strike (in the geologic sense of 'strike') of those shoreline segments changes significantly from Segment 1 near the base of Sandy Hook to Segment 13 at Cape May. The strike of Segment 1 is about N6.6°W and the strike of Segment 13 is N62.8°E, a total change in direction of 69.4°. Table 1 shows that Barnegat Inlet separates the Jersey Shore into two super-segments; north of Barnegat Inlet, the average shoreline strike is about N6°E, and south of Barnegat Inlet, the average shoreline strike is about N39°E. There is a difference of 33° degrees between the averages of these two super-segments. (I left out the Cape May value in averaging the southern super-segment because it is a special case which would only increase the difference if included.)

The theoretical equation to predict longshore transport can be reworked into a 'deepwater' form, indicated by the subscript $_o$. This reworking shows the longshore transport depends on deepwater wave direction through the term, $\sin 2\theta_o$, just as the 'shallow water' version of the equation depends on $\sin 2\theta_b$. See the Shore Protection Manual, Chapter 4, Table 4.76, in editions earlier than the 1983 edition.

If we imagine a train of waves in the Atlantic Ocean whose crests have a north-south strike, traveling west towards New Jersey, then θ_o will be as given in the fourth column of Table 1, derived from the strikes of the shoreline in column 3. The last column of Table 1 converts that θ_o to $\sin 2\theta_o$, the factor which theoretically drives the longshore transport.

The important conclusion to derive from Table 1 is that the existing differences in shoreline direction along the New Jersey Atlantic Shore causes wide variations in transport for the same wave conditions. For example, in Segment 5 just above Barnegat Inlet, longshore transport will be only one sixth (0.172/1.00) of the transport near Ocean City on Pecks Beach, if all other factors are equal. They are not equal, of course, as will be suggested in the remainder of this paper.

Units. Longshore transport rates are in units of volume per unit time. Among American engineers, the rates are given usually as cubic yards per year. To convert cubic yards per year to cubic meters per year, multiply the cubic yards by 0.765. Thus, 100,000 cubic yards per year would be 76,5000 cubic meters per year. To get a geological idea of these volumes, 100,000 cubic yards, if spread over one square mile, would make a layer of sand about 1.16 inches deep. In metric units, 100,000 cubic meters would make a layer of sand 10cm deep when spread over an area of one square kilometer. Because open ocean beaches have annual rates of longshore transport on this order or greater, the importance of longshore transport processes extended over geologic time is very great.

REVERSALS IN LONGSHORE TRANSPORTS AT DEAL, NEW JERSEY

Roosevelt-Phillips Coastal Segment. There is a little segment of the Atlantic coast at Deal, New Jersey, that illustrates well an important aspect of longshore transport: longshore transport can vary not only in magnitude, but in direction. This segment of shore extends 0.5km from the Roosevelt Avenue groin on the north to the Phillips Avenue pier on the south. The groin at the north end connects to a rock revetment along the shore. The pier on the south end is adjacent to a groin and a stormwater outfall. These structures at the north and south ends tend to isolate this little coastal compartment. The discussion that follows is illustrated by photos on Plates 1, 2, and 3 at the end of this report.

This shoreline segment is even more unusual in that it contains the mouth of Poplar Brook, a free-flowing, permanent, freshwater stream that empties directly into the Atlantic Ocean without being structurally confined. No other stream in the United States satisfies those characteristics, as far as I know. Poplar Brook probably does not bring a significant amount of sediment to the beach, but the stream mouth is pushed north or south during a typical year so that it illustrates well the changing direction of longshore transport along this coast. In a typical year, the mouth of the brook shifts north or south at least 150m, which is a significant distance for a stream whose bank full width is 3m to 5m.

The beach at Deal is in the lee of Long Island, New York, for storms generated in the north Atlantic Ocean, but is is exposed to storms from the east and southeast. Because of this siting, only intense local northeasters drive sand from north to south, but normal wave action during most of the year drives sand from south to north. The net transport direction is to the north in this area.

During the local northeast storms, wave action drives sand to the south. The longshore transport of this sand drives the mouth of Poplar Brook to the south, and clears the sand from in front of the revetment between Roosevelt Ave. and the brook. The sand driven to the south buries the storm water outfall adjacent to the fishing pier at Phillips Avenue at the south end of this little coastal segment.

During normal times, and especially in the summer, when waves from the southeast prevail, transport is to the north. At these times, the longshore transport pushes the mouth of the Poplar Brook to the north and deposits sand in front of the revetment between Roosevelt Avenue and Poplar Brook. This sand is supplied from the erosion of the beach at the south end of the segment, uncovering the stormwater outfall next to the Phillips Avenue pier.

In the opening definitions of this paper, the difference between actual and potential longshore transport was emphasized. Longshore transport in the coastal compartment between Roosevelt and Phillips Avenues is limited by the availability of sand. At the north end during northeasters, waves hit the groin or rock revetment and thus expend energy without moving sand. At the south end of the compartment, part of the beach is protected from wave action out of the southeast by the pier, outfall, and groin.

The isolation of this compartment from outside sources is indicated by the darkness of the sand. The sand in this compartment has a high percentage of heavy minerals, suggesting that much of the lighter quartz sand has been winnowed away.

Longshore Transport Components. Imagine you are standing on this beach in Deal facing the ocean between Roosevelt Avenue on the north (to your left) and Phillips Avenue on the south (to your right). Then the longshore transport to your left (from south to north) will be defined as Q_l, and longshore transport to your right (from north to south) will be defined as Q_r. Notice that these definitions are relative to the observer standing on the beach looking out to sea, and they are given in terms of the observer's right and left, and not in terms of compass directions. Thus, in New Jersey, Q_r on the Atlantic Coast beach at Deal is directed to the south, but Q_r on the Delaware Bay beach at Reeds Beach is directed to the north.

Having defined the components of longshore transport, Q_l and Q_r, we can now define the net and gross longshore transports, Q_n and Q_g, respectively, as:

$$Q_n = Q_r - Q_l \tag{1}$$

$$Q_g = Q_r + Q_l \tag{2}$$

It is a matter of convenience in equation (1) which term comes first on the right hand side. By putting Q_r first, most Atlantic Coast net transports are positive numbers, but not at Deal or other Monmouth County locations. It is best to consider Q_r and Q_l as scalar numbers without a + or – sign; that is, for the purposes of equations (1) and (2), they are not vectors.

TRANSPORTS ON THE NEW JERSEY ATLANTIC COAST

Sandy Hook. The best known value of longshore transport on the New Jersey shore is the determination by Joseph M. Caldwell for Sandy Hook (Caldwell, 1966). The calculations were done in 1953. Alternate determinations gave 493,000 and 436,000 cubic yards per year to the north. The average of these two numbers is 465,000 cubic yards per year or 355,000 cubic meters per year.

These numbers were obtained from actual surveys of the northward growth of Sandy Hook, and from records of dredging the channel at the north end of Sandy Hook. There have been more recent estimates of these numbers, but I began my professional career working under Mr. Caldwell, and was impressed by his care and practical sense. For this reason, I will use the Caldwell value.

Sandy Hook is relatively sheltered from wave action out of the north and out of the west by the borders of Raritan Bay, and from wave action out of the northeast by the west-to-east projection of Long Island, New York. Thus, the principal cause of longshore transport at Sandy Hook is wave action out of the southeast. As a first approximation, this means that the longshore transport components are $Q_r = 0$ cubic meters per year (approximately) and Q_l = 355,000 cubic meters per year (approximately) for the observer standing on Sandy Hook looking east at the Atlantic Ocean (New York Bight).

I believe that for these values, the actual transport effectively equals the potential transport because during most of the history of recorded growth of the Sandy Hook spit and related channel dredging, there was no rock revetment in the sand source region dissipating wave energy, as later developed along the Sea Bright and Monmouth Beach coasts.

Sea Isle City/Ludlam Island. It is difficult to get an equivalent value of longshore transport rate for the southerly ocean shores of New Jersey. The estimated rates at any site vary widely with the investigator. For example, at Sea Isle City on Ludlam Island, estimated rates have Q_l from 357,000 to 718,000 cubic yards per year. For consistency, I will use an average of the two estimates by Caldwell reported by Webb and Weggel (1995, Table 2). I am not personally familiar with these data. These estimates, when averaged, yield Q_l = 475,000 cubic yards per year and Q_r = 625,000 cubic yards per year. It is possible that these actual values are somewhat below the potential values of longshore transport because during storms, much of the beach profile is peat and mud, rather than sand, due to the landward retreat of the barrier islands, which are thin, fine sand bodies perched on back bay marsh deposits. Wave energy expanded on the mud outcrops does not move sand.

Implications for New Jersey Ocean Coast. Below the south end of Long Beach Island, the sand gets distinctly finer in a southward direction. The quantities of sand on beaches between the inlets are limited. The spacing between inlets is reduced, so, per unit length of shoreline, the volume of sand stored in ebb tidal deltas increases. It is consistent with other areas having similar plan form of barrier islands that potential transport exceeds actual transport between about Brigantine north of Atlantic City and Cold Spring Inlet in Cape May.

This suggests that, if abundant sand were made available through beach nourishment on that coast, longshore transport would increase. This beach nourishment might have a geological cause, say, the structural uplift of coastal plain sediments, their accelerated erosion, and subsequent deposition on the shore. As a result, probably the barrier islands would loose their 'drumstick' plan form, and some of the smaller tidal inlets would seal off.

If unlimited sand were made available northwards of Island Beach, sand deposition would extend Sandy Hook northward. Sandy Hook could seal off Raritan Bay in a brief interval of geologic time. In historic time, it would become more difficult to maintain navigable channels into Manasquan and Shark River Inlets.

Geologically, the rates of longshore transport are quite important. The annual rates of longshore transport are quite significant when extended over geologic time. Longshore transport is an underrated process for the distribution of sand away from a source.

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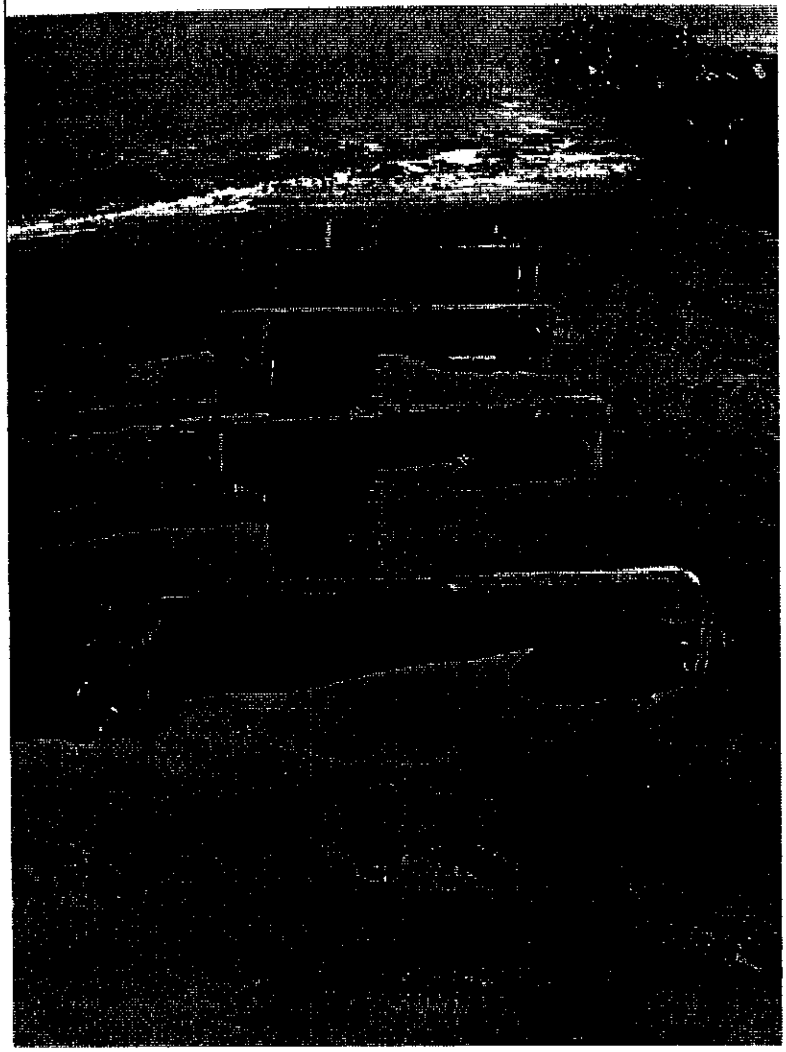
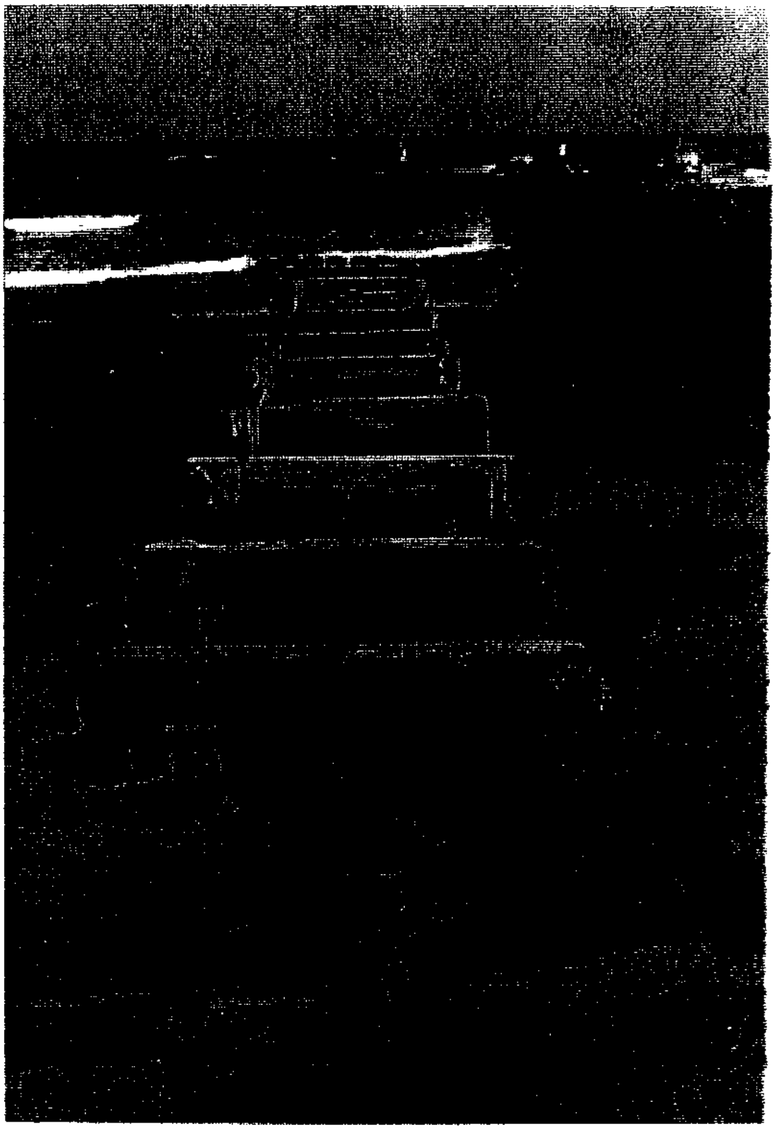
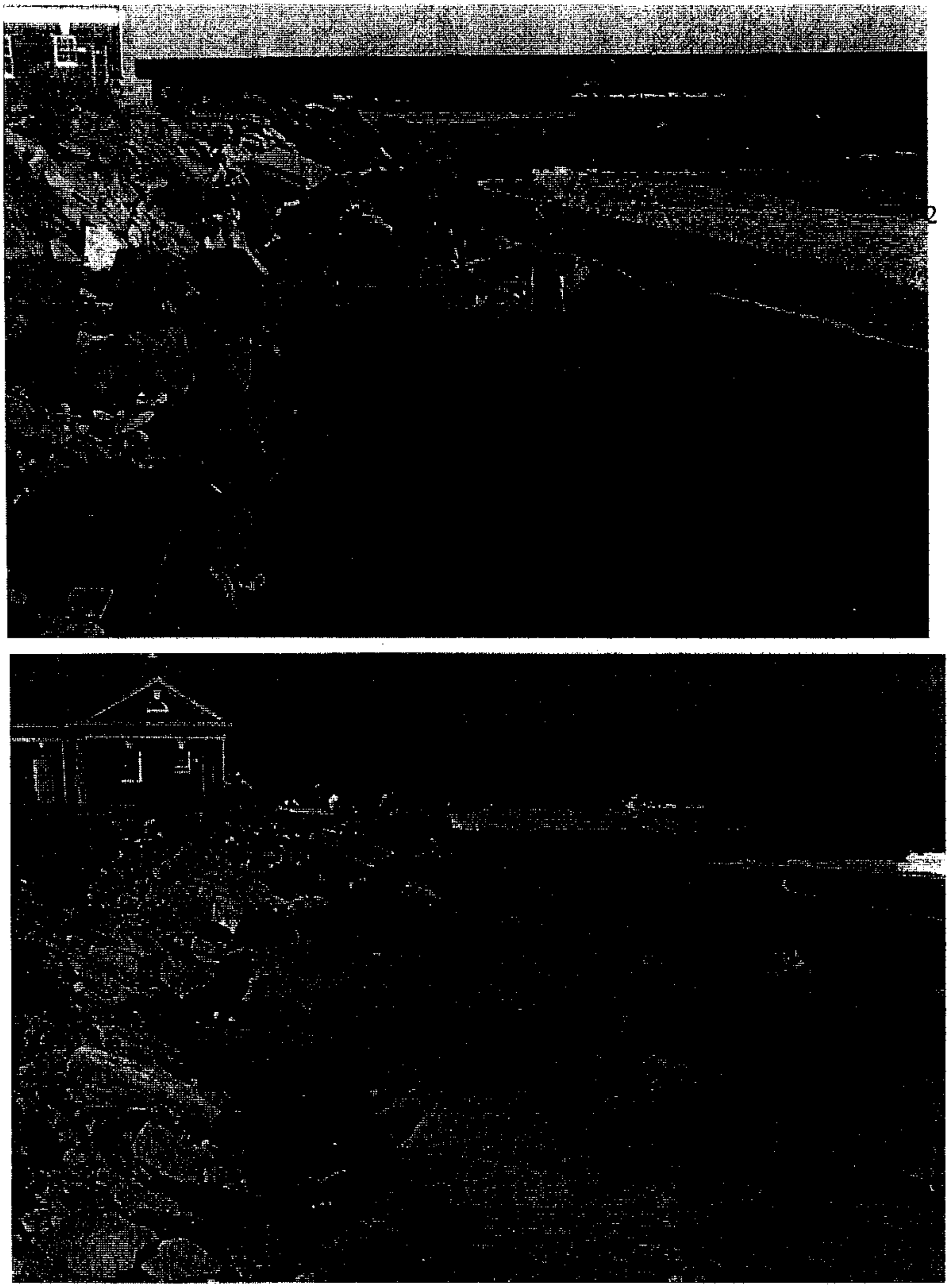
Plate 1



Left. 25 Nov 98. Deal Beach at South end of Roosevelt-Phillips compartment. Transport North to South from local Northeasters.



Right. 14 Aug 99. Deal Beach at south end of Roosevelt-Phillips compartment. Transport south to north removes sand from stormwater outfall.



Above. 29 Nov 98. North end of Roosevelt-Phillips compartment when waves remove sand from in front of revetment. **Bottom.** 14 Aug 99. Same site after deposition during summer weather. Notice sand level relative to concrete slab.

Plate 3

Meandering mouth of Poplar Brook on 4 July 1999. Initial course of stream to right is result of storms during the previous spring; then course reversed in the summer as sand arrives from south, pushing stream mouth to left, to north.

HOLOCENE SEA LEVEL FLUCTUATIONS ALONG THE NEW JERSEY SHORE

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INTRODUCTION

The shoreline of New Jersey represents one of the state's most important natural resources. However, the beaches and barrier islands that attract many thousands of visitors and represent an important revenue source are under attack ... from the sea. Intense anthropogenic modification of the bayside and barrier island beaches and their associated marshes since the turn of the century has weakened these landforms' natural ability to adjust to changes within the system (Nordstrom *et al.*, 1986). Beach nourishment projects have been in operation for decades throughout the State in an attempt to maintain beaches and beachfront property (Nordstrom, 1994). However, predicted and recorded higher sea levels continue to threaten these intensely modified systems.

The present rate of sea level rise is higher now than at any other time in the past 7500 years (Psuty, 1986). This accelerated sea level rise creates concern for shoreline erosion, destruction of wetland habitats, intrusion of saltwater into groundwater, and the effects on hazardous waste sites and other human infrastructures (Psuty and Collins, 1996). Because of the potential future damages, it is important to properly manage coastal development to minimize risks and preserve open spaces to ensure conservation of fragile ecosystems.

In order to predict future rates of sea level rise and its potential effect on this managed system we need to understand how sea level has varied in the past. Interpretation of tide gauge records provides a brief glimpse at changes in sea level for the recent historic period (Psuty and Collins, 1996). However, in order to establish long term changes and trends over thousands of years we must turn to the stratigraphic record preserved in the marshes. In this paper we present a review of Holocene sea level studies within the state.

ENVIRONMENTAL SETTING

New Jersey boasts over 200 km of Atlantic coastal shoreline, stretching from Sandy Hook south to Cape May (Nordstrom, 1994). The coastline is characterized by sandy barrier islands which are separated from the mainland by open water lagoons and tidal inlets (Ashley, 1988). Extensive tidal marshes lie sheltered behind the barrier system and wrap around the coastline into the Delaware Bay.

The tidal marsh regions are subdivided into tidal flats and low and high marshes. Each of these zones is categorized by a dominant vegetation type, which reflects the amount of tidal inundation. The low marsh is associated with a tall form of *Spartina alterniflora,* which is able to withstand long periods of tidal flooding. The low marsh is demarcated by Mean Low High Water (MLHW) and is inundated twice daily. In contrast the less frequently inundated and more common high marsh region is host to a variety of plant species, including a short form of *S. alterniflora, Spartina patens, Distichlis spicata* and *Salicornia* spp. It is inundated once daily and is demarcated by Mean Higher High Water (MHHW). *Phragmites australis*, *Scirpus robustus*, and *Typha angustifolia* grow at elevations above MHHW with increasing freshwater input (Kana *et al.,* 1988; Robichaud and Buell 1983).

RECONSTRUCTING HOLOCENE SEA LEVEL

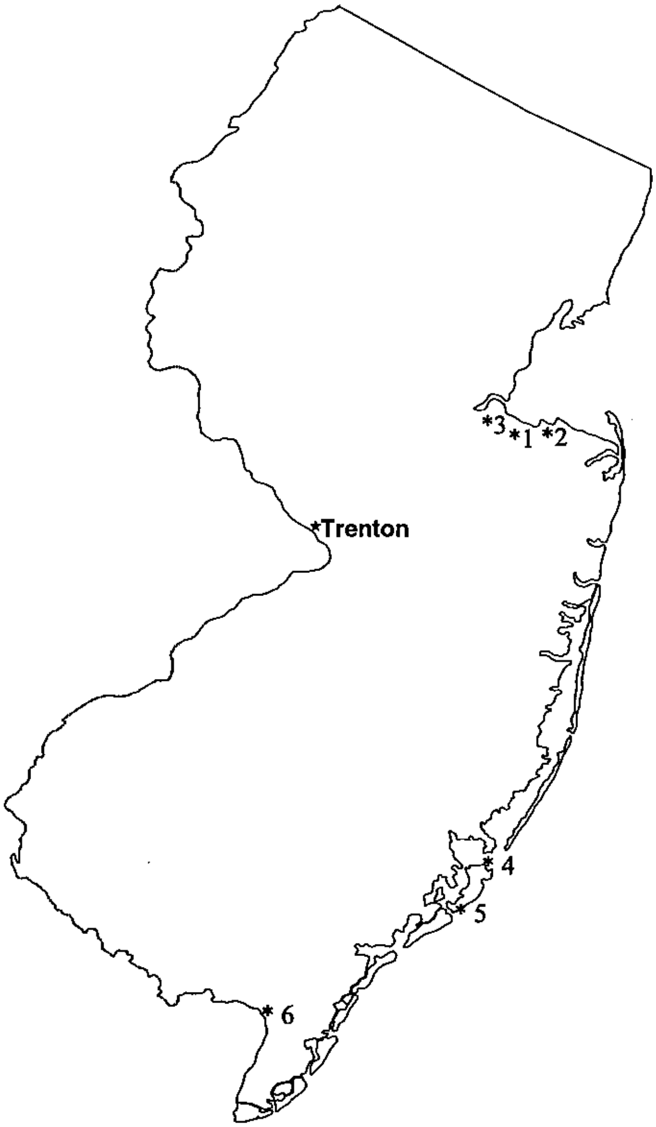
Relative sea level rise can be reconstructed by two methods either alone or in combination, each employing radiometric dating. Traditionally basal salt marsh peats obtained along a transect from bay to upland are radiocarbon dated (Redfield, 1972). This method provides maximum ages for the Holocene transgression and long-term rates of sea level rise. Basal peats are dated to avoid compaction problems attributed to dewatering and compression from the overburden (Bloom, 1964).

The second method of estimating relative sea level rise is the "single cores method" (Varekamp and Thomas, 1998). This method takes advantage of the natural zonation of organisms, such as plants, diatoms or foraminifera, in relation to a tidal datum such as mean tide level (Behre, 1986; Palmer and Abbott, 1986; Scott and Medioli, 1978). Thus the distribution of macro- and microfossils down core are used as a proxy for previous heights of sea level. Accurate dating of changes in biostratigraphy can provide a detailed picture of relative sea level fluctuations (e.g. Thomas and Varekamp, 1991; Varekamp *et al.*, 1992). This has only been feasible in the last decade as Accelerator Mass Spectrometry (AMS) assays require very little organic matter (~5mg) and typically return a small age error (~<50 years). This is in contrast to traditional radiocarbon samples which required a large sample mass (200g) and which typically return larger age errors (>50 years) (Wells, 1995). Historic rates of relative sea level rise are determined using ^{210}Pb (past 150 years) and ^{137}Cs (last 50 years) as radiocarbon analysis is not useful for material younger than 500 years.

Sea level curves are constructed by plotting the depth and age of sediments sampled. Age errors and depth errors (which include calculated autocompaction and habitat_range of organism dated about MSL) are also traditionally plotted on the curve (Van de Plassche, 1986).

HOLOCENE SEA LEVEL FLUCTUATIONS IN NEW JERSEY

The data available for estimating Sea level variations for the Holocene in New Jersey can be broadly divided into northerly and southerly regions. The greatest detail is available from the more southerly region were several studies have been undertaken (Figure 1).



1 Cheesequake (Psuty, 1986; Newman et al, 1987)
2 Union Beach (Psuty, 1986)
3 Pine Creek Marsh (Kenen, 1998)
4 Great Bay (Daddario, 1961; Psuty, 1986)
5 Brigantine (Stuiver and Daddario, 1963)
6 Dennis Creek (Meyerson, 1972; Varekamp and Thomas, 1998)

FIGURE 1:
Map of New Jersey showing location of studies referenced in text.

The Southern Region

Both Daddario (1961) and Psuty (1986) took sediment cores through Holocene sediments down to Pleistocene sediments in areas surrounding Great Bay (Figure 1). Their resultant profiles of sedimentation sequence are very similar. Daddario (1961) identifies freshwater swamp vegetation overlying Pleistocene oxidized sands in the basal sections of his transect. This lower peat includes woody plant remains from forest associated with the mainland. Above this lies a transition layer of possible salt marsh vegetation and varying amounts of sediment. This indicates a change in the rate of rising sea level. Initially the rate is slow but widespread due to the gentle slope of Pleistocene sands. However, the thinness of the transition layer and lack of significant vegetation along with the overlying thick wedge of silts indicates an increase in the rate of sea level rise. This led to development of an open water area. The silts of the open water area were eventually covered by marsh peat due to a decrease in the rate of sea level rise and a positive sediment budget. Several marsh layers were also encountered within the silts indicating periods of stability in sea level rise or a net positive sediment budget allowing periodic extension of the marsh from the fringe into the ancestral bay. Subsequent retreat of the wetlands is indicated by the return of estuarine silts overlying the marsh peat (Psuty, 1986).

A total of sixteen radiocarbon dates are available (Table 1). The initial inland migration of seawater that created the ancestral bay occurred at a rate of 2mm yr^{-1}. This rate decreased approximately 2500 years ago to 0.6–0.7 mm yr^{-1} allowing fringing marshes to expand over the open water silts. The streams and rivers presently draining the coastal zone of New Jersey transport very little clastic sediment into the bays. A number of studies indicate that the offshore zone is the primary source of both fine-grained and coarse-grained sediments for bay alluviation (Psuty, 1986). The reduced rate of sea level rise accompanied with an offshore surplus of sediment would create enlarged barrier islands and flood-tidal deltas, an infilling of the bays and a reduction of open water.

Slightly to the south of Great Bay, near Brigantine City, Stuvier and Daddario (1963) dated basal peats thought to have formed at mean high tide (Figure 1 and Table 1). They obtained a total of five radiocarbon dates from the region. Rates of submergence of 3 mm yr^{-1} between 6000 and 2600 yr B.P. and 1.2 – 1.4 mm yr^{-1} during the last 2600 years were documented.

The submergence rates calculated from the Brigantine City samples project a slightly faster rate of rise than the Great Bay dates (Stuvier and Daddario, 1963; Psuty, 1986). The two regions are approximately 15 km apart. The difference in rates may reflect sampling differences and not actual differences in rate. In particular the data from Great Bay may not be tracking sea level as the material used in the radiocarbon assays was not identified and thus its relation to paleo-sea level is not known. It is therefore possible that these peats represent freshwater peats and thus they may be tracking increased fluvial input. However, the lithofacies sequence is indicative of a marine transgression.

Further south, Meyerson (1972; Figure 1 and Table 1) identified peat rhizomes and pollen to determine the history of a marsh at Dennis Creek (northern shore of Delaware Bay). These cores reflect a series of transgressions and regressions. Six radiocarbon dates were obtained from non-basal peats, which have presumably been subjected to autocompaction. The oldest date indicates sea level occupied the site by about 3000 years ago (Meyerson, 1972). Based upon the biostratigraphy, Meyerson (1972) suggests a variable rate of sea level from this time until the present. A major transgression was noted at around 1800 years B.P. with high marsh environments overlain by deposits indicative of tidal flat or low marsh. This transgression is correlated by Fletcher *et al.* (1993) to a transgression noted in cores from sites along the southern shore of Delaware Bay. This short-term increase in the rate of sea level rise occurs between 3 and 4 meters depth in cores taken from salt marshes. The mechanism responsible for these fluctuations remains unknown, but may be related to changes in the dynamics of ocean currents (Fletcher *et al.*, 1993).

Varekamp and Thomas (1998; Figure 1) also working at Dennis Creek Marsh established recent rates of submergence for the last thousand years. Their data indicates that between A.D. 1300 to 1650 submergence averaged 0.7 mm yr^{-1}, since A.D. 1650 the rate has markedly increased to an average 6.9 mm yr^{-1}. A rate which seems anomalously high when compared to the tide gauge data from Atlantic City (3.85 mm yr^{-1}) (Psuty and Collins, 1996). Varekamp and Thomas (1998) attribute this high rate to forebulge collapse in the Delaware Bay.

The Northern Region

Psuty (1986; Figure 1 and Table 2) reports on two transects in Cheesequake Marsh. Stratigraphy reflects the infilling of the ancestral Cheesequake estuary. Four radiocarbon dates were obtained on unidentified material, the oldest returning an age of 7735 yr. B.P. Several peat horizons are interspersed within the dominant clay matrix. Psuty suggests that these organic units may represent short-term declines or stabilization in sea level rise. Newman *et al.* (1987) also working at Cheesequake dated 7 peat samples. Two of the dates were discounted as they returned anomalously young ages (Newman *et al.*, 1987; Table 2) and a third was not of basal peat. The remaining four dates indicate an average rate of sea level rise of 1.5 mm yr^{-1} for the last 7000 yrs. Newman *et al.* (1987) suggest that the data from the site may be complicated by tectonics.

Most recently Kenen (1998; Figure 1 and Table 2) identified rhizomes and dated basal peats to produce a high-resolution sea level history for Pine Creek Marsh in the upper reaches of the Raritan River Estuary. The earliest dated peat occurs at a depth of 3.9 m and indicates initiation of tidal marsh by 3000 yr B.P. Within this time span rates have varied from 5.4-0.7 mm yr^{-1}, averaging 1.8 mm yr^{-1} for the entire period. Notably a marked transgression is recorded at 1800 yr B.P. which is consistent with the findings of Meyerson (1972) and Fletcher *et al.*, (1993). More recent transgressions have occurred but remain undated. The sea level rates at Pine Creek (Kenen, 1998) compare well with the Southern New Jersey studies, however, the periods of change conflict slightly. This is probably because Pine Creek marsh is located in mid-estuary as compared to the near-inlet estuary sites (Psuty, 1986; Stuvier and Daddario, 1963).

SEA LEVEL RATES OF THE LAST 100 YEARS

High rates of sea level rise are reported for the last one hundred years (Psuty and Collins, 1996), this is partly due to land subsidence due to compaction and groundwater withdrawal from the poorly consolidated sediments that underlay the Atlantic Coastal Plain. For instance, Chi and Reilinger (1984) report a maximum subsidence of 75 mm from 1924-1968 in Atlantic City (1.7 mm yr^{-1}) and 150 mm from 1930-1964 at northern end of Barnegat Bay (4.4 mm yr^{-1}). New Jersey tide gauge records and other data indicate that the rate of sea level rise has increased dramatically during the past 100 years to approximately 3.8 mm yr^{-1} (Psuty, 1986).

HOLOCENE RATES OF SEA LEVEL RISE ALONG THE EASTERN SEABOARD

Reconstructions of relative sea level rise along the eastern seaboard report fairly consistent rates. Variations in rates of change and timing of changes reflect regional effects such as glacio-isostatic rebound and neotectonics, as well as differences in tidal range and methodology (e.g. Newman et al. 1987; Belknap and Kraft, 1977; Belknap *et al.*, 1989).

The general curve for the middle to late Holocene reflects a rate marked by a recent increase in the rate of rise (Douglas, 1991). In the Delaware Bay (Belknap and Kraft, 1977) prior to about 5000 years ago, sea level rose at a rate of 2.9 mm yr^{-1}; the rate of inundation slowed to 2 mm yr^{-1} until about 1700 yr B.P. From Long Island Sound (Gayes and Bokeniewicz, 1987) and Southern Long Island (Rampino, 1979) rates of approximately 2.4 mm yr^{-1} from 7000 – 3000 yr B.P. In Connecticut (Bloom, 1964; Patton and Horne, 1991) and Maine (Belknap *et al.*, 1989) rates of 1.8-1.9 mm yr^{-1} till approximately 2000-1700 yr B.P. are reported. Rates have declined over the last 2000 years to approximately 1mm yr^{-1} (Gayes and Bokeniewicz, 1987; Rampino, 1979; Bloom, 1964; Patton and Horne, 1991; Belknap *et al.*, 1989; Belknap and Kraft, 1977; Van de Plassche; 1991).

The results from Southern New Jersey of 2-3mm yr^{-1} until about 2500 years ago compare well with the regional East Coast trend (Stuiver and Daddario, 1963; Psuty, 1986) and to the north a rate of 2 mm yr^{-1} is estimated until about 2200 years ago (Kenen, 1998). However, markedly different rates of decline are recorded in Southern New Jersey for the last 2500 years, ranging from 0.6-0.7 mm yr^{-1} to 1.2-1.4 mm yr^{-1} (Psuty, 1986; Stuiver and Daddario, 1963). While in Northern New Jersey widely varying rates of inundation are recorded throughout this time period. For instance a slow rise of 0.7 mm yr^{-1} occurred between 2150-1800 yrs B.P., followed by a rapid rise of 5.4 mm yr^{-1} until 1700 yrs B.P., with a return to a lower rate of 1.4 mm yr^{-1} (Kenen, 1998).

Tide gauge data from New Jersey indicates an acceleration in the rate of sea level for the last one hundred years to 3.8 mm yr^{-1} (Psuty and Collins, 1996). Gauges in New York, Philadelphia, Baltimore, and Washington, unlike New Jersey's, are located on crystalline bedrock and thus experience minimal local land subsidence; although, localized graben-like downfaulting influences subsidence rates in the Hudson Bay (Newman et al. 1987). These gauges indicate a slightly lower rate of rise with average rates of 2.5 mm yr^{-1} (Davis 1987).

FUTURE RESEARCH

It is generally agreed by environmental geochemists that global warming will continue to raise the present high rate of sea level rise (Titus, 1988). Titus (1990) reported predicted rates of future sea level rise developed by the Environmental Protection Agency and the National Research Council. It is estimated that sea level will rise 5–20 mm yr^{-1} over the next 100 years.

Kenen (1998) identified a 5.4 mm yr^{-1} rate of rise at Pine Creek Marsh 1800 years ago, and studies elsewhere have also reported an significant transgression at this time (Meyerson, 1972; Fletcher *et al.*, 1993). Detailed stratigraphic evidence of this event from throughout the state may be useful in indicating the duration and effect of this rise on tidal marshlands and barrier islands, and thus serve as a proxy for the proposed accelerated greenhouse rise.

TABLE 1. Radiocarbon Data from the Southern Region

Site	Depth (m)	^{14}C Age	Error ±	Material	Reference
Brigantine	2.5-2.7	1890	40	Peat at MHT	Stuiver and Daddario, 1963
"	4.6-4.8	3000	90	"	"
"	7.3-7.5	3830	100	"	"
"	12.95-13.05	5890	100	"	"
Dennis Creek	2.4*	1760	120	Fresh water peat	Meyerson, 1972
"	3.0*	1335	95	High marsh peat	"
"	5.5*	3030	130	Fresh water peat	"
"	5.7*	2840	110	"	"
"	5.9*	3145	120	"	"
"	7.0*	2150	110	Low marsh peat	"
Great Bay	2.7*	500	70	Unidentified peat	Psuty, 1986
"	4.4*	3035	120	"	"
"	7.0*	3050	95	"	"
"	8.5*	6380	355	"	"
"	8.6*	4495	125	"	"
"	8.6*	4175	145	"	"

* Exact depths are not given in article, represents estimated depths.

TABLE 2. Radiocarbon Data from the Northern Region

Site	Depth (m)	^{14}C Age	Error ±	Material	Reference
Cheesequake	8.5*	6020	215	Unidentified basal peat with cedar fragments	Psuty, 1986
“	11.0*	4330	460	Shell	“
“	11.6*	6610	215	Cedar fragments	“
“	12.5*	7735	195	Unidentified peat	“
“	2.6 to –2.8	1210	185	Basal peat at MHW	Newman *et al.*, 1987
“	2.8 to –3.05	1960	130	“	“
“	3.3 to –3.5	2080	160	“	“
“	11.8 to –12.1	7230	185	“	“
Union Beach	0.4*	660	110	“	Psuty, 1986
“	0.6*	2695	145	“	“
Pine Creek	2.65 –2.77	2130	60	Basal Peat deposited at MHWS	Kenen, 1998
“	2.05-2.15	1690	70	“	“
“	4.11-4.18	2430	80	Wood	“
“	3.15-3.25	1830	60	Peat	“
“	3.82-3.92	2710	60	Basal Peat deposited at MHWS	“
“	2.65-2.75	2170	70	“	“
“	2.42-2.52	1780	70	“	“
“	3.50-3.58	2210	70	“	“
“	1.67-1.77	1410	80	“	“
“	6.40-6.50	2810	70	Shells	“
“	2.42-2.49	1820	80	Basal Peat deposited at MHWS	“
“	2.48-2.53	1970	80	“	“
“	3.65-3.75	2570	60	Peat	“
“	4.06-4.11	2690	80	Basal Peat deposited at MHWS	“
“	2.70-2.85	1370	70	Peat	“

* Exact depths are not given in article, represents estimated depths.

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GEOLOGIC FRAMEWORK OF THE NEW JERSEY INNER SHELF: RESULTS FROM RESOURCE-BASED SEISMIC AND VIBRACORE STUDIES

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ABSTRACT

Distinct depositional regimes in the northern and southern New Jersey offshore regions have a substantial impact on the formation and preservation of sand shoals. We interpret approximately 600 kilometers (km) of seismic data and 40 vibracores, revealing the geologic framework controlling offshore sediment distribution. To the north, seismic and vibracore data from offshore of Mantoloking indicate outcropping or subcropping Tertiary-age coastal plain deposits, dipping gently to the southeast, similar to their outcrop pattern onshore. To the south, these data show numerous shoal features on the inner shelf, designating it as a priority region for sand resource study. A transition zone of elongate linear shoals of Pleistocene-age material offshore of Long Beach Island separates the Holocene shoals to the south and the outcropping coastal plain units to the north.

In the southern offshore, we find varying Holocene lithologies (above a major sequence boundary, S_2) among the seven resource areas. Specifically, in Area G offshore of Brigantine we find: 1) the gravel that marks the S_2; 2) a lower sand layer 1-2m thick; 3) the interbedded silts, sands and clays of the estuarine deposits 1-3m thick; and 4) an upper sand layer 1-2m thick. For Area G, we measure the sand resource from the Holocene R_2 ravinement surface that separates the interbedded sand, silt and clay from the upper sand layer.

In the northeastern portion of Area G, a sheet several meters thick with radiating spurs or lobes overlies older channel structures and is the possible former ebb-tidal delta of Little Egg Inlet. Elongate ridges to the south and west are likely the smoothed remnants of lobes previously attached to the former Absecon, Brigantine, or Little Egg Inlets.

INTRODUCTION

The New Jersey Geological Survey (NJGS) and Rutgers University (RU) are investigating sand sources in the New Jersey offshore. We coordinate with New Jersey Department of Environmental Protection, the U.S. Department of Interior's Minerals

Management Service, and the U.S. Army Corps of Engineers to acquire and interpret offshore geologic data for engineering and geotechnical professionals. This project involves 600 kilometers of seismic data and 40 vibracores from seven areas in the Atlantic Ocean from Mantoloking to Townsends Inlet (Figure 1). The interpretation of the data reveals a geologic framework that illustrates the controls on distribution of offshore sediments. The variety of depositional settings creates distinctly different sea floor morphologies. Following is a generalized interpretation of the Pleistocene/Holocene geology of the New Jersey inner continental shelf with specific emphasis on several sand resource areas. This geologic interpretation benefits each aspect of the sand prospecting effort.

THE PRESENT-DAY NEW JERSEY COASTLINE

New Jersey's beaches are composed primarily of unconsolidated sand, with lesser amounts of silt and gravel, reworked from Cretaceous, Tertiary, and Quaternary coastal plain sediments (McMaster, 1954). The unconsolidated material is eroded either from onshore coastal plain formations in the northern section of the coast or from submerged coastal plain sediments that are redistributed along the coast by sediment transport. The New Jersey coast is the landward boundary of the Atlantic continental shelf, a slowly subsiding passive margin with a low sediment supply that has undergone numerous glacially-controlled sea-level fluctuations during the Pleistocene and Holocene (Ashley and others, 1991).

Coastal plain sediments are directly exposed to wave action from Long Branch south to Point Pleasant Beach. In this part of the coast, called the headlands by Fisher (1965), the modern beach lies directly seaward of a bluff rising as much as 8 meters above mean tide level. The eroded material from the headlands is reworked by waves and is incorporated into the present-day sediment supply. Long-shore currents carry sand northward along the coast to be deposited at Sandy Hook spit or southward to be deposited on the barrier beaches or at inlets (Ashley and others, 1986).

There are no exposed Tertiary coastal plain sediments along the southern New Jersey coast from Mantoloking to Cape May Point. Pleistocene-Holocene sands reworked from submerged coastal plain sediments mingled with eroded northern onshore sediments form the existing barrier islands. These barrier islands range in length from 8 to 29 km.

TECTONIC AND ISOSTATIC INFLUENCES

Basement geology influences the depositional regime. Subsidence of the Triassic/early to mid-Jurassic-age Baltimore Canyon Trough offshore of southern New Jersey has controlled the depositional patterns of the younger offshore sediments that have not been significantly eroded by transgressive events (Figure 2) (Owens and others, 1998). Subsidence allows the accumulation of a thick Pleistocene-Holocene sediment package (up to 12m). The northwestern edge of the basin forms a hinge line extending to the northeast off Barnegat Inlet. This hinge line demarcates the eroding headlands of the northern coast from the barrier-island systems of the southern coast.

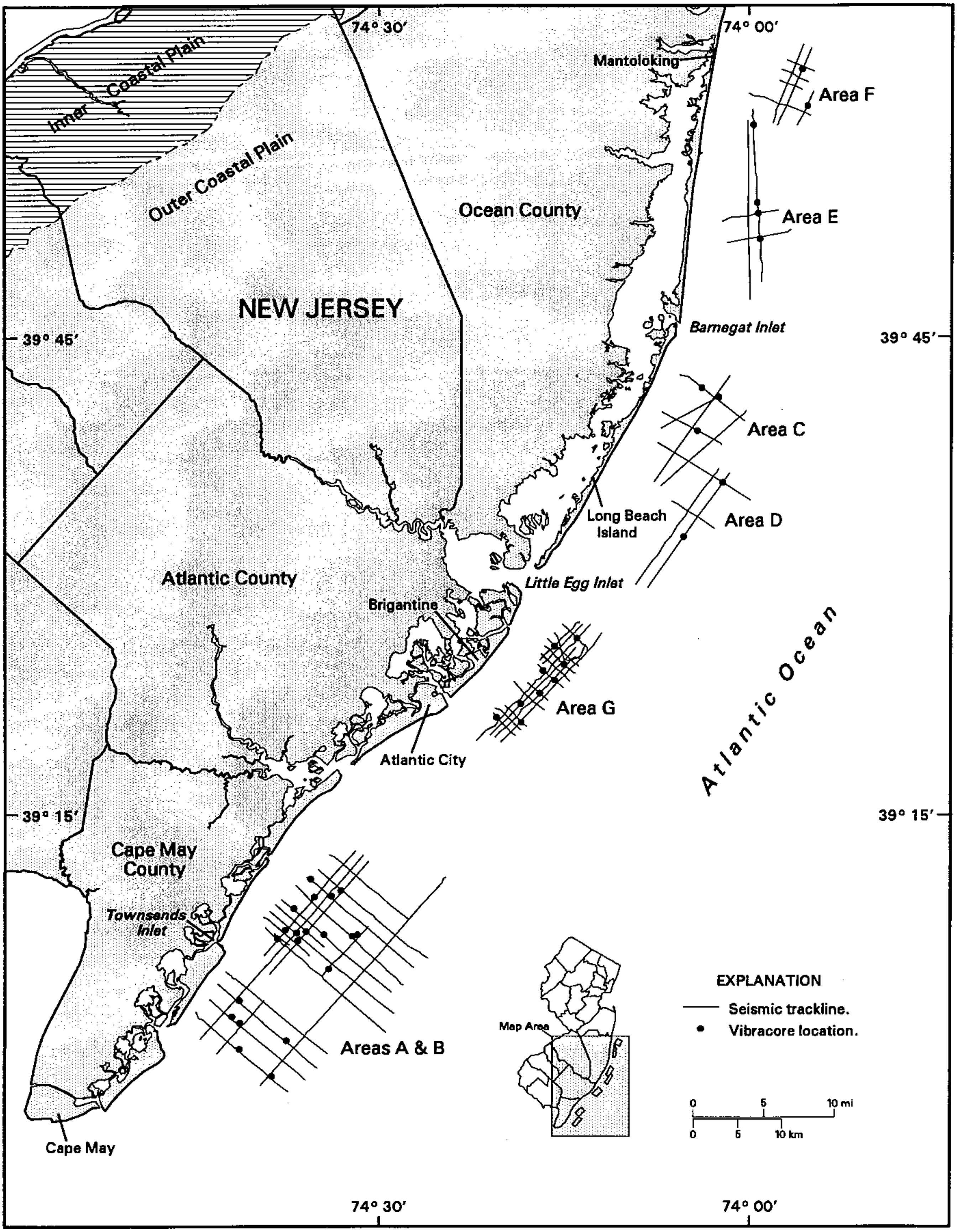


Figure1. Location of seven resource areas as shown by the seismic coverages and vibracore sites. Resource Area G discussed in the case study is offshore of Atlantic City and Brigantine, NJ.

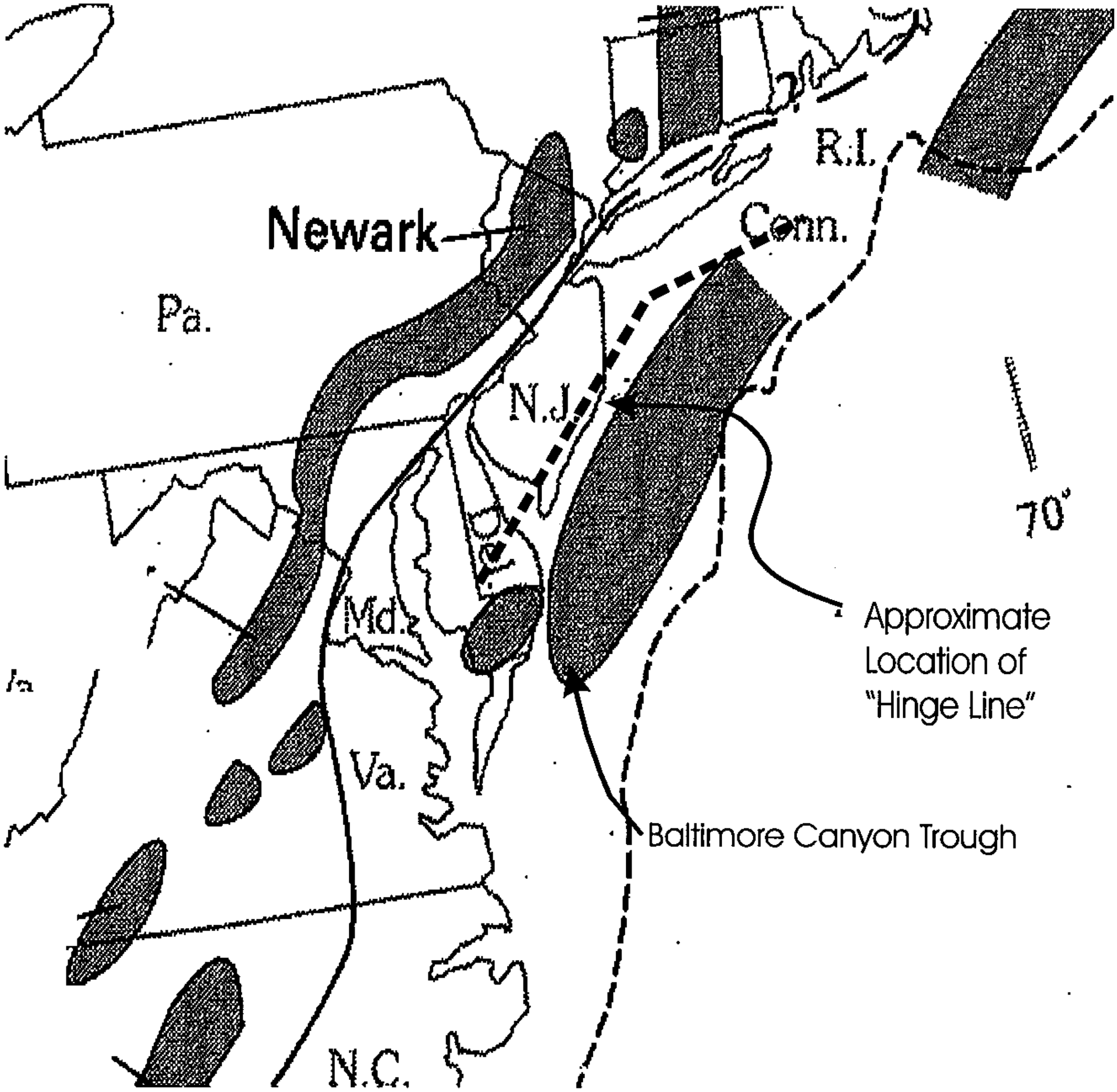


FIGURE 2. Triassic and Early Jurassic Basins in the Mid- Atlantic and the approximate location of the Baltimore Canyon Trough "Hinge Line" that is the boundary between the eroded headland and the depositional basin (from Owens and others, 1998).

The two most landward Pleistocene sea-level highstand shorelines (125 ka and 55 ka) are oriented sub-parallel to the edge of the offshore Triassic/Jurassic basin (Figure 3).

The fate of the Holocene deposits in the northern coastal area is likely controlled by a combination of the tectonics of the Triassic/Jurassic basin and the isostatic response to the last glaciation). The flexural uplift to the north of the hinge line in the vicinity of the New York Bight (Carey and others, 1998) is a probable explanation of sub-cropping or outcropping coastal plain sediments in the offshore with thin to non-existent overlying Holocene sand veneers. The Mesozoic basin also influenced the location and orientation of the Stage 2 glacial forebulge. Glacial rebound north of Barnget Inlet and forebulge collapse to the south would result in limited accommodation space for the Stage 3 and Stage 1 transgressive sediments (S.D. Stanford, oral commun., 1999).

THE PLEISTOCENE-HOLOCENE GEOLOGY OF THE NEW JERSEY OFFSHORE

Transgressive Systems and Highstand Systems tracts deposits

Work by Ashley and others (1991) provides an overview of the late Pleistocene and Holocene geology that typifies the New Jersey inner continental shelf. They note that the last two major glaciations in the late Wisconsinan (-20ka, Stage 2) and the early-mid Wisconsinan (-70 ka, Stage 4) (Figure 4) were of a magnitude sufficient to cause global sea-level lowstands. The shoreline of New Jersey was near the continental shelf edge (Stage 2), and the middle continental shelf (Stage 4) during these lowstands. The sub-aerial erosion surfaces created on the inner continental shelf during these sea-level lowstands correspond to the Type 1 sequence boundaries of Vail and others (1977) and Haq and others (1987) (Figure 5). A type 1 sequence boundary is characterized by subaerial exposure and concurrent subaerial erosion associated with stream rejuvenation, a basinward shift of facies, a downward shift in coastal onlap, and onlap of overlying strata (Van Wagoner and others, 1988). These erosion surfaces are evident on the seismic lines as prominent, laterally continuous reflectors. The most recent of these in the New Jersey offshore is the sequence boundary between the Pleistocene and Holocene sediments. It formed when Pleistocene sediments were exposed on the shelf during the late Wisconsinan glaciation (Stage 2) (see below).

Only significantly warm periods in the Holocene interglacial (Stage 1), the mid-Wisconsinan interstadial (Stage 3) and the Sangamon interglacial (Stage5e) (Figures 4) caused sea-level rises that left transgressive and highstand deposits on the inner shelf (Ashley and others, 1991). As the shoreline traversed the continental shelf during transgression, the areas of deposition of coastal and marine sediments shifted with it, creating a complex system of depositional and erosional features on the inner shelf (Sheridan and others, 1999). Thus, any transgressive and highstand deposits occurring on the shelf are remnants of formerly more laterally extensive depositional sequences that have been eroded by processes active during subsequent sea-level changes. It is likely that deposits from smaller sea-level highstands farther out on the shelf may have been removed by the sub-aerial erosion during Stage 2 and Stage 4 lowstands (Ashley and others, 1991).

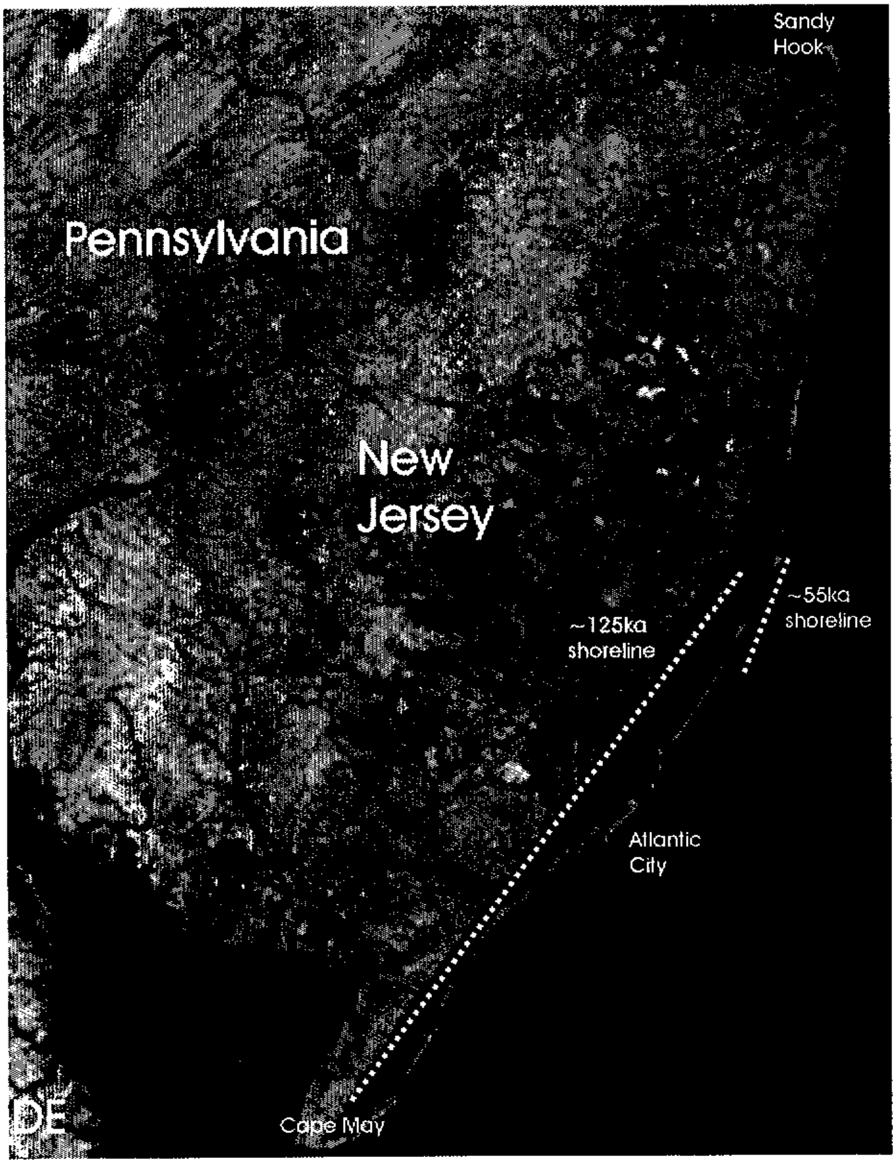


Figure 3. Satellite image of New Jersey, showing the trace of segments of former sea-level highstands (-125 ka and –55 ka) (after Ashley and others, 1991).

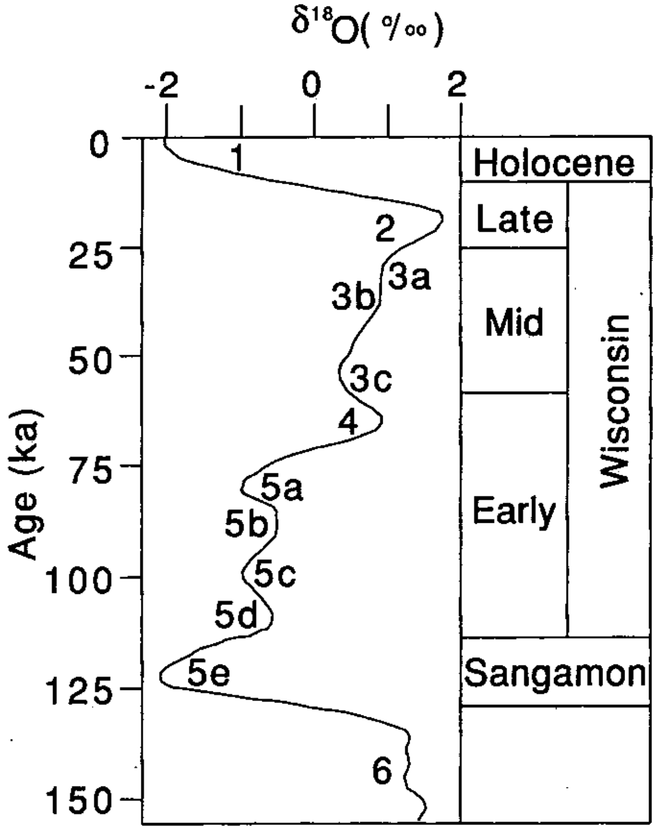


Figure 4. The SPECMAP δ18O curve (modified from Imbrie and others, 1984) correlated to the North American glacial stages. Stage 1 coincides with the Holocene transgression. Stage 3c coincides with the 55 ka shoreline, and Stage 5e coincides with the 125 ka shoreline as shown in Figure 3 (from Carey and others, 1998, after Fulton, 1990).

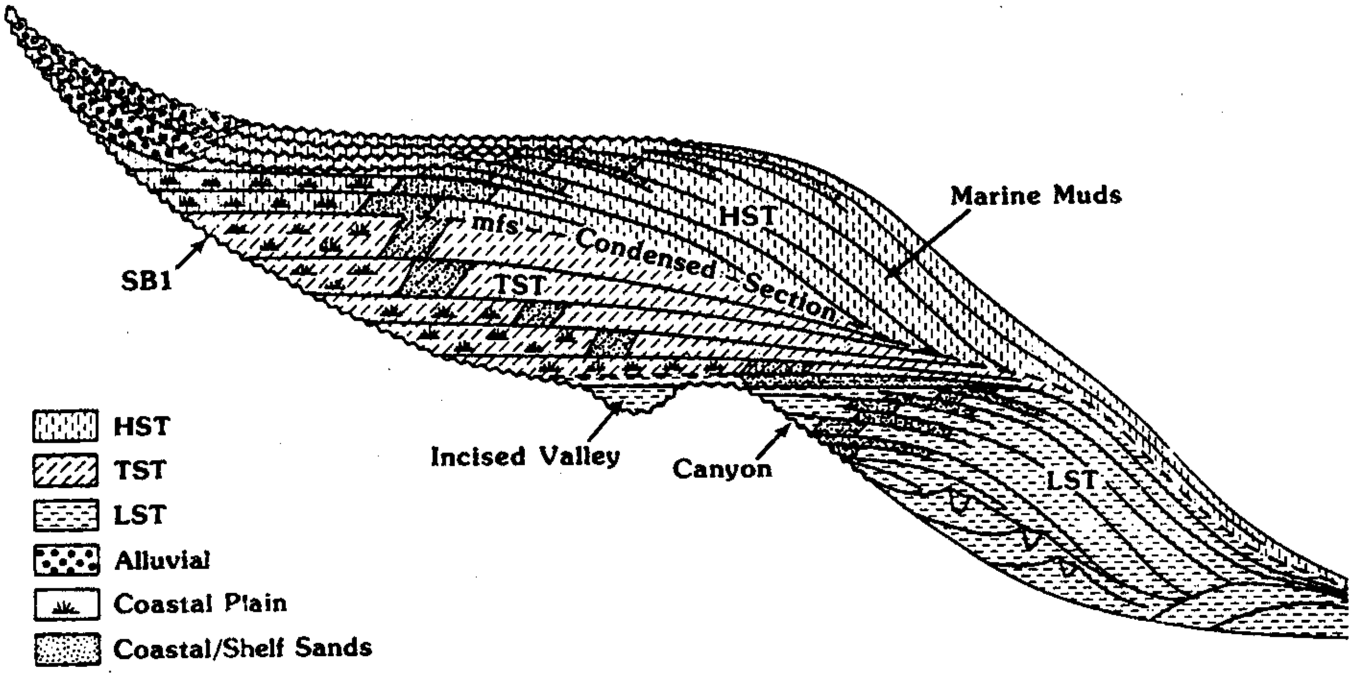


Figure 5. Major features of sequence and associated systems tracts: Incised valleys and canyons; LST = lowstand systems tract; TST = transgressive systems tract; HST = highstand systems tract; SB1 = Type 1 sequence boundary; mfs = maximum flooding surface (from Ashley and others, 1991, Figure 1, after Boyd and others, 1989, Figure 1).

Subsurface Variations in the North and South

Distinct depositional regimes in the northern and southern inner continental shelf have a substantial impact on the formation and preservation of sand shoals. Onshore along the northern coast, remnants of Stage 5 coastal deposits as thick as 20 feet are being eroded from the headlands (MacClintock and Richards, 1936; S.D. Stanford, oral commun., 1999). Offshore, Sangamon and Wisconsinan deposits (if they were present in the northern inner shelf in the past) have been stripped off. Seismic and vibracore data from offshore of Mantoloking reveal outcropping or subcropping Tertiary-age coastal plain deposits dipping gently to the southeast (Figure 6), similar to their outcrop pattern onshore (Owens and others, 1998). In some areas, these coastal plain units are overlain by Pleistocene/Holocene channel fill or capped by ephemeral Holocene sand veneers (Figure 6).

The inner shelf from Barnegat Inlet south has numerous shoal features (Figure 7). This southern offshore region is within or on the margin of the Baltimore Canyon Trough and is influenced by basin subsidence seaward of the hinge line. Evidence of this depositional trend on the seismic data includes: 1) the abundance of Holocene material overlying the Pleistocene unconformity and thus the greater depth to the major Pleistocene reflector compared to farther north; and 2) the increased thickness of Pleistocene sediments, including preservation of multiple Pleistocene and Holocene reflectors (Figure 7 and other seismic lines not shown here).

A transition zone of elongate linear shoals of Pleistocene-age material offshore of Long Beach Island separates the Holocene shoals to the south and the outcropping coastal plain units to the north. These shore-detached and shore-attached ridges, caused by erosion into Pleistocene sediments, tend to be oblique to the strike of the barrier islands by about 30°. They are typically composed of stiff sand, silt, gravel and clay. This poorly sorted material is of marginal value as beach fill. Smaller nearshore Holocene shoals offshore of Long Beach Island have been identified as alternative borrow material.

The inner shelf offshore of Cape May contains numerous large shoals formed by a combination of the accumulation of sediments by long-shore transport and spit growth processes. Given the local abundance of sand offshore of Cape May, we concentrated our sand exploration efforts farther to the north.

COMPOSITE REGIONAL STRATIGRAPHY

Smith (1996) developed a composite regional stratigraphy for Resource Area A offshore of Townsends Inlet (Figure 1), identifying sands overlying the upper Pleistocene sequence boundary (S_2) as potential borrow material (Figure 8). Vibracores from two large shoals in Area A. reveal a 2m-thick unit directly above the S_2 consisting of interbedded estuarine sediments that are unsuitable as beach material. There are up to 2m of sand above the interbedded unit, translating into a total volume for the two shoals in Area A of approximately 95 million cubic meters.

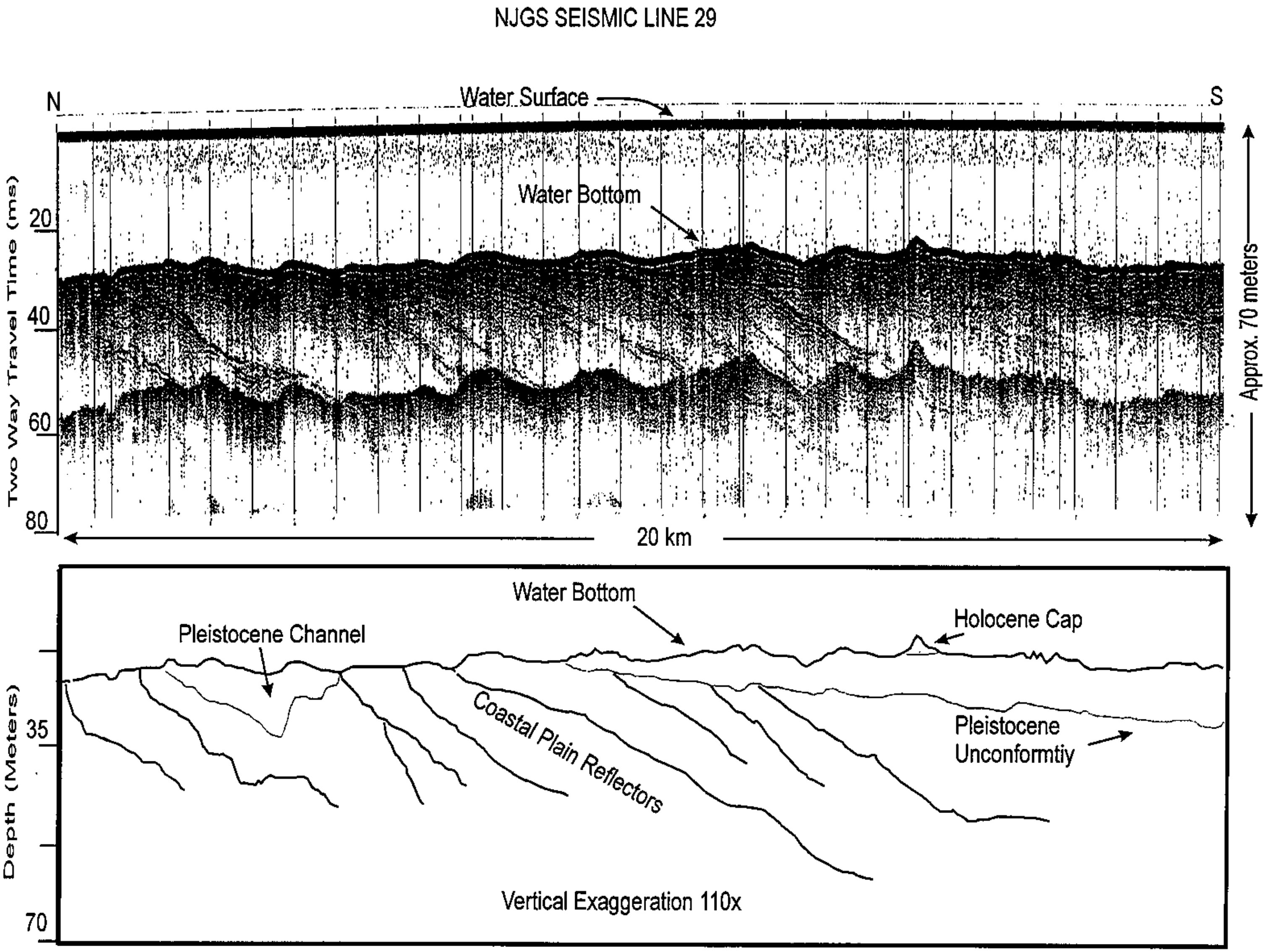


FIGURE 6. Seismic Line 29 offshore Island Beach State Park showing analog data with the interpreted results.

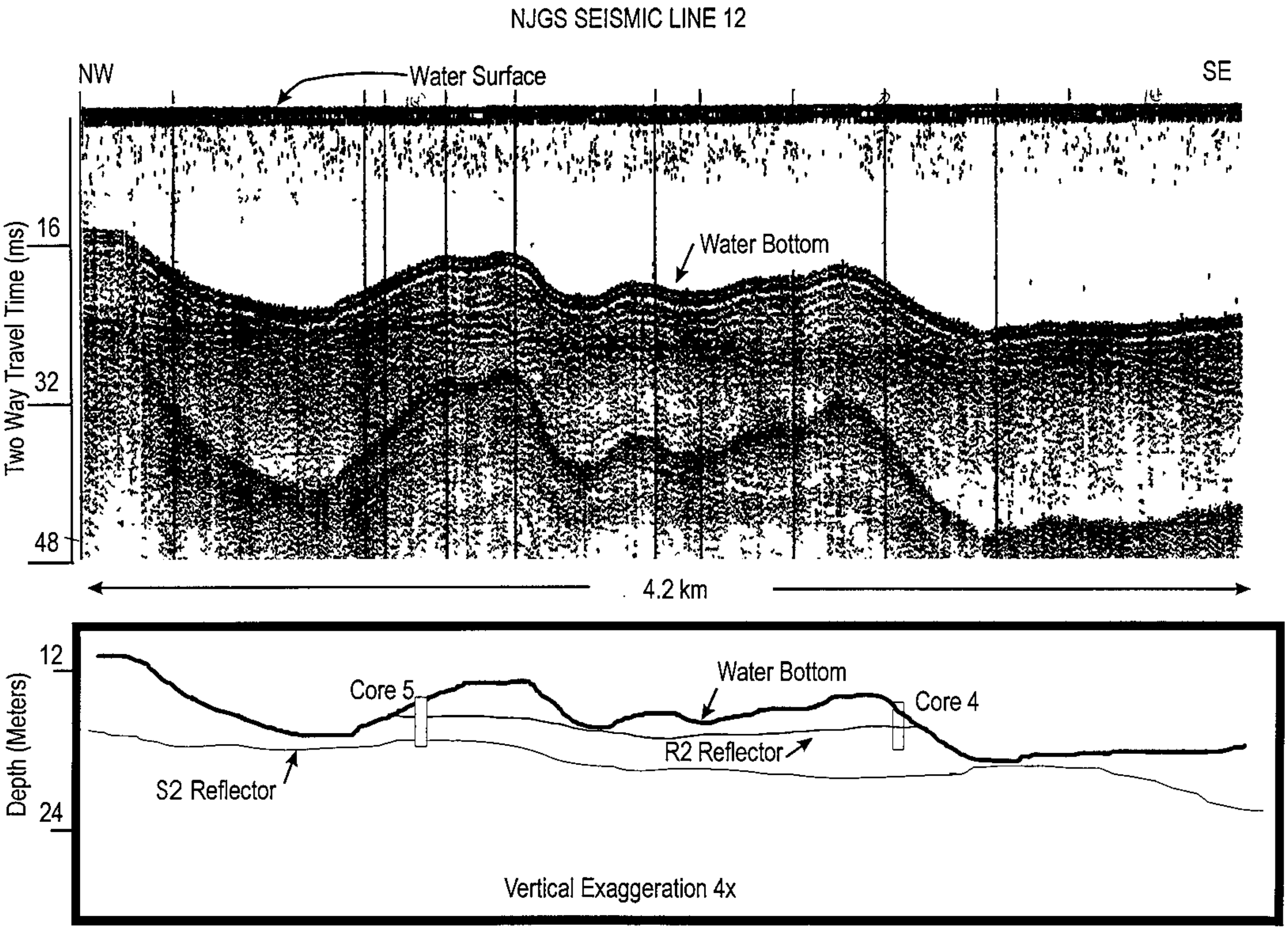

NJGS SEISMIC LINE 12

FIGURE 7. Seismic Line 12 offshore Brigantine, NJ showing analog data and interpreted Holocene shoal features.

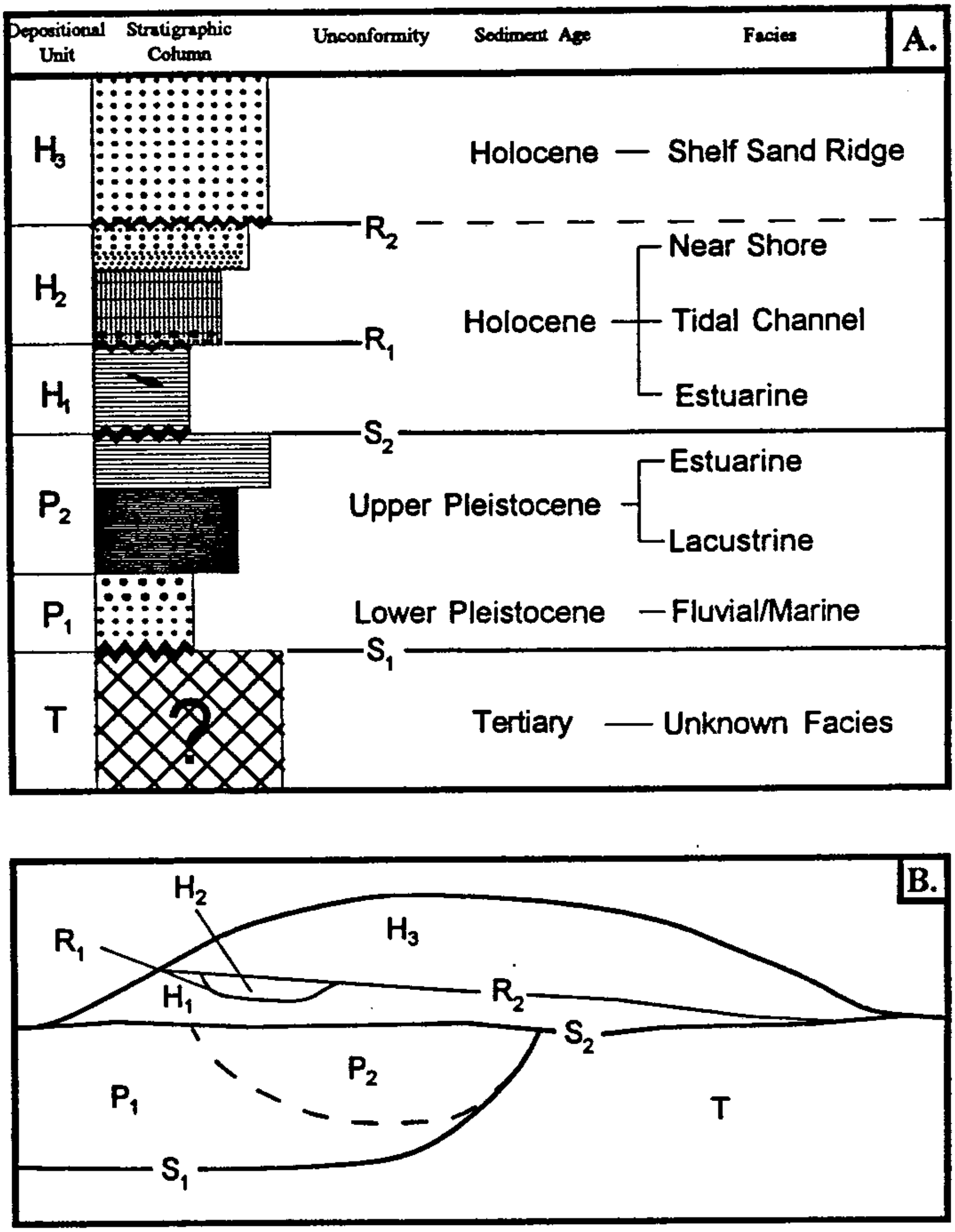


Figure 8. Composite regional stratigraphy of Smith (1996). A) Sediment type is indicated on left margin. S_2 and R_2, the regional and local unconformities, respectively, are key structural components of the Holocene shoal features in Area G. The depositional units are described in the text. B) Generalized cross-section showing sand ridge unconformities (R_1 and R_2) and relative position of Holocene depositional units (H_1, H_2, and H_3), (from Smith, 1996).

Case Study: Sand Resource Area G

Current NJGS/RU studies are developing sand resource areas offshore from Cape May to Mantoloking, NJ (Figure 1, areas labeled from "A" to "G"). Smith's (1996) composite regional stratigraphy is used as a template for the interpretation of the shallow geology in the southern offshore areas. The geology changes subtly from the southern offshore to the northern offshore, and our search criteria for locating offshore sand must adjust accordingly, as seen in the stratigraphy of Area G.

We find slightly different lithologies when we apply Smith's (1996) composite regional stratigraphy to Area G offshore of Brigantine, specifically: 1) the gravel that marks the S_2; 2) a lower sand layer 1-2m thick; 3) the interbedded silts, sands and clays of the estuarine deposits 1-3m thick; and 4) an upper sand layer 1-2m. thick. The S_2 is deeper, the interbedded unit is thicker and/or more variable in thickness, and the R_2 delineates the overlying sand deposits. While Smith (1996) measured sand resources referenced to the S_2, we measure the sand resource from the Holocene R_2 ravinement surface that separates the interbedded sand, silt and clay from the upper sand layer. This method excludes all the materials between the R_2 and the S_2, consisting largely of silt and clay that is unsuitable for beach nourishment material.

Seismic Stratigraphy

Seismic reflectors for Area G can be interpreted to depths of 25 to 30m (Figure 7). The deepest major reflector seen on the profile is formed by the aforementioned gravel layer (S_2). The gravel is fluvial, deposited on a braid plain during the late Wisconsinan glaciation and the accompanying drop in sea level (approximately 20 ka) (Ashley and others, 1991).

Holocene channels cut the S_2 in the northeastern section of Area G, and are now overlain by ebb-tidal deltaic sands. These channel structures are repeatedly incised near inlets where the ebb-tidal deltas form. This interpretation corresponds to Miller and Dill's (1973) large north-south trending channel directly beneath Beach Haven Ridge. In addition to the transgressive ravinement processes at work, migrating inlet channels (shifting back and forth along the coastline) would periodically be cut off from a coarse sediment supply and then filled in with lower energy lagoonal fine sands, silts, and clays.

Volumetric estimates for Area G are delineated from the R_2, the transgressive erosional surface created by the erosive leading edge of the marine transgression. Nearshore marine sands (the upper sand unit in the vibracores) overlie the R_2 (Figure 7).

The contoured surface (bounded by the R_2 at the base and the sediment-water interface at the top) reveals various morphological features (Figure 9). The large, multi-fingered sand sheet to the northeast may have origins as an ebb-tidal delta. It presents the most laterally extensive area for sand dredging. Reconnaissance volumetric estimates indicate a sand thickness of up to 3m.

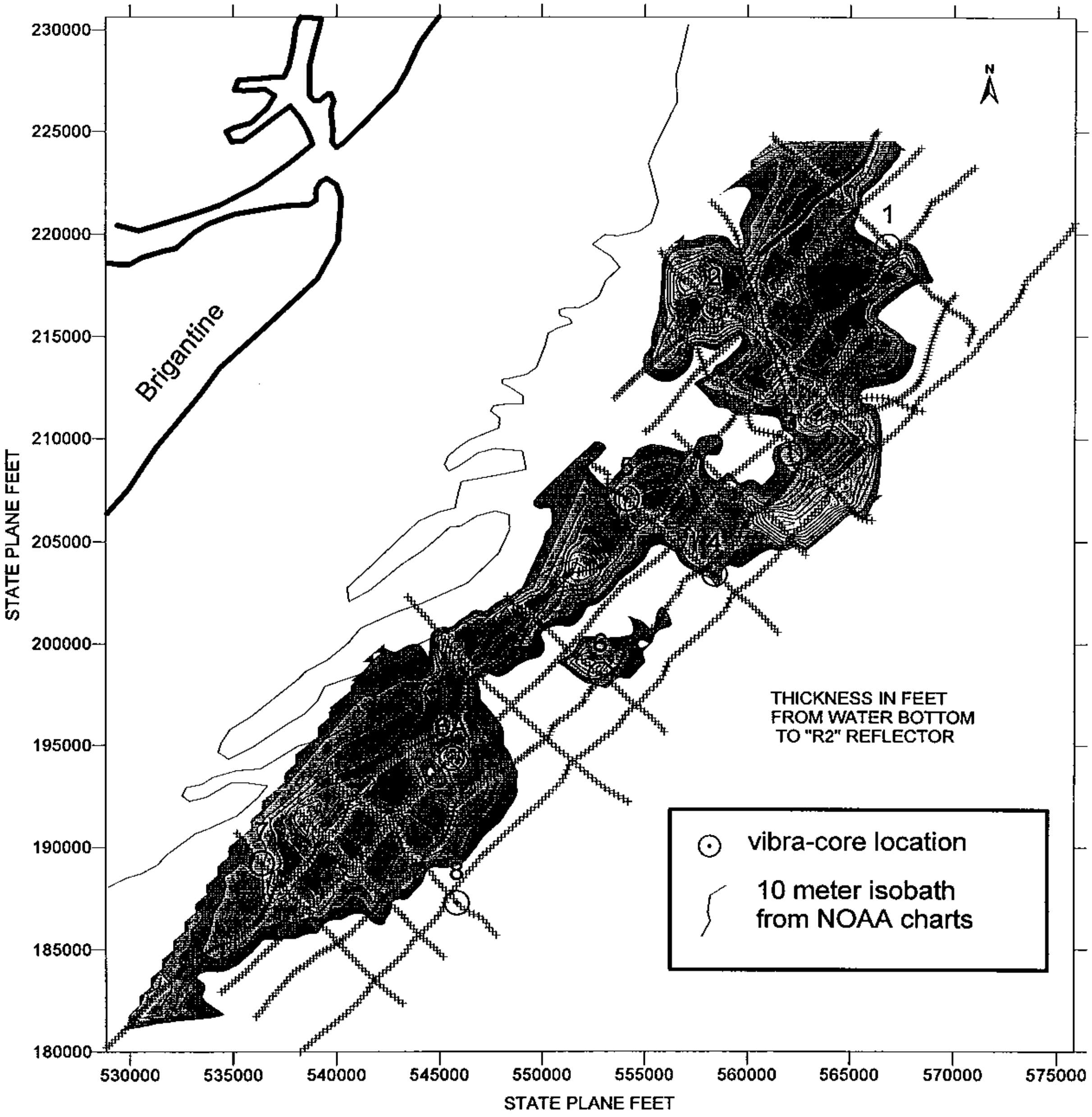


FIGURE 9. Thickness map of sand between the water bottom and the R2 layer offshore of Brigantine, NJ. The seismic profiles and vibracore locations are also shown.

Sedimentology

As noted above, the vibracores collected in Area G reveal a typical sequence of units, including: 1) a basal Pleistocene gravel below the S_2 sequence boundary; 2) a lower sand unit; 3) interbedded silts, sands and clays; and 4) an upper sand unit.

1) The Basal Gravel

This unit is a poorly sorted sandy gravel composed of 90% quartz grains and 10% other rock fragments. Shells are absent. Pebbles are well rounded, semi-oblate, and iron-stained, and range in size as large as 5 cm in diameter. The S_2 reflector that marks the top of this unit is the most prominent reflector on the seismic profiles.

2) The Lower Sand Unit

The lower sand unit that overlies the S_2 sequence boundary was deposited as sea level rose after the late Wisconsinan lowstand of 20 ka. This unit corresponds to Smith's (1996) H_1 unit, described as a sandy mud. The lower sand is the sandy depositional remnant of the transgressive systems tract, unconformably overlain by interbedded fine sand, silt and clay of the continuing Holocene transgressive event. In Core 5, the lower sand is absent and the material grades directly from the Pleistocene gravel into the interbedded sand silt and clay (Figure 10).

3) The Interbedded Unit

The interbedded (and sometimes rhythmically interbedded) fine sands and clays that overlie the lower sand (or directly overlie the S_2) were deposited in the lower energy environment of a Holocene back-bay/lagoon. Vertical root structures and particles of peat/organic material are abundant in some of the silts and clays. Shell material and burrows are common. We correlate this unit with material from the analogous unit of Ashley and others (1991), defined as Depositional Sequence II, Lower Unit, dated at 8810 ± 170 yr B.P. The interbedded unit was likely deposited during the period of rapid rise in relative sea level from approximately 12,000 to 5,000 yrs B.P. Holocene dates in this unit are reported by Snedden and others (1994) at Peahala Ridge offshore of Long Beach Island (3710 – 5900 ± 150 yrs B.P.) and Swift and others (1984) at Beach Haven Ridge offshore of Little Egg and Beach Haven Inlets (6685 – 8595 ± 170 yrs B.P).

4) The Upper Sand Unit

The upper unit is a moderately to well-sorted coarsening-upward sand. It was deposited on top of the R_2 transgressive ravinement surface, and coincides with the H_3 unit of Smith (1996), defined as the uppermost Holocene shelf sand ridge (Figures 8,11). Vibracore grain size data show a rough average phi size for the upper sand of 1.99 (medium to fine sand, Udden-Wentworth scale). The upper unit forms the present day bathymetric high areas. Seismic data indicate locations where these relatively recent features are being eroded by submarine currents that typically cut the shoals on the seaward side (Figure 9, southeast flank of designated area).

Figure 10

Here the contact between the lower Pleistocene gravels and the superimposed Holocene materials (interbedded sands and clays) is shown. Observed only in Core 5, this contact displays the change in sediment type that produces the seismic reflector referred to as S2 - the demarcation of the Holocene/Pleistocene boundary in these sequences.

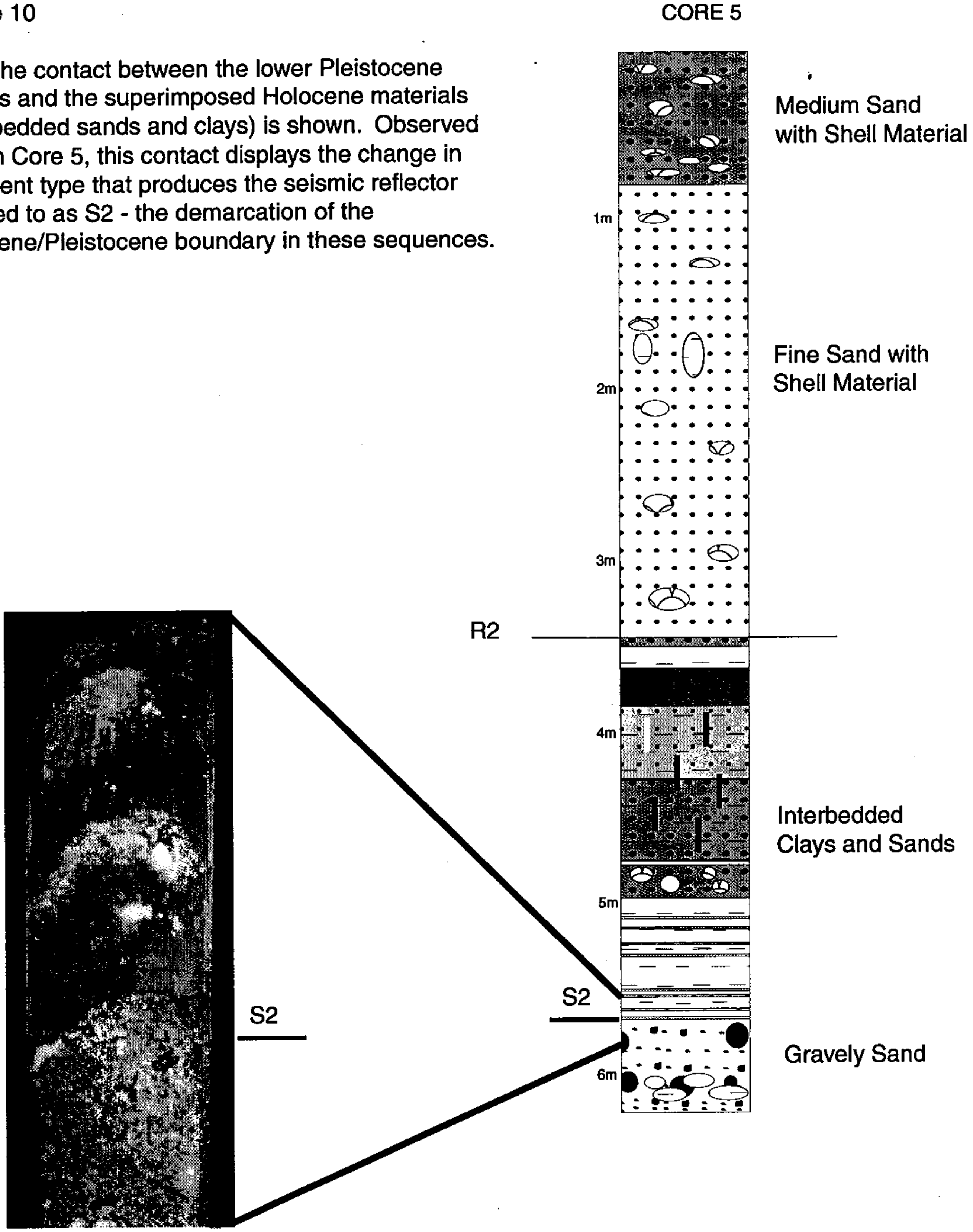
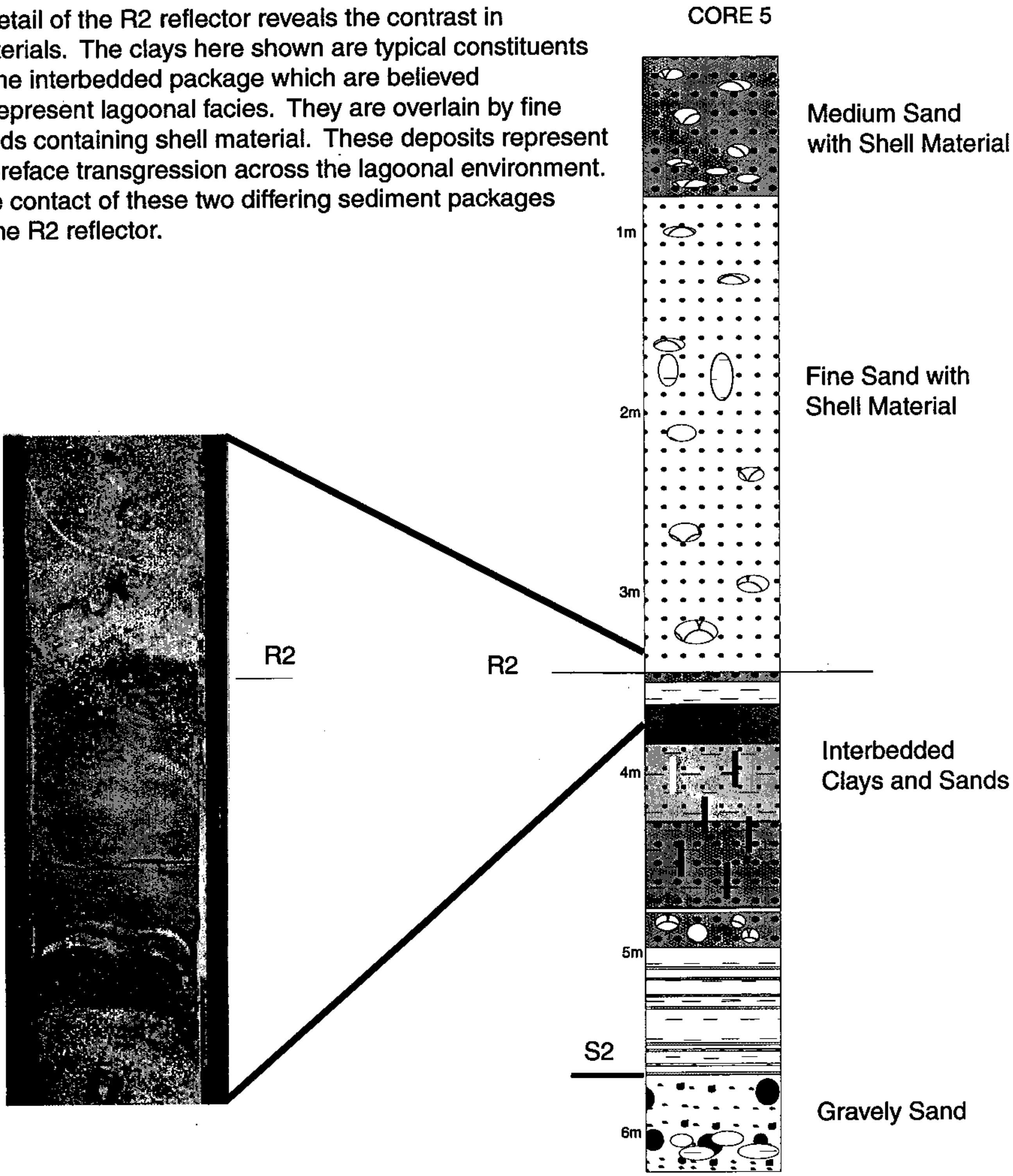


Figure 11

A detail of the R2 reflector reveals the contrast in materials. The clays here shown are typical constituents of the interbedded package which are believed to represent lagoonal facies. They are overlain by fine sands containing shell material. These deposits represent shoreface transgression across the lagoonal environment. The contact of these two differing sediment packages is the R2 reflector.



Interpretation of Depositional Environment

A geologic history emerges for Area G. Submarine structures with a positive relief of up to 6.5m define the area. In the northeastern portion of Area G, a sheet several meters thick with radiating spurs or lobes overlies older channel structures. This is the possible former ebb-tidal delta of Little Egg Inlet. To the south and west of this former ebb-tidal delta we find elongate ridges oriented approximately 30° to the present shoreline that resemble the downdrift shore-attached and shore-detached linear sand ridges south of Barnegat Inlet (Ashley and others, 1991). There is some seismic evidence of possible channel features at the southern end of Area G, potentially the former location of today's Absecon Inlet. The elongate ridges could be the smoothed remnants of lobes previously attached to the former Absecon, Brigantine, or Little Egg Inlets.

CONCLUSIONS

Distinct depositional environments in the northern and southern offshore regions have a substantial impact on the formation and preservation of sand shoals. The predominantly erosional regime of outcropping Tertiary coastal plain deposits in the northern offshore area contrasts with the mainly depositional regime of Holocene sand shoals associated with shifting inlets in the southern offshore area. This interpretation directs us to look first for sand in the southern offshore.

The Holocene transgressive ravinement surface (R_2) separating estuarine sands, silts, and clays from overlying sands offshore of Brigantine provides a distinguishable surface on the seismic and vibracore data for delimiting sand resources. The contoured surface of from the R_2 to the sediment-water interface in Area G reveals an ebb-tidal delta and remnants of shore-attached and shore-detached ridges.

Future work in the northern coastal area will provide the opportunity to add some insight to the offshore geologic framework. Initial seismic exploration reveals mainly Pleistocene/Holocene channel-fill deposits, outcropping coastal plain units of varying lithologies, and relatively thin and discontinuous Holocene sand veneers.

ACKNOWLEDGEMENTS

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HURRICANE HAZARDS IN NEW JERSEY

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ABSTRACT

The New Jersey Coast is subject to heavy destruction from both tropical storms (hurricanes) and extratropical storms (nor'easters) for a number of reasons. It has a long ocean coastline that is fully exposed to easterly winds. Development and population have increased rapidly in the last two decades, a time of lower hurricane frequency. The scarcity of hurricane building codes in many New Jersey coastal communities will result in greater storm damage. Evacuation is a problem because of the few and narrow evacuation routes available. In addition, low elevation "choke points" on those routes will flood quickly at the onset of gale-force winds preceding hurricane landfall. Engineering structures (groins, jetties and stabilized inlets), along with sea level rise, have resulted in increased beach erosion. Heavy development has reduced the heights of the dunes that provide storm surge protection. The Jersey Coast is especially subject to storm surge amplification. The easterly winds at the front of a coast-parallel tracking hurricane drive coastal waters westward. The impounded waters rise to anomalous heights in the Apex of the New York Bight and flood coastal New Jersey.

Nor'easters cause major damage because of their frequency, duration (from several tidal cycles to days) and the long easterly exposure of the New Jersey Coast. Several nor'easters hit the New Jersey Coast each year. Hurricanes that move close enough to the coast to cause major damage occur about every 4 to 5 years.

All of the hurricanes that reach the New York/New Jersey Metropolitan Area are more intense than their counterparts of similar Saffir-Simpson Category in the South. These northern hurricanes move two to three times faster and have larger radii of maximum winds. The historical record indicates that coast-parallel tracking hurricanes are far more frequent than coast-normal tracking storms in New Jersey. Coast-parallel tracking hurricanes generate high surge levels and wave heights as they move along the New Jersey Shore. However, rare coast-normal hurricanes can cause far more serious damage because the powerful right eyewall of the storm moves far inland. On September 4, 1821 a Category 2 hurricane crossed the state overland along the path of the present Garden State Parkway. This storm maintained its power across New Jersey, New York City and well into Southern New England. In New York City, it raised water levels at The Battery 13 feet in one hour, from low tide. In 1903, a Category 1 storm crossed over the Northern New Jersey Coast and moved inland. This scenario was used for the Tropical Prediction Center's SLOSH model for predicting surge levels in the New York/New Jersey Metropolitan Area. The worst-case scenario for that region would be a Category 3 coast-normal tracking storm that makes landfall just north of Atlantic City. This track would place the right eyewall of the storm over the major population centers of New Jersey, New

York and Southern New England, would raise surge levels to exceptional heights and would cause major destruction along the highly-developed shoreline of the Northeast United States.

INTRODUCTION

Hurricane hazard awareness in New Jersey is not as well developed as it is along the southeastern Atlantic and Gulf Coasts. This is primarily because major hurricane landfalls in New Jersey have been a relatively infrequent event in this century. However, the 19th century record shows at least two major hurricane impacts in, 1821 and 1893. Any hurricane landfall in New Jersey can be far more severe than the landfall of a storm of similar power at lower latitudes. The Northeast US is outside of the main hurricane belt, yet the most destructive, although not the most intense, hurricanes of record have occurred here (Dunn and Miller, 1964).

New Jersey has a highly populated and developed 130 mile-long shoreline. Few coastal inhabitants are aware that major hurricanes have traversed the state. They are aware of the moderate coastal damage caused by the nor'easters that hit New Jersey each year. However they are not aware of the potential damage that could be caused by the hurricanes that moved northward offshore. If one of these hurricanes passed close to the coast, as in August of 1893, the damage would be severe.

Coastal development in New Jersey has increased markedly from the 1960's to the present, a time of relatively low hurricane frequency. Research by Gray (1992), discussed later in more detail, suggests that a (multi) decade-long cycle of increased hurricane frequency may have begun in the late 1990's. This makes it vital to understand the hurricane damage potential in New Jersey.

This article describes the special vulnerability of the New Jersey Coast to storm damage. Both nor'easters and hurricanes are threats, but only the latter are considered in detail in this paper. Hurricane characteristics are reviewed briefly in order to understand the unique damage caused by northern hurricanes. The role of hurricane track type (coast parallel or normal) in coastal devastation is considered both from the historical record and the effects of recent hurricanes. We must understand New Jersey's hurricane history so that we can predict what will happen in the near future. Recent research now indicates that in the first decades of the Millennium, both nor'easters and hurricanes will be more frequent, and possibly stronger in the Northeast US.

STORM ACTIVITY IN NEW JERSEY

The coast of New Jersey is affected by both tropical (hurricanes) and extra-tropical storms (nor'easters). The relative dangers posed by the different types of storms are given in Table 1. The shoreline of New Jersey is composed of three distinct components that will respond differently to the same coastal event. These differences involve: relative shelter from easterly winds, bathymetry and coastal configuration, exposure to the open ocean, and the tendency for surge levels to be amplified in that region by local conditions.

The Northernmost region involves Raritan and Sandy Hook Bays, Upper New York Bay and Newark Bay. This is a relatively shallow area 4.9 - 20 meters (16-66 feet) with complex water movements and an irregular bathymetry due to numerous ship channels. The open coast from Sandy Hook to Cape May experiences full ocean conditions with the potential for massive wave generation. The Southwest section of the Jersey shoreline lies along the relatively sheltered Delaware River Estuary. The southernmost exposure of the New Jersey Shore here reduces wave erosion. However, the Delaware River Estuary has a wide opening, 17.7 km (11 miles) that narrows steadily inland. Funnel-shaped estuaries such as the Delaware can generate abnormally high storm surge levels from easterly winds.

NOR'EASTERS **(MOST COMMON)**

Duration through several tidal cycles builds up water levels against the coast and causes increased erosion and flooding.

COAST- PARALLEL TRACKING HURRICANES

Easterly winds at the front of the storm amplify surge levels and wave heights along the New Jersey Coast

COAST- NORMAL TRACKING HURRICANES **(RAREST)**

Massive devastation when the right eyewall of the storm moves deep inland. If the storm then recurves eastward, it is the worst-case scenario for the New York Metropolitan Area.

Table 1- Storm dangers for New Jersey

Many people cannot clearly distinguish between the two. Hurricanes cause greater damage because they are more powerful. However they are far more infrequent than nor'easters in New Jersey. Nor'easters are far less powerful but they can cause great damage because of their size and duration. It is important to realize that the rise of storm surge in each of these events is quite different. In a nor'easter, the water levels rise progressively with each tidal cycle because easterly winds prevent complete draining on ebb tides, whereas flood tides push more water into eastward-facing New Jersey estuaries. In a hurricane, storm surge rises rapidly, to much greater heights than in nor'easters . The differences between these two types of storm systems is detailed in Table 2. Hurricanes will be discussed in detail later in this paper.

PARAMETER	NOR'EASTERS	HURRICANES
ORIGIN, TRACK AND CENTER CHARACTERISTICS	Form in temperate latitudes and migrate east and northward. No distinct eye. Cold core.	Form in tropical latitudes near the Equator. Atlantic Hurricanes migrate eastward and then northward. Distinct eye. Warm core
RADIUS OF DESTRUCTIVE WINDS	Hundreds of miles	Less than a hundred miles
DURATION IN TIDAL CYCLES	Several, possibly over a few days	Generally one or two
AREA AFFECTED	Coastal region primarily. Moderate wind and rain inland	Extreme wind and surge damage in coastal areas. Heavy winds and flooding can penetrate far inland in some hurricanes
STORM SURGE	Generally up to 6 feet	Generally up to 22 feet. May reach 30 feet under certain local conditions. Waves are superposd on the surge dome increasing water heights
MAXIMUM WINDS (Miles per Hour)	Generally up to 74 mph	155 mph plus (Category 5). Gusts can be 20-50% of the sustained wind value.
AVERAGE RECURRENCE INTERVAL (YRS.) OF MAJOR EVENTS	1 - 3	Highly Variable, but generally greater than 5-10 years
DAMAGE COSTS	Hundreds of millions	Hundreds of millions to billions
PREDICTED FREQUENCY IN NEXT DECADES	INCREASE (V. Cardone)	INCREASE (W. Gray)

N.K.Coch 1999

Table 2- Differences between extratropical (nor'easters) and tropical (hurricanes)

NOR'EASTERS

Nor'easters occur several times a year and can provide a preview of the kinds and scale of damages to be expected from the inevitable future landfall of a hurricane along the low-lying and heavily developed coast of New Jersey. Detailed accounts of major nor'easters in New Jersey can be found in Savadone and Bucholz (1993). Only those nor'easters that have affected the developed New Jersey Coast are reviewed here.

March 1962, "The Great Atlantic Storm"

This massive storm system affected 600 miles of the Mid-Atlantic coastline and had devastating effects in New Jersey. Water levels rose to high levels because landfall was near the Spring Equinox and the storm persisted through six tidal cycles (Flood + Ebb). Consequently, successive storm low tides rose to levels typical of normal high tides.

The damage succession during successive tides at Long Beach was detailed by Savadone and Bucholz (1993).

> Tues. AM- dunes out, seawalls and bulkheads undercut
> Tues. PM- Beaches destroyed
> Wed. PM- Debris pushed into whatever houses were still standing
> Thurs. AM- Tide not as high
> Thurs. PM- Storm moving out, water moves into channels through Long Beach
> Fri. AM - Clear and sunny, sea back to normal. (Savadone and Bucholz , p. 114)

On Friday, after three days of storm activity, there were few houses, little beach, no dunes and Long Beach Island was now cut into 5 islands. Three of these inlets were to close through normal littoral drift deposition, and one had to be filled during the restoration process.

One of the most intriguing effects of erosion at the south end of town in Harvey Cedars in the 1962 storm was the uncovering of evidence of great destruction in a historic (19th century) hurricane.

> ..." the rushing waters had uncovered remnants of a forest of swamp cedar that Henry Hudson saw there in his voyage in 1609. The last of which (the trees) had been blown down in the hurricane of 1821. (Savadone and Bucholz, 1993, p. 134)

1991 "Halloween Storm"

Although classified as an extratropical storm, this event was really a hybrid. The storm formed off Nova Scotia as Hurricane Grace was losing power in the Atlantic. A high pressure system prevented the low from moving north. The clockwise winds around that high pressure system sent the storm south along the New England and upper Middle Atlantic Coast.

The confluence of the wind directions at the south of the high and the north of the low systems greatly intensified the strength of the easterly winds affecting the coast. Such a scenario (Figure 1) greatly influences damage along the Middle Atlantic Coast

Major erosion occurred along the coast from Maine (the lower floor of President Bush's vacation home at Kennebunkport was destroyed) to the Middle Atlantic with damage extending down to Palm Beach, Florida. Waves broke over the 100 foot tall Minot Light in Massachusetts. The storm lasted through three high tides, fewer than these of the 1962 storm, but the New Jersey damage was considerable. Dunes and sea walls were undercut, and beach levels dropped as much as five feet in some places (Savadone and Bucholz, 1993, p.150).

December 11-12, 1992 Storm

This low pressure system was located over the Delmarva Peninsula by Friday December 11th. As in the 1991 "Halloween Storm", the confluence of the wind directions at the south of the high and the north of the low systems greatly intensified the strength of

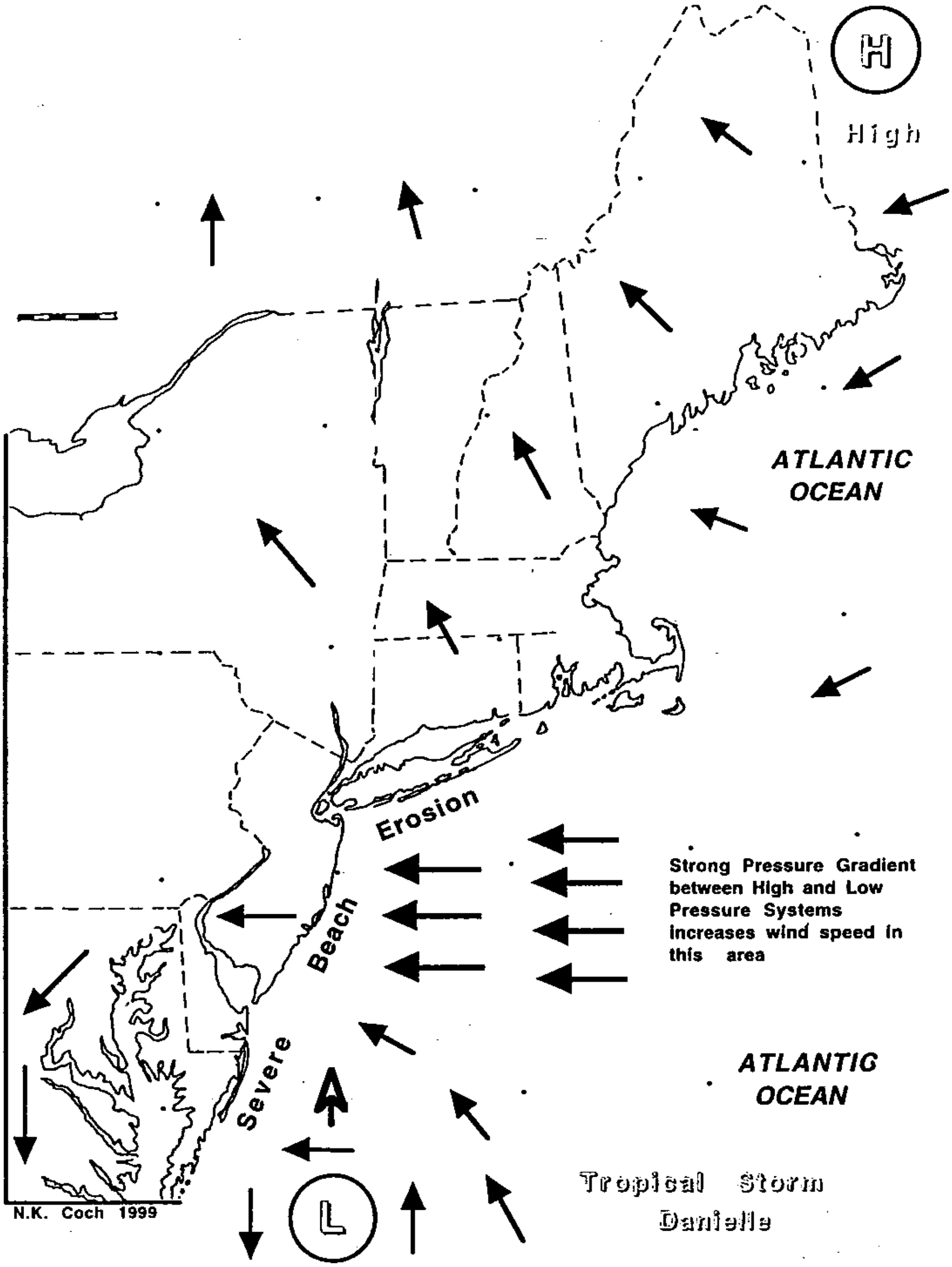


Figure 1 - Reasons for severe coastal erosion associated with Tropical Storm Danielle, September 23-26, 1992. Severe erosion occurred along the New Jersey Shore as a result of the confluence of winds from a high-pressure system to the North and tropical storm Danielle to the South.

the easterly winds affecting the coast (Figure 1). Unfortunately for New Jersey, the confluence area was centered around Wildwood, New Jersey.

Major erosion occurred along the New Jersey Coast. Tides were prevented from receding, while water built up for several days. Twelve to eighteen foot water levels smashed everything along the coast, even rising through storm drains to flood the areas behind. The sea wall in Sea Bright broke in two places scattering 2-3 ton rock blocks in yards. (Savadone and Bucholz, 1993, p. 151-154)

This disastrous nor'easter storm had gusts that locally reached Category One Hurricane force. Wave impact, plus coastal and estuarine flooding through many tidal cycles, caused massive damage. Unprotected portions of the coast, such as the Sandy Hook National Seashore, were breached by overwash channels and suffered severe beach erosion. The northernmost coast of New Jersey, south of Sandy Hook, had massive sea walls to protect barrier island communities, such as Sea Bright, from wave action. However, these seawalls were effective against waves only in the early stages of the storm. (Figure 2)

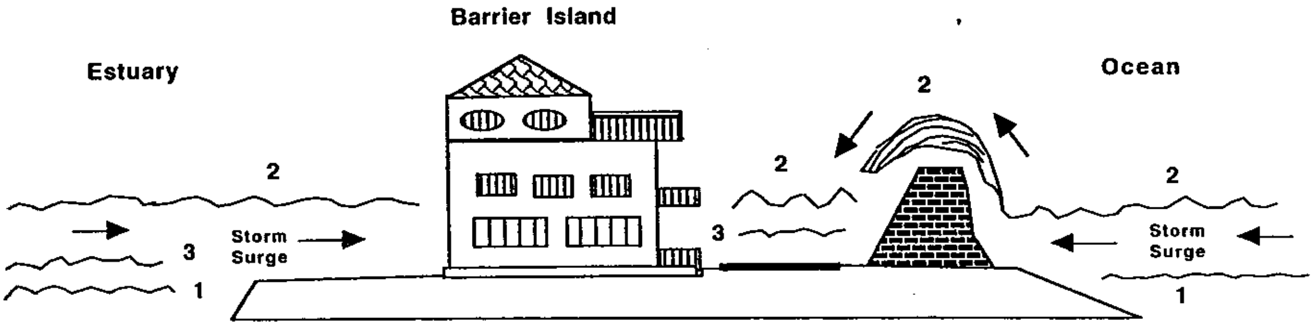


Figure 2- Flooding problems on seawalled coasts in northern New Jersey.

Stage 1: Normal sea level. Waves break on the sea wall.

Stage 2: Nor'easter or hurricane makes landfall. Waves overtop, or break over, top of sea wall. Storm surge builds up in estuary behind barrier-island.

Stage 3: Storm passes and water levels begin to drop in estuary. However, sea wall prevents water form returning to the ocean. Flooding conditions persist in the seawall area for a time after the storm passes.

Wave uprush overtopped the seawalls, and water accumulated behind them. At the same time estuaries, such as the Shrewesbury River to the west of Sea Bright, were flooding communities from the landward side. Ironically, the seawalls increased flooding damage because they prevented impounded waters from returning seaward at low tides or even for a period after the storm ebbed. The combination of seawall overtopping, estuarine flooding, and ebb surge caused serious damage to structures between the seawall and the estuary to the west. Structures built directly on and behind the seawall were totally destroyed . One cabana complex was built behind a seawall with a deck cantilevered over the "beach" in front of the seawall. The December 1992 storm removed the deck, the cabanas, and most of the paved parking lot to the west (Coch 1994a, Figure 20).

HURRICANES

Hurricanes are large scale low pressure systems with definite organized circulation that develop over tropical or subtropical waters just north of the equator in the North Atlantic, Caribbean, or in the Gulf of Mexico.

Hurricane activity is not as frequent along coastal New Jersey as for other regions of the Atlantic Tropical Cyclone Basin (Northeast, South Atlantic, Caribbean and Gulf of Mexico). Since 1893, 21 hurricanes have passed within 125 statute miles of Atlantic City (USACE, 1992, Table 1-1). Details on hurricane formation, intensification and migration are given in Risnychok (1990) and Coch (1994b). Only those aspects that affect New Jersey are considered here.

Structure

A mature hurricane contains a series of spiral bands of high winds and thunderstorms surrounded by a clear area of low pressure and low winds called the eye (Figure 3). The portion of the storm immediately adjacent to the eye is the eyewall, which has the highest wind velocities. The maximum storm winds occur at the radius of maximum winds, generally 24 - 40 km (15-25 mi.) to the right of the center of the eye (Powell et al. 1991). However, the radius of maximum winds can vary from 6.4 km to 80.4 km (4-50 miles) in the Atlantic tropical cyclone basin (USACE, 1992, p.2-5).

Power

The relative strength of a hurricane is described on the Saffir-Simpson Scale (Simpson, 1974). The scale assigns a category from 1 to 5 to each storm based on its central pressure, sustained winds and height of storm surge (Table 3). A more detailed version, describing damage effects, is presented in, Simpson and Riehl (1981, pp. 366-368). In general, higher category storms are less frequent and do greater damage than lower category ones.

It is very important to realize that the strength (Saffir-Simpson Category) is only one of the factors that determine the extent of damage that a hurricane will produce along a section of the coast.

A number of other local and chance factors determine the actual damage that will be caused by a given hurricane. These include the portion of the storm that passes over a given area, its track (coast-parallel or coast-normal), forward velocity, tidal stage at landfall, development and population density, and precipitation. The scale also assumes an average uniform coastline and does not consider local bathymetry and coastline configuration (USACE. 1992, p.2-6).

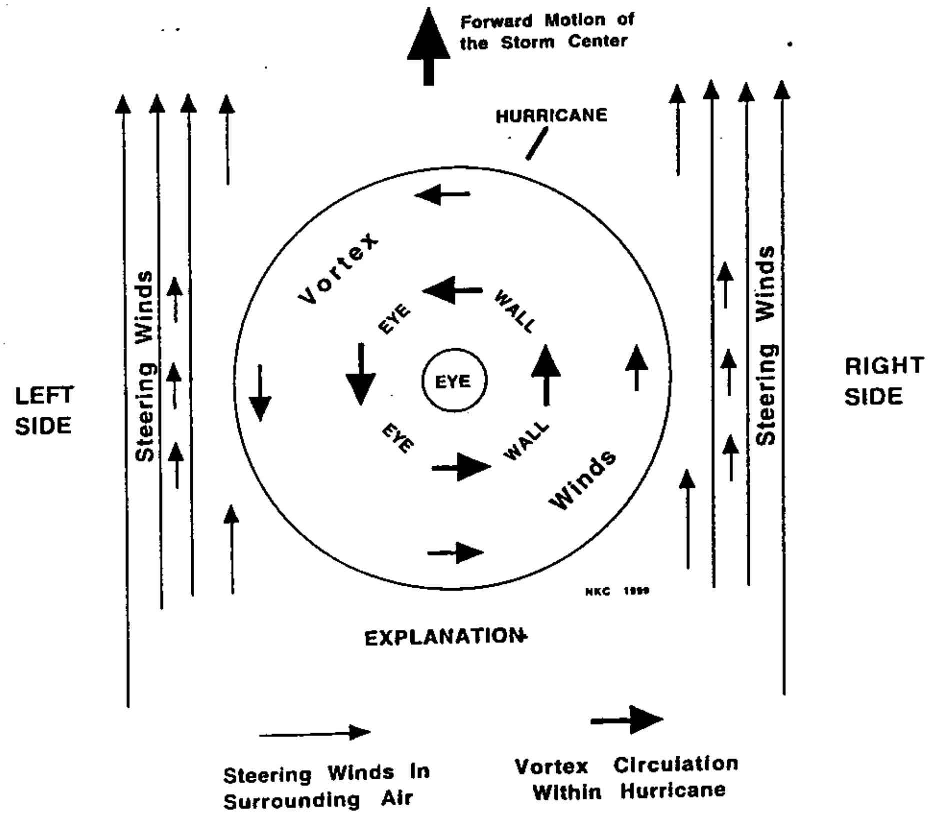


Figure 3- Wind vectors in hurricanes. The high-speed vortex winds move counterclockwise around the eye. At the same time, the storm is moved forward by the wind field around the storm. On the right side of the storm, the two winds are moving in the same direction and are vectorially added.

1 **WINDS 74-95 MPH or STORM SURGE 4-5 FEET ABOVE NORMAL.**
No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery and trees. Also, some coastal road flooding and minor pier damage.

2 **WINDS 96-110 MPH OR STORM SURGE 6-8 FEET ABOVE NORMAL.**
Some roofing material, door and window damage to buildings. Considerable damage to vegetation, mobile homes and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of center. Small craft in unprotected anchorages break moorings.

3 **WINDS 111-130 MPH OR STORM SURGE 9-12 FEET ABOVE NORMAL.**
Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain continuously lower than 5 feet above sea level may be flooded inland as far as 6 miles.

4 **WINDS 131-155 MPH OR STORM SURGE 13-18 FEET ABOVE NORMAL.**
More extensive curtainwall failures with erosion of beach areas. Major damage to lower floors of structures near the shore. Terrain continuously below 10 feet above sea level may be flooded requiring massive evacuation of residential areas inland as far as 6 miles.

5 **WINDS GREATER THAN 155 MPH OR STORM SURGE GREATER THAN 18 FEET ABOVE NORMAL.**
Complete roof failure on many residences and industrial buildings. Some complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Major damage to lower floors of all structures located less than 15 feet above sea level and within 500 yards of the shoreline. Massive evacuation of low areas on low ground within 5-10 miles of the shoreline may be required.

NOTE: Actual storm surge values will vary considerably depending on coastal configuration and other factors

Table 3- Saffir Simpson Scale of hurricane intensity, Source: NOAA (1990)

Lower category hurricanes can cause far greater damage than expected under certain local conditions. Hebert and Case (1990) tabulated the costliest hurricanes, in terms of 1989 dollars at the end of that hurricane season. Observations based on their data include:

1) Seven of the twenty most costly hurricanes damaged areas along the Atlantic coast of the northeastern US;
2) Of those seven, four had forward speeds greater than 64 km/h (40 mi./h);
3) The third most expensive hurricane, Agnes (1972), was only a Category 1 hurricane, but it caused $6.3 billion in damage. The damage from Hurricane Agnes resulted mainly from flooding caused by the torrential rains associated with the storm, and;
4) The last great northeastern US hurricane, the 1938 "Long Island-New England Hurricane" was only a Category 3 event, but was the sixth most costly hurricane up to 1989.

Velocity

Two velocity components are associated with hurricanes. The first is the high velocity vortex winds flowing counterclockwise around the eye (Figure 3). The second is the lower velocity steering winds that surround the storm and direct its movement. The steering winds determine the forward speed of the hurricane, typically 16-23 km/h (10-14 m/h) for a southern Hurricane but 2 to 3 times higher for a hurricane moving in northern latitudes.

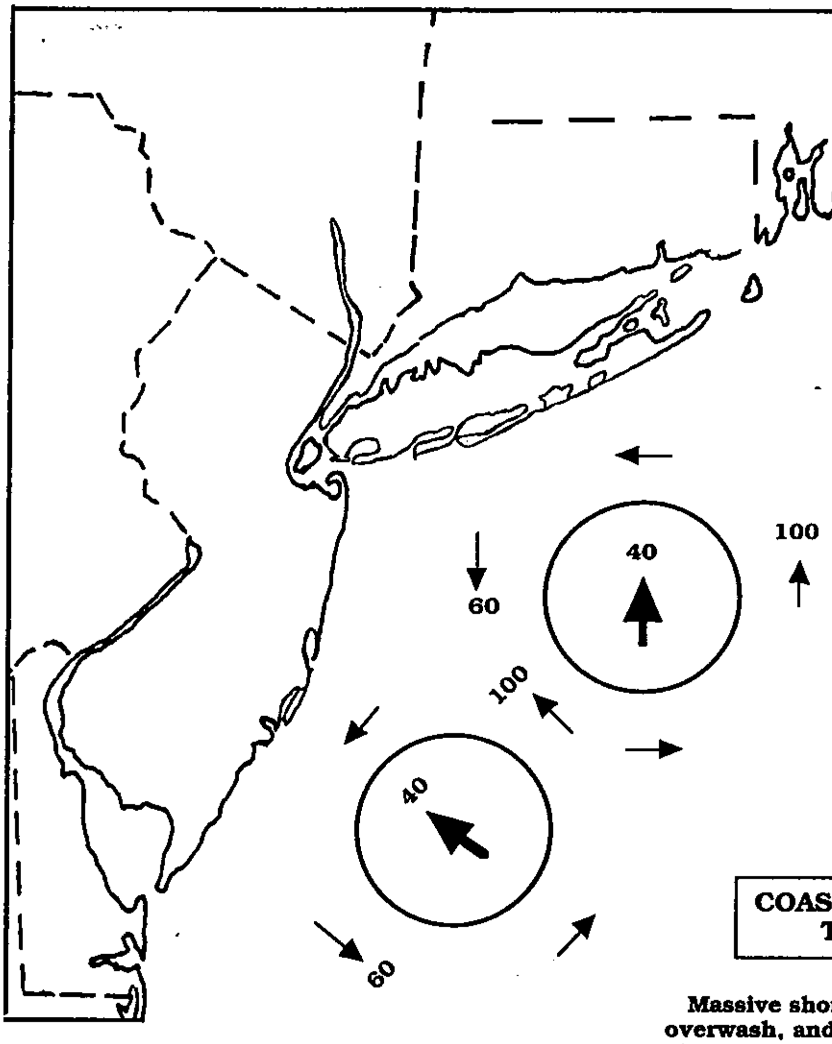
The interplay of these two velocities greatly influences the areal distribution and intensity of both storm surge and wind damage when the hurricane makes landfall. On the right side of the storm (looking in the direction of movement) the rotary winds and the steering winds of the storm are in the same direction (Figure 3). If the winds are 161 km/h (100 mi./h) and the storm is moving forward at 32 km/h (20 mi./h), the effective wind on the right side of the storm can be as high as 161 + 32 or 193 km/h (120 mi./h) - a considerable increase in storm power. However, on the left side of the storm, the velocities are subtractive and the effective wind can be as low as 161 - 32 or only 129 km/h (80 mi./h), barely of hurricane strength (Table 3). The significance of these velocity relationships is that the winds are always stronger and the wind and water damage is greater, on the right side of a hurricane.

Eye Center Track

The track of the hurricane eye center (coast parallel or coast normal) has a great influence on the damage that will result as a hurricane nears land. As massive and powerful as a hurricane is, it is easily blocked by local weather systems and steered by regional upper level wind systems (Coch, 1994a). Hurricanes follow a basic parabolic track and are "steered" by the great anticyclonic (high pressure) air masses overlying the tropical oceans. Typical hurricane movement involves a westward drifting in the easterly (trade) winds of the deep tropics coupled with a tendency for the hurricane to drift northward. This combined drift will soon bring the hurricane to the subtropical zone where the east winds change to west winds resulting in a recurving of the storm track to the northeast.

One of the most important aspects of hurricane paths is the relationship of the track of the storm to the coastline at landfall. In a coast-parallel track (Figure 4) the storm keeps its weaker left side against the Atlantic coast and damage drops off rapidly inland. Most New Jersey hurricanes are of this type. In contrast, in a coast-normal track (Figure 4) the hurricane crosses the coast and the powerful right side cuts a wide 80-160 km (50-100 mi.) swath of heavy destruction deep inland.

SCENARIOS FOR HURRICANE DAMAGE IN NEW JERSEY



COAST PARALLEL TRACK

Easterly and Northerly winds at the front of the storm drive water into the Apex of the New York Bight.

Heavy shore-parallel erosion occurs along the length of the New Jersey Coast

The closer the track is to the New Jersey Coast, the greater the coastal damage

COAST NORMAL TRACK

Massive shore erosion, extensive overwash, and severe wind damage along the New Jersey Shore in the area of landfall. Severe wind damage and flooding accompanies the hurricane as it moves inland and recurves to the east across major urban centers.

This is the worst - case scenario for the New York Metropolitan Area

→ 40 **Vortex Wind Direction and magnitude (mph)**

➡ 100 **Translational Direction and Magnitude (mph) of hurricane**

Figure 4- Effect of type of hurricane eye track on damage in New Jersey. The effects of coast-parallel and coast normal eye tracks are very different, as shown in the diagram text.

NORTHERN HURRICANES

Many northerners think that hurricanes are something that happens to people in the South. For example, Category Four hurricanes, such as Hugo (1989) and Andrew (1992), have shown the destructive power of major southern hurricanes. The occurrence of a Category Four hurricane in the northeastern US is possible, although remote (B. Jarvinen, personal communication, 1993). Category 3 hurricanes have occurred in the North, although they are not the norm.

However, a number of conditions, many unique to this region, can give a Category 3 storm the destructive potential of a Category 4 or 5 storm, especially on its right side. The special conditions that make northern hurricanes so potentially destructive include:

1) their faster forward speed increases damage on the right side of the storm;
2) surge is amplified by exposure to easterly winds, shoreline configuration and shelf slope;
3) the wider wind field of northern hurricanes results in greater areal drainage;
4) more highly developed and populated coasts;
5) low hurricane hazard perception among inhabitants, and
6) difficulty in evacuating many population centers and resort areas in the northeastern US.

The characteristics of hurricanes in the North and South are compared in Table 4.

PARAMETER (Average)	**FLORIDA**	**NEW YORK**	**CONSEQUENCES**
Central Pressure (inches of Mercury)	28.3	28.5	***Southern Hurricanes are more powerful***
Radius of maximum Winds (Nautical miles)	22.0	40.9	***Northern hurricanes damage a significantly wider area***
Forward Velocity (miles / hour)	12.0	36.1	***Northern hurricanes move much faster, decreasing warning time and increasing***

Table 4- Comparison of characteristics of Northern and Southern Hurricanes, Source: Max Mayfield, National Hurricane Center.

One characteristic of northern hurricanes is that they typically move forward at speeds 2-3 times that of storms in the south (Table 4). As they move north of Georgia, they become influenced by westerly wind systems that are stronger at upper levels. This accelerates the forward velocity of the storms. This increase in velocity adds to their destructive potential but also shortens the time that they are over any given area. For example, the fastest - moving hurricane on record, the 1938 Long Island - New England Hurricane, occurred in the Northeast US. The storm moved parallel to the New Jersey Coast, causing heavy coastal damage (Savadone and Bucholz, 1993, p. 49-51). Tannehill (1956) states that the 1938 storm had a forward velocity of 90 km/h (56 mi./h) as it crossed the Long Island shoreline.

Another important characteristic of northern hurricanes is that their wind fields enlarge as they move north. This increases the radius of maximum winds and the area subject to damage (Table 4).

In summary, a northern hurricane of a given category can have a damage potential of a higher category storm in the South. We should not feel complacent because Category 4 Hurricanes are rare in the north, since a Category 3 landfall has the potential to cause the same damage.

HURRICANE DAMAGE

Hurricanes cause damage by surge, waves and wind along the coast and by wind and flooding in inland areas.

Storm Surge

Hurricane landfalls are accompanied by a local elevation of the ocean surface referred to as storm surge. Storm surge consists of two consecutive components. The advancing storm drives water inland as a flood surge that causes major damage (Coch and Wolff, 1991). Ebb surge is the seaward return of water impounded on land as the hurricane moves past an area and the westerly winds at the rear of a hurricane, plus gravity, move impounded waters from land back into the ocean. As a hurricane moves northward off the New Jersey Coast, areas at the front of the storm will be experiencing flood surge while areas at the rear of the storm will be under ebb surge conditions (Figure 5).

Flood Surge

The first written account of flood surge in America was William Bradford's account of sea level rise as the Great Colonial Hurricane (1635) devastated the Plymouth Colony of Massachusetts.

"It caused the sea to swell to the south wind of this place above 20 feet right up and down and made many of the Indians to climb into trees for their safety" (in Ludlum, 1963, p.12).

The highest flood surge can be expected where the tide is high at landfall, the wind is strong onshore and coastal bays and estuaries open into the path of the advancing storm. Astronomical effects, such as Spring Tides, greatly amplify surge levels.

Storm surge is a topic fraught with misconceptions. People commonly visualize the process as a series of massive "tidal "waves hitting the coast and think the major factor in elevating the sea surface is the low pressure associated with the eye of the hurricane. If

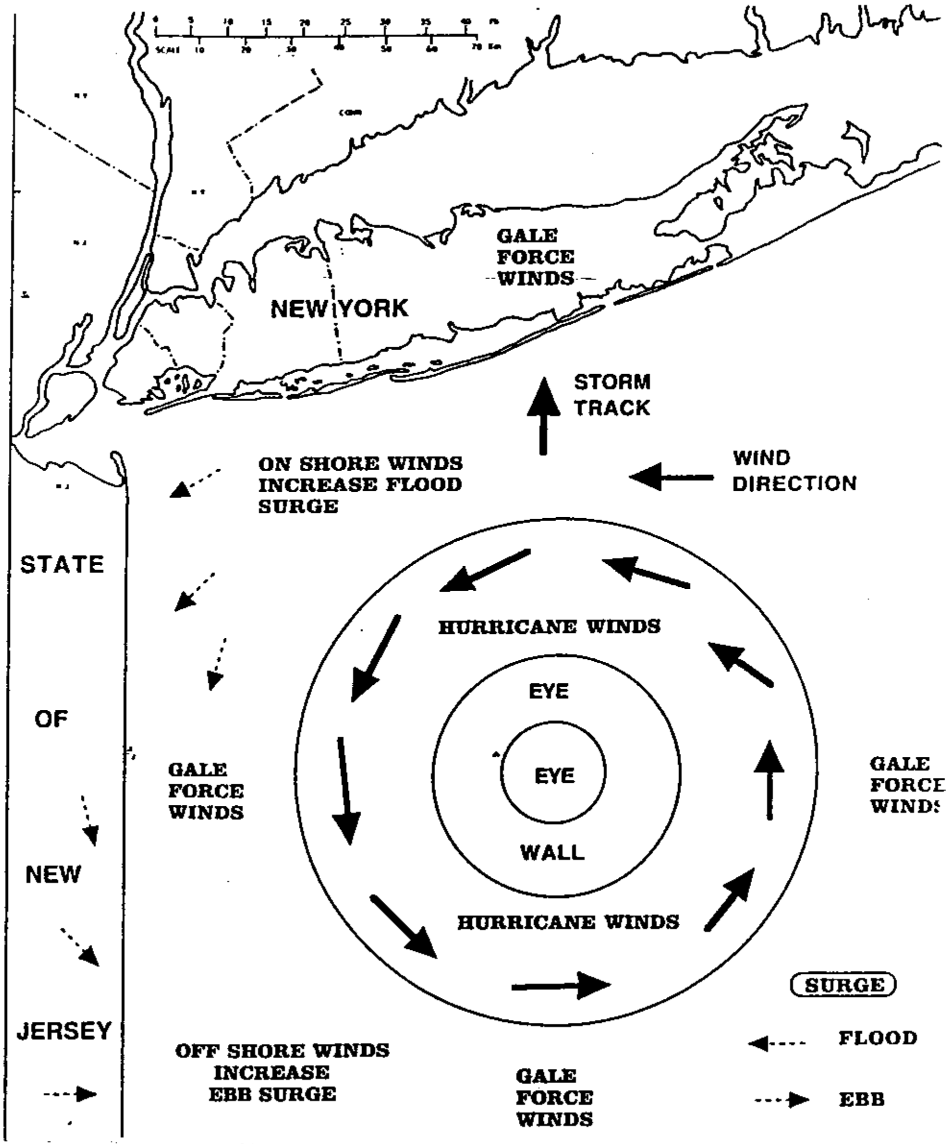


Figure 5 - Coastal flooding scenarios that develop as a hurricane passes parallel to the New Jersey Coast. At any time, flood surge is dominant at the front of the storm while ebb surge is occurring in the rear of the storm.

this was true, the highest surge would be developed under the eye of the hurricane, where the pressure is lowest. In all recent hurricanes, maximum surge levels occur near the radius of maximum winds on the right side of the storm. It is the wind shear that raises the sea surface and the storm surge is really a broad dome of water. The low pressure associated with the storm accounts for only a small portion of the elevation. Sea level rises about 0.3m (1 ft.) for an atmospheric pressure drop of 33.9 Mb (1" mercury) (Pore and Barrientos, 1976). Most of the rise results from the wind shear on the surface of the water. The wind exerts a horizontal force that drives surface and deeper water towards shore where water flow is impeded by a sloping continental shelf, that causes the water level to rise over distances of more than 160 km (99 mi.) (U.S. Army Corps of Engineers, 1993).

Storm surge is also increased by the tidal level (high and low) and the slope and the width of the continental shelf. In general, the gentler the slope and the wider the shelf, the higher the storm surge. The waves that ride on top of the storm surge increase water levels. The slope of the continental shelf in New Jersey ranges from 1 ft/880 ft at Cape May, to 1 ft/440 ft at Barnegat Inlet to 1 ft/220 ft at Sandy Hook. This results in a surge decrease from South to North along the coast. However, the steeper shelf slope in the north, results in higher waves, because they can reach closer to the coast before breaking (USACE, 1992, p. 2-4).

Ebb Surge

As the storm passes a segment of the coast, water impounded there by the advancing storm is released as an ebb surge (Figure 5). The ebb surge is channeled through low areas such as streets, paths, dunes, openings between building sites and causes additional damage to weakened structures. The damage done by ebb surge is more elusive than the visible "dams" of debris washed inland by flood surge. Ebb surge is significantly less intense than flood surge, but is capable of proportionately greater destruction because it affects structures already weakened by waves, flood surge, and wind-borne debris. The height of the ebb surge is a function of the flood surge magnitude, the amount of precipitation preceding and during the hurricane, and the local obstructions that block flow back into the ocean. A number of factors increase the possibility of ebb surge damage at a given location. These factors include; 1) failure or absence of shore protection structures (rip-rap aprons, bulkheads); 2) streets that run perpendicular to the shoreline; 3) areas of open land with little vegetation and ; 4) presence of beach access paths, dune walkovers, and locations on narrow parts of barrier islands seaward of bays (Lennon, 1991).

Prediction Surge Levels: The Slosh Model

Hurricane storm surge for a given coastal segment under a given set of storm conditions can now be accurately predicted by the SLOSH (Sea Land and Overland Surge from Hurricanes) Model of the National Weather Service (Jarvinen and Lawrence, 1985). The SLOSH data are expressed as a colored map pattern or as contour lines that delineate areas in which surge levels will reach given heights. The National Hurricane Center has produced SLOSH maps for most Atlantic and Gulf Coast areas. The detailed SLOSH maps for New Jersey (USACE, 1992) have proved invaluable in determining which areas should be evacuated, in planning evacuation routes and for locating safe emergency shelters. The general SLOSH map for the northern New Jersey-New York area is shown as Figure 6. The significance of the map is discussed later in this paper.

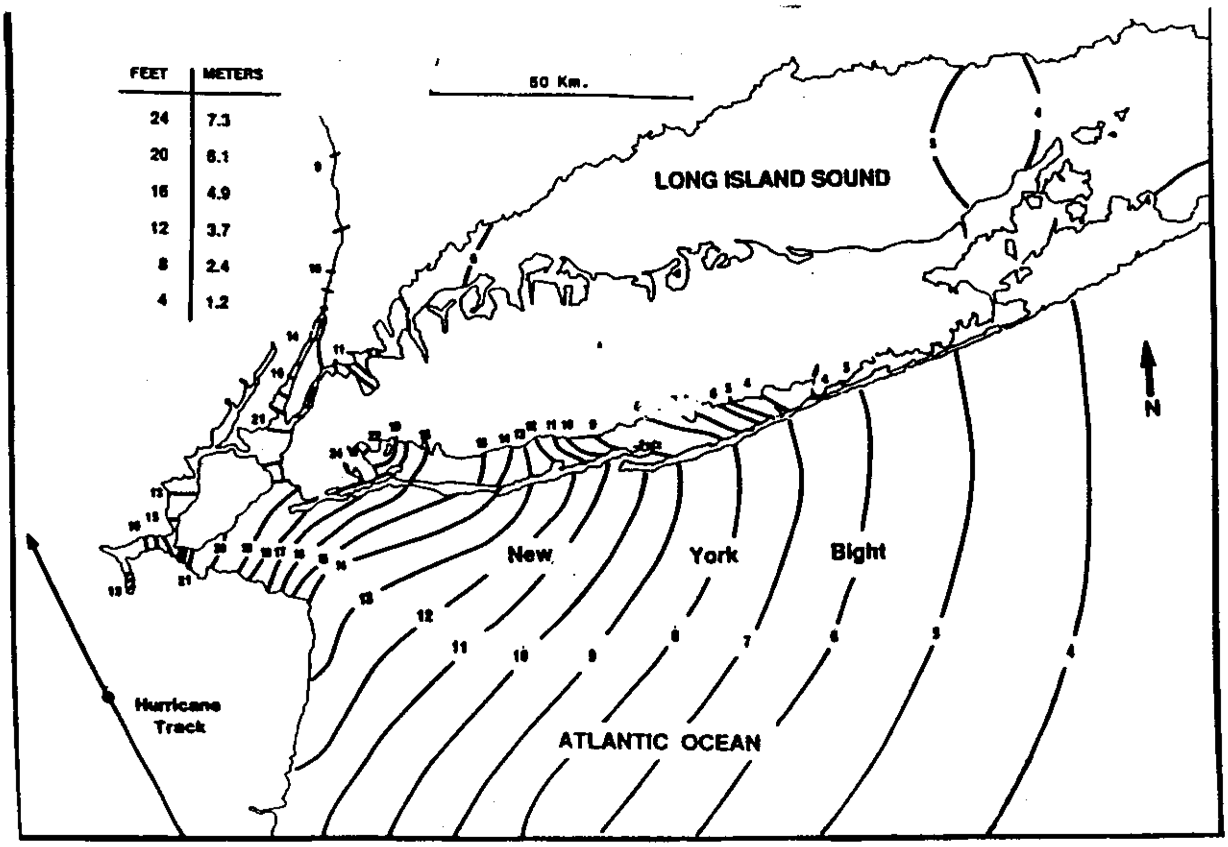


Figure 6 - SLOSH model for the New York Basin. The contours (feet) show the expected rise of the sea surface for a Category 3 hurricane making a landfall in Northern New Jersey and moving NNW at a velocity of 40 miles per hour. Note the amplifications of surge levels westward into the Apex of the New York Bight. Source: Brian Jarvinen, National Hurricane Center.

Detailed county maps of SLOSH levels are given in the New Jersey Hurricane Evacuation study (USACE,1992). Generalized color maps for the New Jersey Coast from Middlesex to Ocean counties were published in the Asbury Park Press (Sun. April 16,1995) in an article on hurricane awareness.

Wind

Wind is the major source of hurricane damage away from the coast. Two wind speeds are commonly referred to when discussing hurricanes, the mean wind speeds, measured over several minutes and gust speeds of short duration. Gust speeds are estimated by applying a gust factor to the mean wind of a given averaging period. Krayer and Marshall (1991) derived an average gust factor of 1.5, based on a study of a number of major hurricanes.

Gust winds can locally create higher water levels than expected and result in the breaching of dunes at low points. This effect was noted in the 1938 Hurricane on Long Island. Howard (1939) pointed out that wind gusts along the South Shore of Long Island had allowed storm surge and superposed waves to breach through higher portions of the dunes on the barrier islands. His explanation is as follows: " Along the coasts where the wind averaged 80 miles an hour these occasional blasts had velocities of more than 100 miles an hour. Locally these gusts may have increased the height of the waves and raised the water level sufficiently to permit the ocean waters to spill across comparatively low places in the bar, though such points may actually have been higher than places elsewhere along the bar that were not affected by the gusts."

Winds cause structural damage by their force, pressure effects and the debris they carry. Winds rushing across the edges of buildings or between them create zones of low pressure that lift off the outer parts of the structure (Sparks, 1991). Loss of the outer covering exposes surfaces that are less resistant to wind and rain. In many cases in Hurricanes Hugo and Andrew, the subsequent water damage equaled, or significantly increased, the cost of the original hurricane wind damage. If windows and doors are not covered with hurricane shutters or sheets of plywood, wind can open up the structure and the unimpeded flow can completely destroy its contents. In general, wind destruction increases with speed, altitude, exposure (lack of other buildings upwind), lack of integrity of the roofing materials and their weak attachment to the frame (R. Sheets, personal communication, 1992). Although the roof integrity can be greatly strengthened with inexpensive metal clips, few building codes require this.

Wind velocity increases rapidly with elevation and exposure. This will be a very significant factor in causing damage along portions of the New Jersey shoreline containing high-rise buildings, such as in Atlantic City. These high structures will sustain storm surge and wave damage to their lower floors. At the same time, their upper stories will be stripped of their outer covering and have their windows broken and interiors blown out. The acceleration in air flow ("wind tunnel" effect) between high-rise structures can be especially damaging to unprotected structures downwind of the high rise buildings. This results in significant damage in a mix of older lower and newer high-rise buildings, such as in Atlantic City.

High rise construction along the New Jersey Coast has never been tested in a major storm. This fact should be appreciated more by inhabitants of the many high rise structures along the New Jersey Coast. The damage to high-rise buildings in Hurricanes Hugo and Andrew showed that hurricane-level construction and zoning codes are essential to minimize damage and loss of life. Saffir (1991) pointed out that structures built in the area 457.2 m (1,500 ft.) from high water along the Atlantic Ocean and Gulf of Mexico must be designed with both wind and water action in mind. He emphasizes that coastal construction must conform to higher standards than inland construction and that in some cases the design engineer or design professional must exceed the minimum requirements of the building codes unless the building or components are expendable. Excellent descriptions of hurricane wind damage mechanisms are given in Sparks (1991). McCormick et al (1984) provide valuable suggestions as to how to increase the wind resistance of coastal structures.

VULNERABILITY OF THE NEW JERSEY SHORELINE TO HURRICANES

The New Jersey Coast is quite vulnerable to damage from coastal storms and hurricanes because of its 130mile length and its total exposure to easterly winds. A number of other factors increase the damage potential along the New Jersey Shore.

Surge Amplification

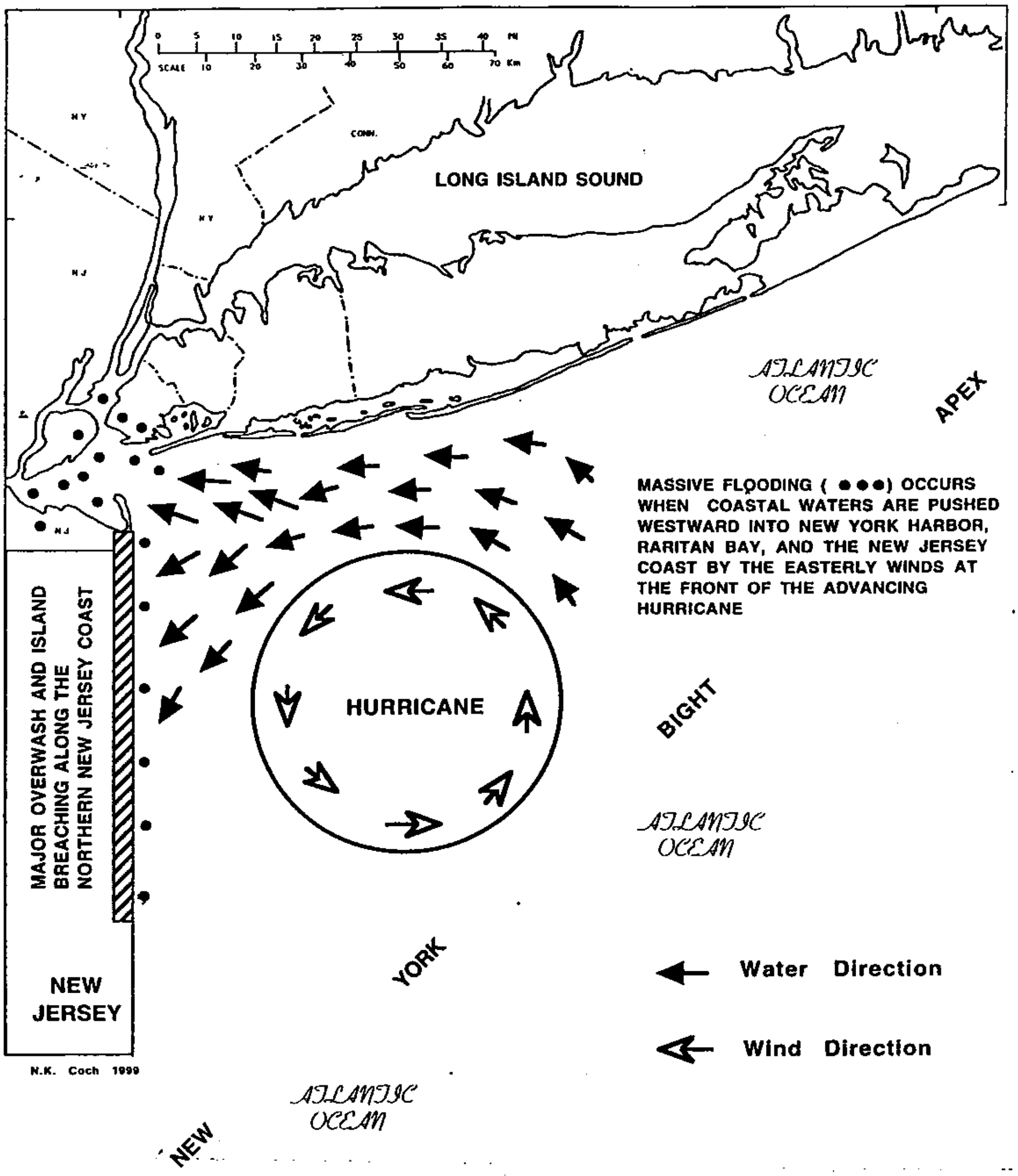
The right angle junction made by New Jersey and New York significantly increases hurricane surge levels in the apex of the New York Bight, the area between Cape May, NJ and Montauk Point, NY. The counterclockwise, easterly, gale-force winds preceding a hurricane will drive the waters in the apex of the NY Bight westward against the North Jersey Coast, into Raritan Bay and into New York Harbor (Figure 7). Rising waters will flood Hoboken, Bayonne, the Amboys, Keyport and Keansburg on Raritan Bay and Sea Bright, Monmouth Beach and Long Branch on the northernmost Jersey shoreline.

Massive and sustained coastal flooding will result as easterly winds slow down ebb tidal flows at the same time that ocean waters are being driven into the estuaries by the wind (Figure 5).

Predicted water levels for a hurricane strike in the New York Metropolitan Area are given on a SLOSH map (Figure 6) for a hypothetical Category Three hurricane moving northwest over New Jersey at 64.3 km/h (40 mi./h). This SLOSH model is based on an actual Category One hurricane track that crossed over New Jersey in 1903. Note that predicted surge levels would be 6 m (20 ft) in Raritan Bay and New York Harbor. Actual water levels could be significantly higher because of local conditions.

Lack of Hurricane Awareness

The low frequency of major hurricanes has led people into complacency in the New York/New Jersey Metropolitan Area.. In addition, blocking fronts have caused hurricanes to recurve eastward before landfall (Bonnie in 1998) and reduction in speed and landfall at low tide (Gloria in 1985) have reduced damage. Hurricane Gloria (1985) had the potential for causing major destruction in the New York Metropolitan Area. However, meteorological and oceanographic conditions seriously weakened the storm as it approached Long Island. Gigi and Wert (1986), reported that Gloria weakened as it moved north and it struck the Long Island coast at low tide, resulting in a surge of only 1.5 m (5 ft). In spite of this weakening and a landfall at low tide, the storm caused considerable damage in the NY/NJ Metropolitan area. On Long Island, Gloria's winds caused such extensive tree damage and utility disruption that electrical and telephone service to some areas were cut off for a week. Unfortunately, there was a tremendous media buildup as the



MASSIVE FLOODING (●●●) OCCURS WHEN COASTAL WATERS ARE PUSHED WESTWARD INTO NEW YORK HARBOR, RARITAN BAY, AND THE NEW JERSEY COAST BY THE EASTERLY WINDS AT THE FRONT OF THE ADVANCING HURRICANE

Figure 7 - Origin of high surge levels in the apex of the New York Bight as a hurricane moves into the area. Easterly winds at the front of the storm drive shelf waters westward where they pile-up in the apex of the New York Bight.

storm headed north. The possible destruction was emphasized, while millions of people experienced minimal hurricane effects. This did not advance hurricane awareness in the northeastern U.S.

Evacuation Problems

Emergency planners define the clearance time for a given area as the time necessary for evacuees to reach safe shelter before the onset of gale- force winds 63 km/h (39 mi./h) (U.S. Army Corps of Engineers, 1993). Emergency managers agree that evacuation must be complete before the onset of gale-force winds. Once gale-force winds arrive, trees start to fall, and water rises across, low "choke points" on evacuation routes. The edge of gale force winds may extend 160-193 km (100-120 mi.) from the eye of the storm. While the sustained winds at the end of clearance time may be 63 km/h (39 mi./h), expected gusts up to 92 km/h (57 mi./h) could be very dangerous to those attempting to evacuate at this late time (A. McDuffie, personal communication, 1993). The pre-landfall hazards time is the period between the arrival of sustained gale force winds and the landfall of the hurricane eye (U.S. Army Corps of Engineers, 1993). During this time, roughly 3-4 hours for a northern hurricane, evacuation will be hazardous or impossible.

Evacuation of New Jersey coastal areas will be difficult because of a lack of awareness of hurricane dangers. This will result in either dismissal of the danger or procrastination until it is too late to evacuate. Communities on barrier islands range from highly populated and urbanized areas (Atlantic City) to small communities such as those between Holgate and Ship Bottom. In addition, many areas on New Jersey's barrier islands are difficult to evacuate because of the few roads leading to the mainland. For example, inhabitants of Long Beach Island will converge on Ship Bottom from Barnegat Light in the north and Holgate in the south in an attempt to reach the mainland via Route 72. Hurricane evacuation is critical because many New Jersey barrier island communities have been overwashed and heavily damaged in past nor'easters. For example, the community of Harveys Cedar, on northern Long Beach Island, suffered flood surge, dune erosion, and ebb surge along with massive structural damage in recent nor'easters (Savadone and Bucholz, 1993, p. 102).

Construction and Development

The high-density development along most of the New Jersey Coast increases the time and expense for evacuation as well as the debris that can be mobilized by storm surge and wind to destroy other structures. Building codes in New Jersey rarely specify wind resistance above basic hurricane force of 121 km/h (74 mi./h). However, the winds of the next great hurricane will greatly exceed this value because of the additional boost given to the storm by its high forward storm speed. Many small coastal structures are built on concrete slabs resting on the ground surface at a dangerously low elevation. These types of structures offered little resistance to surge displacement in Hurricane Hugo (Coch and Wolff, 1991). New building codes in some coastal areas specify elevation of buildings on pilings above "100-year flood levels". The area under the homes is to be kept open to allow the surge to pass through. Unfortunately, in many cases, homeowners violate restrictions by building rooms and permanent structures in the space, defeating the purpose of the code.

Beach and Dune Erosion

Wide beaches and high and wide dunes reduce surge damage along the coast. Thieler and Young (1991) found that fifty percent of all buildings completely destroyed or removed from their foundations in Hurricane Hugo (1989) were fronted by a combination of beaches less than 3 m (10 ft) wide and dune fields less than 15 m (49 ft) wide. They observed that the only sections of the 51 km (32 mi.) of South Carolina shoreline, from Garden City to Folly Beach, that were not overwashed were sections of very high dune fields and large bulldozed dune ridges. Dunes survived when high enough to prevent being overwashed, wide enough to prevent being completely eroded, and when low and well vegetated enough to be rapidly submerged without significant erosion (Theiler and Young, 1991).

Where dunes have built up naturally they should not be reduced in height by construction of structures or parking areas, nor should pedestrian traffic be allowed across them. Pedestrian traffic across the dunes destroys the protective vegetation on the dunes, allowing the wind to deflate sand and create a low area. With time, this lowers the dune surface so that high storm surge can break through these low points.

Eroded dunes in New Jersey have been restored in many different ways. One method is to fill low areas with old cars, appliances, tree trimmings or Christmas trees and then cover them with sand. This does restore the "dune" profile temporarily. However, this mixture has very little wave resistance because storms will erode the sand cover and consequently, the storm beach will be littered with debris such as rusting cars (Savadone and Bucholz, 1993, p.170). Another method of dune restoration is to scrape sand from the foreshore up into the ridge or to dump sand from inland areas into piles making up a "sand berm" which is then vegetated (Savadone and Bucholz, 1993, p. 171). There are two basic problems with this method. Sand scraping may steepen the foreshore enabling waves to rise further up on the beach in the future. In addition, sand grains that are dumped have a more open packing configuration than those that are deposited under the shearing force of water or wind. The looser packing (Graton and Fraser, 1935) of the dumped or bulldozed sand grains tends to decrease their resistance to wave erosion. Artificially-built "dunes" (bulldozed sand ridges) did help to reduce surge damage in Hurricane Hugo, but naturally vegetated dunes would have been more effective.

Dunes are best restored by trapping sand through use of snow fences and by stabilizing the sand by planting beach grasses such as Amophelia s.p. The resulting landforms will have maximum resistance to wave erosion.

ENGINEERING STRUCTURES HAVE CAUSED EROSION

After the 1938 Long Island-New England Hurricane, coastal engineering structures were seen as a way to increase beach width to minimize storm damage and to stabilize storm-cut inlets to provide new access between bay communities and the ocean on Long Island (U.S. Beach Erosion Board, 1946). Jetties built to stabilize major storm-cut inlets began to seriously reduce the natural sand movement along the Jersey Shore. Sand now accumulated at the updrift ends of inlet jetties and within the bays on tidal deltas. In contrast, the beach on the downdrift side of each inlet eroded because sufficient sand was not reaching that area.

Erosion problems have been additionally compounded by the building of numerous fields of groins to trap sand moving along the shore in order to widen local beaches. Severe beach erosion occurred downdrift of some groin fields, such as the southern end of Sandy Hook. Research by Coch and Wolff (1991) showed how amplification of surge within some groin compartments at Pawleys Island, SC resulted in elevated storm water levels on the north side of those groins in Hurricane Hugo. The two to three homes closest to the north side of the groins suffered heavy surge damage and some were washed back across the barrier to collide with others, or into the bay.

New Jersey will probably be on the weaker left side of the next great Northeast hurricane. However, these heavily populated and developed areas will sustain major damage because their beaches have been deprived of sand and protective dunes have not been able to build up .

TYPES OF NEW JERSEY HURRICANES

The angle that the track of a hurricane makes with the New Jersey shoreline has a great effect on the type and scale of damage that results. Although hurricanes can make any impact angle with a coast, only the two end members, coast-parallel and coast-normal tracks, will be discussed.

Coast-Parallel Tracking Hurricanes

The great majority of the hurricanes that have affected the New Jersey Coast have had a coast-parallel track (USACE, 1992, fig. 1-2). A coast-parallel tracking hurricane moves along the shoreline with the weaker left side of the hurricane against the coast (Figure 4). In this hurricane scenario, coastal flooding can be severe and wind damage will be extensive within a belt parallel to the coast. Fortunately, the damage gradient decreases rapidly inland and the storm moves away in a few hours. This expected scenario may not sound very threatening to a New Jersey coastal resident, but the reality may be quite different.

A category 2 hurricane tracked very close to the New Jersey Shore on August 24, 1893 before passing over New York City (Coch, 1997) showed that the storm removed a developed island (Hog Island) south of the present Rockaway Peninsula in New York City. This storm was reconstructed from archival weather data (Coch, 1998) and found to have a radius of maximum winds of 50 miles. This accounts for the extreme damage reported along the western Long Island shoreline at Coney Island, Brighton Beach and Rockaway Beach (New York Times, August 25, 1893). Major flooding also occurred in both Raritan Bay at Elizabeth, Newark, Hoboken and Bayonne and along the northern Jersey shore at Long Branch and, Red Bank (New York Times, August 25, 1893).

Major damage along the Jersey coast was caused by coast-parallel tracking hurricanes in 1938 and 1944. Both of these hurricanes continued northward, made coast-normal tracks across Long Island and New England, and caused damage of historical proportions in those areas. The 1938 storm also caused significant damage along the Jersey Shore (Savadone and Bucholz, 1993, pp. 49-52), but the 1944 storm passed closer to the

Jersey Coast and caused significantly more damage (Savadone and Bucholz, 1993, pp. 53-102).

Most hurricanes affecting New Jersey have tracked along the coast, at some distance offshore. What would have happened if any of those storms had tracked closer to the New Jersey Shore? A National Weather Service analysis of Hurricane Gloria in 1985 provides an answer. Many people consider Hurricane Gloria to have had minimal effects. However, some very simple, and realistic changes could have made it far more dangerous. A slowing of its forward movement to hit at high tide and a shifting of its path westward, would have made it the "Big One" to hit New York City and northern coastal New Jersey. If Gloria had made landfall at high tide, the surge would have been 3 m (10 ft.) above sea level at the Battery, setting a new record for this location (Gigi and Wert, 1986). Each borough of New York City would have experienced tidal flooding on an average distance of 61 m (200 ft.) in from the shoreline. The expected damage and transportation dislocation in the New York/New Jersey Metropolitan Area is described in Gigi and Wert (1986, p. 3-6).

If Hurricane Gloria had hit farther to the west, its damage would have been far worse. According to Gigi and Wert (1986), a 64 km (40 mi.) westward shift of Gloria's path, to along the Jersey Coast, and a landfall in New York City at high tide would have had catastrophic results. The SLOSH model for that scenario predicts a 4.6 m (15 ft.) surge in northern New Jersey and New York City and over 6 m (20 ft.) in Raritan Bay. Major parts of the New York/New Jersey Metropolitan Area would be under water and the resulting beach erosion could have significantly altered the coastline of New Jersey and Western Long Island (Gigi and Wert, 1986, p.7).

In conclusion, even though most hurricanes affecting New Jersey have coast-parallel tracks, a similar storm tracking closer to the coast, is statistically overdue. In addition, it is important to realize that a category 2 hurricane along the Jersey Coast may have the destruction potential of a Category 3 Hurricane in the south.

Coast-Normal Tracking Hurricanes

A coast-normal hurricane track (Figure 4) intersects the coast at a high angle and results in a far greater scale of damage than a coast-parallel storm track. When this type of hurricane makes landfall, its powerful right side (Figure 3) cuts a wide swath of destruction deep inland. In contrast, damage on the left side of the storm drops off rapidly outwards from the eye.

Probably no one in New Jersey has experienced a coast-normal tracking hurricane and believe that no such dangerous hurricanes have occurred in the state. They are wrong.

In early September, 1821, a Category 2 Hurricane crossed over Cape Hatteras, devastated Norfolk, Virginia, passed directly over Cape May moved along the coastal area of New Jersey, over New York City and then into southern New England.

As it passed over southern New Jersey, erosion separated Cape May from the rest of the peninsula and coastal winds flattened the ancient trees on Long Beach Island. Relatively little is known about damage from that storm in most of New Jersey. However, the severe damage in Norfolk and New York City suggests that the damage in New Jersey was also quite severe. The fast-moving storm sped northward at 50 mph and resulted in a rainfall of 3.92cm. in Philadelphia (Ludlum, 1963, p. 84). The high transitional velocity of the storm caused massive wind damage inland. Road crews cutting the Garden State Parkway through the Pine Barrens in 1954 uncovered a section of the ancient forest knocked down by the 1821 Hurricane (Savadone and Bucholz, 1993, p.24)

The ferocity and power of this storm is demonstrated by the severe damage in New York City and Southern New England. On Monday, September 3, 1821, the eye of the hurricane tracked over New York Harbor and the right eyewall passed over what was then the mostly undeveloped land in the present New York City boroughs of Brooklyn and Queens. The 1821 Hurricane raised New York Harbor tides to levels not recorded until Hurricane Donna in 1960 (Gofseyeff and Pannuzio, 1962). This is significant because the 1821 storm made landfall near low tide. In addition, low tide in 1821 could have been as much as 0.3 m (1 ft) lower than now (Gofseyeff and Pannuzio, 1962). The exceptionally high rise in tide (4 m or 13 ft. in 1 hour) was the result of the path of the storm's eye just 19 km (62 ft.) west of New York City (Kussman, 1957). This path would have greatly amplified storm surge in NY Harbor (Figure 6).

Although the number of historic accounts of damage are sparse, what is available describes very extensive destruction. According to The American (For the Country) of September 4, 1821, the 1821 storm caused great damage in what is now the New York Metropolitan Area. "The force of the gale happened fortunately when the tide was nearly out - even then, the water was raised so suddenly as to inundate the lower part of the town"....."Great damage was sustained at the Battery, a part of the embankment at the point being washed away."

Accounts in The American of September 4, 6 and 8, 1821, list a great number of shipwrecks and extensive dock and waterfront damage in New York and southern New England.

The fast-moving storm showed little loss in intensity as it moved northward. Wind damage inland was extensive into southern New England. Massive surge destruction occurred along the Long Island Sound Shoreline, and the Black Rock lighthouse at New Haven was removed. Newspaper reports indicate extensive tree damage over southern New England.

Observations of tree damage in 1821 in Conn. by W.C. Redfield provided crucial data on the true nature of hurricanes. He observed that trees were felled in different directions over the State of Connecticut. His reconstruction of the aerial variations in tree downing directions (Redfield, 1831) showed that a hurricane is not a straight line wind from the ocean, but a counterclockwise-rotating vortex that moves inland. This was a seminal development in tropical meteorology (Coch, 1999).

It is sobering to think of what a repetition of this event today would have on damage figures in the now major cities in New Jersey and New York that lie along the eye path of the 1821 Hurricane.

A coast-normal hurricane also occurred in New Jersey in 1903. That Category 1 storm entered at the middle of the New Jersey Coast and tracked NNW causing only moderate damage inland. However, the significance of this event is that it demonstrated that a coast-normal track across northern New Jersey is possible in the future. In fact, the National Hurricane Center/Tropical Prediction Center has used that 1903 track to make a SLOSH reconstruction for hurricane storm surge levels in the New York Metropolitan Area (Figure 6). The significance of such a track is considered in the next section.

A STORMY FUTURE IN NEW JERSEY

Predictions for an increase in storm and hurricane frequency in coming decades are not good news for New Jersey coastal inhabitants. Analysis of nor'easters indicates that they are becoming more powerful and frequent (V. Cardone, oral communication (1999).

The frequency of Atlantic landfalling hurricanes is also predicted to increase in the coming decades based on statistical and climatological studies by William Gray. There seems to be a strong relationship between Atlantic hurricane frequency and patterns of rainfall in West Africa (Gray, 1990). Between 1943 and 1987 there have been far more hurricanes in wetter years in West Africa than in drier ones. Unlike wet periods in west Africa (1943-1969) when many hurricanes impacted the Atlantic coast, during the dry period (1970-1987) only one major hurricane (Gloria in 1985) affected the North Atlantic coast of the U.S. Hurricane frequency in this past century seems to follow "multi-year cycles" of drought and rainfall (Gray, 1990). The dry cycle in west Africa that began around 1970 may be near an end; and a wet period, accompanied by a higher of frequency of Atlantic Coast landfalling hurricanes, may be starting (Gray, 1990). This climate change has great significance for future hurricane property damage in New Jersey. Most New Jersey coastal development has occurred since 1970, during a time of relatively low hurricane frequency. No matter when the next great northeastern hurricane strikes, it will affect a far more developed and populated New Jersey shoreline than any previous storm. The potential damage could be catastrophic if a hurricane makes landfall in New Jersey and moves inland (Table 5).

• Ocean City, Maryland	20.1
• Asbury Park, New Jersey	52.3
• New York City, New York	45.0
• Long Island New York	40.8

* In Billions of Dollars

Table 5- Hurricane loss predications for Category 4 Hurricanes in the Mid-Atlantic Region, Source: Applied Insurance Research Inc., Boston, Mass.

Major controversy exists at the present time over the possibility of "global warming" and the possible consequences of that trend. If our climate is warming, ocean temperatures will increase, the water will expand, and sea level will rise faster than the normal post-glacial rate. Some say that warmer oceans will spawn more and more hurricanes that will be able to travel further North than ever before. Other experts disagree. There is no resolution of this controversy at present.

However, sea level is rising at a rate of about one foot per century. This will increase coastal erosion, because of the gentle slope of much of the New Jersey coastal area (Figure 8).

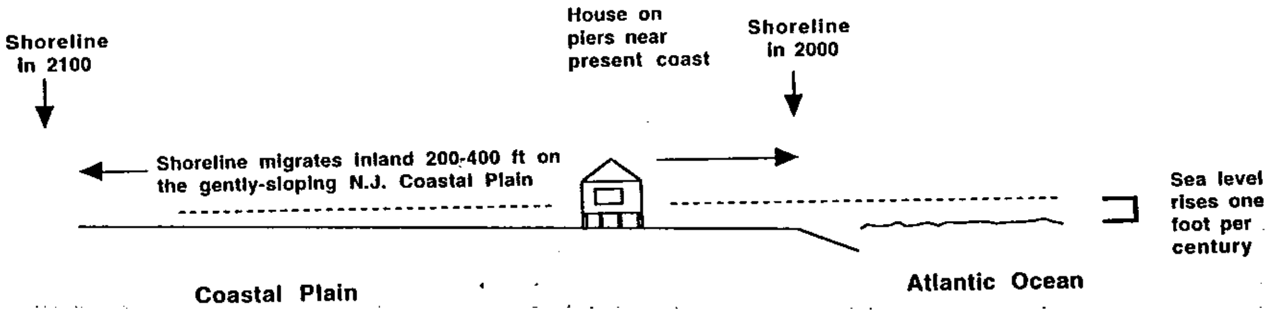


Figure 8- Effect of future sea level rise on the New Jersey Coast. On the gently sloping New Jersey Coast, a rise of one foot in sea level moves the shoreline 200-400 feet inland.

Heavy development has resulted in many fixed structures built on a shifting shoreline. Where the land slope is gentle, a 1 ft rise in sea level can result in the shift of the shoreline 200-400 ft landward. This will result in increased erosion in future storms.

The scenario for landfall of a hurricane in the New York City - New Jersey area involves a well developed Bermuda High and a high pressure system moving eastward across the U.S. In between the two air masses is a low pressure trough (Figure 9). This set up can occur as many as ten times during a hurricane season (from June-October). If the passage of a Category 3 hurricane (Table 2) coincides with such a meteorological set up, the hurricane can move around the western edge of the Bermuda High and enter the low pressure trough. It will then speed up as it moves northward and be steered into the heavily developed coast of the northeastern U.S. with catastrophic consequences (Coch and Wolff, 1990). One common type of hurricane-local weather mass interaction is shown in Figure 9. In this weather scenario, a moving continental high and a semi-permanent oceanic high have a low pressure trough between them. A westward-moving hurricane may move into this trough as it rounds the southwestern edge of the Bermuda High (Figure 9).

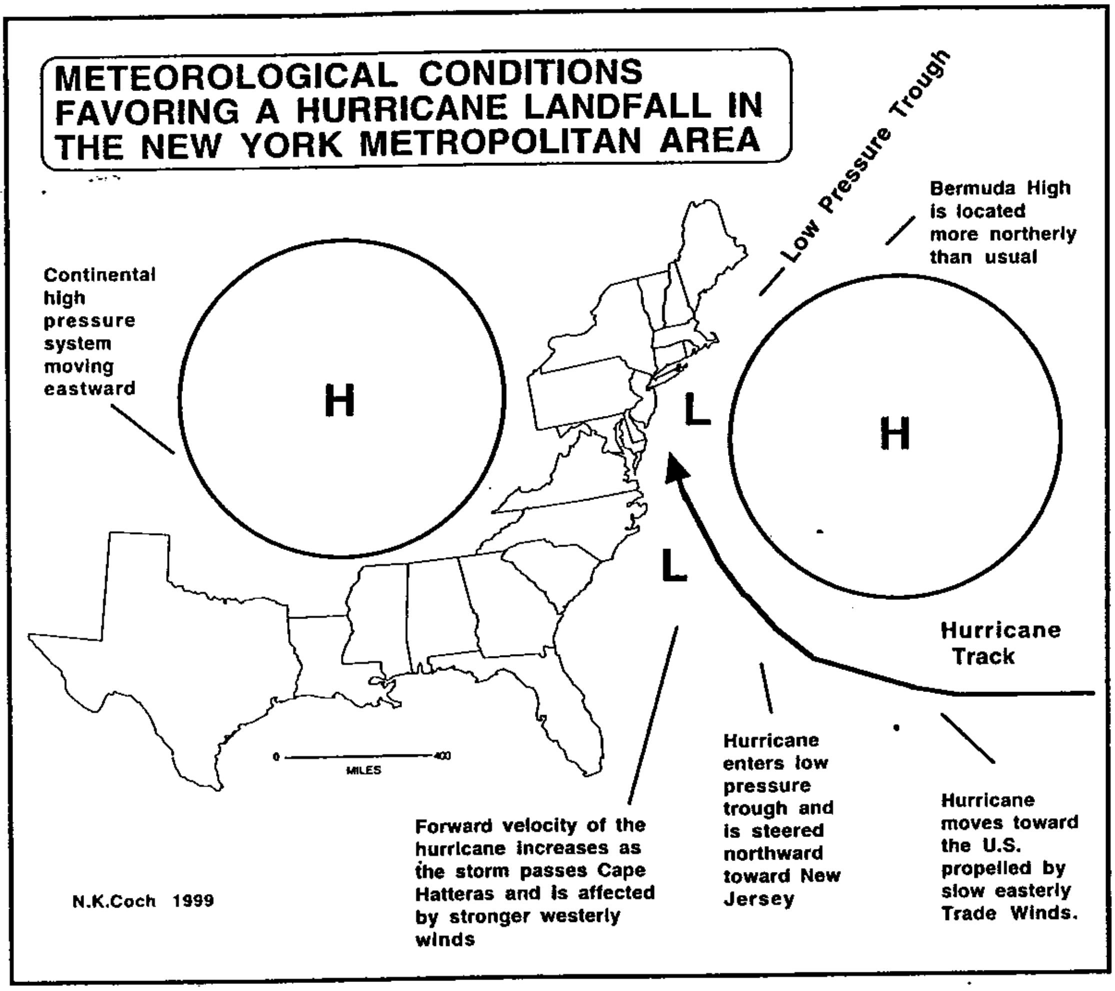


Figure 9 - Meteorological conditions favoring a hurricane landfall in the New Jersey-New York Metropolitan area.

The forward speed of the storm will increase as the hurricane moves northward, confined by the high-pressure systems on either side and steered northward by the upper level winds . This was the weather set-up that made the 1938 New England Hurricane the fastest moving on record (Pierce, 1939). The normal position of the Atlantic High in September is between 30-35 degrees north in September. However In September 1938, the high was located SW of Newfoundland at a latitude of 44 degrees N. This abnormally high location of the Atlantic High blocked the normal eastward recurving path of the 1938 hurricane and deflected the storm northward toward Long Island and New England (Wagner, 1988)

The interaction of a northward-moving hurricane and westerly winds at higher latitudes commonly causes storms to speed up and this allows them to penetrate a considerable distance (hundreds of kilometers) into the northeastern U.S. If a northward-moving hurricane achieves a forward speed greater than 56 km/h (35 mi./h) it can override the cooler northern waters and hit the Northeastern U.S. Shore with undiminished strength (R. Sheets, personal communication, 1992). One of the main reasons that Hurricane Bob (1991) began to lose power so rapidly was that its forward speed of 48 km/h (30 mi./h) was insufficient to prevent the storm from loosing energy as it encountered the cooler waters south of Long Island. In contrast, the devastating September 21, 1938 New England Hurricane was moving more than 96km./h (60 mi./h) over northern waters that were abnormally warm for that time of the year.

Historical patterns would favor a more easterly landfall (central to eastern Long Island) but a more westerly landfall might occur if the Bermuda High were stronger and well developed at that time. This scenario would push the track of the hurricane closer to the New Jersey Coast .

How strong will the inevitable "Big One" be? In the northeast U.S., Category 5 hurricanes are not thermodynamically possible because of the cooler waters offshore, and Category 4 storms are remotely possible (B. Jarvinen, personal communication, 1993). However, a fast moving Category 3 storm in the northeast could have an <u>effective</u> Category 4 wind on its right side (Figure 3).

What would be the worst-case hurricane landfall scenario for New Jersey? The worst-case scenario, for the state as a whole, would be a repetition of the 1821 hurricane, with a track along the length of New Jersey. Another scenario would be far more destructive. This involves a hurricane turning inland north of Atlantic City and then recurving to the east (Figure 9). This track would not only be very damaging to major New Jersey coastal urban centers but disastrous to New York City. Such a path, last taken by a Category 1 hurricane in 1903 would put New York City on its destructive right eyewall (B. Jarvinen, personal communication, 1993).

The regional devastation caused by the last great northeast storm, the 1938 Long Island/New England Hurricane, has been described in many publications. However, few inhabitants of the Northeastern U.S. today are aware of the catastrophic destruction caused by that storm. The first study published was done by teams of the Federal Writers Project In The Northeast States (1938) who offered solutions to reduce the effects of future hurricanes. Have we really learned from that event?

THE WORST CASE SCENARIO FOR A HURRICANE LANDFALL IN THE N.Y. - N. J. METROPOLITAN REGION

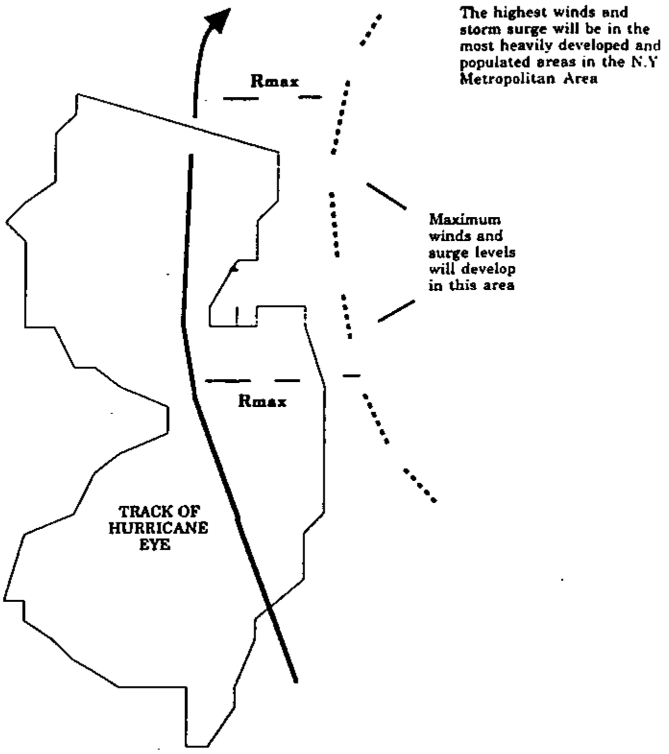


Figure 10 – Worst-case scenario for a hurricane landfall in the New York-New Jersey Metropolitan region. If a hurricane enters New Jersey and arcs northeastward across the state, damage can be dramatic. The highest winds and surge levels would occur in a band at a distance (Rmax) on the right. This band would coincide with the most populated and developed area in the New York-New Jersey Metropolitan region.

"Here the ill wind may bring the proverbial good, once the communities have recuperated from their first shock. There are earnest proposals that the seaside resorts pass zoning laws. The New England Council hopes to persuade owners to build cottages further inland instead of at the shore edge. The open expanse of a century's hazard building may now be rectified. The federal government is cooperating with local bankers to make funds available for reconstruction. There are plans for ocean driveways with underpasses from the settled colony to the broad, uncluttered sand dunes. Army engineers are surveying the beaches. They hope to build jetties in the waters off the coast so as to prevent future washouts. New sea walls will divert dangerous currents" (Federal Writers Project, Works Progress Administration, 1938, p 219-220).

CONCLUSION

All evidence indicates that the Northeast United States will experience a major hurricane, or even a series of major hurricanes, in the next few decades. The eroded nature of our sandy coasts and the absence of protective dunes will offer little protection from storm surge. Wind damage will extend far inland from the coast causing massive structural and tree damage and disruption of utilities, communications and transportation systems. Future damage can be reduced if we adopt effective building codes and coastal management policies that provide hurricane protection and we increase hurricane awareness and mitigation before an inevitable major hurricane hits somewhere on the highly developed coast of the Northeastern U.S.

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REMOTE SENSING AS A TOOL FOR MONITORING NEW JERSEY COASTAL WATER QUALITY

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ABSTRACT

This paper presents the results of a ten-year research venture utilizing multisensor data to assess the water quality conditions in the Hudson/Raritan Estuary and the New Jersey coastal waters. Various types of remotely sensed data including multispectral satellite, videography and imaging spectrometry data in coordination with field data are discussed and results of such analysis are presented.

The study area is the New Jersey estuarine and nearshore waters. These waters are enriched by increased nutrient loading from point, non-point sources such as agricultural and urban run-off causing eutrophication and pollution. To improve the quality of water and control the problem of excessive fertilization, regular monitoring of water quality is required. Currently there is no systematic management tool for operational monitoring and prediction of spreading of pollution. The research is aimed to develop a water quality monitoring system with emphasis on the discrimination between organic and inorganic turbidity promoting eutrophication. Satellite and video data will be complemented by hyperspectral data--AVIRIS and the spectral library that will be used as diagnostic tool for identification of the biological and compositional characteristics of the nearshore (case2) waters.

INTRODUCTION

The Hudson/Raritan Estuary is a complex ecosystem that is important to the New York metropolitan area and is also considered "the most intensively developed and industrialized estuary on the U.S. east coast" (Pearce, 1988). Many diverse organisms continue to use the estuary for part or all of their lives. Included are commercially valuable shellfish and finfish, and other organisms such as polychaetes, phytoplankton and zooplankton that are basic to the estuarine food web. Many fish depend on the estuary as a nursery and critical stages of their life cycle occur in these waters, while others use it as a key migration route between fresh and seawater. At one time both shell- and fin-fish fisheries thrived in the estuary. Some, such as oyster, hard clam and soft clam shellfisheries collapsed or were reduced because of bacterial contamination. The commercial fin-fishery was relocated offshore due to legislation preventing fishing in the estuary. Today, outside of a few pound nets in the Raritan Bay part of the estuary, most fin-fishing has been reduced to sport activity, although some clams are harvested for depuration or transfer to cleaner waters

(MacKenzie, 1990). However the estuary is used for many recreational purposes including swimming, boating and sport fishing, which is now one of the biggest industries. Over the last century the quality of the estuary has degraded in part due to eutrophication, the process of nutrient enrichment through either natural or anthropogenic processes. Eutrophication disrupts the pre-existing natural balance of the system, resulting in phytoplankton blooms of both increased frequency and intensity in response to the over-enrichment. Noxious phytoplankton blooms are among the potential negative impacts, as are shifts to less desirable species of phytoplankton, diminished aesthetics (e.g., from brown tides) and changes in phytoplankton cell size. The latter can adversely affect the nutrition of organisms that have cell size-related food requirements (e.g. clams). Likewise, dense and accelerated phytoplankton blooms ultimately increase oxygen demand on the system leading to episodes of hypoxia. One indicator that the Hudson/Raritan Estuary is in an advanced stage of eutrophication is the high concentration of chlorophyll found in Raritan Bay (Pearce, 1984). Phytoplankton increases are a definite manifestation of eutrophication or enrichment of New Jersey estuarine/coastal waters.

Phytoplankton populations in the Hudson/Raritan estuary, the Bight Apex and coastal waters of New Jersey are dominated by diatoms (>20 µm) such as Skeletonema costatum during the unstratified winter/spring months (November-April) and by Nannochloris atomus (between 0.7-20 µm) dating the stratified summer/fall months (May-October). Diatoms typically dominate at all times in the offshore waters of the Bight.

Dinoflagellate blooms off New Jersey are recurrent events during the summer. Since 1968, red tides have been associated with Olisthodiscus luteus (1976, 1978, 1979) and Prorocentrum micanas (1968, 1972, 1983). The bloom of Gyrodinium aureolum off the coast of southern New Jersey in 1984-85 was termed "green tide" because of it's brilliant green color. Nannochloris atomus is another common species that causes green tides in New Jersey waters (DEP, 1986).

Brown tides are caused by the bloom of the Aureococcus anophagefferеus. It had first appeared in Narragansett Bay, Rhode Island and Long Island's Peconic and Great South Bays as well as the New Jersey's Barnegat and South Bays. The brown tides occur in spring and summer months. They can kill shellfish and block sunlight to the underwater plants destroying the habitat of many marine resources. The brown tides have a major effect on the shellfishing industry. In 1985 a brown tide in Peconic Bay reduced a $ 2 million scallop industry to a few thousand dollars. Research has shown that iron can stimulate growth of brown tides. Environmental factors such a warmer climate, increased salinity of water and lack of rainfall could contribute to the bloom formations, but the exact causes or cure are not known yet (NY SeaGrant, 1998).

Remotely sensed data can provide greater economy in many types of hydrologic surveys than using conventional methods. This is possible since certain bio--and geochemical constituents of surface/nearsurface water produce signals that can be indexed by optical remote sensors. A cost-effective and utilitarian method must be found to monitor phytoplankton as indicator of eutrophication in these waters. The objective is to provide quantitative data in support of use of remote sensing technology as an operational monitoring tool for better management of water quality conditions and to calibrate future spaceborne data in support of ecological and social/economic investigations.

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

The study area is the Hudson/Raritan Estuary south of the Verrazano Narrows, and bordered by western Long Island, Staten Island and New Jersey (Figure 1).
The partially mixed drowned river estuary is relatively shallow (< 8 m) (Oey et al., 1985). The major fresh water discharges are the Hudson, Raritan, Passaic and Hackensack Rivers. The estuary is connected to the Atlantic Ocean through the Sandy Hook-Rockaway Point transect and to Long Island sound through the East River. Hudson/Raritan estuarine waters are degraded by municipal and industrial wastewater discharges, land runoff and combined sewer outflows contributed to low dissolved oxygen. The freshwater discharge from the Hudson River contributes a monthly average discharge ranging from about 100 m3/s in dry seasons to about 1800 m3/s in spring, while the combined monthly average discharges of the Raritan, Passaic and Hackensack rivers ranges from 10 to 100 m3/s. The number of wastewater inputs include 26 major waste treatment plants, about 100 point sources of industrial and municipal origin and in excess of 700 combined storm drains and sewer outflows (O'Connor and Mueller, 1984). There are four major sewage sources; two with a combined mean discharge of 11 m3/s are located near the mouth of the Passaic River and near the mouth of Kill Van Kull that opens to the Upper Bay. A third in the East River has a mean discharge of 42 m3/s, and the fourth sewage source is Jamaica Bay with a mean discharge of 14 m3/s. (Oey, et al. 1985).

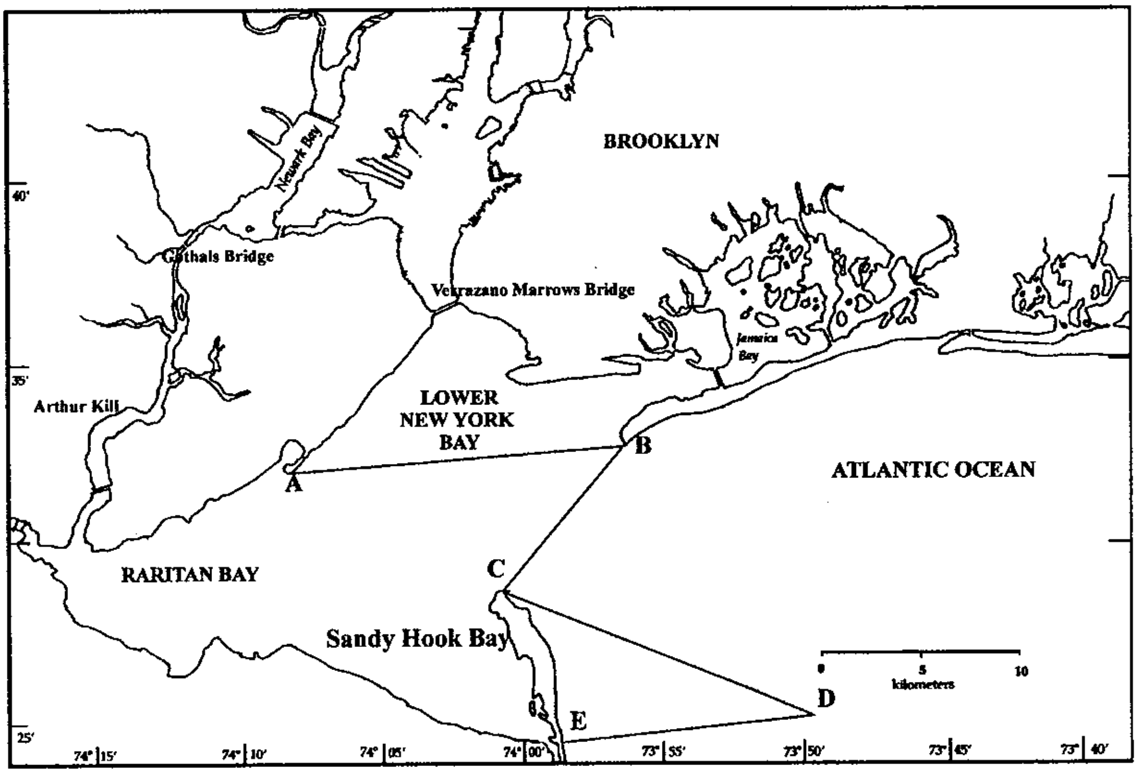

Figure 1. The map of the study area with the location of the transects

The volume discharged into the system from Staten Island, New Jersey and the Raritan River is small compared to these sources. Conditions in the Raritan-Lower Bay part of the estuary can be quite variable due to its shallowness and the speed with which it can change in response to factors such as tide, rain and wind. However, the net movement of water within the estuary is counter-clockwise. The following two factors govern the circulation patterns in the estuary: 1) the geometry of the estuary with open boundaries (Sandy Hook connection with the Atlantic Ocean and East River Strait connection with Long Island Sound and 2) surface wind stress which is considered part of the surface boundary conditions. The estimated flushing time of the estuary, 16-21 days or 32 to 42 tidal cycles (Jeffries, 1962), tends to retain pollutants entering the system and delay dilution with receiving waters.

Geologic characteristics of the Hudson/Raritan estuarine floor, are comprised of four major sedimentary regions: the Sandy Hook Bay Muds, the West Raritan Bay Muds (Nagel, 1967), the Keansburg Sands, and the Lower Bay Sands. Accumulation of fine-grained sediments is usually indicative of lower energy conditions and protected environment. In contrast, the presence of sand often characterizes high-energy conditions and an environment exposed to vigorous waves or strong tidal currents. The principal area of mud accumulation extends from west--Raritan Bay into east--Sandy Hook Bay. The sediment generally becomes finer westward towards the mouth of the Raritan River (Coch, 1986) and sandy along the New Jersey coast south of the mud deposit. This sand, derived from the erosion of the Cretaceous beds of sand at the New Jersey shore, persist due to prevailing northwesterly winter winds that raise waves of sufficient energy to prevent the deposition of fine-grained sediment near this coast (Mutler, et al., 1984). Extensive sand banks are located to the north of the muds of Raritan Bay and Sandy Hook Bay (Coch, 1986; Kastens et al., 1978; Jones et al., 1979). These sediments are primarily relic glacial sands and they cover almost the entire floor of the Lower Bay. Strong tidal currents at the mouth of the Lower Bay have reworked these deposits into large shoals and the penetration of the ocean waves into the Lower Bay prevent the retention of the fine-grained sediment except at a few small but significant sites (Mutler et al., 1984). These sites are borrow pits that were produced by sand mining operations. Within the pits, mud accumulates at rapid rates, even though conditions prevent its deposition on the surrounding sand banks (Olsen et al., 1984).

RESEARCH MATERIALS AND METHODS

Estuarine/near-shore waters are very complex, dynamic and productive bodies of water. Their complexity makes them spatially and temporally heterogeneous. The spectral characterization of these waters is produced by the organic, inorganic and dissolved organic matter (DOM). Various types of remote sensing data were utilized to analyze the characteristics of the Hudson/Raritan estuarine waters for environmental monitoring. Results demonstrated that the remotely sensed data provide information for better understanding of estuarine nearshore environment important in numerous ecological, social and economic studies.

Hydrologic targets induce disproportionate signals in various bands, giving rise to the wide range of distinctive hues that are observable for natural water column and bottom cover type(s). The greater the amount and specificity of color information available, the better a

remote hydrologic application will generally perform. This is particularly true for estuarine applications, where independent variations of optically important water column constituents, bottom cover types and water depths all tend to occur simultaneously. At the same time, all hydrologic targets share general characteristics induced by the water medium itself, specifically, a strong absorption of light with wavelengths shorter than those of blue light (~0.4 μm), or with wavelengths longer than those of near-infrared light (~1.5 μm). Outside these limits, signals within or beneath any hydrologic volume are attenuated so much as to be negligible for practical remote detection. The result is that color information useful for subsurface hydrologic applications is generally limited to that within the range between blue and near-infrared. Description of the remote Sensing data used are as follows:
1) Landsat-5 Thematic Mapper data, 2) XYbion MSC-02 multispectral video data, complemented by the Imaging spectrometer--AVIRIS data, and a library of absorption spectra of phytoplankton which is currently in progress.

1. ***LANDSAT- 5 (TM) DATA***

To achieve the objective of the project, the relatively "inherent" optical property target reflectance (R_t) was selected, since it is the most adaptable for the vast majority of hydrologic optical modeling, and readily calculable from the most types of remote sensing data. For the TM data this transformation began with the conversion, in each band, of digital numbers (DN) to detected radiances (L_d):

$$L_d = m_r DN + b_r$$

where m_r and b_r are the (fixed) values of radiometric gain and bias, respectively (Markham and Barker, 1986). Note that this approach does not account for variability in TM gain and/or bias, i.e. "striping" (variation caused by the radiometric difference between forward and reverse scanning in Landsat multispectral data). Striping occurred in the TM images of our study site and proved to impact our method significantly, as described below. The above radiance retrievals were then transformed to planetary reflectances (R_p):

$$R_p = \pi d_2 L_d / \cos\Theta E_0$$

where the factor π accounts for undetected light (scattered away from the sensor); d is the earth-sun distance in astronomical units(assumed to be one here due to small variability); Θ is the solar zenith angle in degree; and E_0 is the mean solar (exoatmospheric) irradiance (Markham and Barker, 1986). These planetary reflectance require further correction for (two-way) atmospheric transmittance (T) and reflectance (R_a) influences, in order to extract R_t:

$$R_p = R_a + TR_t$$

Single, image-wide values of both R_a and T were defined and applied, based partially on a dark pixel (lowest nonzero DN) determination, as described by Stein (1989):

$$R_t = (R_p - R_a)/T$$

The values for atmospheric reflectance (R_a) and the scaling factor (1/T; atmospheric opacity) specific to the scene were then applied to all points within the TM imagery.

Numerous chlorophyll-a fluorescence (CHL) measurements were continuously acquired in situ by the Research Vessel Kyma while underway, permitting over 200 comparisons against corresponding TM pixels along the study transects, as delineated in Figure1. Covariances between CHL and R_t in all TM bands-individually and in band ratio combinations were evaluated. The best correlations was observed for TM Rt4/Rt2; the ratio of near-infrared/green reflectance (Figure 2). This implied a phytoplankton-induced signal of green absorption and/or near-infrared backscattering. Such interpretation was consistent with lab reports and other sea truth data (USEPA, 1986) indicated the presence of a diatom bloom. Figure 2 shows that the correlation was very strong for cruise line D-E (southernmost in Figure 1). However, the strength of this correlation was greatly reduced for the other two study transects. It was noted that line D-E was the only transect which happened to parallel exactly the TM scan direction and would so have avoided any striping/banding variations within the various TM bands.

2. *MSC-02 VIDEO DATA*

The Multispectral Video Camera #2 (MSC-02) is a CCD-array imaging device, detecting radiation in 6 bands in the visible/reflective spectral range as TM bands 1-4 (0.4-1.1 µm). This is the only electromagnetic spectral range in which signals from the hydrologic volume--i.e., originating below the surface and thus directly from the water column--can be significantly detected. The MSC-02 uses replaceable, six-band filters sets, enabling precise retrieval of imagery having the desired color information. As configured here, the MSC-02 thus provided better spectral coverage for the target applications than attainable using the best available satellite data, Landsat Thematic Mapper (TM) and CZCS. The MSC-02 was deployed as follows: Using a Hughes 300 helicopter, video data were acquired from between 400-500 meters above mean sea level, producing spatial resolution of about 1 meter. The flight pattern as shown in figure 1 providing maximal over-flight of ship transects along which surface water sampling data were collected.

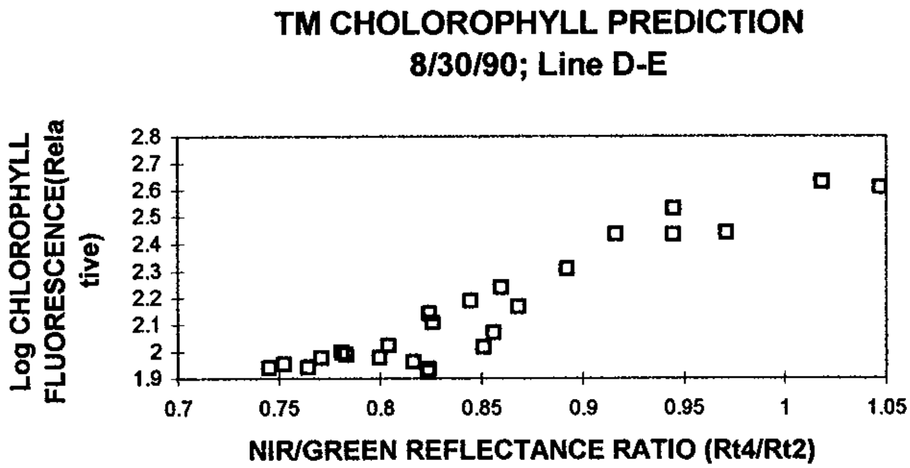

Figure 2. TM band ratio (Rt4/Rt2) vs log chlorophyll concentration

Pre- and post-mission camera calibration sequence were performed to determine the optimal F-setting (aperture) for the MSC-02, and to enable later calibration of image data to relative radiometric values. MSC-02 video was digitized in each of its 6 spectral bands over the flight legs shown in Figure 1. This was achieved by automatic field-grabbing and continuous, sequential averaging of the digital numbers within each field's central 25x25-pixel window using identifiable ground-control features - beaches, jetties and channel markers - common to both the MSC-02 and base map of the study area.

The camera-based nature of the MSC-02 enabled us to perform independent calibration of the MSC-02 data, using a multiple-aperture relative radiometric response technique, involving calibration on the ground just before and after the mission. This approach requires determination of relative irradiances upwelling from the target (aE_u) and down-welling during the mission (aE_d; as reflected from a Halon-coated reflectance panel):

$$Rt = aE_u/aE_d$$

where the scaling factor (a) is identical for both measurements and therefore cancels out. These relative irradiances must first be calculated from the video data, requiring for each band a calibration function f(DN) which has been claimed to be linear over most of the response-range of the MSC-02 (Niedrauer and Paul, 1989), i.e.:

$$aE_x = f(DN_x) = m_x\, DN_x + b_x$$

Where m_x and b_x are relative radiometric gain and bias, specific to each of the bands. For calculation of aE_u, video calibration data of the Halon panel (with reflectance (R_c) assumed equal to 1.0) were successfully acquired only for MSC-02 bands 2,3,4, and 6, and these only from two or three F-stops (The panel was too bright, saturating most band/aperture combinations). However this did permit linear regressions to crudely determine the required calibration functions for bands 2, 3, 4 and 6. It should be mentioned that MSC-02 flight legs did not coincide completely with the true ship tracks (Figure 1). Geo-referencing of the offshore legs- C-D and D-E is additionally subject to maximal uncertainty due to their distances from identifiable ground control features particularly at their seaward ends.

The MSC-02 data set was of high quality, depicting hydrologic volume and some bottom features as well as surface phenomena including swells, small waves and frontal foam lines. The most striking features detected were bright oil slicks appeared from the air as rainbow-like patterns of blue-green and even reddish-purple in some areas.

Three days prior to the mission on 11 June 1990, a quarter of a million gallons of home heating oil spilled into the Kill Van Kull, the busy waterway between Bayonne and Staten Island that normally handles some 200 ships daily. Throughout this mission, weather was overcast prohibiting imaging by any of Landsat-5's sensors, but the videography was acquired successfully without any intervention of clouds between the aircraft and the water surface. The coincidence of this oil spill and subsequent overcast condition provided an opportunity to test the capacity of the MSC-02 as a low cost oil spill-response monitoring system under demanding weather conditions.

At the time of the mission, it was reported that there was only one beach area--Norton point near Coney Island -- where oil (as tar balls) was in evidence (NJ Star Ledger, 10 June 1990). Several MSC-02 frames clearly showed bright slicks in this area.

The first order Spectral Curvature Index (SC) I which is an algorithm suggested by Lyzenga (1988) was used to calculate the index for MSC-02:

$$\text{MSC-02 SCI-246} = 2*[R_t4]-[R_t2]-[R_t6]$$

The MSC-02 data, once transformed in the appropriate algorithm, covaried well with phytoplankton abundance despite decidedly suboptimal calibration data. While viewing geometry of the MSC-02 resulted in detection of sun glint that prohibited an under-atmosphere correction to the TM data performed in the ultimate application more reliably than TM. This suggests the potential for the MSC-02 index to define (spatially-dependent) de-striping corrections to the TM phytophankton algorithm, which would be optimal since the MSC-02 alone can never achieve the kind of contiguous coverage provided by TMs field of view. Figure 3 compares MSC-02 algorithm retrievals and fluorescences along just line D-E, showing correlation almost as good as the best observed for the TM band ratio (corresponding to the same ship samples). Clearly, this physically-based spectral curvature index is effective as a phytophankton algorithm. Its performance, however, is expected to be heavily dependent upon the accuracy of the original R_t's on which it is applied.

3. *SEA TRUTH DATA*

Sea truth data were collected using a shipboard automated sampling system. Water was pumped continuously through the sampling system from a depth of 1 m below surface. Temperature, conductivity and fluorescence of water passing through the system were monitored and averaged for each minute during this period. The corresponding year, month, day, time, latitude and longitude using Loran C unit also were recorded.

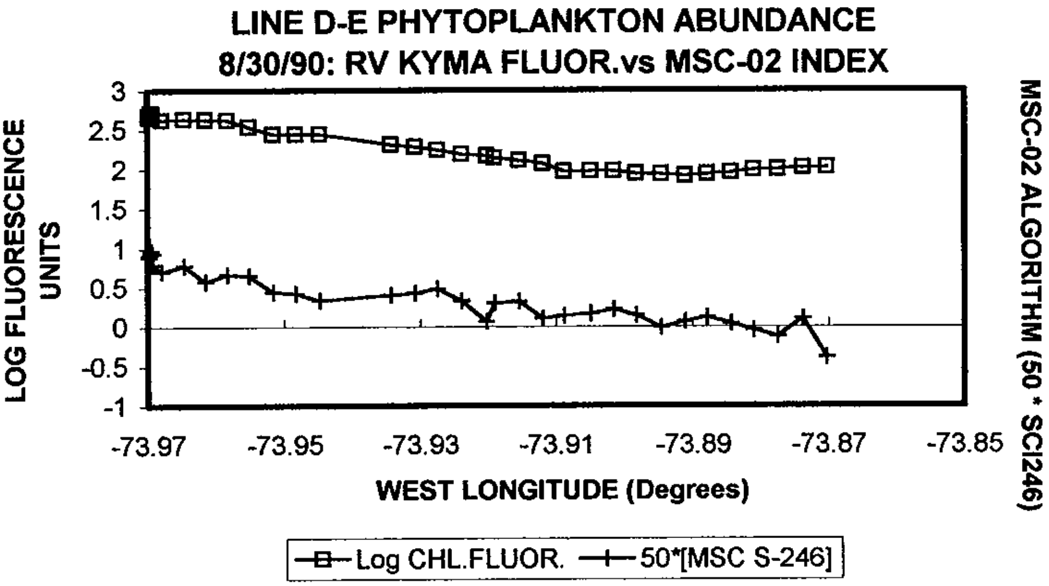

Figure 3. MSC-02 Spectral Curvature Index (SCI) vs log fluorescence

A continuous-flow fluorometer set-up for chlorophyll-a analysis was used to measure pigment fluorescence. Periodically water samples were collected for phytoplankton speciation. At five-minute intervals, water was collected from the automated system effluent for turbidity, salinity and chlorophyll pigment analysis. Chlorophyll-a and phaeopigment concentrations in these samples were determined according to Evans et al. (1987). Discrete samples collected for chlorophyll pigment analysis were used to determine if fluorescence recorded by the continuous-flow fluorometer was representative of actual pigments concentrations in the water passing through.

Since the continuous-flow fluorometer measures the combined fluorescence of both chlorophyll-a and phaeopigments and cannot distinguish between the two, chlorophyll-a and phaeopigment concentrations determined from discrete samples were added, using molecular weights, to estimate the concentration of chlorophyll-a derived pigments that would be responsible for fluorescence recorded from corresponding water passing through the underway fluorometer. Because of the greater number of observations obtained using the underway system and the high degree of correlation between the two sets of data, fluorescent data generated from the continuous-flow fluorometer was used to develop and test algorithms.

The overall results suggested great potential for the XY Bion MSC-02 as an inexpensive, flexible monitoring tool for an area which is very susceptible to oil spills and other types of water pollution. The sensitivity and accessibility of MSC-02 data suggest utility for real time response to dynamic events. Video data can have several advantages including real time access, sensitivity to limited amounts of energy and operation economy. The main disadvantages of video include low spatial resolution and uncertainties in calibration (Meinser 1986, and Everitt and Escobar 1989). The video data obtained in this mission are used to supplement multi-date satellite analyses, for a meaningful description of the physical and biological processes of this coastal/estuarine environment. Use of both MSC-02 and TM data indicated that the broad band airborne/spaceborne sensors may be unable to adequately resolve the organic/inorganic components of the nearshore waters where they coexist (Bagheri, et. al., 1993). The aformentioned results have been the main impetus to initiate the use of the high spectral resolution data obtained by airborne/spaceborne imaging spectrometers. Thus development of a spectral library that includes the absorption spectra for the most common phytoplankton species found locally within the Hudson/Raritan Estuary (Table 1) was undertaken to complement the analysis of the high spectral resolution imaging spectrometer data (Bagheri et. al., 1999).

ONGOING RESEARCH

With the advances in computer and detector technology the new field of imaging spectroscopy is developing (Goetz and Vane, 1993). Spectroscopy has been an accepted science in analytical laboratories for many years in many disciplines. It is based on the accurate measurement of spectra emitted by samples under controlled, experimental conditions, and comparison of such spectra to known standards. Imaging spectroscopy on a small scale is performed routinely with scanning electron microscopes. On a large scale, spectral images of the planet earth provide both regional and global perspective to scientists. Imaging Spectrometry consists of the acquisition of images in many narrow contiguous spectral bands throughout the visible and solar reflected infrared portions of the spectrum. The current/ongoing water quality modeling research conducted in Hudson/Raritan Estuary is focused on the data acquired by Airborne Visible Infrared Imaging Spectrometer (AVIRIS), field spectroradiometer and discrete water sampling. The AVIRIS images the earth's surface in 224 spectral bands approximately 10 nm wide (nominal width is 9.6 nm) covering the region 400-2500 nm from a NASA ER-2 aircraft at an altitude of 20 km. The ground resolution is 20m * 20m. The instrument is composed of four spectrometers (A, B, C, and D). The A spectrometer records the data for the first 32 bands while the B, C and D spectrometers record 64 bands each. Because of band overlap between the four spectrometers, there are 210 discrete bands available that will be used in atmospheric correction. Using the AVIRIS data the raw data will be spectrally and radiometrically calibrated to radiance/reflectance for analysis. Based on these measurements optical water quality models will be constructed linking the inherent optical properties to the subsurface irradiance reflectance. To achieve the objective of the project, a spectral library of the optical water quality parameters is under development. The library includes: 1) phytoplankton grown in culture, and 2) phytoplankton present in field samples, collected during times of blooms (July and August 1995 and 1996). Phytoplankton collected in the field were concentrated through filtration and analyzed using standard extraction and spectrometric techniques to generate characteristic absorption spectra. The methodology to determine the Chlorophyll-a concentration from extraction through spectrometric analysis, and subsequent verification by statistical analysis, is outlined as follows:

Sample extraction. Sample extractions were performed using standard techniques (Strickland & Parsons, 1972; Evans and O'Reiley, 1983). Phytoplankton from field samples were concentrated by filtering between 100 and 500 ml of water through glass-fiber filter (Whatman GF/F) and in some cases filter fractionated through (20, 0.7, 0.2 μm) filters. Cultures of Phytoplankton were filtered through 0.7 μm only. Phytoplankton pigments were extracted in 10 ml 90% acetone in a darkened freezer for 24 hours. Chlorophyll-a and phaeopigment concentrations were calculated using the Strickland-Parsons formulae (1972).

Spectrometric analysis. All optical spectra were measured using PC-based S-1000 Fiber Optic Spectrometer manufactured by the Ocean Optics Inc. and designed for use with single strand optical fiber. Absorption readings of pigments was obtained from two types of phytoplankton samples (i.e., laboratory cultures and field samples) collected during times of bloom. For each sample, pigments were extracted in 90% acetone and the acetone containing pigments were individually decanted into a 1 cm path length spectrometer cuvette. The extinction of the extract was measured from 326 to 850 nm. Spectral absorptions for the extracted and field samples were measured relative to 90% acetone.

Statistical analysis. Initially a custom program was coded to perform the derivative analysis. The fourth degree stochastic model emerges from the 4th derivative deterministic model because of the trends and fluctuations (critical points such as maxima & minima) in the scatter plots of the specific absorption spectra in our analysis. Using the culture data set, the coefficients of the 4th derivative equation were calculated in order to minimize the root mean square error. Then the corresponding graphs, and their maximum and minimum wavelengths were identified using MATHCAD. Expansion of the 4th derivative deterministic model to a 4th degree stochastic polynomial model resulted in p-values of less than I% for the curve fit:

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4$$

Observing the results for Aureococcus, Thalassiosira and an unidentified brown tide phytoplankton, correlation coefficients of 89%, 87% and 93% were obtained for the predictive model.

As the first step, determination of chlorophyll-a and phaeopigment concentrations were based upon spectrometric analysis, producing characteristic absorption spectra. To further refine and discriminate pigment compositions which affect remote color sensing recorded by sensors, mathematical models--spectral derivative and polynomial regression analysis--were applied to the absorption spectra. Using these models, it was possible to identify optimum wavelengths characterizing pigment compositions of the phytoplankton species in the estuary. This established the usefulness of polynomial regression as a means to provide the calibrated sea truth data for the application of remotely sensed data of high spectral resolution.

Ongoing research will construct optical water quality models linking the inherent optical properties to the subsurface irradiance reflectance. The water constituents will be expressed in their specific (per unit measure) absorption and backscatter coefficients. Subsequently the water constituents or parameters will be retrieved from the remote sensing upwelling radiance/reflectance signal. It is expected that the detailed spectral information afforded by imaging spectrometer--AVIRIS will provide the data necessary to examine both spectral and spatial variations in water quality parameters and sources of pollution. The ability to accurately predict optical signals produced by hydrological constituents using remotely sensed data is unique and has potential to be utilized as a management tool in estuarine/near-shore environments that are most subject to intensive pollution.

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COASTAL MANAGEMENT PROJECTS IN CAPE MAY COUNTY, NJ

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INTRODUCTION

The modern history of beach nourishment in New Jersey began in New Jersey in 1950 with a 250,000 cubic yard transfer of sand around Shark River Inlet by truck. This project was done during the winter and utilized a relatively primitive transfer system to effect inlet bypassing. Sand was excavated from the beach on the south side of the inlet, loaded in trucks and carried across the bridge to the northern side. Each truck backed out a temporary wooden trestle built over the surf zone and dumped its load into the water. The Philadelphia District Army Corps of Engineers executed an inaugural dredge fill project in Ocean City, NJ in 1952 with 2.52 million cubic yards of sand pumped onto the beach. This was large even by modern project standards, but suffered rapid losses because of the project's proximity to Great Egg Inlet and the choice of a sand source with a mean grain size substantially less than that of the native beach. Other projects followed in the 1960's and 1970's driven more by severe erosion, rather than careful planning. None of these projects was monitored using ground surveys, only aerial photography. Beach restoration following the 1962 northeast storm utilized beach nourishment of all types such as trucked-in sand, inlet dredging, cross-island pumping of bay floor sediments. The latter method was used in Barnegat Bay, but the excavation was done to 40 feet in localized "pits" to access pre-Holocene coastal plain sediments. This methodology has been abandoned due to the adverse environmental impacts presented by creating multiple stagnant bodies of deep water in the shallow bay environment.

The State of New Jersey voters passed ballot referendums in 1977 ($20 million) and 1983 ($50 million) to allow funding of selected coastal protection projects. A priority list was assembled by the Department of Environment Protection's Division of Construction and Engineering. The legislation required that the local partner in each project pay 25% of the cost with the State fund paying 75%. The State proceeded to fund multiple beach nourishment projects between 1978 and 1987 with this money. Some locations were in Sea Isle City, 1978, Atlantic City, 1982, Strathmere, 1984, and Avalon, 1987. By the mid-1980's it had become clear that bond referenda were not going to provide sufficient funds to deal with a complex array of problems. The State turned to the Federal government and the Army Corps to partner in large-scale projects. The Federal requirement of 35% State and local funding required that the State create a stable fund for matching these projects. Pl:95 became law in 1994 providing $15 million in funding annually for all types of shore protection projects. The State then embarked on a massive project in cooperation with two ACOE districts to place 150 million cubic yards of sand on beaches (24 miles in

Monmouth County, 13 miles in Cape May County). Using these funds, the State also cooperated directly with local interests to put 2.19 million cubic yards of sand on beaches at four sites in the state. In 1998, the stable funding source was increased to $25 million annually to meet the demands of multi-county ACOE feasibility studies moving towards design approval and funding for construction. Continued political effort is being conducted lobbying Congress so that the alliance with the ACOE can continue to implement these projects in spite of the recent change in the maintenance-funding ratio to 50-50.

CAPE MAY COUNTY PROJECTS

This county consists of five barrier islands and an extensive coastline in Delaware Bay. Each island has unique coastal situations, which have needed different management solutions. From north to south, the past decade has seen the following activities:

Pecks Beach:

This was the initial project in New Jersey where the Philadelphia District Corps of Engineers established a 50-year maintenance program to provide both shore protection and recreational improvements along an entire coastal entity. Actually, the USACOE funded the northern three quarters of the island's beach to 34th Street and the State of NJ completed the nourishment in 1995 from an offshore borrow source. Since the inception of construction during the summer of 1992, the USACOE has performed three routine maintenance-dredging projects and one following a disaster declaration in December 1992.

Ludlum Island:

Consisting of two communities, Ludlum Island has seen three State-sponsored projects since 1978. In addition, three groins were built in the northern community of Strathmere in Upper Township, and three were added to an existing groin field in Sea Isle City. The last of these was completed in the spring of 1999, accompanied by a 345,000 cubic yard beach restoration between 88th and 93rd Streets in Sea Isle City.

Seven Mile Beach:

Two communities also divide this NJ barrier island's shoreline. Avalon to the north has completed a major project, the last funded by NJ bond money in 1987 (2.35 million cubic yards). Since that time the community has funded maintenance events in 1990, 1992, 1993, 1995, 1997, 1998 and 1999. The projects in 1993, and 1998 were restorations undertaken because of FEMA storm disaster declarations. This community has played a led role in promoting beach maintenance as part of the municipal budget process. The local government has been proactive in lobbying in Washington DC to continue the USACOE shore protection program, frequently presenting information at coastal conferences. Stone Harbor has recently completed a beach nourishment project and plans to expand its activities in conjunction with the Corps District.

Five Mile Beach:

The Wildwoods have seen beaches with excess sand, but detailed study has shown that the northern end of the island may see 300+ feet of change annually in shoreline position. Other than armoring the Hereford Inlet shoreline in North Wildwood to prevent inlet migration from taking upland property, no beach structures or nourishment has occurred since 1911. The jetties at Cold Springs Inlet, competed in 1911 have been the cause of severe erosion along the Cape Island shoreline to the tip of Cape May County. Their ability to trap sand has been notable in producing the shoreline accretion on Five Mile Beach. Today's File Mile Beach is a combination of Two Mile and Three Mile Beaches in 1925. A small inlet, present on a map made in 1756, closed by human intervention and allowed the two small islands to become one. Turtle Gut Inlet's ebb-tidal delta migrated to the shoreline and added a large volume of sand to the "Wildwoods".

Cape Island:

The second Cape May County shoreline project under USACOE jurisdiction was placed there following court findings that the jetties at Cold Springs Inlet were directly at fault depriving the down-drift beaches of sand and promoting shoreline erosion. Cape May City began receiving new sand from offshore in 1990 with multiple maintenance projects since. The shoreline is dramatically different since the project began. Southerly transport has carried sand southwest of Cape May City into a natural area to its benefit. The Philadelphia District has also begun final design work on projects specifically tailored to benefit the natural environment along the southern Cape Island shoreline as well as improve the municipal beaches in Cape May Point.

Delaware Bay Shoreline:

The western shoreline of Cape May County is unique in that sand is not being derived from shoreline erosion locally. The majority of the shoreline fronts salt marsh meadowlands built in the bay environment. Slow erosion of this shoreline has produced a wide, low-gradient terrace in front of a narrow, steep beach with a low dune. The sand moves north along the coast, eventually petering out to a marsh-cliff coast. This limited sand budget restricts development to a narrow strip at the beach. Erosion problems result in buildings being left standing on pilings out in the bay at high tide as the shoreline retreats eastward past them. The USACOE has a program in the feasibility phase to provide sand to a section of this shoreline as an environmental enhancement as its primary design feature.

The Cape May County Mosquito Commission has jurisdiction over wetlands management decisions regarding both fresh water and salt water wetlands in Cape May County. Seventy-two years ago private owners built sand dikes across two inlets draining the salt marshes that were fed through Schellingers and Green Creek Inlets. Fresh water drained out through two 24-inch diameter pipes placed under the sand dikes closing the inlets. Tide valves prevented incoming flow. As decades passed, the salt marsh plants died off and freshwater plants moved onto the salt marsh surface. The environmental issue was the eventual dominance of the original salt marsh surface by the tall reed Phragmities communis. This dense, tall plant prevented habitat utilization by the normal range of salt marsh animals.

In 1994 the Mosquito Commission received permits from the US Army Corps of Engineers and the NJ Department of Environmental Protection allowing the re-opening of both inlets to normal tidal flow. Schellingers Creek was opened by digging through the sand dike March 1995. After upgrading the internal drainage channels, the salt-water flow rapidly eliminated the Phragmities and allowed Spartina grasses to re-establish.

In 1998, the Commission applied to the New Jersey Department of Commerce, Division of Maritime Resources for a grant. Funds had been set aside for use by the Dredging Project Facilitation Task Force to find suitable uses for dredge spoils generated in the coastal zone of New Jersey. The project covered by the grant calls for the transfer of suitable sand from the spoil holding area adjacent to the Cape May Canal in Cape May County, NJ. Approximately 8,000 cubic yards of sand are to be truck-hauled to eroded beaches near Schellinger's Creek in Middle Township in Cape May County. Testing of the sand source indicates a 30% match in size distribution, with a poorer sorting of the spoil than on the beach. Since the material is going to be used to rebuild the dune and uppermost beach along the affected shoreline, the exact size match is not as critical. This project is to determine if beneficial use can be made of some of the thousands of cubic yards of sediment dredged from channels, lagoons and canals in the State.

THE EFFECTS OF DEVELOPMENT ON THE DUNE SYSTEM OF A BARRIER ISLAND COMMUNITY

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INTRODUCTION

The dune system in natural settings consists of primary, secondary, and tertiary sections, is a source of natural protection for the barrier islands and wetlands from the damaging effects of wave action caused by storms. This system acts a natural supply of sand to the beach. There are four necessary elements for successful dune growth and maintenance: 1) sufficient space at least 150 feet landward of the high water line, 2) sources of sediment, 3) wind, and 4) proper vegetation.

Dunes in most of New Jersey are landward of the spring high tide line, but because of the narrow beach widths, these dunes are eroded during significant storms. This problem is due to buildings that have been constructed where the dunes should naturally be. As a result of rising sea level and high rates of erosion of parts of the shore most beaches along the New Jersey shore are narrowing. In an undeveloped area such as Island Beach State Park, the beach and dune system respond to sea level changes and storms by moving landward and upward without a significant change in width in either of the systems.

As a result of hurricanes and northeasters, especially the March 1962 storm, many dunes were leveled and had to be rebuilt from scratch. A new dune line was established 150 feet landward of the mean high water line. By default this dune became the primary dune and development pushed directly up and into this dune. Because this new dune was set in an emergency situation, little or no regard was taken as to the position of the dunes before the storm. There is a strong possibility that many buildings now exist seaward of the primary dune that existed before the 1962 storm. Thus these narrows dunes can no longer adequately protect the barrier island from storms nor can they supply sand to the beach when necessary, thereby not mitigating the increased rates of beach erosion.

PROCEDURES AND RESULTS

The purpose of two studies on Long Beach Island communities was to use aerial photographs taken before the 1962 storm and those in 1986 and determine the number of buildings that have been constructed in or seaward of the pre-1962 dune system. These photos, 1 inch to 200 feet scale, are positives that are clearly visible on a light table. The 1961 photos were used to map the dune system because they show the natural dune geomorphology prior to its being demolished by the 1962 storm. The seaward extent of the dune was based on the beginning of the foredune vegetation and dune crest where there was a change from primary to secondary vegetation growth. Superimposed over these outlines was a map of the 1986 structures that were built seaward of the 1961 dune crest.

Although the results are still being worked up the preliminary results clearly show one to four houses per block that are seaward of the pre-1962 primary dune line. Dunes and beach widths tend to be more narrow in 1986 as compared to 1961.
Example of changes noted in one area:

	1961	1986	1961	1986
Ave. Dune width	49m	41m	83m	34m
Ave. Beach width	45m	30m	37m	15m

CONCLUSIONS

The changes in beach width can be attributed in part to the buildings constructed in or seaward of the original 1961 dune system. With these structures occupying part of the natural sand supply for the beach, it is difficult for sand from the dunes to replenish the beach when the dunes are scarped by storms. Furthermore, the buildings are much closer to the mean high water line and do not provide ample beach width across which dry sand can be transported by the wind. This smaller distance does not contribute to increasing dune growth over time.

This specific analysis of air photos has shown one effect of development on the delicate balance in the natural beach-dune system. These findings may be indicative of the kinds of changes the New Jersey shore will continue to face in the future as more development occurs and sea level continues to rise. Further conclusions will be published when this project is complete.

FOSSILIFEROUS CONCRETIONS FROM NEW YORK BIGHT BEACHES: IMPLICATIONS FOR LATE PLEISTOCENE AND HOLOCENE COASTAL ENVIRONMENTS AROUND SANDY HOOK AND WESTERN LONG ISLAND

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ABSTRACT

Concretions that preserve early Holocene fossils frequently wash ashore on ocean beaches in the New York Bight (coastal Long Island and New Jersey). The fauna they contain includes both normal and brackish water organisms, mostly invertebrates, plant material and bone. We examined concretions from two locations, Rockaway Spit in Queens, NY, and the Seabright/Sandy Hook Spit in Monmouth County, NJ. The Rockaway beach locality yields specimens (crabs, gastropods, oysters, bay scallops, horseshoe crabs, marsh grasses, and root structures, preserved in a silty matrix) consistent with a brackish tidal creek/marsh environment. The concretions from the New Jersey beaches are dominated by a more normal littoral marine fauna including jingle shells, clams, gastropods, razor clams, encrusting corals, slipper shells, and lobster fragments. In addition, the matrix is more sandy, and frequently preserves roots from cedar trees. A radiocarbon determination from an oyster shell in one Rockaway concretion yields an age of 7,610 (±150) years BP. The occurrence of these materials on open ocean beaches is an expression of the landward migration of the shoreline during the ongoing Flandrian transgression (Latest Pleistocene and Holocene). The fossil assemblages are similar to modern fauna in some ocean beach locations in the New York City area. The character of concretion formation is consistent with ongoing processes in local modern depositional environments, and implies the occurrence of major storms or spring flooding events.

INTRODUCTION

Fossil-bearing concretions and beach rock material derived from nearshore sources frequently wash up on the ocean beaches in the New York Bight. Concretions and beach-rock materials were collected over a period of several years from beach wrackline accumulations on Sandy Hook Spit in Monmouth County, NJ and from Long Island's Rockaway Spit in Queens, NY (Figure 1). Many of the concretions and beach-rock samples show identical lithologies, and have common microfauna and macrofauna components. All fossil species observed in the concretions have modern living counterparts in the region. To gain a better understanding of the habitats of the fossil assemblages represented, modern beach and bay environments were examined, including the sedimentary deposits that host both faunal living and death assemblages. In New Jersey, modern sedimentary environments were examined along the beaches along Sandy Hook, along the banks of the Shrewsbury and Navesink Rivers estuary, along the tidal creeks in Cheesequake State Park, and along the south shore of Raritan Bay. In New York, modern sedimentary environments were examined along the ocean-side beaches of Rockaway Peninsula between the community of Rockaway Beach to the jetty at Breezy Point. Sedimentary environments were also examined throughout Jamaica Bay. Additional tidal creek habitats were examined at Caumsett State Park on the North Shore and around Montauk Point on Long Island. These examinations demonstrated that each environment has unique living and recent death assemblages that change with the seasons. These evaluations provide information about the taphonomy of beach fossils, the sedimentary processes related to the origin of concretions, and changes in shoreline geometry associated with the ongoing Flandrian transgression (the global late Pleistocene-Holocene sea level rise).

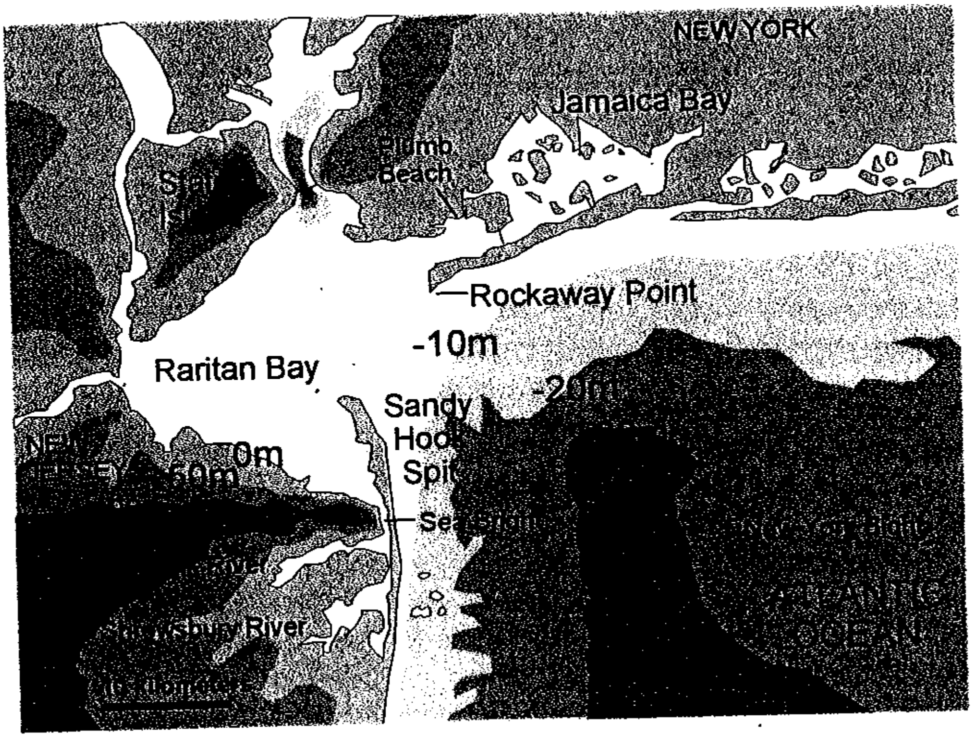

Figure 1. Map of the inner New York Bight showing the location of study areas (Sandy Hook, NJ and Rockaway Peninsula, NY); note that shading shows land surface topography at 50 meter intervals, whereas bathymetry is shown at 10 meter intervals.

GEOLOGIC AND ENVIRONMENTAL SETTING

The modern landscape and coastline of the New York Bight reflect the effects of Pleistocene glaciation and the ongoing marine transgression onto coastal areas throughout the Holocene. The late Pleistocene/Holocene transgression in the New York Bight is complicated by contradicting forces: the rising global sea level from the melting of glacial ice opposes the regional isostatic crustal rebound caused by the removal of the massive continental glaciers that covered much of the area until about 20,000 years ago. In addition, these forces have not proceeded at equivalent rates. Weiss (1974) used foraminiferal biofacies to determine that the maximum level of salinity in the lower Hudson River estuary occurred approximately 6,500 years ago. This might suggest that the fastest rate of regional post-Pleistocene sea level rise occurred in the Hypsithermal interval, the warmest period in the early Holocene (Pielou, 1991). Since 6,500 years before present, overall global temperatures have dropped and the rate of sea level rise has diminished. As a result, glacial rebound in the New York City region may actually be currently proceeding faster than sea level rise. This may also be inferred from lowered salinities deduced from foraminiferal biofacies in the lower Hudson River estuary from 3,000 years ago to the present (Weiss, 1974). Studies of sediments beneath the Delaware River estuary have yielded information about the Holocene transgression. About 10,000 years BP, the lower Delaware Bay was a tidal river basin. By 8,000 years BP, sea level rise and marine flooding had moved the shoreline upstream, and the main center of river sediment deposition migrated northwest into the main channel of lower Delaware Bay. By 3,000 years BP, the shoreline and the main center of sediment deposition had migrated northward to near its current configuration (Fletcher et al., 1990). Both the Hudson and Delaware River valleys show that the most rapid transgression occurred during the interval associated with the Climactic Optimum - the warmest period of the early Holocene, approximately 8,000-7,500 years BP.

Bathymetric charts show that the relief of the sea bottom of the New York Bight is much more subdued than that of the adjacent land in the region (see Figure 1). On shore, elevations approach 80 to 100 meters within 3 kilometers of the shoreline in the Atlantic Highlands, New Jersey and on Todt Hill in Staten Island. In contrast, the steepest sea bottom gradient is offshore of Sandy Hook where water depths approach 20 meters within 5 kilometers from shore. By comparison, along western Long Island the distance from shore to water depths of 20 meters is roughly 10 kilometers. The different gradients of the sea bottom, in conjunction with regional wind and wave current patterns, influence the migration and rate of buildup of beach deposits, barriers, and spits. In the New York Bight, the dominant incoming sea swells and tropical storm-generated waves propagate from the southeast. In northern New Jersey, this wave energy produces a northward longshore drift that carries sand northward to Sandy Hook where it is deposited. On Long Island, wave energy produces a westward longshore drift that, with the help of human shoreline modifications, has resulted in the modern buildup of Rockaway and Coney Island spits. The tidal currents of the greater Raritan Bay/Hudson River estuary system keep portions of the inner harbor flushed free of sediments. This is particularly evident in the Verrazano Narrows where water depths are greater than 30 meters. According to Williams & Duane (1974) the seabed throughout much of Outer New York Harbor region is underlain by about 10 to 20 meters of marine sediments of Holocene age. These deposits blanket a scoured surface of Pleistocene fluvial sand and gravel deposits, which, in turn, overlie a Pleistocene erosional surface on top of Coastal Plain strata between 20 to 40 meters below the sea bottom.

FOSSILIFEROUS CONCRETIONS FROM THE NEW YORK BIGHT

Plates I through VII represent the variety of concretions and invertebrate fossils from the beaches of the New York Bight. Specimens shown are representative of the materials we collected over a nine year period (1989-1998). Although not illustrated in this text, both marine and terrestrial vertebrate bone and teeth are not uncommon on area beaches. Wild pig, deer, elk, seal, shark, fish, whale, and even walrus bone have been recovered. Although most concretions are probably early Holocene, some are younger. Shells are frequently found embedded in rust attached to recent shipwrecks and other shore structures and debris that wash onto New York Bight beaches. New Jersey concretionary matrix varies from conglomeratic to fine sandy clay, ranging from barren bioturbated sand (Plate I-1), sand with root traces (Plate I-2), to extremely fossiliferous coquina and conglomerate which includes eastern hemlock [*Tsuga canadensis*] cones (Plate I-3).

The concretions from Rockaway Spit appear to be derived from a common source that is probably not far offshore from Rockaway Beach. The most common concretions are small irregular water-worn fragments bearing the juvenile gastropods with a tan-colored micaceous, sandy matrix (Plate I-4,5,6). Many concretions from Rockaway Spit contain oyster shell along with the gastropod, *Massarius obsoletus* [mud dog whelk] (Plate II and III). Both the oysters and these gastropods are species that neither survive in fully marine waters nor in sandy beach habitats, and are therefore relatively old.

Other lithified recent sediments are not uncommon on area beaches. Plate IV-1,2,3 shows indurated black bay mud, with 2 and 3 representing casts of a mussel and a clam, respectively. Hardened black mud partially baked to a brick red by either natural or man-made fires is abundant, particularly on the Rockaway beaches. These hardened black muds frequently contain an abundance of plant debris, probably marsh grasses, roots, and flotsam wood. In some areas, the organic content is high enough to be considered peat. Old cedar stumps found on Rockaway Beach after a winter storm in 1996 contained partially mineralized wood containing limonite and pyrite.

As abundant as certain species are in the modern environment, they may be largely under-represented in the concretion fauna. Surprisingly, clams of most varieties are not represented in the fossil collections. A single specimen of *Mercenaria mercenaria* [quahog or hard shell clam] (Plate IV-4) was found in nine years of collecting on Rockaway Beach. Although *Spisula solidissima* [soft shell clam] is the most abundant species on both ocean and bay beaches of the New York Bight, not a single specimen was found in fossil form. This perhaps illustrates the importance of understanding the taphonomy of different species. For instance, during winter die-off events, the dead and dying of *Mercenaria mercenaria* and especially *Spisula solidissima* can pile as much as a meter deep or more in some wrackline deposits. However, few of their shells may be remaining on the beach several months later. Either their fragile, porous shells cannot withstand the pounding of the surf or the churning by surf zone bioturbation, or they have been transported away from the beach. For example, at Plumb Beach in Brooklyn, NY, these shells occur in abundance in back beach dune storm sand deposits.

Other shell species tend to be well represented in the concretions collected.

Jackknife or razor clams (Plate IV-5) and bay scallops (Plate IV-6,7,8,9,10,11) also occur on both ocean and bay side beaches, and are not uncommon as fossils on all area beaches. On Sandy Hook, *Anomia simplex* [jingle shells] and *Mytilus edulus* [blue mussels] are most abundant in most fossiliferous concretion or beachrock samples. On Rockaway, *Crassostrea virginica* [Atlantic oysters] and *Aequipecten irradians* [bay scallops] are most common in concretion matrix.

Arthropod fossils also occur on all area beaches examined. However, the species represented by the New York collection sites are different from the specimens found on New Jersey beaches. Fossil crabs from Rockaway Beach include nearly complete specimens of *Callinectes sapidus* [blue claw crabs] (Plate V-1,2), *Carcinus maenas* [green crab] (Plate V-3,4,5), and fragments of *Limulus polyphemus* [horseshoe crab] and possibly *Cancer irroratus* [Atlantic rock crab] and *Ovalipes ocellatus* [lady crab]. Although today, these species can be found washed ashore on open ocean beaches, they are much more abundant, particularly in their juvenile forms, in bays and tidal creeks. All the specimens shown on Plate V are juveniles and are nearly complete specimens (except for missing legs). Arthropods collected on Sandy Hook include *Libinia emarginata* [spider crab] (Plate VI-1,2,3,4,5,6) and claw and exoskeleton fragments of *Hoarus americanus* [rock lobster] (Plate VI-7). Spider crabs are scavengers in greatest abundance in the surf and nearshore zone. Today, rock lobsters thrive in the cooler, shallow bays of the New England coast north of Cape Cod, and in the cooler deeper waters offshore in the New York Bight. Fossil *Balanus balanoides* [rock barnacles] occur attached to bay scallops and have been observed in concretion matrix on both New York and New Jersey beaches.

Plate VII illustrates unusual encrustation on concretions and shells, and represent both fossil and recent specimens. Encrusting organisms include corals, calcareous sponges, bryozoans, and algae. Encrusting organisms typically live in normal or near normal marine settings. Plate VII-1,2 show concretions coated with the encrusting coral, *Astrangia danae* [northern stony coral]. Stony corals found today in the New York Bight typically show a single season's growth before being killed off by winter cold. These probable fossil specimens also show only a single year's growth. Concretions, pebbles, and sometimes durable shell fragments show evidence of multiple stages of overgrowth by organisms that attach to objects on the seabed. For example, Plate VII-3 shows an oyster shell encrusted by a mix of calcareous sponge, base plates of barnacles, bryozoans, and other shell fragments. Calcareous sponges include *Halichondria sp.* [crumb of bread sponges] and *Cryptosula pallasiana* [fig sponge]. Recent sponge specimens are typically white, whereas fossil specimens tend to be colored dark brown, gray, or black. Sponges are show encrusting *Crepidula fornicata* [slipper shell] (Plate VII-4), *Crassostrea verginica* [Atlantic oyster] (Plate VII-5), *Mytilus edulus* [blue mussel] (Plate VII-6), and a *Mercenaria mercenaria* [quahog] (Plate VII-7).

CONCRETION FORMATION

Rapid burial of organic remains and shell material preserved in New York Bight concretions probably occurred during coastal storms. The influence of catastrophic storms on coastal environments is well known from the destruction of coastal communities and the opening of new inlets, such as the formation of the inlet at Westhampton Beach during the nor'easter of 1992, and the devastation of 1938's hurricane on Fire Island (Coch, 1993). Modern catastrophic storms cause the transfer of large quantities of sediments across shelf environments in water depths up to as much 80 meters (Morton, 1988). Storm-generated currents overwhelmingly control the buildup and destruction of barrier islands and inlets and the flood of sediments into estuarine settings from both landward and seaward source areas. Using the historical records of the National Park Service to examine changing shoreline configurations, longshore drift has extended the western end of Fire Island (including Robert Moses State Park) at a rate of 50 meters per year since 1825. Rockaway Spit has grown westward at a rate of about 25 meters per year since 1866. Sandy Hook has been building northward about 10 meters per year since 1764. The down-current extension of these spits progresses at the expense of beach erosion and the degradation of more ancient offshore deposits, and perhaps of ancestral barrier islands that existed far seaward of their current configurations. Using the modern seabed gradient in the New York Bight, a slight increase in sea level would translate into significant barrier migration on Long Island, whereas the migration of Sandy Hook would be minimal.

The beach sand on western Long Island and on Sandy Hook shows evidence of sediment mixing across the Hudson Channel in the New York Bight. For example, the green mineral, glauconite, reworked from the sedimentary formations of the New Jersey coastal plain occurs in the sands at Rockaway Beach, but it is essentially absent on beaches farther east on Long Island. Likewise, garnet sand derived from Long Island glacial deposits (ultimately traced to the Connecticut Highlands) is abundant on Sandy Hook, but less so on beaches to the south. This cross-Bight sediment mixing may be related to reworking of sediments derived from ancient beach and shore deposits. Identifiable rock fragments derived from Cretaceous and Tertiary sedimentary formations in New Jersey can be found on beaches in New York, especially in the winter when gravel bars episodically build up on the beaches. However, the characteristic fossil fauna in concretions of early Holocene age differ between the New York and New Jersey beaches. This suggests that they are probably derived from local sources close to the beach. Little is known about both the origin of these deposits, and their association with underlying sediments. Late Pleistocene marine clays and sands have been assigned to the Gardiners Clay Formation beneath Long Island (Weiss, 1954). Minard (1969) recognized a Quaternary glauconitic sand unit in the vicinity of Sandy Hook. A radiocarbon date from peat deposits associated with this unit yielded a Late Pleistocene date of 14,150 (±450) years B.P. Minard also obtained a radiocarbon date of 9840 (±300) years B.P. from plant material derived from a foraminifera clay unit between 85-92 feet below sea level beneath Sandy Hook. An analysis of a oyster shell from a Rockaway concretion yielded a value of 7,610 (±150) years BP. It is likely that the beach fossils presented in this report are derived from Holocene sediments.

Figure 2 summarizes the geologic/environmental setting of coastal deposits and modern habitats. The larger scale environmental settings, shelf/nearshore, beach/barrier island, and bay and landward, can each be further subdivided. Major faunal habitats illustrated include: A - offshore sublittoral zone, B - inshore surf zone, C - intertidal beach zone, D - barrier island terrestrial zone, E - bay, marsh or lagoonal zone, and F - terrestrial coastal zone. Each of these zones have unique corresponding sedimentary depositional environments ranging from sand or gravel-rich "high energy" facies to mud-dominated "low energy" facies. The geometry of Holocene sedimentary facies in the subsurface reflects the landward migration of shore environments through time. In general, modern marine deposits overlie or contain material derived from older shore or bay deposits. For instance, on Westhampton Beach on eastern Long Island, peat derived from early Holocene bay marsh deposits is eroding from exposures in the lower surf zone offshore.

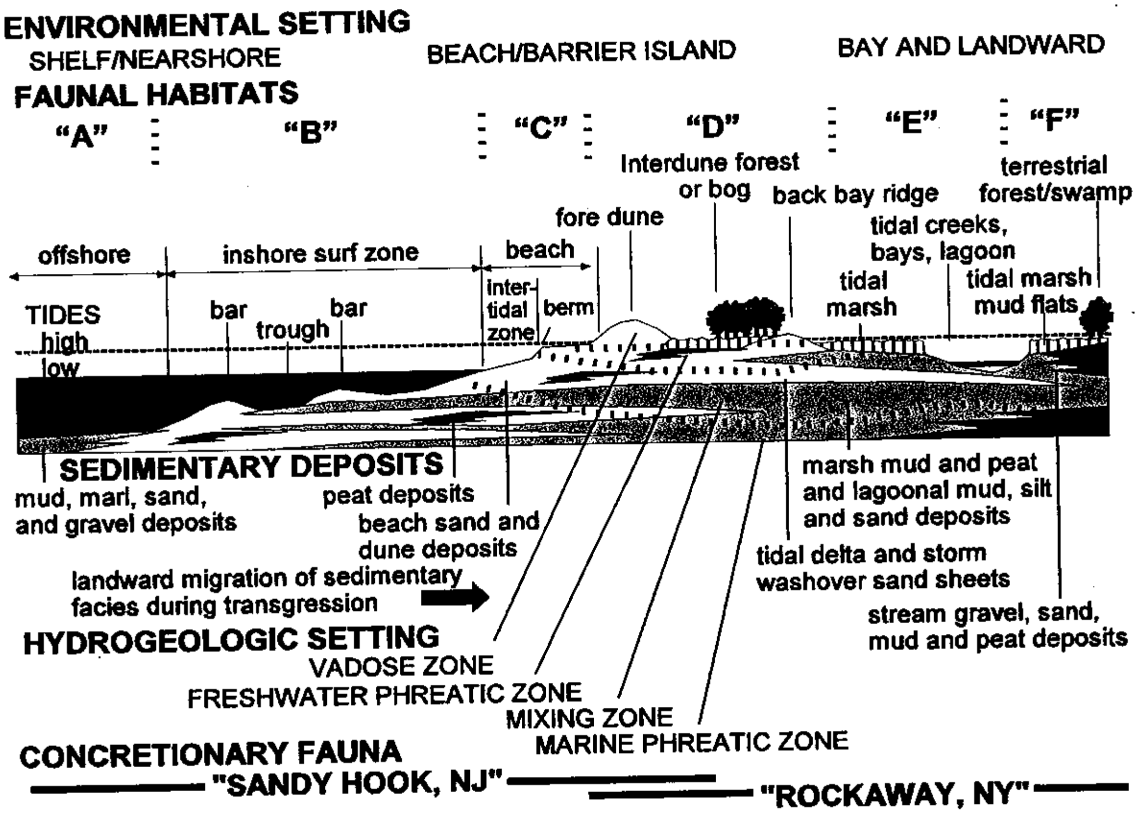

Figure 2. Geologic, hydrologic, and environmental setting of coastal habitats and features.

The modern coastal environment provides many of the ingredients for the early or rapid formation of concretions and local lithification of host sediments. The primary cements of the concretion matrix revealed in thin sections include microcrystalline calcite, ferroan calcite, clays, siderite, pyrite, and apatite. Berner (1968) demonstrated with laboratory experiments that chemical reactions involving decaying clams buried in marine saturated mud can form concretions in as little time as a year, with ammonia generation and methanogenesis driving the precipitation reactions to form calcite and other minerals.

Examination of concretions in the Cretaceous marine shales of the Western Interior reveal that bioturbation features are not crushed within concretions by comparison with the compacted host sediments where traces tend to be flattened or obliterated (Stoffer, 1998). The preservation of uncrushed bioturbation features is an indication of very early diagenesis and lithification prior to subsequent burial. Waage (1964) inferred that concretions with an abundance of delicate shelled fauna in the Cretaceous Fox Hills Formation of South Dakota represent rapid kill, burial, and early diagenesis. Molluscan faunas, mostly bivalves, in the concretions represent broods killed by catastrophic storms. This model probably applies to the origin of fossiliferous concretions in the New York Bight.

In the New York Bight, sources of calcium carbonate in the host sediment include desegregated shell debris, glacially-derived carbonate sand, and super-saturated seawater. Sources of iron include an abundance of magnetite, glauconite, and other ferromangesian minerals in the sand and iron dissolved in acidic groundwater. On barrier islands, the mixing zone between the freshwater phreatic zone with the underlying seawater-saturated sediments (marine phreatic zone) is an ideal environment for early diagenesis. Concretions derived from this interval preserve shell material, bioturbation and bedding structures typical of nearshore bar, beach, or washover fan sand deposits. These deposits are penetrated by roots of cedar and other interdune forest plants. This interval becomes locally tightly cemented by mineral precipitation reactions driven by the complex thermodynamic of the mixing of supersaturated interstitial marine and fresh waters. Methanogenesis or other bacterial processes probably assist in these reactions.

PALEOECOLOGICAL INTERPRETATION

Consideration of the habitats, life cycles, and death assemblages of the modern New York Bight fauna is crucial to understanding the character of the concretion faunas from the area beaches. The range and abundance of species are controlled by ecological factors such as turbitidy, sedimentation rate, wave and current energy, light penetration, nutrient supply, salinity, temperature, competition, and predation. The different subenvironments offer a spectrum of physical and chemical characteristics, and therefore, suitable or tolerable conditions for the different fauna and flora can change over short distances, or change from season to season. Table I is a summary of both published data and observations from this study relating to the occurrence of species in their living faunal habitats and ranges along the Atlantic seaboard, observed setting of modern death assemblages on New York Bight beach wracklines, and their occurrence in concretions and as fossils found on beaches in New York and New Jersey.

Perhaps the most significant ecological controlling factors affecting shelled fauna in the New York Bight are wave energy and salinity. These factors define the greatest differences between environments on the open ocean side of the beach as compared to environments in the bay, lagoon, or estuary side of the barriers and spits. Mobile species with hard shells can escape or withstand destruction by wave energy and dominate active surf zones. Species with necessary osmotic tolerances can handle the highly variable concentrations of salt versus freshwater in an estuarine environments. Conversely, these species typically cannot withstand the more intense predation and epizoan encrustation that occurs in a more fully marine setting. In the New York Bight, salinities range from below 1‰ in rivers and streams entering the sea and in ponds in the back beach area on the barrier islands to normal ocean salinities. Salinities in Raritan Bay range from an average low of about 12‰ at the mouth of the Raritan River to about 32‰ offshore from Sandy Hook (MacKenzie, 1992). Ponded marine water in and along tidal creeks can approach hypersaline conditions from evaporative concentration during the summer months. These same tidal creeks and ponds can suddenly be flooded by fresh water during storm events. This factor alone illustrates the variability and complexity of coastal habitats. When favorable conditions persist, species will spread their range to utilize available resources, usually to the detriment of prey or competitors.

Oysters grow about half an inch per year in salinity ranges from 5-10‰, and about an inch per year in salinity range from 12-20‰. Higher salinities allow other encrusting marine organisms to take space away from oysters (algae, bryozoans, and slipper shells). The abundance of oyster shell on the beaches of Rockaway Peninsula are intriguing. Local oyster stocks known from this area from historic times have been depleted for about a century (Mackenzie, 1992). The modern beach is not a suitable habitat for oysters to inhabit. Therefore, oyster shells that wash up on the New York beaches are most likely old.

The concretion material from Rockaway Beach yields oysters, bay scallops, crabs (mostly blue-claw and green), and mud dog whelk (a small gastropod). The abundance of these species suggests that the source area of these fossils was a bay-side environment. Gastropods are mostly juvenile, and occur distributed throughout the matrix in varying concentrations in nearly every concretion sample collected. In addition, both the crabs and the bay scallop shells tend to be small compared to modern specimens that wash onto the beach. The oysters, on the other hand, appear "normal" or even larger in size than modern oysters from Long Island. The fauna suggests an estuary or bay setting. The juvenile population of crabs, and the chaotic orientation of juvenile gastropods in the concretion matrix probably represent a spring brood that was catastrophically buried by a storm or flood event. This event was probably localized to the vicinity of Rockaway Peninsula and occurred long before the modern shoreline configuration. In any case, the fossil fauna on Rockaway Beach suggests that the shoreline has migrated landward significantly since early Holocene time, with the modern beach now residing on deposits that were once bay or lagoonal environments.

The sandy concretion material on Sandy Hook typically contains a hash of jingle shells, and juvenile blue mussels, razor and/or jackknife clams, and slipper shells. These shells, along with the limited collection containing juvenile spider crabs, suggest that fossils from Sandy Hook represent storms occurred when juvenile faunas were at their peak. Whether this coincides with spring nor'easters or summer hurricanes is unclear. These Holocene fossils represent species that currently inhabit the waters around Sandy Hook. This suggests that despite inferred sea level rise, the geometry of shoreline environments in and around Sandy Hook has not changed significantly since early Holocene time. The infilling of offshore areas with sand contributed from longshore drift through the Holocene along the Jersey shore is probably quite significant. The concretions and beachrocks that wash ashore on Sandy Hook are much more variable in abundance, composition, appearance, and fossil content than the concretions on the Rockaway beaches. Many of the concretions that wash ashore on Sandy Hook are possibly derived from older Quaternary or possibly late Tertiary deposits. For instance, approximately between 0.5 and 3.0 kilometers offshore from Shrewsbury, New Jersey are several submarine obstructions known to local fisherman as the "Shrewsbury Rocks." Old fishermen in Sheepshead Bay (Brooklyn) yielded entertaining stories from the early Twentieth Century regarding fights between lobster trappers and fishermen competing for space around the Shrewsbury Rocks. These "rocks" may represent submerged outcroppings of Tertiary rock formations. Another possibility is that they may represent remnants of tightly cemented Quaternary barrier island deposits. One seaman, Captain Jim of the "Jet," told a story of his grandfather looking down into the clear water over the Shrewsbury Rocks in the 1890s and seeing them as white from the encrustation of living coral. During the pollution crisis of the 1960s the entire inner New York Bight was nearly sterile. Today, much of the coral fragments found on Sandy Hook beaches are probably derived from the erosion of crusts form the Shrewsbury Rocks. Perhaps the return of natural coral crusts to the Shrewsbury rocks will be the sign of environmental recovery of the New York Bight.

ACKNOWLEDGEMENTS

In the early stages of this research, park policy allowed for the collecting of "a bucket of shells for research and educational purposes." With the increased interest in protecting park resources, collecting of natural materials is currently prohibited in all national park lands without permission. This research could not have been conducted without the support and interest of park rangers of National Park Service, particularly Jose Rosario and John Tanacredi for supplying a research permit to study beach rocks and fossils within Gateway National Recreation Area in 1996. Special gratitude is also extended to many members of the New York Paleontological Society and students from Brooklyn College who helped to collect and identify fossils and modern fauna.

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TABLE 1

Common Name and Species Name[1]	Range[2]	Living Faunal Habitats[3]						Observed Setting of Modern Death Assemblages[4]				Concretion Fauna[5]	
		A	B	C	D	E	F	New Jersey		New York		NJ	NY
								Beach	Bay	Beach	Bay		
Lamp Shell[6] *Terebratulina sepentrionalis*	NB	X	X										S
Crumb of Bread Sponge[7] *Halichondria* sp.	NB	X	X					S		S		S	S
Fig Songe[8] *Suberites ficus*	NB, VA	X	X					S		C		C	C
Red Crust Bryozoan *Cryptosula pallasiana*	ALL		X	X				C		C		C	S
Boring sponge *Cliona cleata*	ALL	X	X	X				C		C		C	C
Northern Stony Coral *Astrangia danae*	VA, CP	X	X					C		S		S	S
Atlantic Oyster *Crassostrea virginica*	ALL					X			C		C	S	A
Blue Mussel *Mytilus edulus*	ALL xFL			X				A		A		C	S
Ribbed Mussel *Geukensia demissus*	ALL					X			C		C		S
Razor Clam *Ensis directus*	NB, VA			X		X		A	A	A	C	A	C
Hard-Shell Clam (Quahog) *Mercenaria mercenaria*	ALL		X	X		X				C			
Soft-Shell Clam *Spisula solidissima*	NB, VA	X	X	X				C	A	A	A		
Surf Clam *Spisula solidissima*	ALL xFL		X	X				C		C			
Blood Ark *Anadara ovalis*	ALL xNB		X	X				C		C			
Bay Scallop *Aequipecten irradians*	VA		X			X		C		C		A	A
Jingle Shell *Anomia simplex*	ALL xNB		X	X				A		C		A	

Glassy Lyonsia *Lyonsia hyalina*	ALL xFL	X	X	X		X							A
Slipper Shell *Crepidula fornicata*	ALL		X	X				C	A	C	A	S	
False Angel Wing *Petricola pholadiformis*	ALL			X		X	X						S
Atlantic Oyster Drill *urosalpinx cenerea*	ALL	X	X	X		X						C	C
Mud Dog Whelk *Nassarius obsoletus*	ALL					X					A		A
Channeled Whelk *Busycon canaliculatum*	ALL		X	X						C			
Moon Snail *Lunatia heros*	NB, VA	X	X								A		
Sand Dollar *Echinarachnius parma*	NB, VA	X	X	X				C					
Rock Barnacle *Balanus balanoides*	NB, VA			X				C		C	S		
Blue Claw Crab *Callinectes sapidus*	ALL	X	X	X		X		C	A	C	A	S	A
Spider Crab *Libinia emarginata*	ALL	X	X	X		X		C	C	A	C	C	
Atlantic Rock Crab *Cancer irroratus*	NB, VA	X	X	X		X		C	C	A	C		S
Green Crab *Carcinus maenas*	NB, VA	X	X	X		X					C		C
Lady Crab *Ovalipes ocellatus*	C	X	X	X				C		A			S
Horseshoe Crab *Limulus polyphemus*	ALL	X	X	X		X		C	A	C	A		S
Northern Lobster *Hoarus americanus*	NB, VA	X	X	X		X		S	C	S	S	C	
fish and shark vertebrae and teeth	ALL	X	X			X		C	C	C	C	S	S
Salt Marsh Cordgrass *Spartina alterniflora*	ALL				X	X	X				A		A
Eastern Red Cedar *Juniperus virginiana*	ALL				X		X		A		A	A	C
Atlantic White Cedar *Chamaecyparis thyoides*	ALL						X			S			S

TABLE I EXPLANATION

[1]"Common name and species name" were derived primarily from the *Peterson Field Guide - Atlantic Seashore* and supplemented by other sources where identification was more difficult (including Gosner, 1979; Massachusetts Audubon Society, 1993; National Audubon Society. 1981a,b; and, Tanacredi & Badger, 1995). It is important to note that this is not a complete faunal list for the region. Only specimens observed as fossils or modern species that occur in abundance in some coastal areas are included in this list.

[2]"Range" information of modern species are derived primarily from the *Audubon* and *Peterson* field guides (Gosner, 1979; Massachusetts Audubon Society, 1993; National Audubon Society, 1981a,b; and, Tanacredi & Badger, 1995). Coastal range divisions are as follows:

NB - northeastern states and Canadian Maritime provinces north of Cape Cod representing the Atlantic Boreal Region.
VP - Virginia Province, includes the region between Cape Cod and Cape Hatteras.
CP - Carolina Province, south of Cape Hatteras to Florida.
FL - Florida
ALL - Range includes the entire Atlantic Coastal region.

An "X" next to a range shows that the species occurs in all regions except the one indicated. Ranges are somewhat generalized since some Boreal Region species can tolerate colder, deeper water farther south. The opposite is true for warmer water species endemic to the American Atlantic Temperate Region (south of Cape Cod). For example, southern species may temporarily extend their range farther north when winters are unseasonably warm. Where species are "endemic," meaning where they occur in greatest abundance, the range is shown in capital letters.

[3]"Living faunal habitats" information was derived from field guides and from our own observations. Information applies for faunal habitat ranges in the New York Bight region only.

[4]"Observed setting of modern death assemblages" refers to study areas in the New York Bight region. The data are based on our qualitative observations of flotsam on beach and bay side high-tide wracklines: "A" means abundant - hundreds to millions of specimens are seen at certain times on the beach; "C" means common - typically at least a dozen specimens can be observed at certain times on the beach; "S" means scarce - perhaps a single specimen might be found; blank means none have been observed in nine years of observation. For New Jersey, the "beach" study area included the beach between Longbranch, NJ and the northern end of Sandy Hook Spit; the "bay" study area extended from old Forth Hancock southward into the estuary of the Navesink and Shrewsbury rivers and along the bay shore below the Atlantic Highlands. For New York, the "beach" study

area extended from Belle Harbor to Rockaway Point (Queens); the "bay" study area included the vicinity of Plumb Beach and the shores in and around Jamaica Bay near Floyd Bennett Field (Brooklyn).

[5] "Concretion fauna" refers to recognized species remains found encased (at least partially) in concretion matrix or in clumps of consolidated sediments (beachrock or mudrock) found in the wracklines along New York Bight beaches. Data are based on occurrence in this study's research collection: "A" means more than 10 specimens; "C" means 4-10 specimens; "S" means specimens; blank means none found.

PLATE CAPTIONS

Plate I

1. Sandstone concretion display marine bioturbation. Sandy Hook, NJ.
2. Coquina (shell hash) displaying A) gastropod, B) cones from eastern hemlock [*Tsuga canadensis*] , C) *Anomia simplex* [jingle shell], D) shark vertebrae, E) quartz pebble. Sandy Hook, NJ.
3. Sandstone concretion displaying wood (cedar root). Sandy Hook, NJ.

4,5,6. Concretions containing juvenile gastrpods (dark specks) and brachiopod: *Lyonsia hyalina* [glassy Lyonsia]. Rockaway Beach, NY.

Plate II

1. *Crassostrea virginica* [Atlantic oyster] in growth position in concretion matrix. Rockaway, NY.
2. *Crassostrea virginica* [Atlantic oyster] in growth position in concretion matrix. Rockaway, NY.
3. *Crassostrea virginica* [Atlantic oyster] in growth position in concretion matrix. A) gastropod *Nassarius obsoletus* [mud dog whelk]. Rockaway, NY.

Plate III

1. *Crassostrea virginica* [Atlantic oyster] in growth position in concretion matrix along with the gastropod: *Nassarius obsoletus* [mud dog whelk]. Rockaway, NY. Insets are enlarged 3 times.
2. *Crassostrea virginica* [Atlantic oyster] in growth position in concretion matrix along with the gastropod: *Nassarius obsoletus* [mud dog whelk]. Rockaway, NY.
3. *Crassostrea virginica* [Atlantic oyster] in growth position in concretion matrix along with the gastropod: *Nassarius obsoletus* [mud dog whelk]. Rockaway, NY.

Plate IV

1. Lithified black clay concretion containing traces of roots, possibly marsh grass. Rockaway, NY.
2. Cast of a pelecypod (blue mussel?) in black clay. Rockaway, NY.
3. Cast of unidentified clam in black clay. Rockaway, NY.
4. *Mercenaria mercenaria* [quahog or hard shell clam] in concretion matrix. Rockaway, NY.
5. *Ensis directus* [razor clam] in concretion matrix. Sandy Hook, NJ.
6. *Aequipecten irradians?* [bay scallop?], or possibly related species. Sandy Hook, NJ.
7. *Aequipecten irradians* [bay scallop]. Rockaway, NY.
8. *Aequipecten irradians* [bay scallop]. Rockaway, NY.

9. *Aequipecten irradians* [bay scallop]. Rockaway, NY.
10. *Aequipecten irradians* [bay scallop]. Rockaway, NY.
11. *Aequipecten irradians* [bay scallop]. Rockaway, NY.

Plate V

1. *Callinectes sapidus* [blue claw crab]. Juvenile form; dorsal (left), ventral (right). Rockaway, NY.
2. *Callinectes sapidus* [blue claw crab]. Juvenile form; dorsal (left), ventral (right). Rockaway, NY.
3. *Carcinus maenas* [green crab]. Juvenile form; dorsal (left), ventral (right). Rockaway, NY.
4. *Carcinus maenas* [green crab]. Juvenile form; dorsal (left), ventral (right). Rockaway, NY.
5. *Carcinus maenas* [green crab]. Juvenile form; dorsal (left), ventral (right). Rockaway, NY.

Plate VI

1. *Libinia emarginata* [spider crab]. Juvenile form, ventral view. Sandy Hook, NJ.
2. *Libinia emarginata* [spider crab]. Juvenile form; dorsal view. Sandy Hook, NJ.
3. *Libinia emarginata* [spider crab]. Intermediate form; dorsal view. Sandy Hook, NJ.
4. *Libinia emarginata* [spider crab]. Intermediate form; dorsal view. Sandy Hook, NJ.
5. *Libinia emarginata* [spider crab]. Adult form; dorsal view. Sandy Hook, NJ.
6. *Libinia emarginata* [spider crab]. Adult claw. Sandy Hook, NJ.
7. *Hoarus americanus* [Norther Lobster]. Adult claw. Sandy Hook, NJ.

Plate VII

1. *Astrangia danae* [Northern stony coral] encrusting a concretion. Rockaway, NY.
2. *Astrangia danae* [Northern stony coral] encrusting a concretion. Rockaway, NY.
3. *Halichondria* sp. [crumb of bread sponge], barnacle base attachments, and other shell hash encrusting an oyster shell. Sandy Hook, NJ.
4. *Halichondria* sp. [crumb of bread sponge] encrusting *Crepidula fornicata* [slipper shell]. Sandy Hook, NJ.
5. *Halichondria* sp. [crumb of bread sponge] encrusting *Crassostrea virginica* [Atlantic oyster]. Sandy Hook, NJ.
6. *Halichondria* sp. [crumb of bread sponge] encrusting *Mytulus edulus* [blue mussel]. Sandy Hook, NJ.
7. *Halichondria* sp. [crumb of bread sponge] encrusting *Mercenaria mercenaria* [quahog or hard shell clam]. Sandy Hook, NJ.

Plate I

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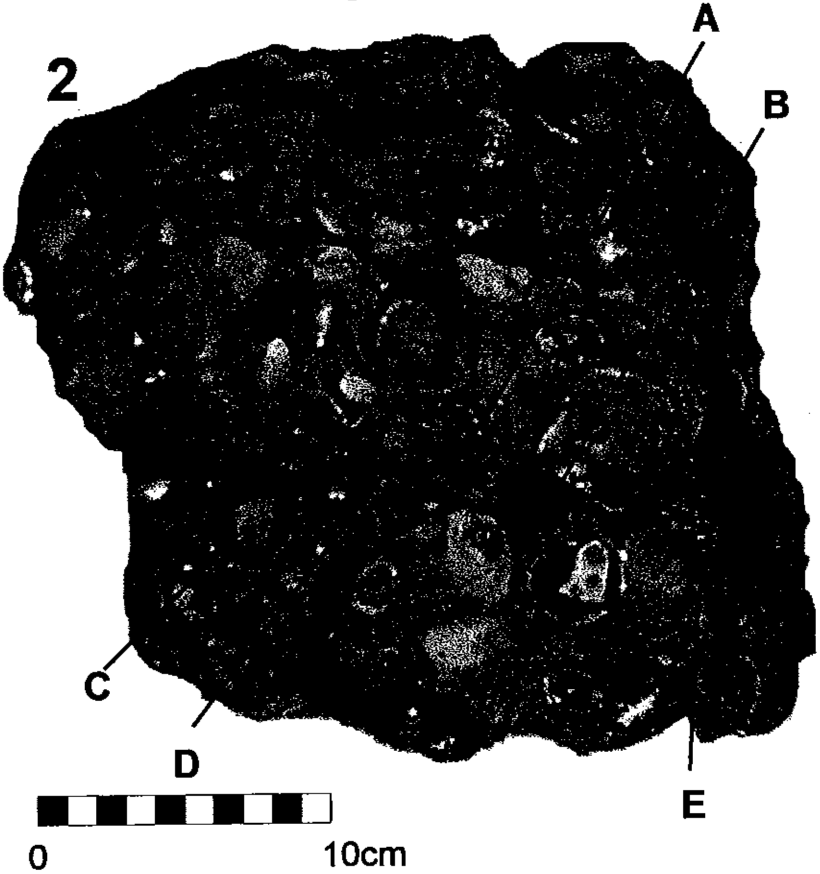

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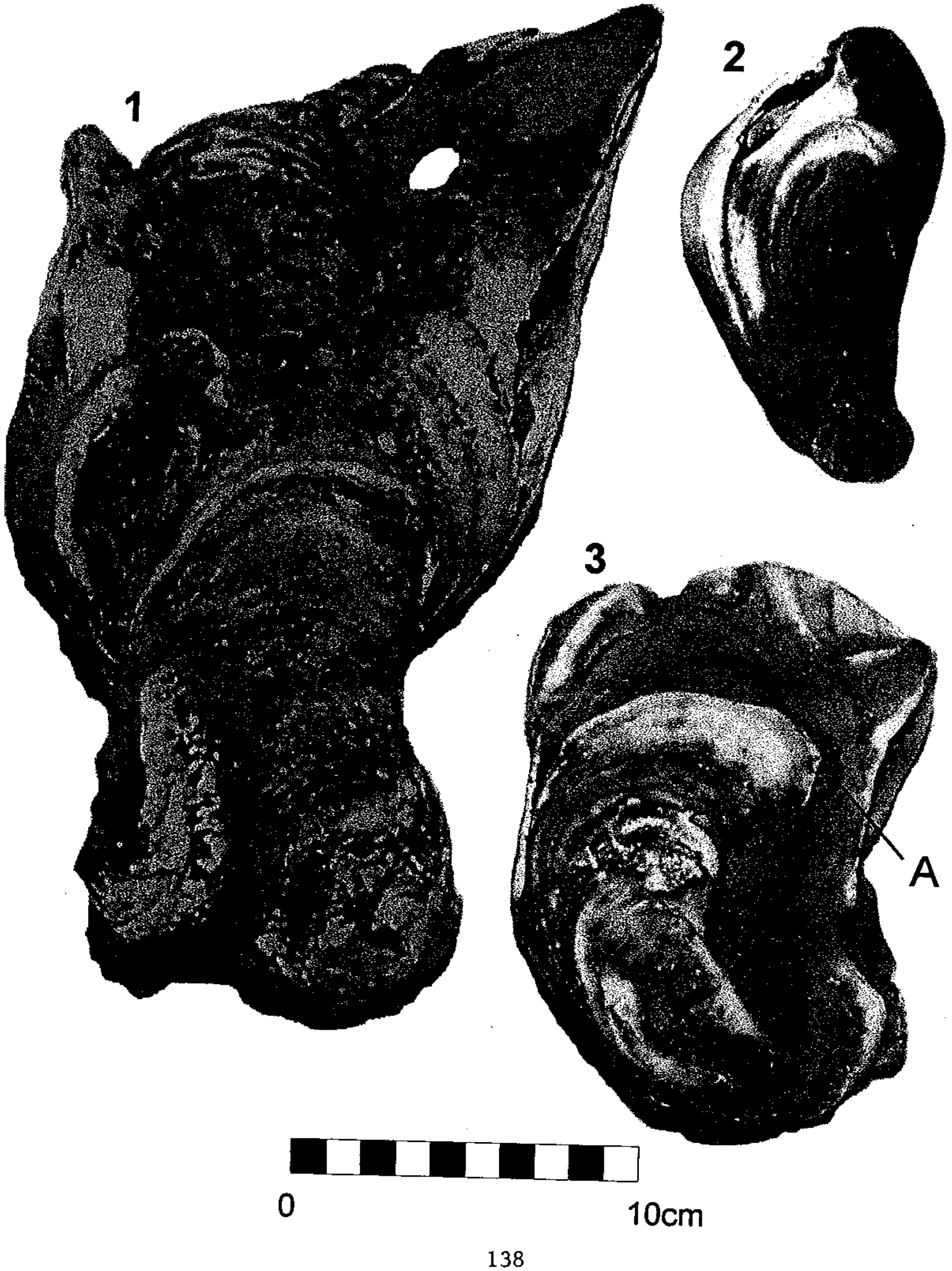

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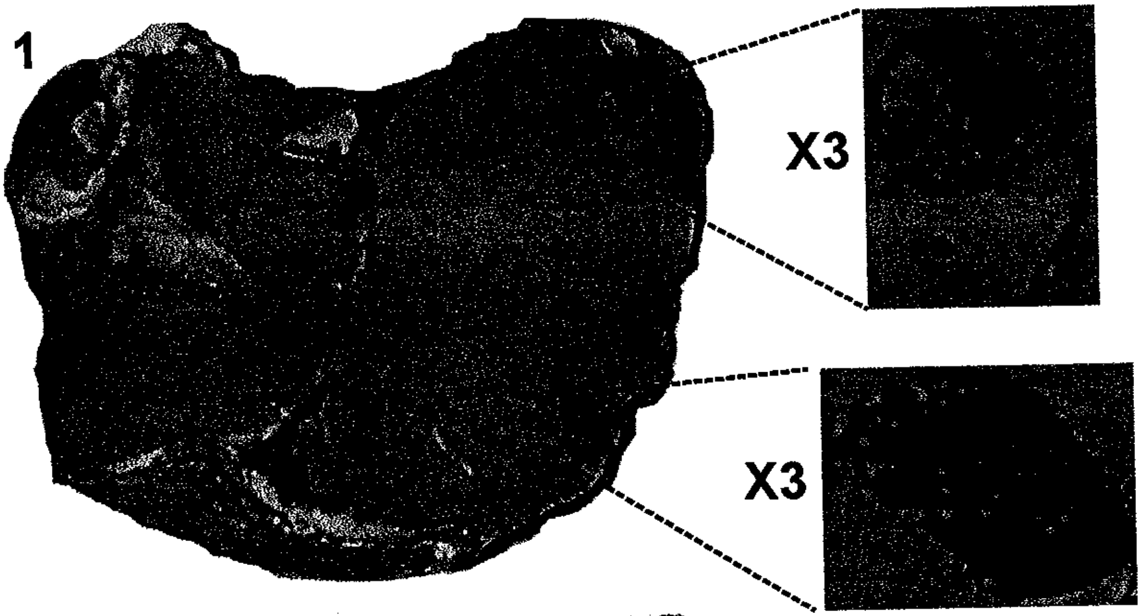

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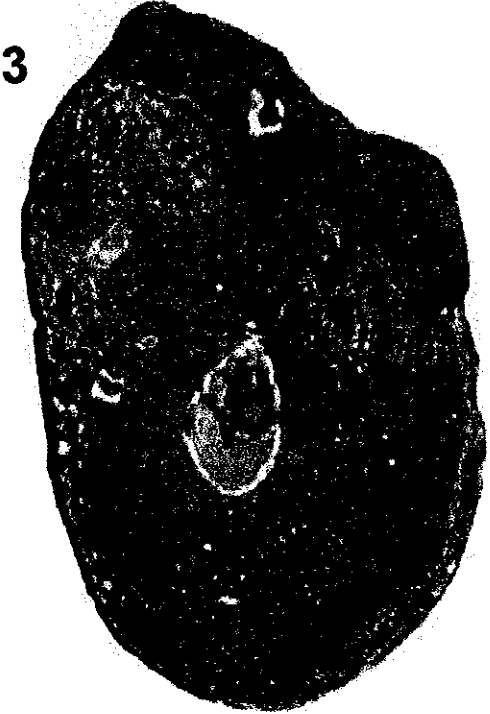

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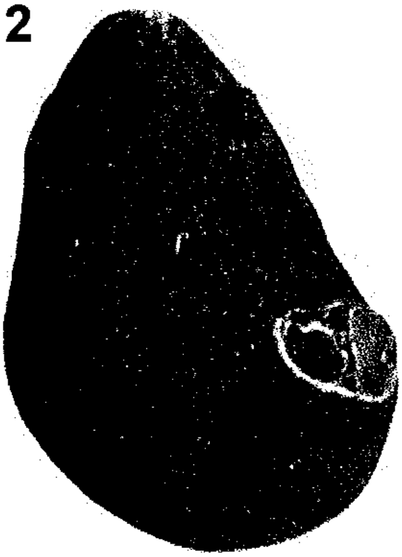

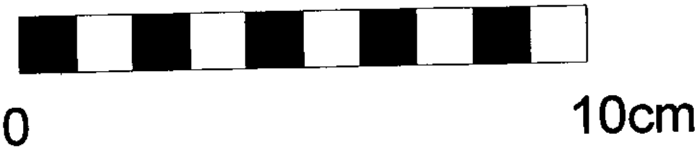

Plate IV

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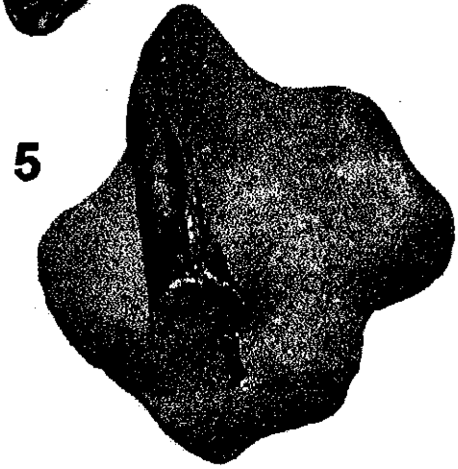

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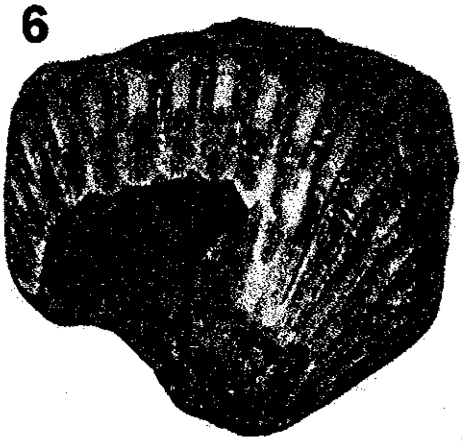

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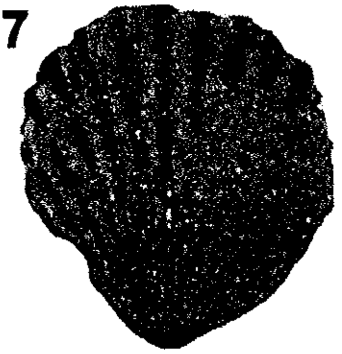

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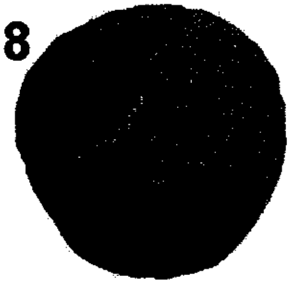

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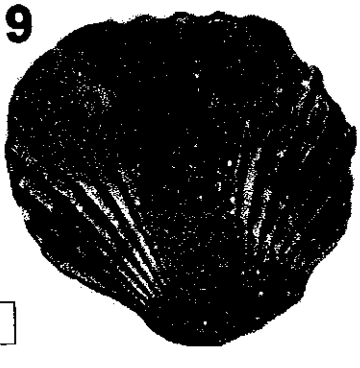

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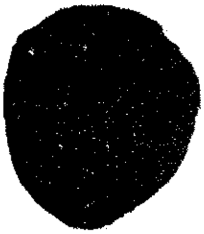

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Plate V

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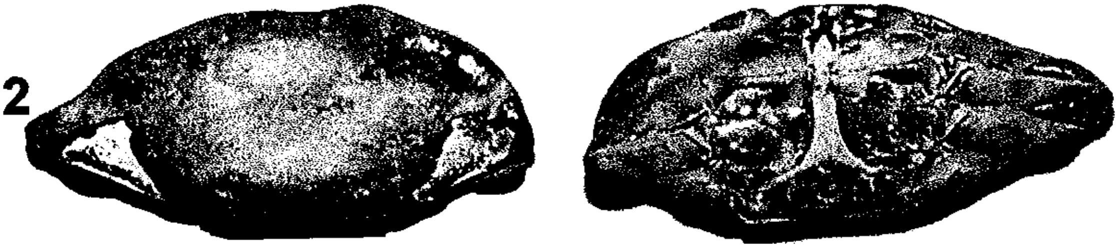

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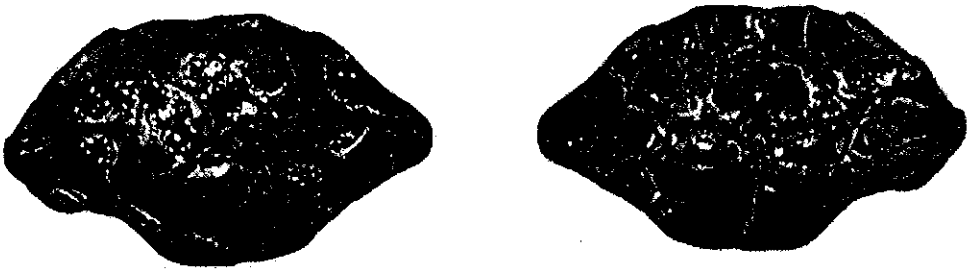

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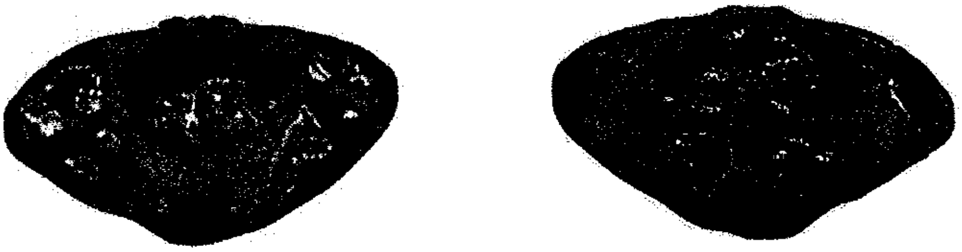

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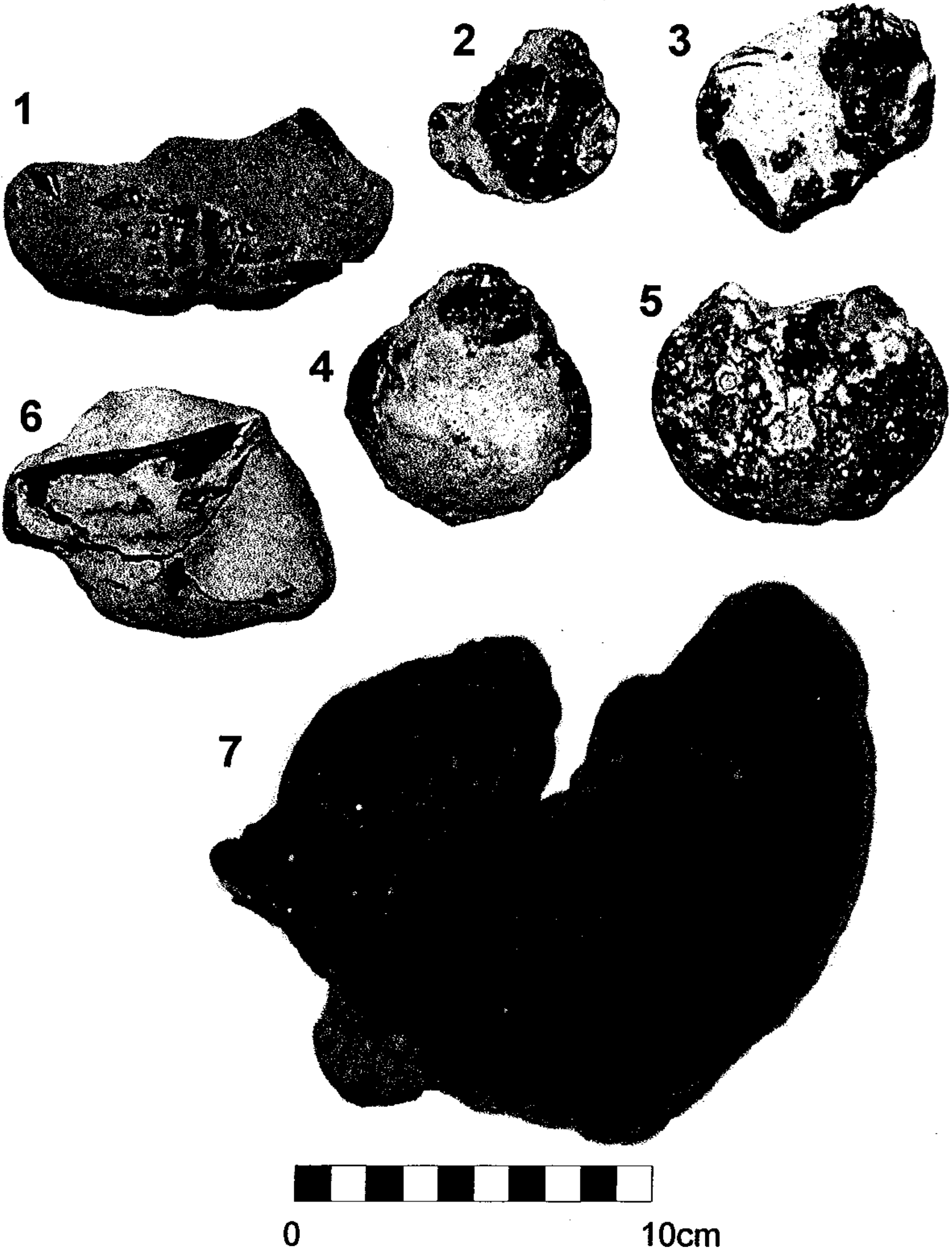

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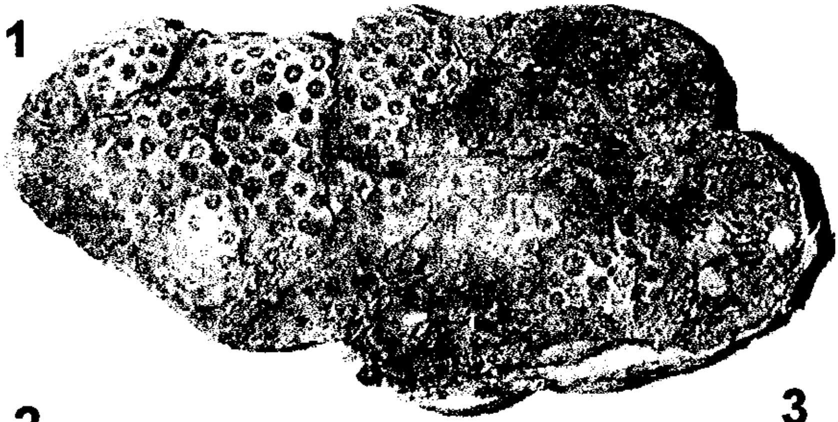

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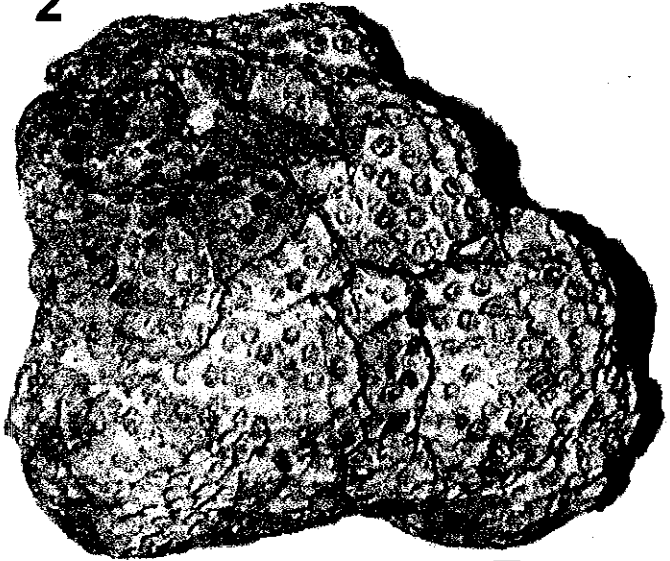

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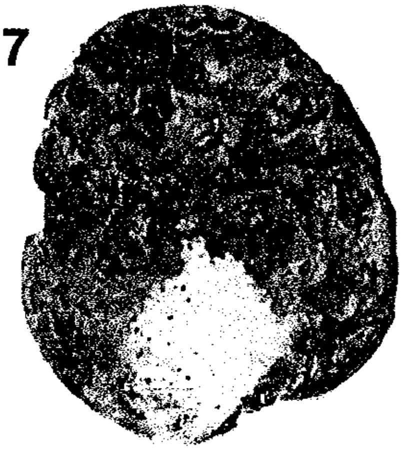

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SUN, SAND, AND SCIENCE: ENHANCING K-12 SCIENCE EDUCATION BY INCORPORATING INQUIRY BASED MARINE SCIENCE INTO THE CURRICULUM

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INTRODUCTION

In 1996 the National Research Council published the National Science Education Standards. That document called for a change in the way that our nation's schools taught science. Recognizing that in order to achieve the national goal of scientific literacy for all citizens students would need to be involved with the entire process of science, not only the memorization of science facts, the National Research Council suggested that K-12 classrooms become places where students investigate scientific concepts in depth. It suggested that students iterate the scientific method beginning with formulating questions (working hypotheses), data collection, analyzing the data that they collect, and communication (dissemination) of the results of their investigations. The National Science Education Standards also included guidelines for the broad areas of science that should be taught, and standards for the technological proficiency of schoolchildren. For the first time the area of Earth science was put on a par with Physics, Chemistry, and Life science. Guidelines for the content areas of Earth science include the study of Earth systems, including the world ocean, and the impact of humans on the environment. Guidelines for technological proficiency suggest that students be fluent in using technologies to acquire data, analyze the data collected, and use technology to report their findings.

Since the publication of the National Science Education Standards, a number of States have developed their own guidelines for K-12 science teaching. Many of these documents reflect the spirit of the national standards in calling for the teaching of inquiry based science. For instance, the State of Ohio developed the Ohio Competency-Based Science Model (State Board of Education, 1994), which for the first time asked that Earth science be taught as a subject area at every level from kindergarten through the twelfth grade. The state model includes student science learning outcomes that are tested in a statewide proficiency-testing program in science, including Earth science. Beginning in 2003, Ohio students will have to pass the state proficiency test in science at the tenth grade level in order to graduate from high school. New Jersey has also developed science standards for K-12 schools. The New Jersey State Department of Education published the Core Curriculum Content Standards (1996) for several curriculum areas, including science. That document calls for the incorporation of New Jersey's unique natural resources in the teaching of science. It also suggests that science be taught from a systems perspective, with K-12 science education focused on achieving student understanding of the structure, dynamics, and geophysical systems of the Earth, and developing an understanding of the environment as a system of interdependent components affected by human activity and natural phenomena.

In Ohio, and in many other States around the country, teachers are being asked to teach Earth science, a subject that they may not have taken, or may not have been comprehensively prepared in during their own academic careers. In addition, they are being asked to teach science in an interdisciplinary, interactive way, engaging students in the process of science, infusing technology into the learning process in their own classrooms. In order to meet the needs of teachers for standards based science activities that draw K-12 students into the process of science The New Jersey Marine Science Consortium has developed hands-on science activities focused on one of the most important New Jersey natural resources, the physical and biological environment of the seashore. Wright State University, given its location in the mid-continent, has identified internet resources that provide students the opportunity to explore and enrich their own understandings of the ocean and coastal processes. This workshop provides K-12 teachers with both hands-on activities for use at the shore, and minds-on internet activities to enrich student understandings. The following activities were developed by New Jersey Marine Science Consortium educators for K-12 schoolchildren.

THE EDUCATION PROGRAM
AT THE
NEW JERSEY MARINE SCIENCES CONSORTIUM
BUILDING #22, FORT HANCOCK, NEW JERSEY 07732 (732)872-1300

EXPLORING BEACH SAND

Beaches are composed of materials deposited there by waves. The composition and appearance of sand on different beaches depends on many things including geologic factors as well as natural and human forces.

If you were to look at sand from beaches worldwide, you would observe many differences, including color, texture and composition. For instance, if you traveled to Bermuda you would find the sand pink in color. The sand on some of the beaches on the Hawaiian Islands is black. If you found yourself walking the beaches in the Bahamas you would notice that the sand there is white.

Why do you think sand comes in so many different colors?

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Sand is made of rocks, minerals and shells that have been worn down into loose gritty particles through the process of erosion. The major minerals found in the sand on Sandy Hook beaches are:

1. Quartz	Silicon Dioxide. .Glass-like. Is clear to white when pure, but is often colored.
2. Feldspar	Any one of a group of moderately hard, light colored minerals found in igneous rocks. Principally aluminosilicates of potassium, sodium and calcium.
3. Magnetite	An oxide of iron appearing in sand as dark specks; its presence can be verified through the use of a magnet because of the mineral's iron content.

The sand along the new Jersey shore comes from the mountains of the northeastern states. Rock is broken into pieces by the actions of water and wind and carried by rivers and streams to the ocean to create sand deposits. These sand deposits are then carried up and down the coast by the longshore current to form the beaches that you see.

Compare and contrast four different sand samples.

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What is the sand made of ?

Using the table below as an example and for reference, write the same categories for your sand sample: grain color, possible identification, possible source area.

The most common grains found in sand can be broken down into the following categories:

Grain color	Possible identification	Possible source area
clear or frosted	quartz	Common mineral in granite and sandstone created from ancient beaches.
black, brown, grey	small pieces of rock (lithics)	Erosion of any source material. Very common in sands from rivers or from tectonically active areas.
shiny black (usually very angular)	basalt	Volcanic.
green (usually very angular)	olivine	Volcanic.
pink, white, milky (usually has a glossy luster)	small pieces of shell (can include whole shells)	Coastal beaches and coral reefs.
white, peach, reddish-brown (usually a dull luster)	feldspar	Common mineral in granite.
silver, gold, brown (sparkles, flat, mirror-like luster)	mica	Common mineral in metamorphic schists of mountain regions. Also found in granites.

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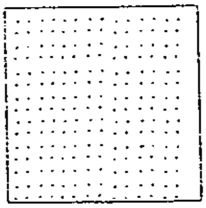
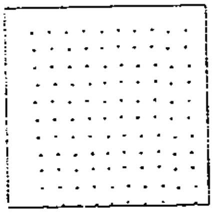
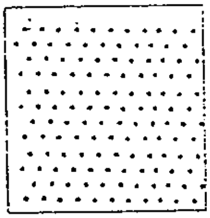
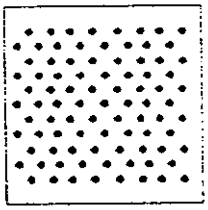
Grain size -- How big are the sand grains ?

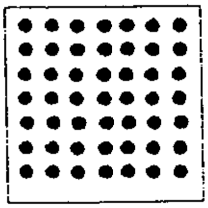
Use the diagram below to estimate the general size categories of your sample. For example, you might observe a sample that has 50% size 6, 40% size 3, and 10% size 1.

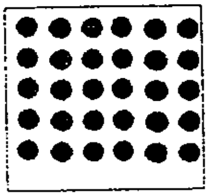

Size 1
0.1 mm

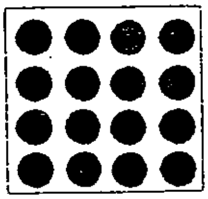

Size 2
0.25 mm

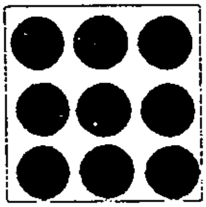

Size 3
0.5 mm


Size 4
1.0 mm


Size 5
2.0 mm


Size 6
3.0 mm


Size 7
5.0 mm


Size 8
7.0 mm

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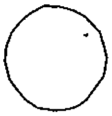
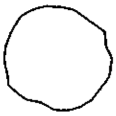
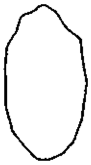
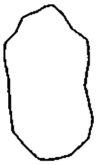
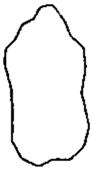
Grain shape -- How do the sand grains appear ?

Grain shape – How do the sand grains appear?

Use the diagram below to estimate the shape of the grains in your samples. Be sure to include the sphericity (how close to a ball shape is the grain?) and the roundedness/angularity (how sharp are the angles of the grain?)

	very rounded	rounded	sub-rounded	sub-angular	angular	very angular
high sphericity						
low sphericity						

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Topic: **BEACH PROFILING**

Grade Level: K-12th

New Jersey Science Standards: 5.1, 5.2, 5.4, 5.5, 5.7, 5.8, 5.9, 5.12

Skills: Measuring, Observing, Configuring, Graphing, Referencing, Drawing Conclusions

Scope: Science, Math, Technology

Science Framework: The investigation of beach profiling can lead to the discovery of changes that occur on the beach due to natural phenomenon and human interaction.

Mathematics Framework: Mathematics is used as a cycle of investigation that is intended to lead to the development of valid ideas.

Technology Framework: Technology extends our abilites to cut, shape, or put together materials; to move things from one place to another; to reach farther with our hands, voices and senses.

Sequence: Spend at least 30 minutes at the beach measuring changes in the elevation of the beach from point to point (2 meters apart) on the beach.

Objectives: Students will be able to 1) Understand that waves, winds, currents shape the beach and redistribute thousands of tons of sand each day. 2) Identify storm and tide levels as well as how a beach is changing over time 3) Make and record observations 4) Graph the beach profile.

Materials: 2 inexpensive 2"x 1" x 2 meter (39.37" or about 40") wooden poles with measurement lines on them at intervals of ten centimeters from a zero point at eye level
(four feet from the bottom is adequate). Data sheet, pencil, graph paper.

Activity: Students using a horizontal reference line on the 2 meter pole, take vertical measurements based on the horizon (where the ocean meets the sky). Standing 2 meters apart and starting at the base of the dunes, students move forward toward the ocean after each measurement of rate of change is sighted. Students then graph data to provide a visual representation of the beach profile.

Issue Statement: Waves, wind and currents shape the beach and redistribute thousands of tons of sand each day. Beach profiling can give an indication of how a beach is changing and provides a way of comparing these changes over time.

Background: Sand along New Jersey's shore comes from the mountains of the Northeastern States. Rock is broken into pieces by the actions of water and wind. It is then carried by rivers and streams to the ocean to create sand deposits. These sand deposits are then carried up the coast by the longshore current to form the beaches that you see.

Key Vocabulary:

Littoral Drift - The movement of sediment by the longshore current. The littoral drift moves more than 370,000 cubic yards of sand per year along New Jersey beaches.

Longshore Current - A current located in the surf zone and running parallel to the shore in a northerly direction as a result of waves breaking at an angle on the shore.

Sand Dune - A hill or ridge of sand piled up by the wind. At Sandy Hook, seeds from birds planted vegetation which stabilized the shifting sands. As more plants grew, sand grains were blown across the beach and trapped. Repeated burials enhanced the formation of a primary sand dune barrier, thus reducing erosion by the ocean waves.

Barrier Flat - The area lying between the salt marsh and dunes of a barrier island, it is usually covered with grasses and forest.

Beach - Sediment seaward of the coastline through the surf zone that is in trasnport along the shore and within the surf zone.

Berm - In the summer the berm is low and wide. It is the beach on which beach-goers sunbathe and frolic. The winter berm is higher and narrower, as most of the sand moves underwater to create the bars. The reason for the shift is the change in wave action with the season.

Backshore - The part of the beach located above the mean spring high tide line and covered by water only during storms with extreme high tides. Also called the spray zone.

Foreshore - The part of the beach between the normal high and low tidal marks. Also called the intertidal zone.

Possible Extensions: While on the beach use collection bags to pick up trash found on the beach. Discuss how the trash got there and what can be done to improve the trash problem.
Make a collection of shells found on the beach and identify each one. In the classroom, use trays filled with sand to make models of the profiles found on the beach.

References:

New Jersey Marine Sciences Consortium. 1987. The Hook Book. Sandy Hook, New Jersey.
Willard Bascom. 1980. Waves And Beaches. Anchor Press/Doubleday Publishing Company.
Harold V. Thurman. 1993. Essentials of Oceanography. Fouth Edition. Macmillan Publishing Company.

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Topic: **BEACH ZONATION**

Grade Level: K-12th

New Jersey Science Standards: 5.1, 5.2, 5.4, 5.5, 5.7, 5.9, 5.10, 5.12

Skills: Applying, Classifying, Social Interacting, Identifying, Drawing Conclusions

Scope: Science, Math, Social Science, Technology

Science Framework: Working in small teams instead of individually, students ask and answer questions about their surroundings and share their findings with classsmates..

Mathematics Framework: Making observations, collecting and sorting using information gathered and problem solving skills. Math supports/informs solutions to problems/questions.

Social Science Framework: The gaining of knowledge through understanding human and environmental interactions.

Technology Framework: Humans have the ability to gather data, interpret findings and in turn develop ways of communicating ideas to others.

Sequence: Spend about 30 minutes at the beach. Identify the different zones of beach. Use small collection bottles to collect one sample of the sand at each zone: the base of the dunes, the berm, berm crest, and the foreshore area of beach.

Objectives: Students will be able to: 1) Distinguish the different zones of the beach by observation of characteristics. 2) Identify the areas where samples were taken. 3)Understand that zones of the beach respond to movements of the ocean. 4) Draw conclusions after making observations about the size of sand grain found in the different zones of beach.

Materials: a trip to the beach, 4 containers for collecting sand.

Activity: Students collect one sample from each of the different areas of beach: 1) Base of the dunes, 2) Berm, 3) Berm Crest, 4) Foreshore. Conclusions are drawn about the different size of sand grains found in each area.

Issue Statement: The beach is one of the earth's most dynamic environments. The beach, or zone of active sand movement, is ever changing and migrating, and we now know that it does so in accordance with the earth's natural laws. It is important to keep in mind that the beach extends from the toe of the dune to an offshore depth of 40 to 50 feet. Man interferes with the natural beach processes in all the zones by building structures such as homes, snow fences, jetties, groins, sea walls and by replacement of sand to the foreshore.

Background: The part of the beach on which we walk is only the upper beach. The natural laws of the beach control a logical environment that builds up when the weather is good, and strategically but only temporarily retreats when confronted by big storm waves. This system depends on four factors: wave energy, water level, the amount of beach sand, and shape of the beach. The relationship among these factors is a natural balance referred to as a dynamic equilibrium. When one factor changes, the others adjust accordingly to maintain a balance. When we alter the system, as we often do, the dynamic equilibrium continues to function in a predictable way, but in a way that often has repercussions for our use of the system. It is to our benefit, therefore, to understand how the natural shoreline system functions.

Key Vocabulary:

Dune - Winds blow sand inland during dry periods forming natural hills or mounds which are stabilized by dune grasses. Dunes are protection against excessive flooding during storm-driven high tides.

Berm - The portion of the beach from the base of the dunes to the berm crest. The place where people place their beach chairs and umbrellas.

Berm Crest - The highest part of the berm found just before the drop off to the ocean.

Foreshore - The portion of the beach exposed at low tide and submerged at high tide.

Backshore - The portion of the beach which extends from the normal high tide to the coastline.

Nearshore - The zone between the low tide shoreline and breakers.

Possible Extensions: While at the beach make observations of shore birds and document the species found. At the library do research on their nesting habits, path of migration, what they like to eat, etc. Make observations of the type of waves hitting the shore that day. Draw conclusions as to the type that cause the most erosion.

References:

Norstrom, Gares, Psuty, Pilkey Jr., Neal, Pilkey Sr. 1993. Living with the New Jersey shore. Duke University Press.

The American Association for the Advancement of Science. 1993. Benchmarks For Science Literacy. Project 2061. Oxford University Press.

Harold V. Thurman. 1993. Essentials of Oceanography. Fourth Edition. Macmillan Publishing Company.

INTERNET TECHNOLOGY

The internet has rapidly evolved into an excellent resource for classroom teachers. The internet is especially useful to bring scientific data into the classroom, and as a resource to extend and enhance student learning by providing additional information regarding the marine environment. During the workshop several age appropriate internet websites will be presented. The URL's and a brief description of each follows:

Whalenet
http:whale.wheelock.edu
This site offers data from current and archived whale, turtle, seal, and porpoise tagging projects. The site offers age appropriate questions and activities designed to facilitate the use of the data available on the site in the K-12 classroom. Whalenet is interactive, allowing K-12 students to participate in research with marine scientists. The site uses advanced satellite tracking to monitor and research migration patterns of marine animals.

Project Tomorrow-Institute for Marine and Coastal Sciences, Rutgers
http://marine.rutgers.edu/pt/home.htm
The Institute for Marine and Coastal Processes of Rutgers University has done an outstanding job of developing a marine sciences resource internet site for classroom teachers. Teacher resources and workshops, on line classroom activities, real time data sources for student exploration, and hotlinks to related pages make this site extremely useful to teachers everywhere.

Consortium for Oceanographic Activities for Students and Teachers
http://www.coast-nopp.org

This extraordinary website contains classroom activities for elementary, middle and high school classrooms. Interdisciplinary topics include tracking tides, beach stratification, and sea level rise. Additional topics include plate tectonics, marine and aquatic habitats, pollution, and deep-sea technology.

The National Oceanographic Partnership Program
http://www.drifters.doe.gov/

This internet web site contains data that allows K-12 students to track ocean currents from ocean drifting buoys. Before starting to track the drifters, activities let students learn about longitude and latitude, how to plot drifter position and tracks, and calculate drifter speed and direction. By using this site, K-12 teachers will create authentic links between mathematics and science, and let students see how information on ocean currents is gathered.

CONCLUSION

The need for scientific literacy in today's rapidly changing technological world has driven change in the way that science is taught in our schools. Rather that science taught as a collection of facts to be memorized, students are experiencing the way science is done, by posing questions, collecting and analyzing data, and reporting results. The examples of hands-on activities presented here, and those presented at the GANJ teacher workshop are designed to allow each and every student to experience marine science, extend their knowledge of the marine environment, and become comfortable with fast emerging telecommunication technology. Many thanks to those scientists and educators who create K-12 learning activities, disseminate them in print and on the internet, and maintain websites for use by K-12 students and teachers.

REFERENCES

American Association for the Advancement of Science. (1989). Project 2061, Science for All Americans. Washington, D.C. Oxford Press

National Research Council U.S. (1996). National Science Education Standards . National Academy Press, Washington, D.C.

New Jersey State Department of Education (1996). New Jersey Core Curriculum Content Standards. Trenton, New Jersey.

Ohio State Board of Education (1994). Ohio's Model Competency-Based Science Program Columbus, Ohio.

FIELD TRIP ROAD-LOG
New Jersey Beaches and Coastal Processes from Geologic and Environmental Prospectives (the Beaches of Cape May County)

Stewart Farrell
Richard Stockton Coastal Research Center
Stockton College
Pomona, NJ 08240
(With mileage by J.H. Puffer)

Note: Additional and revised road-log information (a hand-out) may be available during the day of the trip; please contact Stewart Farrell for a copy.

MILEAGE

INCR.	**CUM.**	
0.0	0.0	From Townsend Life Center Parking Lot 3 on the Campus of Richard Stockton College, proceed past the Campus Center to intersection with College Drive.
0.2	0.2	Turn right at intersection with College Drive and proceed south to intersection with Jimmy Leeds Road.
1.3	1.5	Turn left onto Rt. 561 (Jimmy Leeds Road) and proceed south east, past the Garden State Parkway, to intersection with Rt. 9.
4.2	5.7	Turn right onto Rt. 9, proceed south to Rt. 52.
10.9	16.6	Turn left onto Rt. 52 proceed southeast to Wesley Ave.
3.0	19.6	Turn left onto Wesley Ave., proceed north three blocks to South Street.
0.3	19.9	Turn right onto Sixth Street, proceed three blocks east to the beach and park.

0.4	20.3	**STOP 1: Sixth Street, Ocean City.**

Observe the conditions presently in effect following the ACOE project which began in the spring of 1992.

0.4	20.7	Proceed west on Sixth Street to intersection with Wesley Ave.
2.4	23.1	Turn left at intersection with Wesley Ave. and proceed to its end.
0.01	23.1	Turn right, go one block.
2.7	25.8	Turn left, onto Rt. 61 (Central Ave.), proceed south 2.7 miles.
0.3	26.1	Turn right, stay on Rt. 619!
2.0	28.1	Turn left, stay on Rt. 619, through Corson Inlet State Park and across the Corson Inlet Toll Bridge to intersection with Sea View Street, Strathmere.
0.1	28.2	Turn left onto Sea View Street and park along the beach.

STOP 2: Sea View Street, Strathmere, Upper Township.

Currently an inlet migration problem some two years in the making. Erosion has removed over 150 feet of dunes and beach. Emergency projects are in place, but planning has yet to address mitigating the true causes.

0.1	28.3	Take Sea View Street back to intersection with Rt. 619 (Landis Ave.).
2.7	31.0	Turn left onto Rt. 619 and proceed south to intersection with 1st Street, Sea Isle City
0.1	31.1	Turn left at 1st Street, proceed east to the beach and park.

STOP 3: 1st Street Sea Isle City.

Restoration of dunes using geo-textile bags. Narrow, erosion-dominated beach where many attempts have been made to hold back the sea from claiming Commonwealth Avenue.

0.1	31.2	Take 1st Street back to Rt. 619 (Landis Ave.)
3.6	34.8	Turn left onto Rt. 619 and proceed south to intersection with 93rd Street.
0.1	34.9	Turn left onto 93rd Street, proceed east to the beach and park

STOP 4: 93rd Street Sea Isle City.

New project completed in 1999. Construction of the groin was coupled with the placement of 345,000 cubic yards of sand on the beach. Geo-tubes lie below the sand along the 93rd Street shoreline in front of the gray condominium building.

0.1	35.0	Take 93rd Street back to Rt. 619.
0.8	35.8	Turn left onto Rt. 619 and proceed south across Townsends Inlet Toll Bridge to 8th Street.
0.3	36.1	Turn left at 8th Street, proceed east to the beach and park.

STOP 5: 8th Street and the beach, Avalon.

Discussion of proposed new inlet shore protection structures, Avalon's beach management program, and breakwater units.

0.3	36.4	Take 8th Street back to Rt. 650 (Ocean Drive).
2.0	38.4	Turn left at intersection with Ocean Drive and proceed south to 56th Street, Avalon.
0.1	38.5	Turn left at 56th Street, proceed east to the beach and park.

STOP 6: 56th Street, Avalon.

Natural dune system, presently the tallest, widest, and most nearly original in the State of New Jersey in a developed community.

0.1	38.9	Take 56th Street back to Ocean Drive
5.7	44.6	Turn left onto Ocean Drive and proceed south across Stone Harbor Bridge and Grassy Sand Toll Bridge, to intersection with Rt. 147 (North Wildwood Road).
1.4	46.0	Turn left onto North Wildwood Road, proceed east to the beach at the Herford Inlet Lighthouse and park

STOP 7: North Wildwood

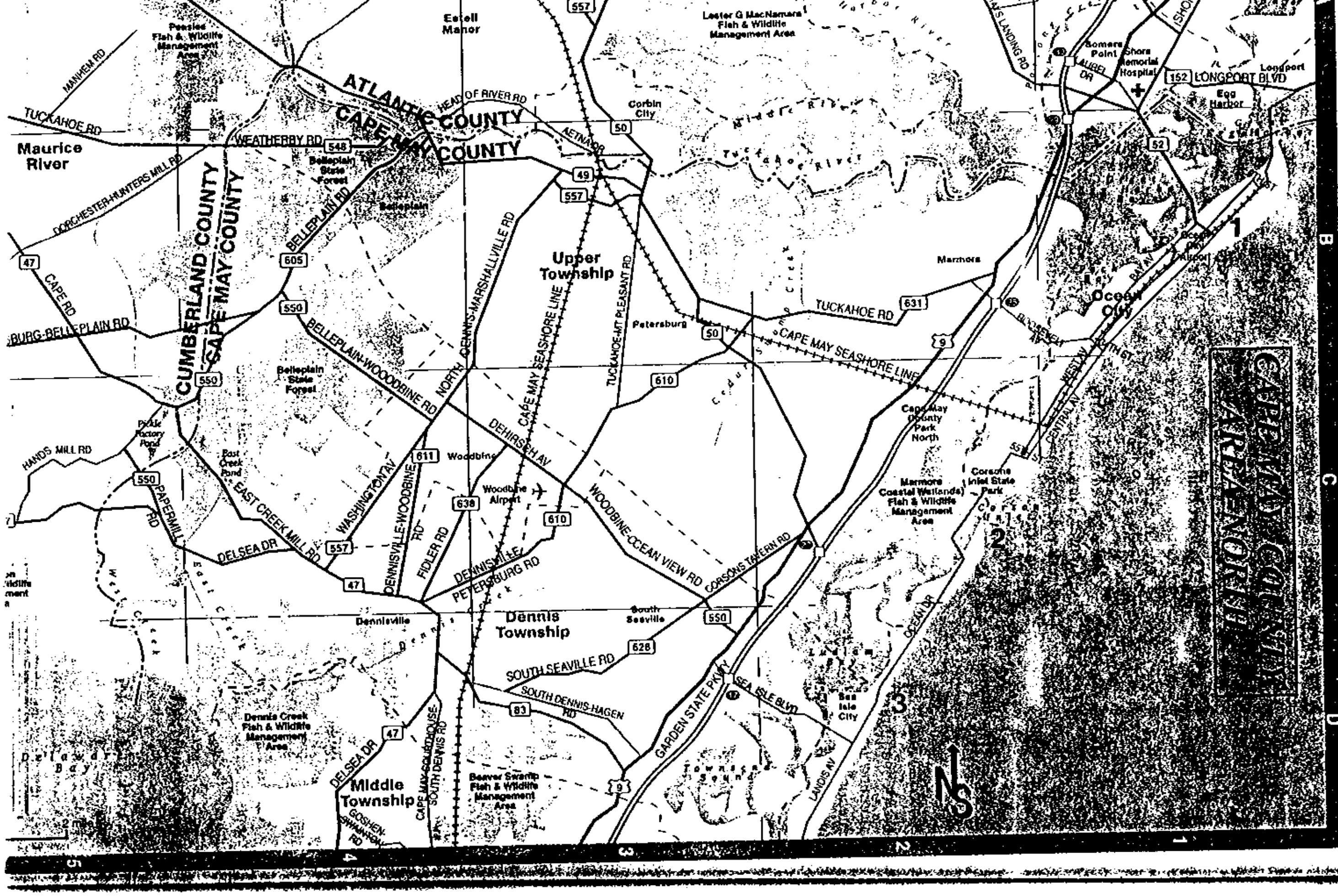
Optional stop to look at an armored inlet shoreline.

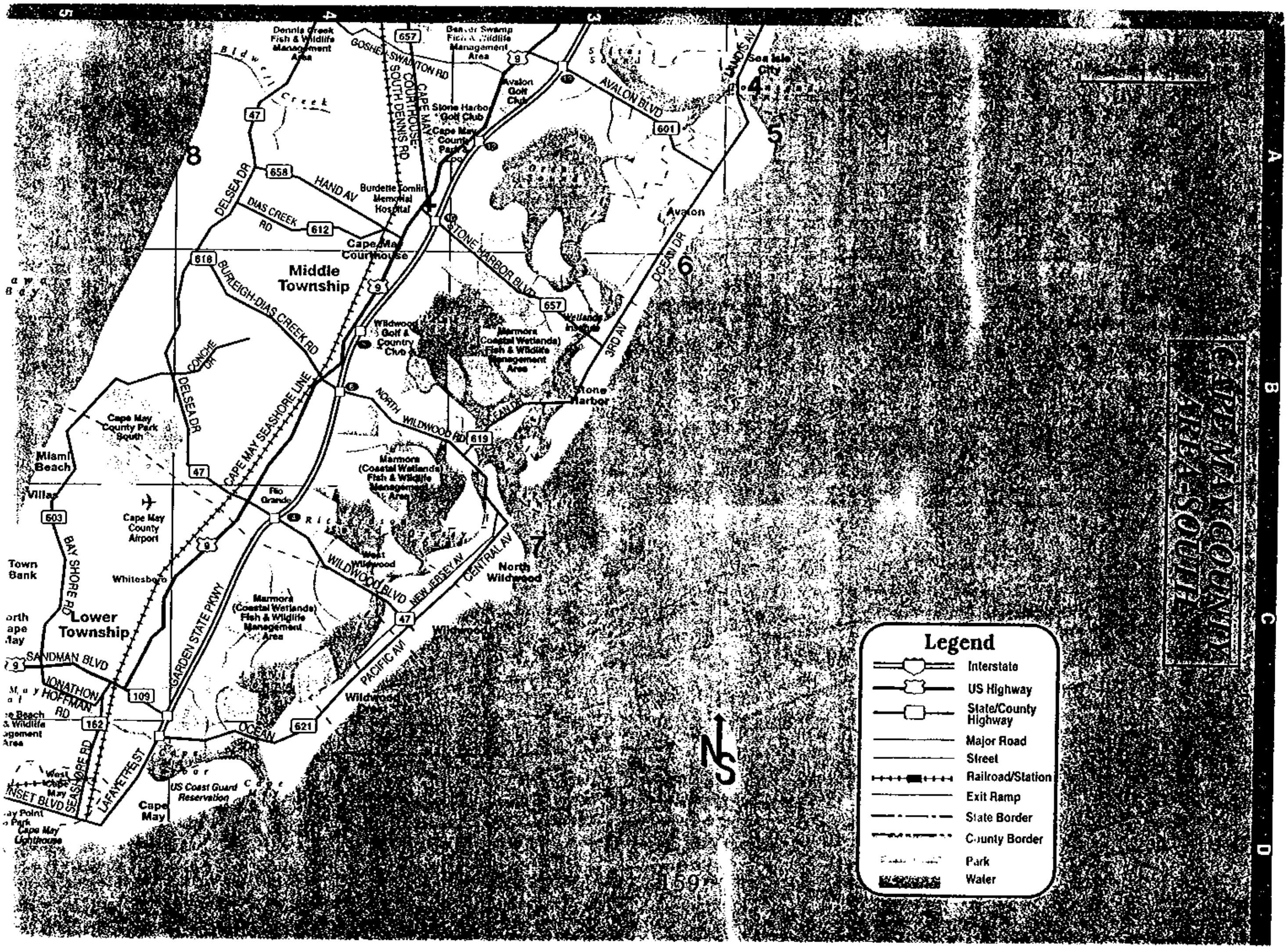
7.2	53.2	Take Rt. 147 (North Wildwood Road) west, across the Garden State Parkway where it becomes Rt. 618 (Indian Trail Road) to the intersection with Rt. 47.
1.8	55.0	Turn right onto Rt. 47 (Delsea Drive), proceed 1.8 miles north to intersection with road to Kimbles Beach. (Note: Hand Ave is about 100 yards north of the road to Kimbles Beach).
1.1	56.1	Turn left onto road to Kimbles Beach, proceed west to the beach and park.

STOP 8: Schellinger's Creek, Middle Township

Inlet opening and stabilization to re-create an open salt marsh environment.

1.1	57.2	Return to intersection with Rt. 47.
0.1	57.3	Turn left at intersection with Rt. 47 (Delsea Dr.), proceed about 100 yards north to the intersection with Rt. 658 (Hand Ave.).
3.0	60.3	Turn right at intersection with Hand Ave. and proceed east to intersection with Rt. 9.
0.4	60.7	Turn left onto Rt. 9 and proceed north to intersection with Rt. 657 (Stone Harbor Blvd.).
0.2	60.9	Turn right onto Rt. 657 and proceed east to intersection 10 of the Garden State Parkway.
33.0	93.9	Proceed north on the Garden State Parkway back to Townsend Life Center.


CAPE MAY COUNTY AREA-NORTH


CAPE MAY COUNTY AREA-SOUTH

jmz geology
consulting geologists
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G.A.N.J. FIELD TRIP GUIDE for the TRIP SATURDAY OCTOBER 16, 1999
RICHARD STOCKTON COASTAL RESEARCH CENTER

***

RECENT or CURRENT PROJECTS in CAPE MAY COUNTY, NEW JERSEY

***

Lead by;
Dr. Stewart C. Farrell

Ocean City Beach at Sixth Street.

The municipality of Ocean City occupies the entire length of Pecks Beach, a barrier island extending from Great Egg harbor Inlet in the north to Corsons Inlet, 8 miles to the south. Long-term erosion problems have plagued the northern portion of the island between Surf Road and 34th Street, with the most severe erosion experienced from 5th to 18th Streets. When the municipality was first established in the mid-1870's, numbered cross-island streets were created starting at First Street near Great Egg Harbor Inlet and running south. Initially, the northern most cross-island street was called North Street. This location commanded an inlet view.

During the next 25 years, inlet changes and storm events acted to cut eleven blocks from the south end of Absecon Island on the north side of Great Egg Harbor Inlet. An 1891 inlet survey shows the main channel of the inlet coming out between the islands and swinging southwest around Ocean City. According to the survey's bathymetry, one would have been able to walk 2000 feet seaward from 6th Street and the beach at low tide. The ebb-tidal shoal was actively feeding sand back to the northern end of Pecks Beach.

During the next 20 years, the additional inlet width generated by the loss of 11 blocks of Longport on Absecon Island allowed major shifts in the location of the main ebb-tidal channel. The main outlet channel swung to the northeast, abandoning the earlier location proximal to Ocean City. Flood-tidal currents acting unopposed by strong ebb tides moved hundreds of thousands of cubic yards of sand north along the beach and into the inlet opening. This created a huge sand spit attached to the North Street area of the island. The relatively sudden appearance of hundreds of acres of dry beach and incipient dunes attracted early 20th Century developers like vultures to carrion. By 1925, the municipality had created a posh new subdivision still called "The Gardens".

Unfortunately, neither the municipal officials delighted with the new ratables, nor the developers, flush with the cash from lot sales considered that this new landmass might be temporary. The municipality did its part by moving the boardwalk a couple of hundred feet seaward on the accreted beach between 12th and North Street during the 1920's.
By 1935, "Mother Nature" was conspiring against the new homes by gradually shifting the main ebb-tidal channel toward Ocean City again. During the next 10 years the local and State response to ever narrowing beaches and loss of inlet shoreline in "The Gardens" was to build rock groins at every other street end. The last of these were completed in the 1950's at the north end of town. The largest beach nourishment project ever attempted at that time, was authorized by the Philadelphia District Army Corps of Engineers in 1952 to pump 2,520,000 million cubic yards of sand between 12th Street and Morningside Avenue. The sand came from the inlet and flood-tidal delta areas and was considerably finer than the native beach. By 1954, the majority of the sand had migrated back to the inlet and was temporarily redeposited along the inlet beaches.

The municipality responded by trying almost any variant on groin design proposed by anyone claiming to have the "ultimate solution" to beach erosion. There are "T" groins, "L" groins, Strathmere then proceeded to lose 2,500 feet of the inlet shoreline, leaving the ancient shore protection structures exposed as they are in 1999. The present conditions are almost a copy of the 1971 situation. An early New Jersey shoreline examination trip allowed this author the chance to photograph the erosion of the undeveloped north Strathmere shoreline.

Between 1971 and 1986 the erosion pattern dramatically reversed and Corsons Inlet narrowed to the least distance between high tide shorelines seen in 150 years. The opening width of 625 feet was only 11% of the maximum width seen in 1885. The 1986 position of the southern tip of Peck Beach overlaps the 1962 location of the northern extent of the Strathmere spit.

In 1995, the Upper Township governing body requested that the Coastal Research Center develop a coastal monitoring plan for the Township oceanfront. Quarterly surveys are conducted at six locations in Strathmere. The East Seaview Avenue site had an impressive dune positioned 100 feet seaward of the pavement. Within one year the site was experiencing dune retreat at a rate, which exceeded normal expectations. The inlet shoals associated with the ebb-tidal delta became so extensive that the survey rod man could walk over 2000 feet beyond the low tide line, crossing bar after bar on route.

By the winter of 1998 – 1999 the situation threatened the road and homes on the north side of East Seaview Avenue. The old timber structures were again exposed and the 100-foot wide dune was gone. Upper Township spent $100,000 on trucked-in sand to provide stopgap reinforcement to this shoreline segment, but Hurricanes Dennis and Floyd quickly redistributed the material. This problem is related to inlet dynamics, with shoreline erosion occurring all year, not just during storms. Northeast events make things much worse quickly, but are not the cause of this instability. The State of New Jersey derived 1.6 million yards of sand from Corsons Inlet for Strathmere beaches in 1984. The modest monitoring effort that followed overlapped the start-up of the NJ State shoreline-monitoring program in 1986. Data indicate that the shoreline was stable until 1996, and that the beach nourishment project lasted over 10 years, then degraded quickly.

Presently, the Philadelphia District ACOE is in the process of a feasibility study for Corsons Inlet to Townsends Inlet. This rapid deterioration of the Strathmere shoreline is currently under detailed scrutiny.

Strathmere in Upper Township & First Avenue in Sea Isle City;

This site for 2000 feet along the highway has been a storm-related problem for many years. The road has been subject to wave action in 1983, 1984, 1991, 1992, 1993, 1995, and 1997. The narrow beach allowed any storm to reach the toe of the artificial dune. A five-year storm could be counted on to breach the dune somewhere along this stretch. The first countermeasure was to place I-5 material as dune core and put sand over the core. I-5 gravel consists of gravel, sand and 15 - 20% silt as a binder. Properly compacted during installation, this material is 5 times more resistant to erosion as normal dune sand. Each breach would transport scarce sand resources west of the highway, and off the beach. Property owners would hire contractors with "Bobcat" excavators to dig sand from under their homes so the parking site under the dwelling could be used.

The El Nino year of 1997- 1998 erased 2,000 feet of the I-5 core as relentless, minor storms kept road crews busy clearing beach sand from the road. Photographs show that the highway occupied a position on the "storm beach" at about the mid-tidal level. Wave bores of 2 feet crossing the road were common under conditions typical of the "annual" winter storm.

The County and Sea Isle City cooperated in the construction of a geo-textile core for the replacement dune. Beach sand was used to hydraulically fill the bag, then additional sand was trucked in to cover the core. Nothing was done to deal with the narrow beach, so storm waves continue to reach the toe of the dune. The geo-textile core should resist repetitive annual storms. The 5-year storm will overtop the core, but probably leave it in place. Larger scale events will have negative consequences for this project.

Sea Isle City, Ninety-second Street;

In 1975, Craig Everts completed a study for the ACOE on the shoreline stability at Ludlam Island. He plotted the shoreline stability for the entire island. At that time, there were multiple groins in the central section of the Sea Isle City municipal coastline. "In the study area groins have worked in the classical, semi-successful manner of updrift impoundment and downdrift erosion." The last 25 years have compounded that statement as the municipal officials have opted to extend the groinfield several times. Two groins were added south to 78th Street. In the early 1990's, serious erosion had scoured the sand from under homes located at 80th Street. Not willing to continually add new sand to the shoreline, the City moved to add two more groins at 83rd and 88th Streets. Each time the construction was accompanied with beach nourishment. However, shoreline erosion made its appearance south of the 88th Street groin 18 months following its completion.

The large, multi-unit dwelling at 92nd Street was threatened with structural damage during the winter of 1997 – 1998 and the municipality saw the dunes and southern shoreline vanish into the inlet. Loss rates accelerated to the point where pumping sand onto the beach at 88th Street would have been a nearly continuous operation. The municipality determined that an additional groin was needed at 93rd Street, almost at the Townsends Inlet bridge. This structure is a cross between a typical coastal groin and an inlet jetty. The NJDEP and the ACOE ordered it to be shortened 350 feet and lowered in cross sectional profile to meet concerns that it would alter the inlet tidal hydraulics and consequently the sediment distribution around the ebb-tidal delta. In addition, a considerable bond was ordered posted to cover "unforeseen" consequences of this structure. The City also must monitor the performance of the project, which included 365,000 cubic yards of beach sand placed from 88th to 93rd Streets. Please feel free to comment on the projected impacts of this project as we go forward in time.

Avalon Inlet Shoreline, Eighth Street and Avalon Avenue;

Avalon has been the most proactive municipality in the State of New Jersey in determining what would benefit the coastline and how to go about getting it done. In 1993, a major project involved beach nourishment, installation of geo-textile bags, and installation of an innovative submerged, offshore breakwater. The beach was hit hard by the December 1992 northeast storm, a 25- to 35-year event. Following a Presidential disaster declaration, Federal Emergency Management Agency (FEMA) Disaster Survey Reporting teams determined that the beach qualified under FEMA's Category "G" municipal infrastructure guidelines as an "Improved Beach". This meant that the community could receive reimbursement for restoring the beach to its design cross section with FEMA assistance.

The Townsends Inlet shoreline was defended by an aging bulkhead and revetment of rocks, originally designed to mitigate against shoreline retreat from tidal scour. It was not intended to withstand 35 years of storm wave attack. During the 1992 storm event, several inlet property owners suffered moderate to severe damage to their homes. This damage was repetitive from the October 1991 northeast storm Halloween day. A third event in March 1993 added to their grief. One owner who surrounded his property with softball-sized stone to avoid cutting grass, found tons of his "landscaping" inside his home. Over 200 stones had been tossed through the windows into the second floor bedroom. In March 1993, his $5,000 wet bar on his inlet-side deck was found in the center of 8th Street.

As part of the 1993 project, the contractor deposited 110,000 cubic yards of sand along the inlet shoreline in a typical beach nourishment effort. The beach nourishment was just the platform for the installation of a 12-foot diameter geo-textile tube. The newly placed sand was excavated in a trench between the short groins. The fabric was laid in the trench, and inflated with hydraulically pumped sand. This was new to the contractor who elected to use a machine-handled 12-inch discharge line fed by a powerful dredge. The effect was like trying to fill a bathtub with a fire hose under full working pressure. Eventually the task was completed using a 6-inch hose positioned by hand and driven by a smaller pump. The sand lasted about six months, moving rapidly along the shoreline to the bridge. Detailed monitoring showed that incoming tides and ocean waves create a situation where sand must be supplied to this shoreline at over 100,000 cubic yards per year to maintain modest sand beaches. The geo-tube is a temporary solution until the approved ACOE design for a new, higher bulkhead and revetment is built. The new construction is planned to go where the geotubes are located. Seaward installation was required because no easements were retained for land behind the present bulkhead and the rocks prevent placing any new bulkhead within their immediate vicinity. The area, presently water, will be in public hands when the new wall is completed.

The shore-parallel submerged breakwater was the design of Breakwaters International, located in Somerville, NJ. The units weigh 21 tons, are 10 feet long and 6 feet tall. The design was planned to allow wave forces to ramp up the seaward surface of steps. As the wave surged over the unit, openings in the unit would act to create vertical flow on the back surge to prevent suspended sand from crossing the line of units.

With great political fanfare, the first installation of the "Mark III" model was undertaken in Avalon between the 8th Street jetty and a point 1000 feet south. The unit's operation had been previously tested at Stevens Institute of Technology in their large ship-towing tank, modified to have waves and a beach. Stevens and the CRC were given the task of monitoring the performance of the completed breakwater and the beach, respectively. Lessons were learned almost immediately.

- Do not put breakwater units on sand without scour pads or they sink up to 8 feet vertically
- Do not build submerged breakwaters with open ends. Wave overtopping produces exit currents that increase beach erosion at the open end.
- A single line of units on an Atlantic Ocean coast does not justify its 700-dollar per foot cost in decreased erosion or shoreline retreat.

Subsequent installations in New Jersey were placed on stone mattresses to prevent sinking. Both other installations were tied to groins at both ends and thus eliminated the scour from "wave pumping" currents. The installation in Cape May Point is still functioning well, retaining a perched beach landward of the installation. The installation in Belmar, NJ was buried by the NY District ACOE beach restoration project in Monmouth County.

Dunes – The Way They Should Be Along the New Jersey Shoreline, 56th Street in Avalon;

Termed the "High Dune Area" by the officials in Avalon, the dunes here are totally natural from before development. The shoreline has prograded seaward in the past 40 years, creating additional dune ridges at the shoreline. The elevation ranges from 35 to 55 feet on the back dunes. Climax forest growth of American Cherry and Juniper, along with old bayberry plants indicates an age of 100 years since sand deposition ceased dominating the geomorphology. It is 945 feet to the present high tide line from Dune Drive. In 1980 there were six, small "cottages" on individual lots scattered throughout the high dunes. The municipality owns the remaining land, reportedly worth 1.1 billion dollars if subdivided and sold off. They were urged to purchase these lots as they came up for sale in the late 1970's, but it was not done. The last "cottage" is currently on the market for 3.5 million and consists of a single story, 5-room home and just under 1-acre of dunes. A prospective buyer emerged with a proposal to replace the

2,200 square foot dwelling with on of 17,000 square feet of interior space, costing $7,000,000. Instead of welcoming the new ratable with an annual property tax of $205,000, Avalon successfully fought the project, objecting to the destruction of 40,000 square feet of virgin dune vegetation. This was not an issue of storm hazard; it was dune and the environmental aesthetics! At a foundation elevation of 46 feet, and a distance of 900 feet from the high tide line, the last worry was wave or flood damage.

North Wildwood at Surf Avenue;

This is Hereford Inlet, another in the migratory inlets in New Jersey. This shoreline has been progressively armored over the past 40 years. The work was done in a piece-meal fashion and design work varied greatly in quality. The stop is at the last segment to be completed. Historically, the inlet shoreline has advanced into the inlet and retreated again three times. The first instance was recorded in 1891 where a narrow spin has extended into the inlet (3,300 ft.), parallel to the old inlet shoreline. By 1937, the ocean beach had prograded 800 feet seaward since 1891 and a second spit has commenced growth into the inlet. By 1939, the spit was 1,900 feet wide and 2,900 feet long. This spit eroded away and a series of old wooden bulkheads defines the southwestern limit of shoreline retreat. These can be found along the middle of the block closest to the present wall. By 1963, the spit had re-grown a third time. Its duration was very short the last time, with erosion threatening developed properties in the late 1960's. The armor along the channel margin was placed by many entities. Everything from asphalt to sidewalk sections was used. The State stepped in and completed several projects over the past 35 years with heavy basalt stone. A fourth spit began to grow during the summer of 1998, extending 500 feet into the inlet and westward along the shoreline in front of the stop location. By July 1999, erosion had stripped away over half of its deposit. The inlet opening to the sea had breached the tidal shoal very close to the shoreline, so migration back to the long-term position was quick. There may be no remnant of this spit by the time the trip occurs.

Schellingers Creek, Middle Township, Delaware Bay;

The last stop is to contrast processes and problems in Delaware Bay with those on the oceanfront. The beach is notably coarser, but is only a thin veneer on an erosional surface of lagoonal mud and salt marsh. The shoreline study indicated that the beach is retreating at the rate of 2.0 feet per year. While not a rapid rate, the lack of ocean waves has compressed the spacing between dunes, backshore and placement of dwellings. Until 1994, the State had no power to regulate construction of less than 25 dwelling units. Consequently, there are so many 24-unit subdivisions and motels in the State, that future generations will ponder what we thought was so magical about the number 24. In 1994 the regulatory authority was extended to single family homes, but not before hundreds were placed too close to the Delaware shoreline. This expensive example along the beach north of Millman Road is a textbook classic. The owner managed to convince the Township to vacate the former right-of-way to Delaware Avenue and adjust it landward to give him building lots on the bay. He then built 22 feet from the shoreline in 1988. At two feet per year, that gave him an 11-year time horizon into the future.

Erosion picked up a bit in 1995 when the Cape May County Mosquito Commission obtained ACOE and NJDEP permits to re-open Schellingers Creek to tidal flow following 75 years as a fresh water meadowland. The meadowland had turned into a 2,500 acre Phragmities swamp with little coastal marsh habitat potential. Re-opening the inlet would allow salinity to eradicate the Phragmities and re-introduce the normal salt marsh vegetation.

The presence of the armor surrounding the end of Millman Road, together with the opening of the inlet accelerated erosion along this reach to 6 feet per year. The owner presently has the best bay-view along the shoreline. Unfortunately, the view comes to visit each high tide. When the wind comes from the northwest, which it commonly does during the winter, the view gets "up close and real personal".

To mitigate its contribution, the Commission has obtained a grant from the NJ Marine Resources Council to "Demonstrate the Beneficial Uses of Dredged Material". Sand will shortly be transported from the ACOE dredge disposal pit and placed along the beach as a restoration of the 1996 shoreline, with a dune. The project runs from Millman Road to Schellingers Creek Inlet (750 ft.). At the inlet, new retaining structures were built from recycled plastic bulkhead materials to contain the wanderlust possibility for the inlet. The length and opening angles were designed to enhance beach stability. Monitoring since September 1996 shows that the ebb-tidal delta, now associated with the inlet, contains 8,500 cubic yards of sand. The Commission is placing 10,000 cubic yards of sand along this shoreline in its effort to stabilize the situation. The home is on the market for $800,000 if anyone on the trip has any interest in a spectacular bay view, although there is limited front yard space at high tide.

RETURN TO STOCKTON -- THANK YOU FOR YOUR INTEREST.