
Reports

6-11-1977

Coastal Processes and Resulting Forms of Sediment Accumulation Currituck Spit, Virginia/North Carolina

Victor Goldsmith
Virginia Institute of Marine Science

Harold F. Hennigar

Andrew L. Gutman

Nancy T. Blake

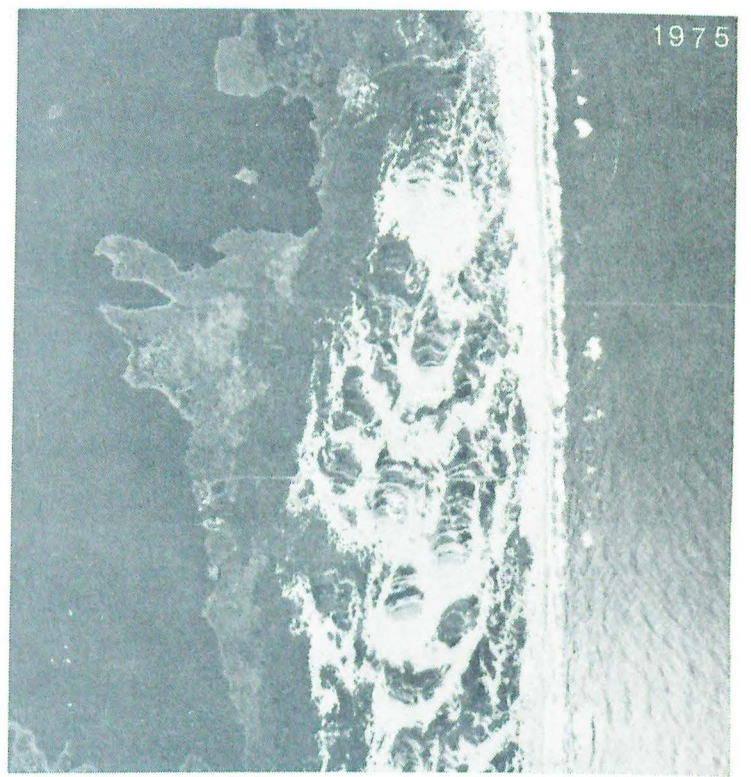
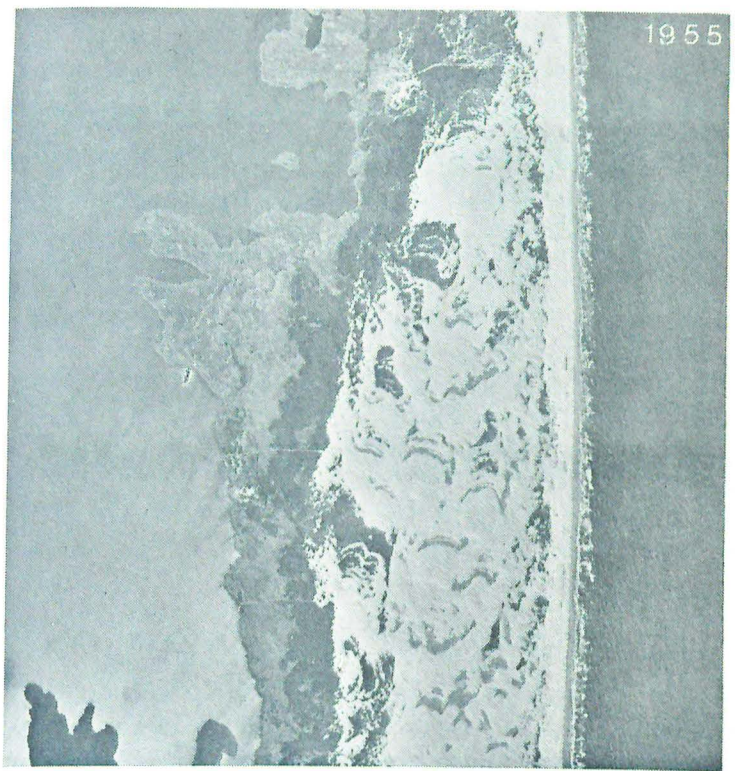
Follow this and additional works at: <https://scholarworks.wm.edu/reports>

 Part of the [Marine Biology Commons](#)

Recommended Citation

Goldsmith, V., Hennigar, H. F., Gutman, A. L., & Blake, N. T. (1977) Coastal Processes and Resulting Forms of Sediment Accumulation Currituck Spit, Virginia/North Carolina. Special Reports in Applied Marine Science and Ocean Engineering (SRAMSOE) No. 143. Virginia Institute of Marine Science, College of William and Mary. <http://dx.doi.org/doi:10.21220/m2-pdbp-nd15>

This Report is brought to you for free and open access by W&M ScholarWorks. It has been accepted for inclusion in Reports by an authorized administrator of W&M ScholarWorks. For more information, please contact scholarworks@wm.edu.

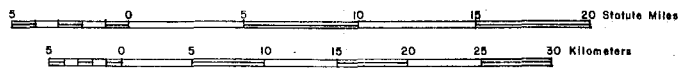
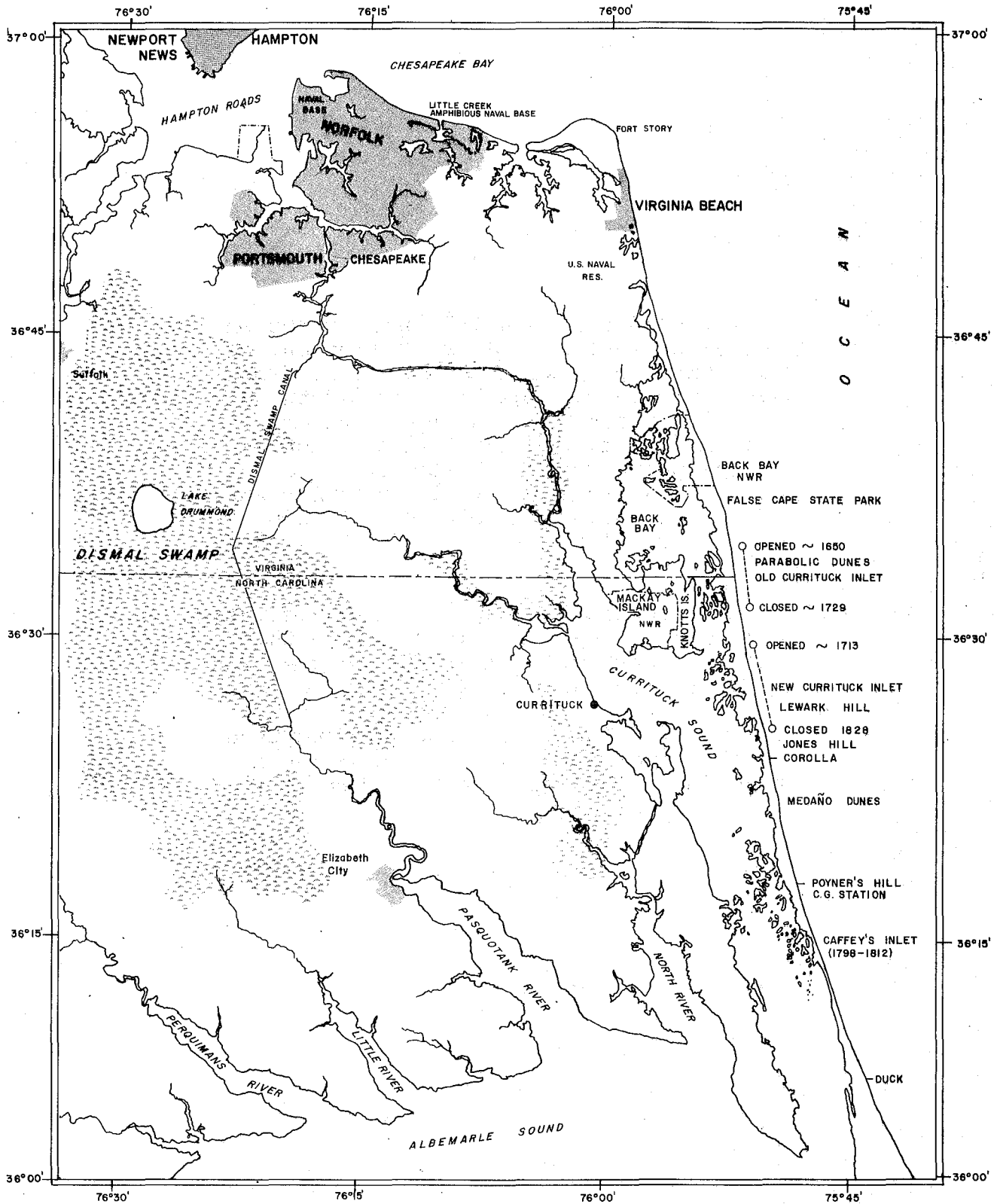


COASTAL PROCESSES AND RESULTING FORMS OF SEDIMENT ACCUMULATION

CURRITUCK SPIT, VIRGINIA/NORTH CAROLINA

The four sequential photographs on the cover include 3.4 km (2.1 miles) of Currituck Spit, within False Cape State Park, Virginia. The Virginia/North Carolina State line is approximately 2.3 km (1.4 miles) south of the bottom of the photographs. North makes an angle of approximately 10° to the right of the shoreline. Scale is 1:33,200, or 2.54 cm (1 inch) = 0.84 km (0.52 miles).

Discussions of these dune, vegetation, and beach changes are included in this volume. Barbour's Hill, the largest and northern-most dune on all four photos, has a relief of approximately 17 m (54 feet). The wave refraction pattern in 1975 indicates the obliquely-north-trending False Cape ridge system.



COASTAL PROCESSES
AND
RESULTING FORMS OF SEDIMENT ACCUMULATIONS
CURRITUCK SPIT, VIRGINIA-NORTH CAROLINA

FIELD TRIP GUIDEBOOK

Compiled and Edited by:
Victor Goldsmith

With the Assistance of:
Harold F. Hennigar
Andrew L. Gutman
Nancy T. Blake

EASTERN SECTION
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
AND

DEPARTMENT OF GEOLOGICAL OCEANOGRAPHY

VIRGINIA INSTITUTE OF MARINE SCIENCE
GLOUCESTER POINT, VIRGINIA 23062



William J. Hargis, Jr., Director
Special Report in Applied Marine Science
and Ocean Engineering (SRAMSOE) No. 143

June 10-11, 1977

Preface

"The Way We Were"

In addition to studying the coastal processes and resulting forms of sediment accumulations, this area of Currituck Spit provides an opportunity for viewing a past era on the Outer Banks, which may be representative of other east coast barriers as well. The isolated village of Corolla, whose residents support themselves through haul-seine fishing, hunting, and house construction, the active cattle ranch, the sand sheets caused by overgrazing, and similar cultural aspects, depict the Outer Banks the way they were at the turn of the century.

As is clearly shown, these practices have definitely left their inprint on the present topography and vegetation of the Banks. It is necessary to delineate the effects of such practices, even in so-called natural areas, in order to gain the desired understanding of coastal processes.

Thus, it is hoped that the uniqueness of this isolated area, which provides the theme for this excursion into the past, will also provide the clues for our understanding of the natural history and present configuration of Currituck Spit, Virginia-North Carolina.

COASTAL PROCESSES AND
RESULTING FORMS OF SEDIMENT ACCUMULATIONS
CURRITUCK SPIT, VIRGINIA/NORTH CAROLINA

CONTENTS

	Page
Preface	v
Acknowledgements	xxiii
I. STOP DESCRIPTIONS	
1. Back Bay Wildlife Refuge Headquarters Parking Lot	1
2. Beach Profile Location No. 12	1
3. Beach Profile Location No. 15	5
4. Stump Field and Beach Cusps	6
5. Barbour's Hill	11
6. Parabolic Dunes	13
7. Fresh Water Marsh and Cattle Ranch	17
8. Seagull (Town Abandoned) and Remnant Sand Sheet	20
9. Lewark Hill Medaño	20
10. Jones Hill	24
11. Currituck Lighthouse	26
12. Downtown Corolla	28
13. Whalehead Hill Medaño and Whalehead Development	30
14. "Treacherous Red Sands" Narrow Beaches and Ocean Sands Development	33
15. C.E.R.C. Research Pier Facility at Duck, North Carolina	35
16. Overwash	24

II. CONTRIBUTIONS

Page

A. Introduction

1. Introduction to the Geography of Currituck Spit and the Included Studies
Victor Goldsmith 1-1
2. The Holocene Geology of Dam Neck, Virginia: A Brief Introduction
Linda Zellmer 2-1
3. A Brief History of Currituck Spit (1600-1945)
Harold F Hennigar 3-1
4. Relict Inlet Features of the Currituck Inlets
John J. Fisher 4-1
5. Introduction to the Coastal Processes at Virginia Beach, Virginia
John C. Ludwick 5-1
6. The Wetland Vegetation of Back Bay and Currituck Sound, Virginia-North Carolina
Gene M Silberhorn 6-1
7. Bird Population: Distribution and Relation to Beach Usage on Currituck Spit, Virginia-North Carolina
S.C. Sturm 7-1
8. Evolution of the Virginia-North Carolina Boundary
Wolf Prow 8-1
9. Shipwrecks Along Currituck and the Outer Banks
Robert A. Gammisch 9-1
10. Fare-thee-well, Currituck Banks
Gary Soucie 10-1
11. Characteristics of the Eastern Shore of Virginia (For Contrast with Currituck Spit)
Thomas E. Rice 11-1

B. Processes

12. Delineation of a Wave Climate for Virginia Beach, Virginia
Andrew L. Gutman 12-1

	Page
13. Wave Climate Models and Shoreline Wave Energy Distribution: Currituck Spit, Virginia-North Carolina Victor Goldsmith	13-1
14. Tides and Nearshore Currents Near Cape Henry and Along Currituck Spit Christopher S. Welch	14-1
15. Storm Surges at Hampton Roads (Sewells Point), Virginia N. Arthur Pore and William S. Richardson	15-1
16. An Investigation of Littoral Transport Between Virginia Beach and Sandbridge, Virginia Richard C. Cunningham, Jr.	16-1
 C. <u>Continental Shelf</u>	
17. Shelf Geomorphology Adjacent to Currituck Spit, Virginia-North Carolina Victor Goldsmith	17-1
18. Stability and Local Effects of an Offshore Sand Storage Mound, Dam Neck Site, Virginia Inner Continental Shelf William J. Saumsiegle	18-1
19. Morphologic Time Series from a Submarine Sand Ridge on the South Virginia Coast John F. McHone, Jr.	19-1
 D. <u>Beach</u>	
20. Measurements of Historical Shoreline Changes Along the Coast of the Virginian Sea Carolyn H. Sutton, Anita W. Haywood and Adam A. Frisch	20-1

	Page
21. Beach Trends in the Southeastern Virginia Coastal Compartment Victor Goldsmith, Susan C. Sturm and George R. Thomas	21-1
22. Temporal Occurrence of Beach Erosion and Accretion in Southeast Virginia Beaches Adam A. Frisch	22-1
23. Beach Response in the Vicinity of a Shoreface Ridge System: False Cape, Virginia Victor Goldsmith, Gerald L. Shideler, John F. McHone and D.J.P. Swift	23-1
24. Beach Cusps Asbury H. Sallenger, Jr.	24-1
25. Forecasting Storm Related Beach Erosion Intensity Along the Oceanic Coastline of Virginia William S. Richardson	25-1
 E. <u>Dune</u>	
26. The "VAMP" Coastal Dune Classification Victor Goldsmith, Harold F. Hennigar and Andrew L. Gutman	26-1
27. Evolution of Coastal Sand Dunes: Currituck Spit, Virginia-North Carolina Harold F. Hennigar	27-1
28. Orientation of Coastal Parabolic Dunes and Relation to Wind Vector Analysis Andrew L. Gutman	28-1
29. Movement of Large Sand Hills: Currituck Spit, Virginia-North Carolina Andrew L. Gutman	29-1
30. Internal Geometry of Foredune Ridges, Currituck Spit Area, Virginia-North Carolina Peter S. Rosen, Elizabeth S. Barnett, Victor Goldsmith, Gerald L. Shideler, Mark Boule and Yvonne E. Goldsmith	30-1

	Page
F. <u>Sedimentology</u>	
31. A Review of Grain Size and Mineralogy Data of Currituck Spit from the Literature Victor Goldsmith	31-1
32. Beach Slope and Grain Size Changes: Currituck County, North Carolina George R. Thomas, Victor Goldsmith and Susan C. Sturm	32-1
33. Some Deformation Structures in Recent Beach Sands Carl H. Hobbs, III	33-1
34. A Preliminary Investigation on the Origin of the "Treacherous Red Sands"; Currituck Spit, North Carolina Kathleen Farrell	34-1
35. Aeolian Grading of Sand Across Two Barrier Island Transects, Currituck Spit, Virginia-North Carolina Andrew L. Gutman	35-1

COASTAL PROCESSES AND
 RESULTING FORMS OF SEDIMENT ACCUMULATIONS
 CURRITUCK SPIT, VIRGINIA/NORTH CAROLINA

ILLUSTRATIONS

I. <u>FIGURES</u>	Page
Frontispiece. Location Map of Currituck Spit and Vicinity	ii
Photo Mosaics. Comparison of 1955 and 1975, and showing all STOP locations (4 p.)	xxv
Stop 1. Sandbridge and Back Bay National Wildlife Refuge	2
Stop 2. Erosional Beach and Accretional Beach	3
Stop 2. Cumulative Volume Change at Profile Line 12	4
Stop 3. Cumulative Volume Change at Profile Line 15	6
Stop 4. Stump Field at False Cape State Park, Virginia	9
Stop 5. Barbour's Hill Slipface	11
Stop 6. Parabolic Dunes at False Cape State Park	14
Stop 6-7. Contrasts at Virginia-North Carolina State Line	16
Stop 7. Cows in the Marsh and Astray in the Dunes	19
Stop 8a. Remnant Sand Sheet, Seagull, North Carolina	21
Stop 8b. Views of Sand Blowing over the Fore-dune at Seagull	22
Stop 9a. Lewark Hill, North Carolina	24
Stop 9b. Lack of Fore-dune Between Lewark Hill and the Beach	25
Stop 9c. Off-road Vehicles at Lewark Hill	26
Stop 10. Jones Hill Slipface	29
Stop 11. Currituck Lighthouse, Corolla, North Carolina (Then and Now)	31
Stop 12. View from Currituck Lighthouse, Corolla	33
Stop 13a. Whalehead Hill Medaño	36
Stop 13b. Whalehead Development Roads and Field of Transverse Dunes	37
Stop 14a. Fore-dune 10 km South of Corolla	40
Stop 14b. Site of Former Caffey's Inlet, North Carolina	41
Stop 14c. AID Fore-dune	42
Stop 15. C.E.R.C. Research Pier Facility, Duck, North Carolina	44
Stop 16. Last Active Overwash on Currituck Spit	28

Figure	Page
1. Regional Location Map of Currituck Spit, Virginia-North Carolina	1-2
2. Location Map of Profile Lines from the VIMS-CERC Shoreline Studies	1-3
3. Map of Beach in Currituck County, North Carolina	1-4
4. Temporal Sequence of Inlet Locations Along Currituck Spit (1775-1848)	1-5
5. Historical Sea Level Changes at Hampton Roads, Virginia	1-7
1. Sea-level Curve for the Atlantic Continental Shelf	2-2
2. Location Map of 35 Cores	2-4
3. Diagrammatic Stratigraphic Cross-Section from Cores Extending Offshore from Dam Neck, Virginia	2-5
4. Photograph of Coarse-Grained Layer	2-6
5. Photograph of Pebble-Cobble Layer Underlying Iron-stained Sands	2-7
6. Comparison of Inner Shelf Stratigraphic Sections	2-10
1. Historical Inlets Along the Outer Banks Coast	4-2
2. Typical Inlet Features (Present-day and Relict)	4-4
3. Index Map for Sediment Study of Flood Tidal Deltas	4-5
4. Textural Histograms of Flood Tidal Delta Sediments	4-8
1. Rudee Inlet Stabilization Plan	5-6
2. Potter Erosion Prevention Apparatus, Virginia Beach, Virginia	5-8
3. Sand Sources for Virginia Beach Replenishment	5-9
1-4. Generalized Vegetation Cover Maps of Marshes of Back Bay and Currituck Sound (north to south)	6-3 6-4 6-5 6-6
1. Bird Census Data Along Currituck Spit, Virginia-North Carolina	7-2
1. The Recorded Shipwrecks of the Cape Hatteras Coast	8-2

Figure

	Page
1. Regional Location Map of the Virginia Barrier Island Group	10-2
2. Shoreline Positions (1852 and 1962) of Hog Island	10-7
3. Sequential Changes in Barrier Islands (1955-1974)	10-11
1. Bathymetry of the Virginian Sea	12-2
1a. & 1b. Sources of Wave Climate Data for Dam Neck, Virginia	12-2 & 12-3
2. Temporal Distribution of Wave Climate Data for Dam Neck, Virginia	12-4
3. Seasonal Average Significant Wave Heights	12-8
4. Seasonal Average Significant Wave Periods	12-11
5. COSOP Wave Rose (April 1954-December 1965)	12-12
6. Chesapeake Light Wave Rose (January 1970-December 1972)	12-13
7. Ship Observation Wave Rose (December 1948-December 1973)	12-14
8. Virginia Beach Gage Average Significant Wave Height	12-16
9. Summer COSOP Wave Rose (April 1954-December 1965)	12-17
10. Winter COSOP Wave Rose (April 1954-December 1965)	12-18
11. Percent Frequency Occurrence of Significant Wave Heights	12-21
1-3. Wave Refraction Diagrams from Virginian Sea Wave Climate Model	13-3, 13-4, 13-5
4. Shoreline Wave Height Distributions	13-10
1. Regional Location Map of Currituck Spit, Virginia-North Carolina	14-2
1. Regional Location Map of Currituck Spit, Virginia-North Carolina	15-2
2. Tide Frequency at Sewells Point in Hampton Roads, Virginia (Oct-May)	15-12
3. Tide Frequency Curves at Virginia Beach and Hampton Roads	15-12
4. Relation of Storm Surges at Hampton Roads with Winds at Norfolk, Virginia	15-13
5. Atmospheric Pressure and Hampton Roads Storm Surge	15-15
6. Track of the August 22-24 Hurricane and Associated Storm Surge at Sewells Point	15-17

Figure

	Page
1. Littoral Transport Station Locations Between Virginia Beach and Sandbridge, Virginia	16-2
2. Littoral Current Versus Time at North Station (July 6, 1973)	16-4
1. Bathymetric Map of the Virginian Sea	17-2
2. Three Dimensional Computer Projection of the Continental Shelf	17-3
3. Bathymetric Profiles	17-4
4. Width of Shelf Undergoing Wave Refraction by Waves of Different Periods	17-6
5. Linear Sand Ridge on the Continental Shelf	17-10
1. Bathymetry of the Dam Neck Disposal Site, Virginia (July 1975)	18-5
2. Bathymetric Profiles Across the Dam Neck Disposal Site (1973-1975)	18-6
3. The Distribution of Bottom Sediment at the Dam Neck Disposal Site	18-8
4. Shoreline Wave Energy Changes Related to Pre-Dump Bathymetric Conditions at the Dam Neck Disposal Site.	18-10
5. Simple Wave Refraction Pattern for a Hemispherical Shoal	18-11
1. Regional Location Map of Currituck Spit, Virginia-North Carolina	19-2
2. Block Diagram of the False Cape, Virginia Submarine Sand Ridge	19-4
3. Beach and Nearshore Profiles at False Cape	19-4
4. Bathymetric Map of False Cape Ridge (March 13, 1971)	19-6
5. Bathymetric Map of False Cape Ridge (April 24, 1971)	19-7
6. Bathymetric Map of False Cape Ridge (June 9, 1971)	19-8
7. Bathymetric Map of False Cape Ridge (September 19, 1971)	19-9
8. Profiles of False Cape Ridge	19-11
9. Profiles of False Cape Ridge	19-12
10. Inferred Breaking Wave Climate for the False Cape Inner Ridge	19-14
11. Fair Weather Drogue Data (August 1971)	19-16
12. Simultaneous Surface Wind and Bottom Current Components (July 1971)	19-17
13. Helical Flow Proposed for the False Cape Inner Trough	19-19
1. Map of Shoreline Changes-Cape Henlopen to Cape Charles, Virginia	20-4
2. Map of Shoreline Changes-Cape Henry, Virginia to Cape Hatteras, North Carolina	20-5

Figure	Page
1. Beach Profile Locations and Wave Observation Sites on Currituck Spit	21-5
2. Cumulative Beach Volume Range at Nine Month Intervals - All 18 Locations	21-15
3. Cumulative Volume Change at Profile Location Number 1	21-16
4. Cumulative Volume Change at Profile Location Number 11	21-18
5. Cumulative Volume Change at Profile Location Number 12	21-19
6. Cumulative Volume Change at Profile Location Number 15	21-20
7. Cumulative Volume Change at Profile Location Number 18	21-21
8. Typical Profile of an Accretional Beach	21-26
9. Typical Profile of a Narrow Beach	21-27
1. Comparison of Mean Monthly Nearshore Wave Heights on the East, West and Gulf Coasts	22-2
2. Typical Beach Profile	22-4
3. Cumulative Volume Change at Profile Location Number 1	22-5
4. Cumulative Volume Change at Profile Location Number 10	22-6
5. Cumulative Volume Change at Profile Location Number 8	22-7
6. Cumulative Volume Change at Profile Location Number 13	22-8
7. Times of Erosion at Profile Locations 1-18 (Fall 1974-Fall 1976)	22-9
8. Times of Erosion (Fall 1969-Fall 1976)	22-10
1. Beach Profile Location Map, Currituck Spit, Virginia-North Carolina	23-2
2. Erosion/Accretion at ODU Profiles (June 1969-September 1971)	23-5
3. Bathymetry of Southeast Virginia Shelf	23-8
4. Cumulative Volume Changes at Profile Location Number 15 (1972-1976)	23-9
5. Cumulative Volume Changes at Profile Location Number 16	23-10
6. Cumulative Volume Changes at Profile Location Number 17	23-11
7. Cumulative Volume Changes at Profile Location Number 18	23-12
1. Development of Beach Cusps	24-3
2. Cross Sections Through a Beach Cusp	24-5
3. Measured Cusp Spacing Versus Computed Cusp Spacing	24-8
4. Mean Spacings of Beach Cusps on Different Energy Shorelines	24-9
5. Measurements of Cusp Spacing Around Giant Cusps	24-11

Figure	Page
1. Photograph of Storm Damage at Virginia Beach, Virginia (March 1962)	25-3
2. Storm-related Erosion Intensity Scale	25-6
1. Major Dune Vegetation	26-3
2a. Dune Bedding	26-4
2b. Foredune Crossbed Azimuths and Amount of Dip, Currituck Spit, by Location	26-5
2c. Foredune Crossbed dip Angles and Azimuths, Currituck Spit, by Shoreline Orientation	26-6
3. Eolian Sand Transport Off and Onto Beach	26-7
4. Artificially Inseminated Dune (AID)	26-9
5a. Effect of Sand Fencing in the Dunes	26-10
5b. Effect of Bulldozing in the Dunes	26-11
6. Natural Dune Growth Around Vegetation	26-12
7. Medaño Dunes	26-14
8. Parabolic Dune	26-14
9a. Parabolic Dune Crossbeds, False Cape, Virginia Dip Versus Azimuth	26-17
9b. Parabolic Dune Crossbeds - Amount of Dip	26-18
9c. Parabolic Dune Crossbeds - Dip Directions (Azimuth)	26-19
1. Location Map of Currituck Spit, Virginia-North Carolina	27-3
2. Aerial Photographs of Jones Hill (1940-1975)	27-4
3. Summation of Jones Hill Migration (1940-1975)	27-5
4. Photographs of False Cape State Park (1937-1975)	27-7
5. Photographs of Parabolic Dunes at False Cape State Park	27-9
6. Photographs of Corolla, North Carolina Compartment (1940-1975)	27-11
7. Vegetation Maps of the Corolla Compartment (1940-1975)	27-12
8. Changes in Total Vegetation Area of the Corolla Compartment and Relation to Sand Fencing	27-13
9. Photographs of Poyner's Hill Compartment (1940-1975)	27-15
10. Photographs of False Cape State Park (1955) and Corolla (1975)	27-17
11. Photographs of False Cape State Park (1937) and Poyner's Hill (1975)	27-18
1. Regional Location Map of Currituck Spit, Virginia-North Carolina	28-2
2. Aerial Photograph of Parabolic Dune Field	28-3
3. Diagram of Phases of Parabolic Dune Growth	28-4
4. Aerial Photograph of Barbour's Hill	28-5
5. Comparison of Corolla and Hatteras Wind Resultants	28-7
6. Corolla Station Annual Vector Mean Wind Resultant (January 1976-January 1977)	28-9
7. Parabolic Dune Field of False Cape, Virginia	28-10

Figure	Page
8. Corolla Station Wind Rose	28-12
9. Corolla Station Wind Resultant Excluding Offshore Winds	28-14
10. Hatteras Station Wind Rose	28-15
1. Regional Location Map of Currituck Spit, Virginia-North Carolina	29-2
2. Aerial Photographs Showing Movement at Whalehead Hill (1961-1977)	29-4
3. Aerial Photograph of Whalehead Hill	29-6
4. Aerial Photograph of Barbour's Hill	29-7
5. Movement of Two Large Sand Hills (January 1976 to January 1977)	29-9
6. Photograph of Whalehead Hill Dune Movements	29-10
7. Corolla Station Wind Rose (February 1976-February 1977)	29-11
8. Volume Discharge of a Large Sand Dune	29-14
1. Regional Location Map of Currituck Spit, Virginia-North Carolina	30-3
2a. Hatteras Wind Rose (1946-1970)	30-4
2b. Norfolk Wind Data (1951-1960)	30-5
3. Foredune Crossbeds, Currituck Spit, By Location	30-7
4. Foredune Crossbed Dip Angles and Azimuths. All Locations Combined	30-14
1. Grain Size Data, Cape Henry to Cape Hatteras	31-2
2. Mineralogy Data, Cape Henry to Cape Hatteras	31-4
1. Map of Currituck County, North Carolina	32-2
2. Beach-face Slope Angle Versus Distance in Currituck County	32-3
3. Beach-face Grain Size Versus Distance	32-4
4. Beach-face Slope Angle Versus Beach-face Grain Size	32-5
1. Bathymetry of the Virginian Sea	34-2
2. Structure Contour Map of Shelf Area in Vicinity of Albemarle Channel, North Carolina	34-5
1. Regional Location Map of Currituck Spit, Virginia-North Carolina	35-2
2. Profile of Barrier Island Showing the Location of Sediment Samples	35-4
3. Grain-Size Moments Across Transect A in False Cape State Park, Virginia	35-9
4. Grain-Size Moments Across Transect A in False Cape State Park, Virginia	35-10
5. Grain-Size Moments Across Transect C South of Corolla, North Carolina	35-12
6. Grain-Size Moments Across Transect C South of Corolla, North Carolina	35-13

COASTAL PROCESSES AND
RESULTING FORMS OF SEDIMENT ACCUMULATIONS
CURRITUCK SPIT, VIRGINIA/NORTH CAROLINA

ILLUSTRATIONS

II. TABLES

1. History of Currituck Banks	3-17
1. Southeastern Virginia Bird Observations (October 1974-November 1976)	7-4
1. Limitations and Biases of the Wave Climate Sources for Dam Neck	12-6
2. Occurrence of Extratropical Storms During Operation of the Virginia Beach Gage (1964-1968)	12-20
1a. Tide Heights During Storms at Sewells Point in Hampton Roads, Virginia (1879-1956)	15-4
1b. Tide Heights During Storms at Sewells Point, Virginia (1956-1969)	15-7
2. Maximum Tides from Northeasters (October-May, 1927-1973)	15-9
3. Extratropical Winter Storms (1956-1969) and Related Storm Surge at Sewells Point.	15-11
4. Tropical Storms (1926-1961) and Related Storm Surge at Sewells Point	15-11
1. Depth to Outer Edge of Terraces on the Continental Shelf and Slope of the Virginian Sea	17-7
1. Volume of Sediment Stockpiled at Dam Neck Disposal Site, Virginia (1967-1974)	18-2
2. Apparent Mean Depth Differences for Bathymetric Profile Comparisons at Dam Neck Disposal Site (1973-1975)	18-4
3. Currents at the Dam Neck Disposal Site (July- August, 1973)	18-9
4. Parameters Required for Sediment Movement	18-12
5. Percent Time of Bottom Sediment Entrainment by Waves at the Dam Neck Disposal Site	18-14
1. Beach Profile History in Southeast Virginia	21-3
2. Gross Quantities of Nourishment Material Placed on Virginia Beach	21-10
3. Qualitative Description of 27 Month Beach Trends in Southeast Virginia	21-12
4. Statistical Significance of 27 Month Beach Trends in Southeast Virginia	21-13

Table	Page
5. Statistical Significance of Long-term Beach Trends in Southeast Virginia	21-14
6. Average Cumulative Volume Changes for Four Beach Usage Types in Southeast Virginia	21-23
7. Average Cumulative Volume Change by Reach	21-23
1. Percent Time of Erosion by Season and Profile Location, Southeast, Virginia (1974-1976)	22-11
2. Percent Time of Erosion by Season and Profile Location (1969-1976)	22-12
1. Beach Volume Trends for Profile Locations 12-18	23-13
1. Storm Related Erosion Intensity Matrix for Virginia	25-7
2. Observed and Forecasted Qualitative Erosion Intensities	25-7
1. Parabolic Dune Orientation From Aerial Photographs	28-16
1. Annual Rates of Coastal Dune Movements at Various Locations	29-5
2. Sand Transport At Currituck Light Station (March 1976-March 1971)	29-17
1. Dune Bed Dip Angle Distribution, Currituck Spit, Virginia-North Carolina	30-8
2. Dune Bed Dip Directions, Currituck Spit	30-11
1. Wind Data Prior to Sediment Sampling for Sand Grading Study	35-5

ACKNOWLEDGEMENTS

An attempt at a compendium of all known information about an area as dynamic and diversified as Currituck Spit, Virginia-North Carolina, necessitates assistance from an equally diversified group of resources. First and foremost are the students and researchers at VIMS; those from the early years when there was the aura of mystery begging for explanation and understanding (A.H. Sallenger, Jr., P.S. Rosen, Y.E. Goldsmith, C.H. Sutton, M.J. Carron, M. Boule, D. Stauble, and others) and the present students, who have assisted in the planning and logistics for this trip (A. Frisch, R.A. Gammisch, L.R. Zellmer, and E. Barnett). R.J. Byrne and J.M. Zeigler provided their knowledge and guidance, with great benefits, to all the VIMS' investigations included herein.

The value of this Guidebook rests primarily in the hands of the contributors, who gave willingly of their efforts and their expertise, and I extend my appreciation to all thirty-one contributors. J.C. Ludwick at Old Dominion University (O.D.U.) graciously offered to compile and edit the O.D.U. research efforts in this area. Audubon Magazine and Gary Soucie allowed the inclusion of their article. Unless otherwise noted, the authors are affiliated with VIMS.

The Back Bay Wildlife Refuge personnel (D. Hollands, Head, F. Smith and R. Field) extended significant assistance and advice over the last five years. False Cape State Park personnel (L. King and W. Taylor) were also quite helpful to these studies. Early researchers graciously gave of their data and their knowledge of the area (W.H. Harrison, G.L. Shideler, J.F. McHone and D.J.P. Swift).

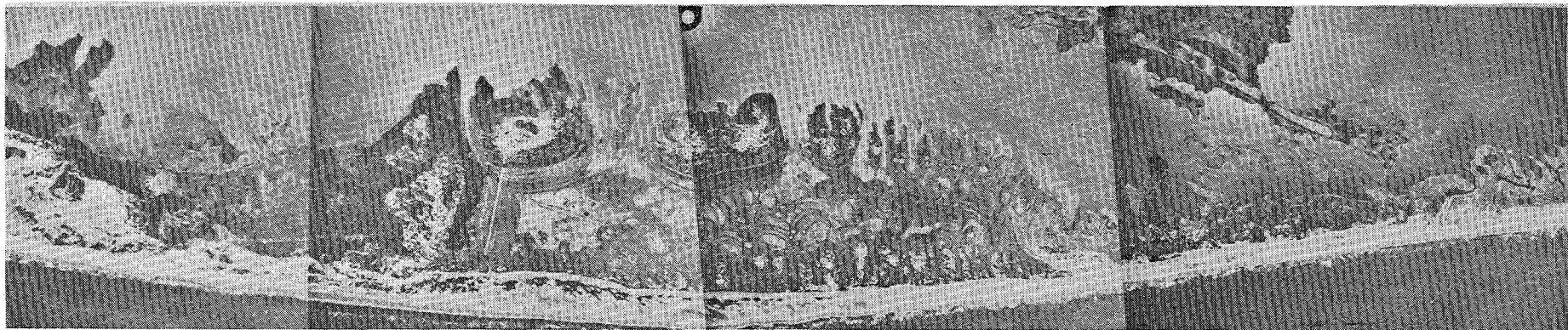
Financial and administrative support for this volume was furnished by the Virginia Institute of Marine Science (W.J. Hargis, Jr., Director), National Society of Economic Paleontologists and Mineralogists (R. Shaver, President), and the Eastern Section, S.E.P.M., to which I express my grateful appreciation. Beach profile studies in this area were supported by a contract (DACW-72-C-0008) with the Coastal Engineering

Research Center of the U.S. Army Corps of Engineers (1974-1976), and wave climate studies were supported by the VIMS Sea Grant Program through an award from the National Oceanic and Atmospheric Administration (Grant No. 04-6-158-44047). The Chesapeake Bay Ecological Program Data Center at NASA-Wallops furnished the anemometer and the remote sensing data used in these studies.

A number of very competent and talented people contributed directly to this volume, including C. Diggs, K. Thornberry, W. Jenkins, K. Stubblefield, M. Williams, J. Gilley, S. Motley, and J. Stubbs. M. Germann provided editorial assistance.

Most importantly, I wish to express my thanks to the participants, without whose interest this trip and this volume would not have come to fruition.

STOP DESCRIPTIONS

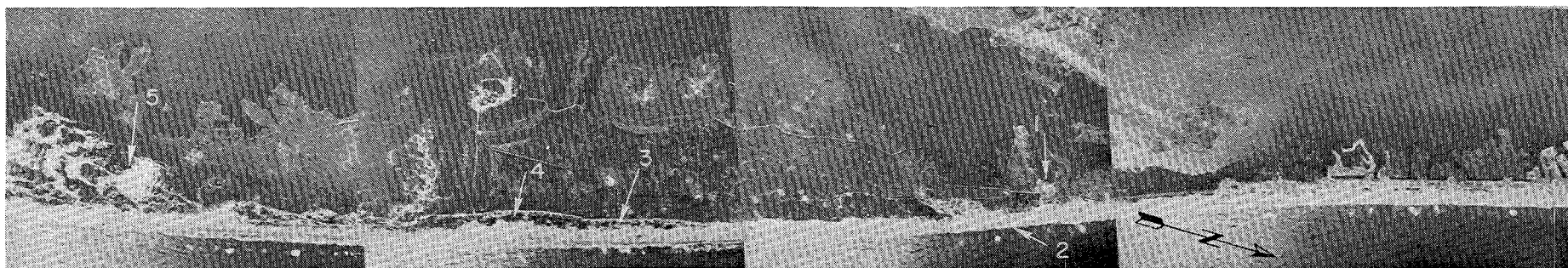


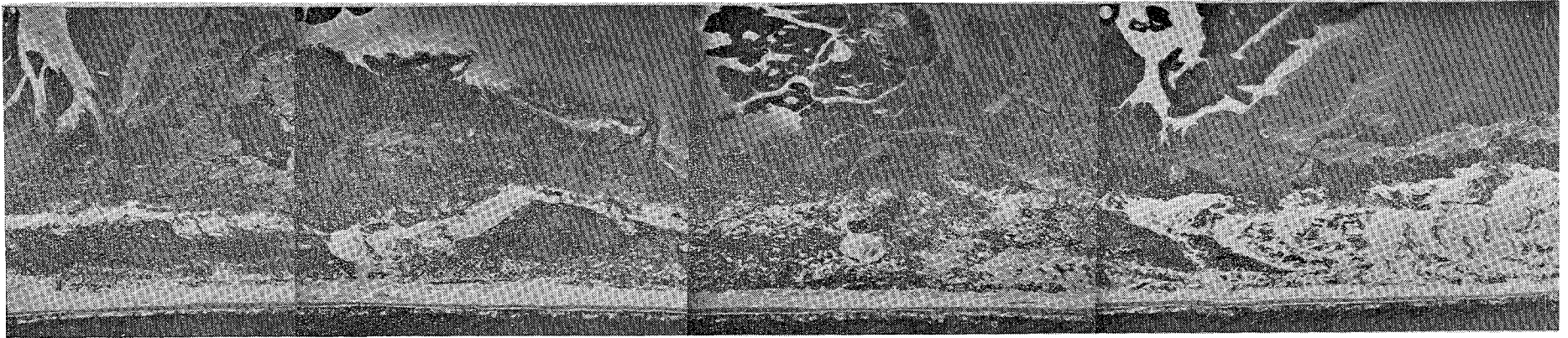
Uncontrolled Photomosaic of Currituck Spit, Va./N.C.

Numbers below correspond to STOP descriptions

Top: March 29, 1955 C&GS SCALE— @ 1:53,300

Bottom: April 16, 1975 NASA SCALE— @ 1:70,000



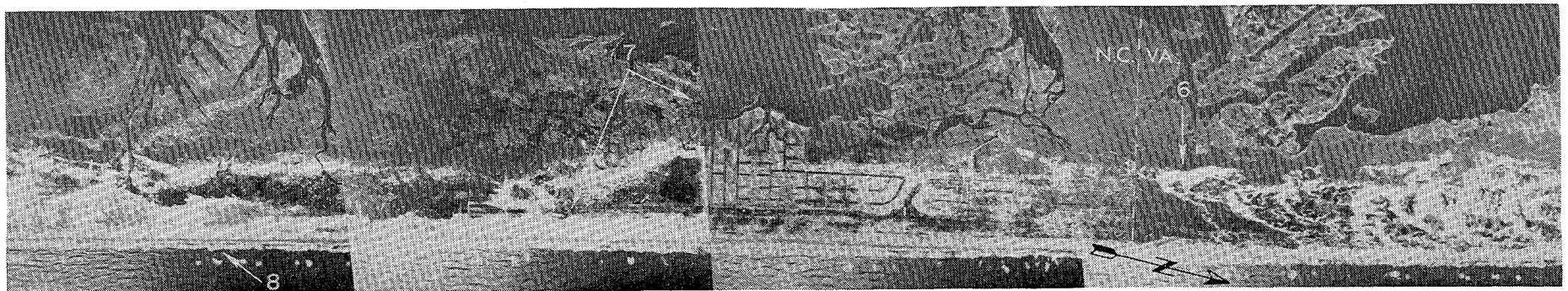


Uncontrolled Photomosaic of Currituck Spit, Va./N.C.

Numbers below correspond to STOP descriptions

Top: March 29, 1955 C&GS SCALE— @ 1:53,300

Bottom: April 16, 1975 NASA SCALE— @ 1:70,000



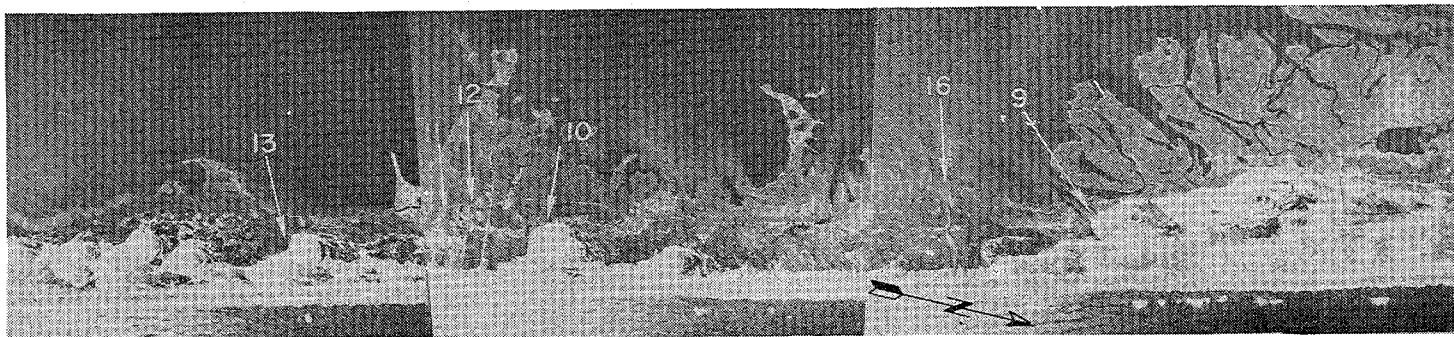


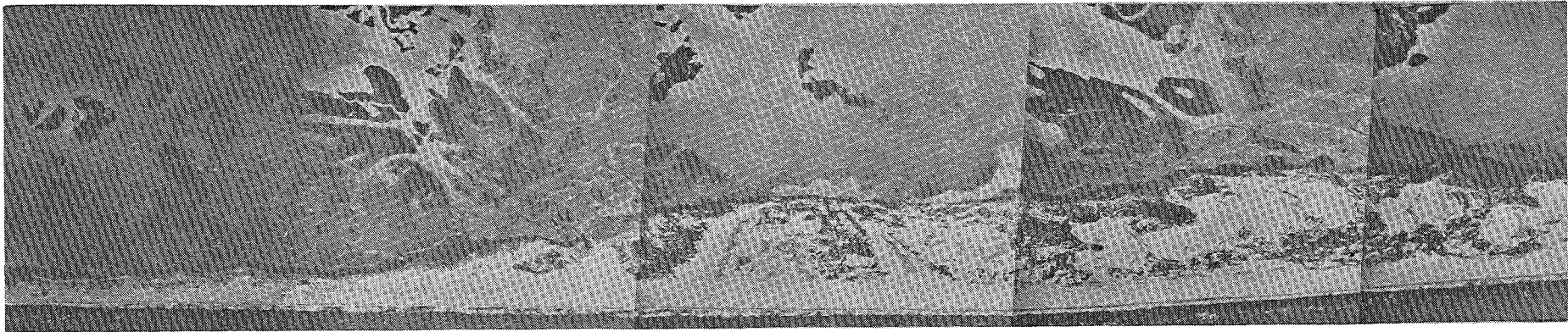
Uncontrolled Photomosaic of Currituck Spit, Va./N.C.

Numbers below correspond to STOP descriptions

Top: March 29, 1955 C&GS SCALE— @ 1:53,300

Bottom: April 16, 1975 NASA SCALE— @ 1:70,000



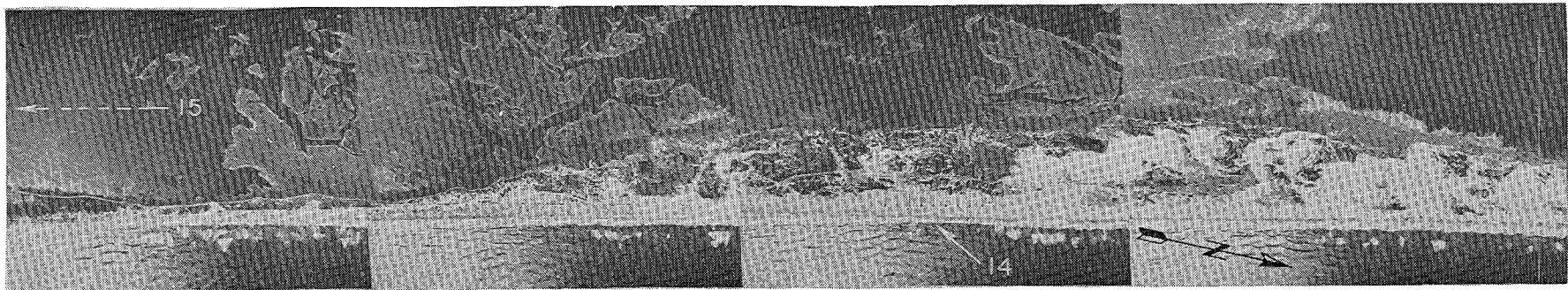


Uncontrolled Photomosaic of Currituck Spit, Va./N.C.

Numbers below correspond to STOP descriptions

Top: March 29, 1955 C&GS SCALE— @ 1:53,300

Bottom: April 16, 1975 NASA SCALE— @ 1:70,000



STOP DESCRIPTIONS AND ROAD LOG

Mileage

Back Bay Wildlife Refuge, Virginia

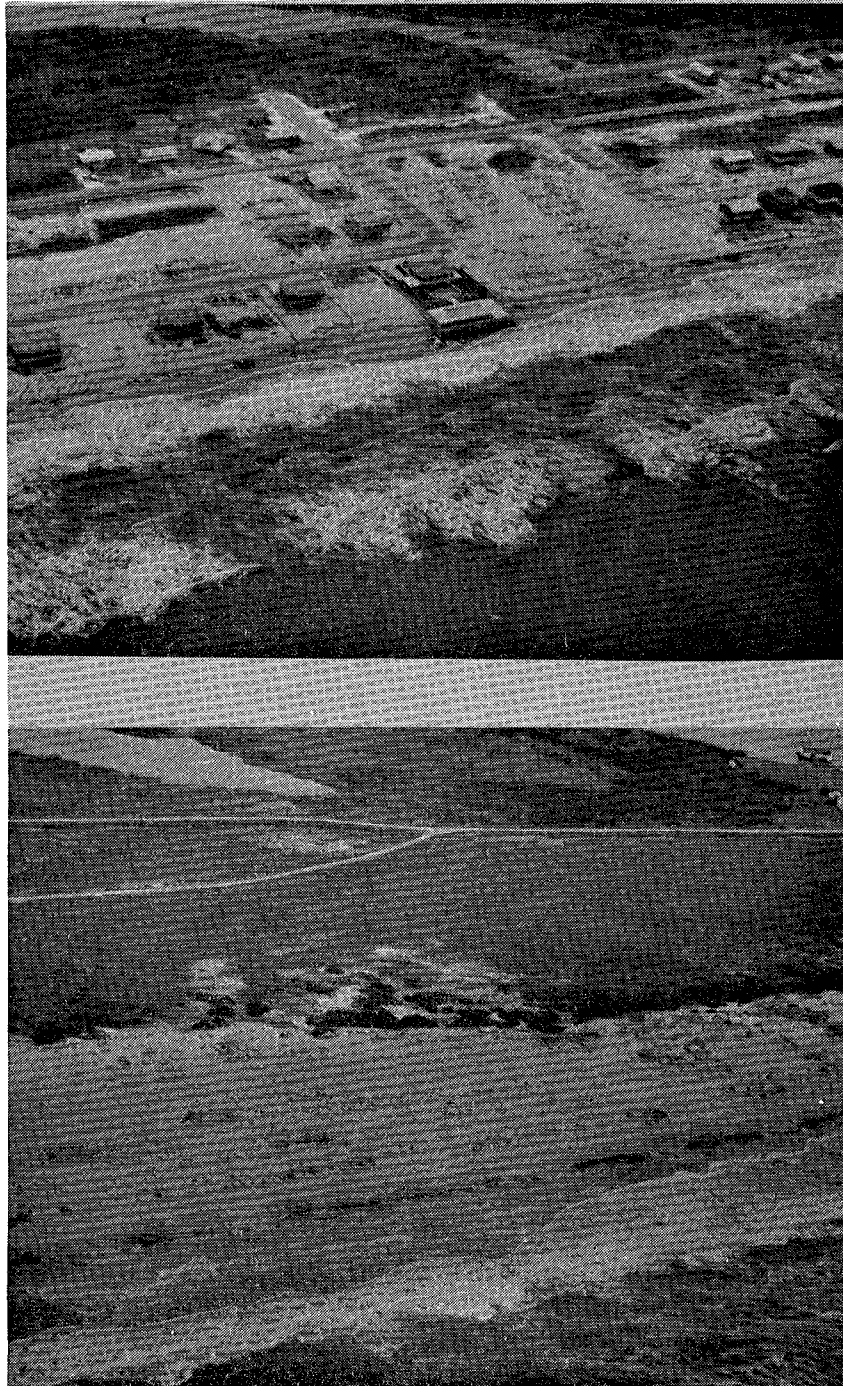
0.0 STOP 1. Refuge Headquarters Parking Lot

An introduction to the area will be given by Refuge personnel. Access through this area is restricted to full time residents of Currituck County, North Carolina, commercial fisherman, federal, state and local officials "in the course of their official duties", and very few others. This is because of conflicts between the Refuge's two roles--wildlife protection and recreation, with the former being emphasized. (See introductory articles.)

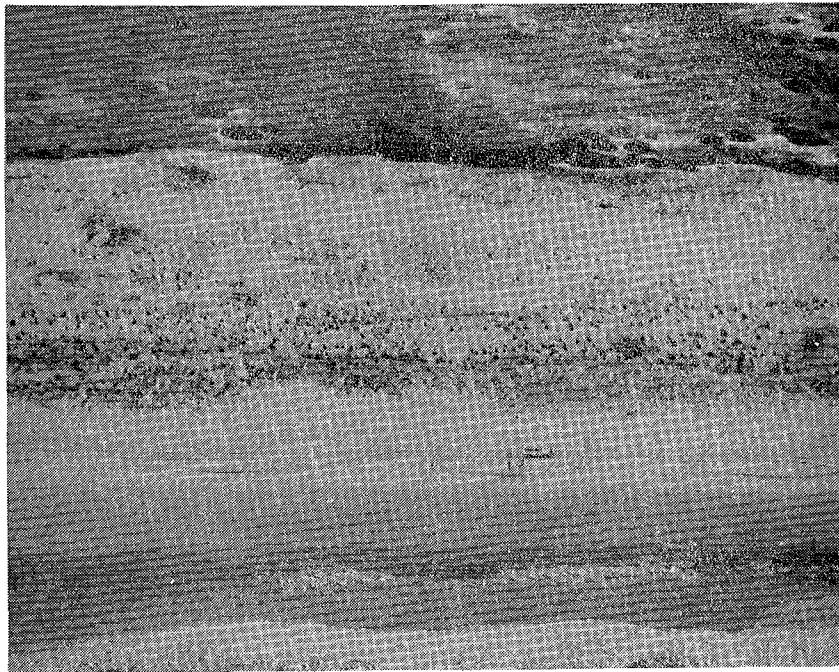
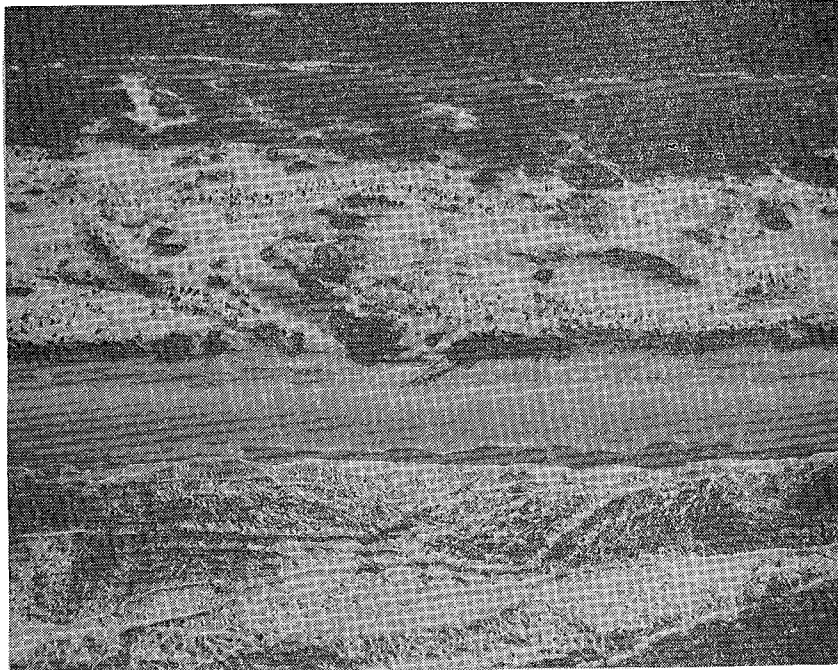
All drivers should reduce air in tires to about 18-20 pounds. When proceeding onto beach, depart from ramp rapidly, and one at a time, in order to get through soft sand.

0.5 STOP 2. Beach Profile Location No. 12

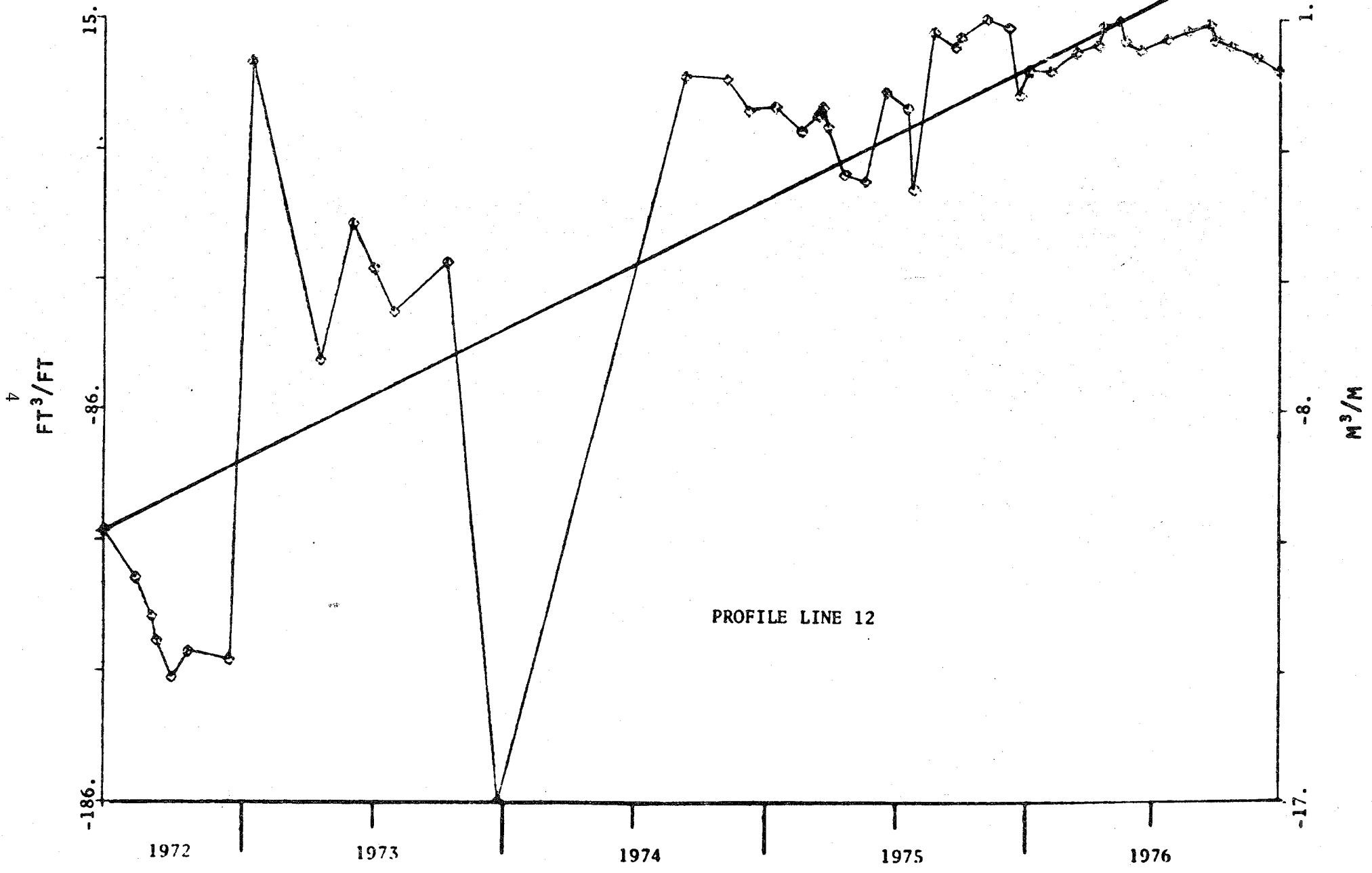
At present this is the southern extent of the zone of relatively narrow, "erosional", or inactive beaches forming the hypothesized longshore transport diverging nodal point. North of this area net transport is to the north, south of this area net transport is to the south. Whereas, this beach underwent severe wave erosion in the 1972-1974 period, it widened slightly (along with most of the other 18 beach profile locations) due to a lack of storms since 1974. However, the foredune has been almost completely eroded since 1974, not by waves, but by eolian deflation from southwest winds. Wind was funneled through the topographically lower portions of the foredune, causing the dune



STOP 1. Contrast the development in Sandbridge (above) with that at Back Bay National Wildlife Refuge (below), approximately 5 Km apart. The area encompassed by both photos, one of the narrowest portions of the spit, was extensively overwashed in 1962.



STOP 2. Contrast the narrow erosional beach at the north end of Back Bay (top, April 5, 1976) with the more accretional beach three Km to the south (bottom, October 5, 1976). Beach Profile data suggests that a new long-shore drift diverging nodal point exists in this general vicinity.



Mileage

erosion and resulting in extensive wind shadows (oriented towards the northeast) and sheet deposition on the beach. This is indicative of the importance of eolian deposition on the beach.

Historically (1930's and 1940's), this was an area of extensive overwash with foredunes absent, or quite low. Also, this may have been the previous site of an old inlet. From the top of the new front foredune, one can see across the spit, which is relatively narrow here, into Back Bay. It has been suggested that with the blockage of the overwash into Back Bay after 1962, and the active AID Program (dune fencing and planting) resulting in high continuous foredunes in this area, that dramatic differences occurred in the shallow and restricted Back Bay. The species composition of vegetation in the Bay altered due to changes in salinity, and consequently, the waterfowl feeding in the Bay was drastically affected. However, it was found that maintenance of salinity at approximately 3‰ induced flocculation and subsequent settling of fine particles. This has decreased turbidity in the Bay, with a resulting increase in aquatic vegetation. Salt water is now pumped regularly into Back Bay from the Ocean at Little Beach Island Coast Guard Station, about two kilometers north of the Refuge.

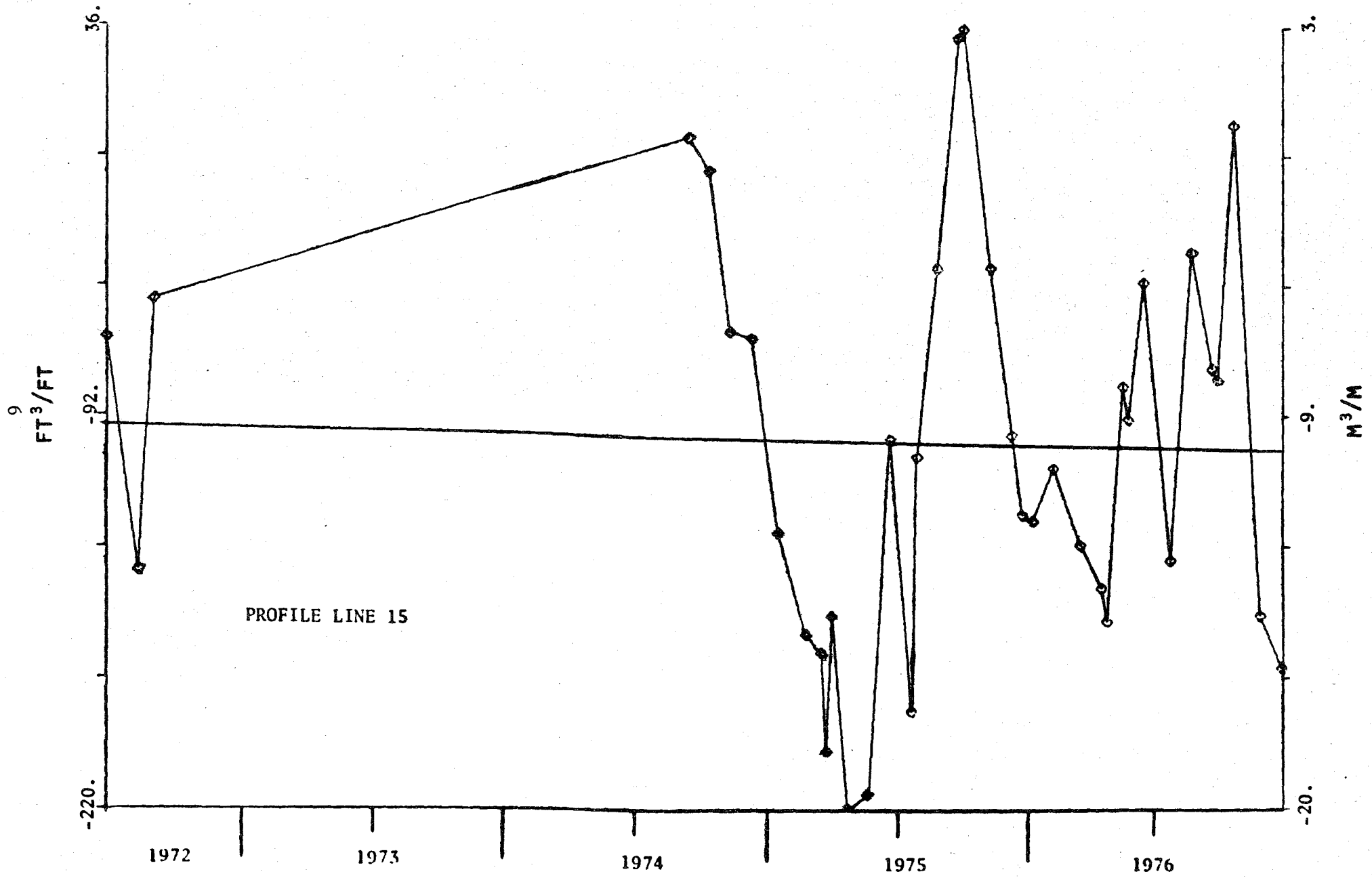
Note the gently, seaward-dipping beds in the back dunes and ripple crests oriented parallel to slopes.

Note also the profile survey monumentation and 1.2 X 2.4 m aerial target, oriented parallel with, and on the profile line.

3.4 STOP 3. Beach Profile Location No. 15 (optional)

Located at the Back Bay Refuge-False Cape State Park boundary

The beach is much wider at this location than to the north, as this is in the beginning of the accretional area



Mileage

(since 1974) caused by net longshore transport to the south from the Dam Neck-Sandbridge and northern Back Bay areas.

Historically, this is the location of Old Currituck Inlet (closed 1730). The former flood tidal delta may account for the great width of the spit in this area (approximately 1.5 km), in contrast to the Back Bay Profile 12 location (width approximately 0.5 km). A view across the island can be obtained from the top of the third dune line. Note the extensive vegetation, including a small maritime forest. A small fresh water pond is located behind the dunes, and probably owes its origin to bulldozing of a depression below the ground water level.

False Cape State Park, Virginia

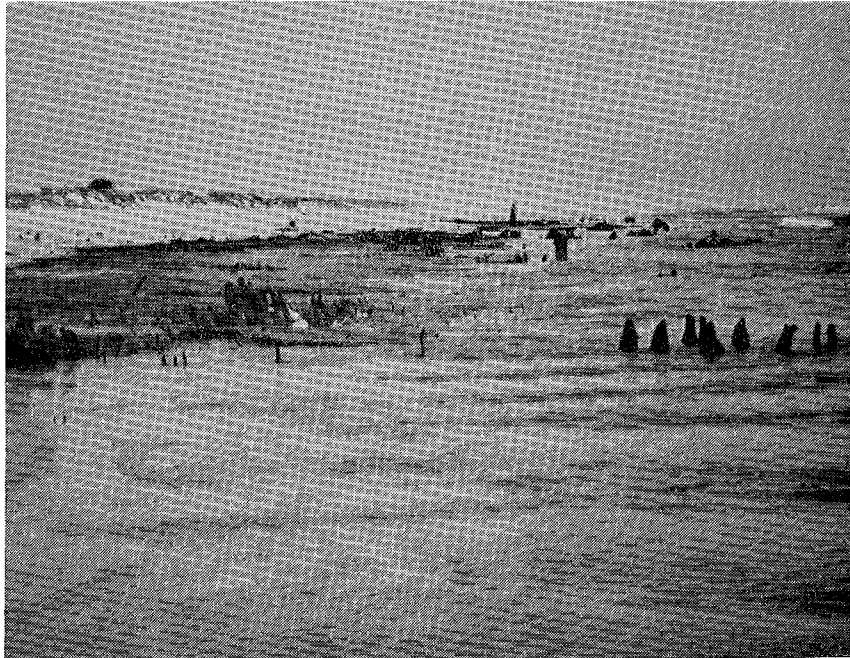
4.1 STOP 4. Stump Field and Beach Cusps

The STOP 3 description is also applicable here.

According to Swift, et al. (1971), one of these Cedar tree stumps were dated at 725 years B.P. + 70 years. However, either there may be a problem if this was the site of an old (i.e., historical) inlet, or the tree data (exact location unspecified) may be from a tree in one of the few beach areas not cut by an inlet in the last 725 years. Tree stumps extend along the beach intermittantly south to Corolla.

This was the site of Old Currituck Inlet (about 1650 to 1730) during the early history of the inlet. The inlet then migrated about 3-4 km to the south, where it finally closed.

Associated with the tree stumps is a relatively loose, fresh Spartina alterniflora peat, which extends south for several miles, as evidenced by intermittant exposures observed over the last five years. Peat thickness is less than 40 cm and contains fine sand. In some places the peat appears to overlie "lagoonal muds", and in other places,



STOP 4. Stump field at False Cape State Park, Virginia dated at 725 years BP. Photos taken in November 1975 (top) and February 10, 1977 (bottom), at times of maximum exposure. See STOP 4 discussion.

Mileage

sand, which may be the relict tidal delta. If the peat has grown up from the relict tidal delta, it would be less than 200 years old.

The mode of sand transfer to the beach during the accretional phase is not well understood on Currituck Spit, as there is an absence of ridge and runnel activity. The accretional cycle is initiated following storm erosion by an offshore bar located as shallow as about 1 m below MLW. This bar has never been observed to migrate above low water. Eventually, sand accumulates in the berm vicinity via "sheet flow" from waves at high tide. There is also some berm overwashing along with deposition and water entrapment behind the berm. However, a landward-dipping slipface has not been observed anywhere above the low tide line.

Beach cusps occur more frequently and are more pronounced in False Cape than in adjacent areas. This is one of the areas studied extensively by Sallenger (1974, and this volume), who related the initiation and spacing of the cusps to edge waves.

- | | |
|-----|---|
| 4.4 | Peat Outcrop |
| 5.2 | More Tree Stumps |
| 6.8 | Leave Beach at Pole with Red Arrow, then First Right Turn (Back North). |
| 7.6 | <u>Barbour's Hill</u> (See photos on cover) |

(Because of lack of turn-around space, it will be necessary to continue north on this road to end, then left to turn around and back to Barbour's Hill - an additional distance of 1.4 miles.)

Mileage

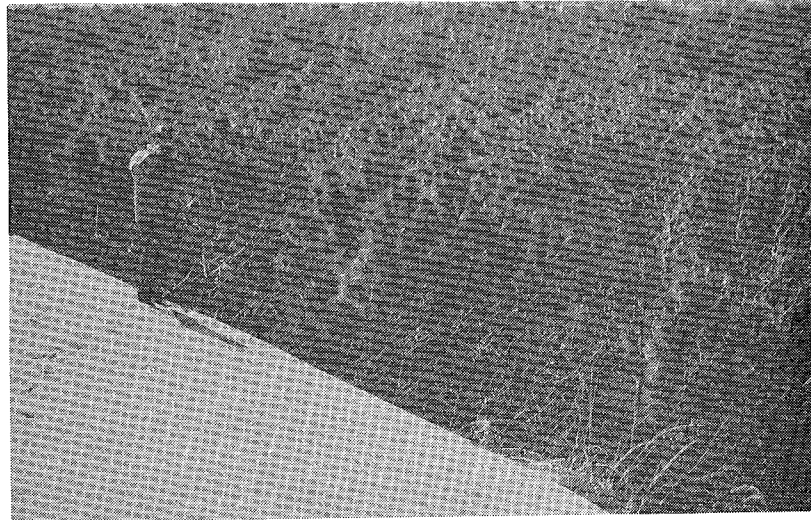
9.0 STOP 5. Barbour's Hill

At the summit of this hill you will be approximately 20 meters¹ above sea level. The slipface on the south end of the dune is about 5.5 meters high. Notice the thick vegetation, which extends from behind the continuous multiple ridge foredune system up to the base of this sand hill. This foredune and vegetation has effectively cut off the flux of wind-blown sand between the beach and the sand hill. Consequently, vegetation has been able to colonize the sand hill. This decreased amount of sand transport to the dune, and vegetation anchoring, has slowed the south-southwest march of this dune to around 1.5 meters per year. This dune, with the abundant vegetation surrounding it provides a good contrast with the sand hills to the south near Corolla. A complete discussion of these sand hills can be found in this volume in an article entitled, "Migration of Large Sand Hills, Currituck Spit" (Gutman, 1977).

¹The most recent topographic map, revised in 1954, indicates an elevation of 16.4 meters for this hill.

Return to Beach

- | | |
|------|---|
| 9.8 | Beach |
| 10.6 | Profile Location No. 17 (Raydist Pole) |
| 11.4 | Turn Off Beach at Telephone Pole With Green Sign and Orange Spray Paint |
| 11.9 | Go Left at Fork |



STOP 5. Barbour Hill slipface (top, February 10, 1977), approximately 5.5 m high and migrating at 1.5 m year (1976-1977), burying the maritime forest shown below (February, 1977).

Mileage

12.0 STOP 6. Parabolic Dunes

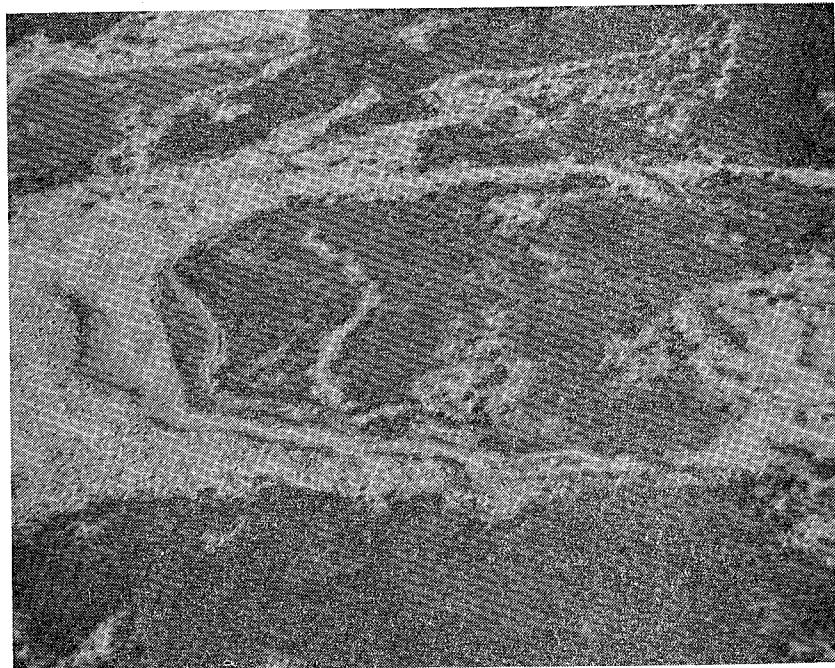
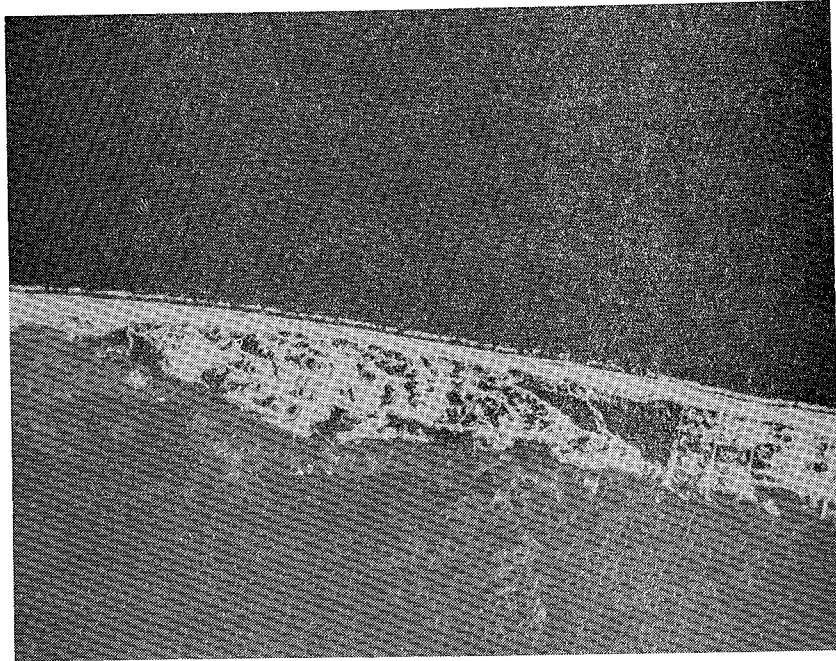
This is the northernmost extent of New Currituck Inlet, closed since 1828.

These dunes have formed since the late 1930's and have been apparent on aerial photography as parabolic dunes since the mid-1950's. Originally (1937) a sand sheet covered the spit from Ocean to Sound, but with the inception of sand fencing during the 1930's, sand supply from the beach was cut off and the sand sheet began to break up into large sand hills or medanos (1950). By 1955, these medanos were in turn becoming stabilized by vegetation and as they migrated toward the southwest, they became smaller, and eventually formed into parabolic dunes (see the discussion by Hennigar in this volume and photos on cover).

The vegetation on the slipface and in the upwind deflation zone indicate that this dune is stabilized at present. The age of trees (about 10 years) in the blowout, give a clue as to how long this dune has been quiescent.

The axis of dune orientation (i.e., azimuth of bisector of two arms) is N 9° E. The west arm of the dune is much better developed than the east arm. This may be due to the west arm of this parabolic also being the east arm of a second coalescing parabolic to the west, or to the dominance of the north-northeasterly winds due to the forest vegetation to the west. We will walk along the crest of the two parabolics and observe the active slipface on the west side, where the sand is precipitating down into the maritime forest. The orientation of these parabolic dunes is discussed by Gutman in this volume.

The internal geometry (direction and amount of dip of the beds) of the easterly parabolic dune was measured in 1975 by V. Goldsmith, P.S. Rosen, M. Boule and Y.E. Goldsmith and was plotted by E. Barnett. The most surprising aspect is that most beds have low angle dips with mean dips of 12.2°, 12.9°, 13.5° and 10.4° for all beds, the west arm, the east arm, and the south end, respectively. Also, there is a wide scatter in dip direction (Az), although most beds dip towards the sector of 60° to 160°. This is approximately 90° counterclockwise from the downward direction apparent from the surface geometry. This is probably due to the importance of the northwest winds which swept up



STOP 6. Parabolic dunes at False Cape State Park (top, NASA Infrared vertical, April 1975), and oblique closeup (bottom, March, 1976) of a parabolic at the north end (right, above) of the dune field.

PARABOLIC DUNE CROSSBEDS, FALSE CAPE, VIRGINIA

DUNE OPEN TO NNE

- + WEST ARM
- ⊞ EAST ARM
- ⊕ SOUTH END

WINDS FROM SW

WINDS FROM NW

WINDS FROM N AND NNE

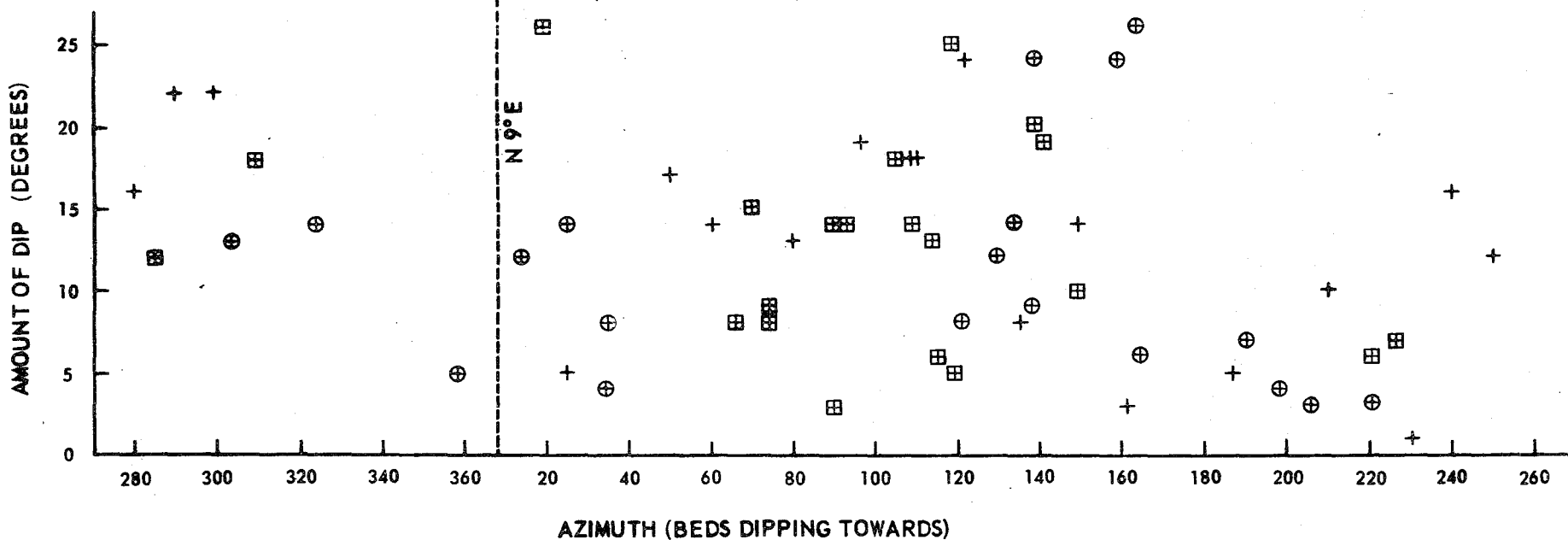


MAJOR WINDS
(BLOWING TOWARDS)

MAGNITUDE
FREQUENCY

AXIS OF DUNE ORIENTATION
(BISECTOR OF ARMS)

N 9° E



Mileage

sand in the center deflation zone, and which are most apparent in beds in the east arm, which dip primarily towards 60° to 140° . The beds in the west arm, in contrast, are evenly distributed and dip in all directions. However, the beds in the south end dip primarily towards 120° to 220° azimuth, and thus are most representative of the apparent wind direction, as interpreted from the surface geometry (i.e., the axis of dune orientation is 189° azimuth).

In summary, the internal geometry is more representative than the surface geometry of the multidirectional wind regime and is also suggestive of much back-and-forth eolian transport within individual compartments, which are isolated by vegetation. This aspect, plus the low dips typical of vegetated dunes, indicate that these parabolic dunes are closer in genesis to vegetated dunes than to transverse, medano dunes.

- 12.6 Return to Beach
- 13.0 These High (12 m above MSL) Vegetated Dunes are Location No. 12 of the Internal Geometry Studies (Rosen, et al., this volume)
- 13.2 Virginia-North Carolina State Line-Right Turn
- Currituck County, North Carolina
- 13.4 Left turn onto Main Street, Corova
- 13.7 Big Lady - Photo Stop Upon Demand
- 14.7 Display of Beach Architecture and Design
- 15.5 Continue on Down Road and Bear to Right
- 16.3 Right at Canal - You are Now on a Cattle Ranch



STOP 6-7. Virginia/North Carolina State line looking north (top, January 15, 1975) and south (bottom, October 27, 1976) illustrating contrasts between False Cape State Park, Virginia, and Corova, North Carolina.

Mileage

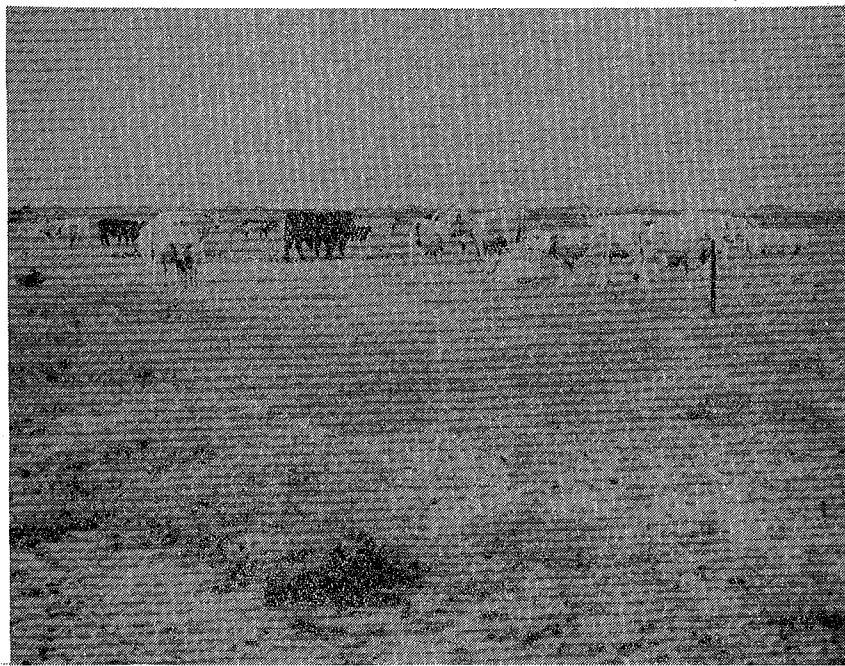
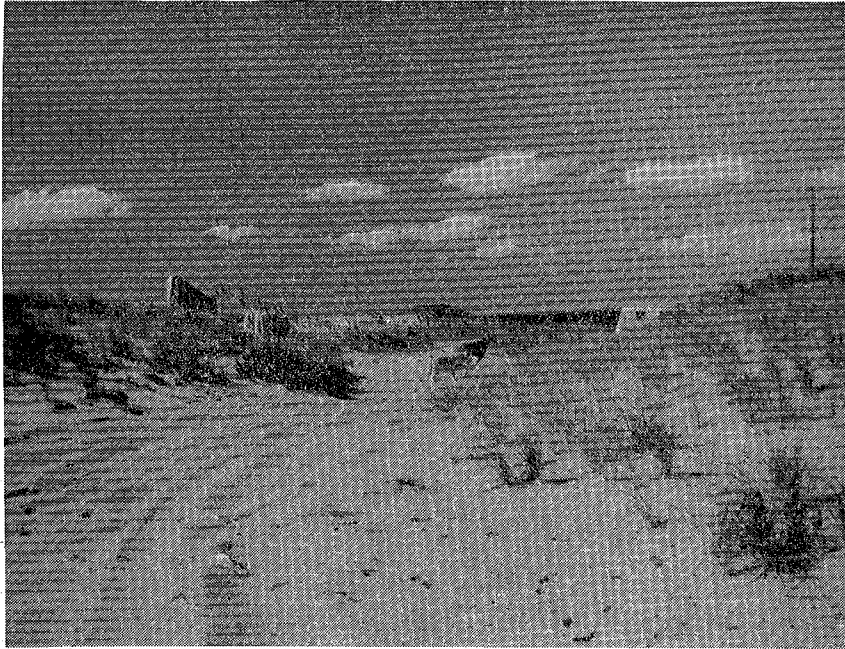
17.1 STOP 7. Fresh Water Marsh and Cattle Ranch

Ride across causeway to Knotts Island Bay (a narrow body of water between Currituck Sound and Back Bay). Those who wish to see water moccasin snakes should go first, as they will be either in the water ditches or sunning themselves on the trees. Be careful!!!

The trees are primarily cedar and maple. Live oak is found in drier areas within the ranch. This wooded swamp is probably typical of the environment represented by tree stumps on the beach between False Cape and Corolla. It is one of the few remaining areas of natural maritime forest, as other forested areas on the spit are composed of pine and live oak. The pine is probably a result of the initial plantings in the interior. Older residents of the area can recall planting much of the pine during the late 1930's.

The effects of this shift in species composition have not been determined. However, in the False Cape region 30 foot high pines have been found growing out of bare sand. It would seem that pine is eminently suitable to grow in this region. Differences in salt spray tolerance have not been measured. An interesting fact to note is that the majority of trees are evergreen and their leaves are not shed during the winter. The success of planting is probably a direct result of this as the leaves serve as obstacles to the wind and reduce wind velocities close to the ground. Consequently, sand transport is reduced.

The several hundred head of cattle on this active ranch generally stay in the low marshy areas but their tracks, etc., have been observed on the dunes. However, approximately two dozen horses have been observed most often in the dunes and on the beach. There is, of course, much controversy as to the effect of overgrazing by cattle, horses, goats (and even wild rabbits). The horses and goats have been removed from Core Banks by the National Park Service because of such fears, Hennigar (1977, and discussed in the volume) has hypothesized that the combination of overgrazing and severe storms 'unleashed' the extensive sand sheets of the 1930's through 1950's. An example of one of the few sand sheets remaining from this period will be seen at the next stop.



STOP 7. Home on the range in a sand flat on the ranch at Penney Hill, North Carolina, (bottom, September, 1976) and astray on a dune in False Cape State Park (top, October, 1976).

Mileage

As we ride through the ranch, which is a relic from another age, as it is typical of one of the main activities along the whole Outer Banks in the 1800's and early 1900's, note the absence of shrubs and the presence of stunted Live Oak. The absence of shrubs may be due to either extensive grazing or periodic flooding (perhaps from the Sound side). Note also the extensive canal network, all of which was built since 1963.

Continue on road to east through the ranch (the new feed pens are testimony that this is a presently active and expanding ranch), to the ranch headquarters, formerly Penney's Hill Coast Guard Station, and back onto beach.

18.8

Beach

The beach here continues quite wide from False Cape. The foredunes between the southern end of False Cape State Park and Penney Hill Coast Guard Station are the highest (up to 12 m at the State line) vegetated dunes along Currituck Spit. However, beginning at Penney Hill, there occur offshore-dipping, wind blown sand deposits at the seaward base of the foredunes, which become much more extensive to the south as the foredunes decrease in elevation and finally disappear all together at Lewark Hill.

Coincident with the decrease in the foredunes, the beach becomes increasingly wider. Although beach-dune interaction has been observed to be a very important process on Currituck Spit, as elsewhere, it is not yet proven that the extensive eolian deposition on this beach by the westerly winds (2/3 of the important wind components) account for the wider beach in this area. (See the historical shoreline changes in this area, Fig. 2 in Sutton & Haywood this volume)

20.4

Shipwreck

Mileage

21.4 STOP 8. Seagull (Town Abandoned) and Remnant Sand Sheet

(Stop at circular foredune, highest along this portion of the beach, and gaze westward)

This is the only active sand sheet left since the 1930's, when all the area encompassed on this trip was an active sand sheet. This area was also extensively overwashed in 1962. All that is left within the sand sheet area is one house and several cattle pens.

Historically, this was the site of the New Currituck Inlet which closed between 1828-1830. The extensive width of the inlet (about 2.5 km) may have partly affected the subsequent history of this vicinity.

West of the sand sheet is a shrub and small maritime forest. Further west is a very extensive marsh, which owes its origin to the former inlet flood tidal delta and to the subsequent overwashing.

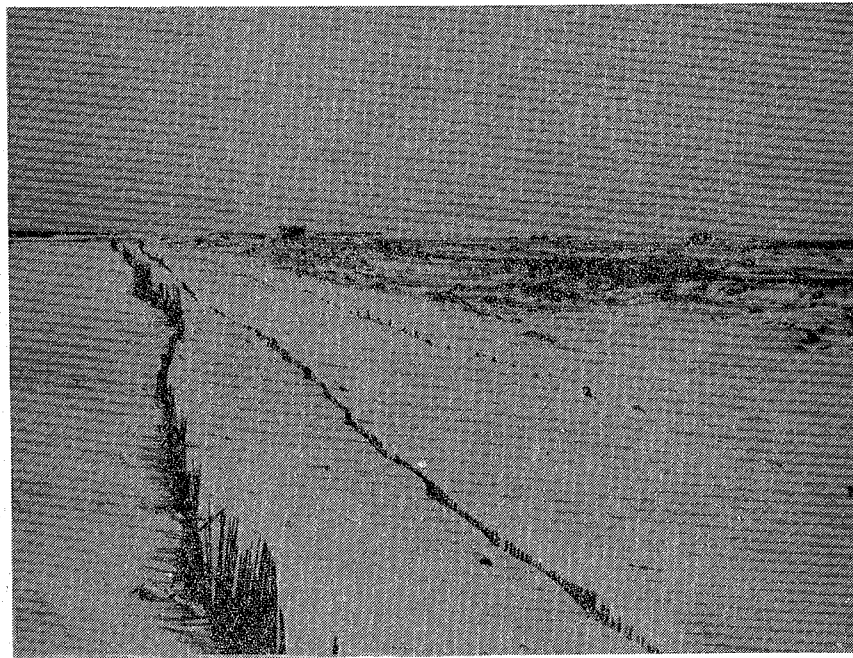
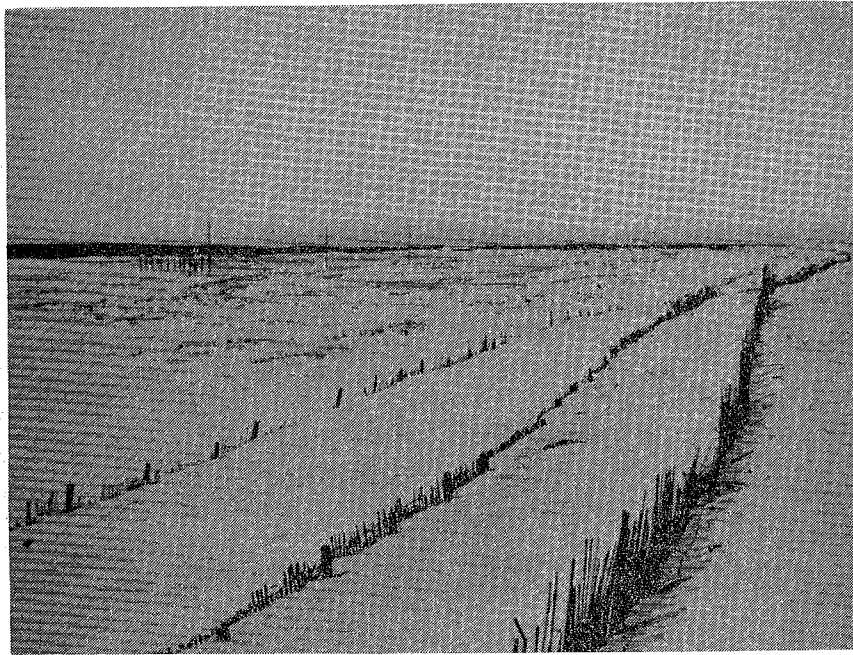
Note the sand fencing, which is enplaced randomly, in time and space, all along the spit by the developers when money is available or when it is required by local need (i.e., gaps in the dunes, or new houses needing protection).

To the south of this stop, a slipface becomes quite apparent on the seaward side of the AID foredune, despite of, or because of, the sand fencing.

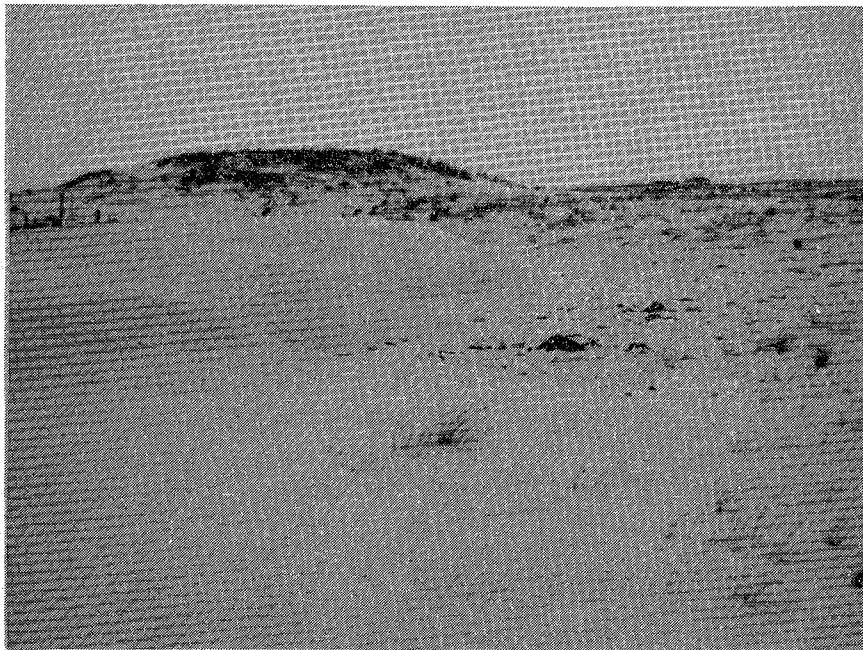
23.1 More Tree Stumps

23.6 STOP 9. Lewark Hill Medaño

This is estimated to be the second highest hill (i.e., medaño) for the east coast of the United States south of Long Island. (The highest dune is probably Jockey's Ridge in Kitty Hawk, North Carolina, 70 km to the south.) This is a presently active and dynamic dune. Monthly overflights



STOP 8a. Remnant sand sheet, Sea Gull, North Carolina, with views of sand-fenced foredune looking north (top, March, 1977) and south (bottom, March 1977) from same location. Sand fencing is in general very effective at trapping the sand, but without stabilizing vegetation the sand is not held in place (see Figure STOP 8b).



STOP 8b. Views on either side of the foredune at Sea Gull, North Carolina shown in Figure STOP 8a. The importance of both westerly winds blowing sand on the beach (top, March, 1977), and easterly winds blowing sand inland (bottom, August 1976), across this foredune is illustrated.

Mileage

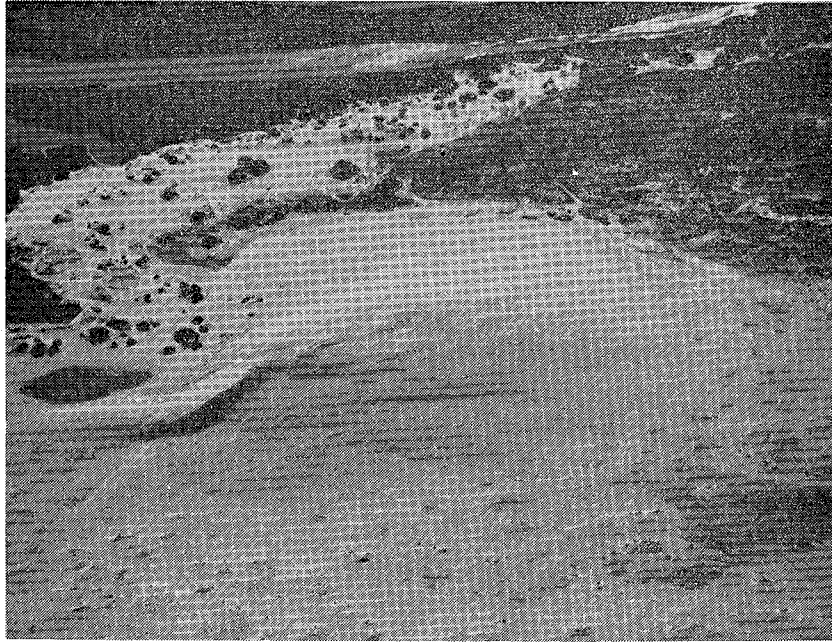
made during the 1974-1976 interval indicated dramatic differences in the surface morphology on a monthly time scale. Although the slipface is dominantly on the southwest side of the dune, a second slipface often develops on the east side in response to either northwest or southwest winds. The higher than average occurrence of westerly winds (i.e., lack of northeasters) during the past year, resulted in a very apparent slipface on the seaward side of the dune. The dominant bedform of sediment transport is in the form of sand waves about 1 m in height and 20-40 m wavelengths. (Sediment transport actually occurs primarily by saltation.) These eolian sand waves only appear during high velocity wind conditions and quickly dissipate with decreasing wind velocity. Thus, the upper surface of the dune is quite dynamic, with much back-and-forth motion of sand.

A major question, therefore, is how much net movement in one direction (e.g., towards the southwest) actually occurs. Relative to total transport, there is probably very little net transport, due to the wind regime. Thus, the cause of the large height is the movement of sand from the three major wind directions, which results in the upward build up, and in this rather distinctive sand hill shape, defined here as a medaño.

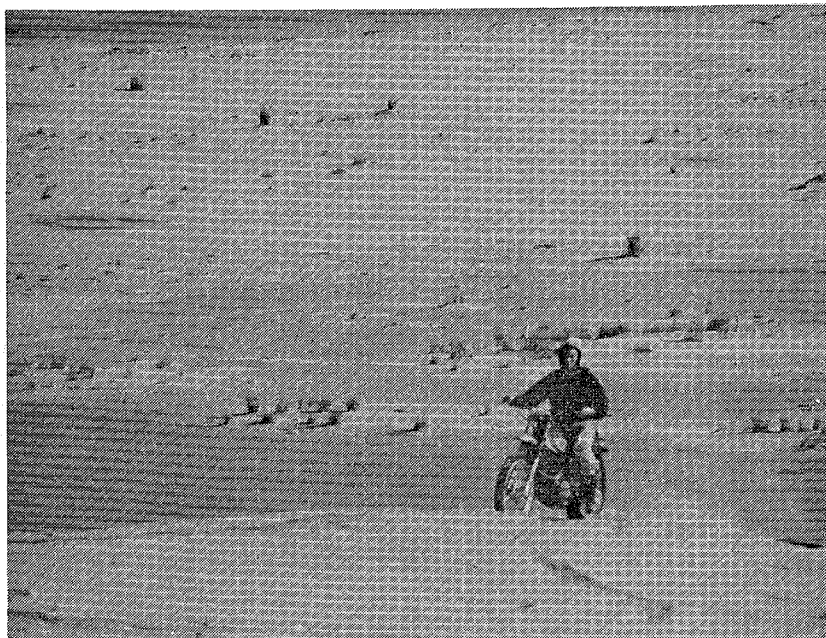
Historically, this is the southern end of New Currituck Inlet, closed since 1828.

From the top of the dune, the following features may be clearly seen:

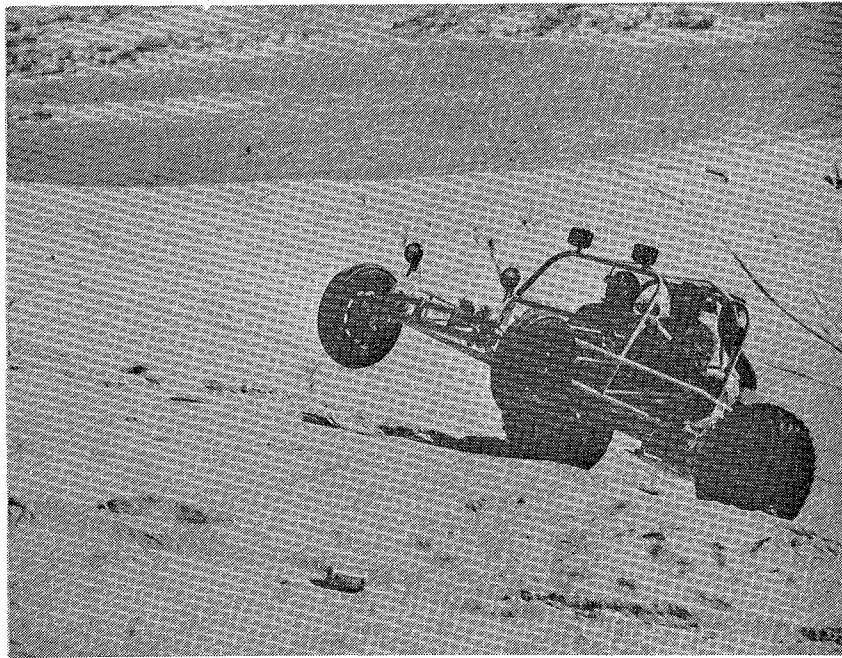
- (a) Relict sand sheet to the north
- (b) Extensive marsh on top of the relict flood tidal delta (west)
- (c) Old tidal channels being buried by eolian deposition (west)
- (d) The spit recurves into the Bay, marked by lines of vegetation (southwest)
- (e) Evil Kneivel and his cohorts racing up the slipface (southwest)
- (f) Extensive former overwash plain (south)
- (g) The lack of a foredune between Lewark Hill and the beach, which greatly aids in the dune-beach interaction. This may be due to the large amount of vehicles traversing this area between the beach and Lewark Hill every weekend.



STOP 9a. Lewarks Hill looking northwest on April 5, 1976 (top) and February 12, 1976 (bottom) illustrating the rapid temporal variations in the surface morphology due to the polymodal directional wind regime. Note the development of the slipface on the east side (top) and the eolian-formed sand waves (bottom) following periods of high winds.



STOP 9b. Overgrazing as a cause of devegetation and migrating dunes (top, March, 1877) has been largely replaced by increased horsepower, off-road recreational vehicles (bottom, November 16, 1975). Notice the total absence of vegetation of a foredune between this medaño (Lewark Hill) and the beach, probably caused by the dozens of vehicles which visit this sand hill each weekend.



STOP 9c. More off-road vehicles at Lewark Hill, North Carolina. Note the deleterious effects to the vegetation (See Figure STOP 9b caption).

Mileage

L U N C H

24.2

More Cut Tree Stumps

24.8

STOP 16.

Overwash

This will be the last stop of the trip, on the way back from Dare County, North Carolina, to Back Bay.

This is the approximate southern extent of New Currituck Inlet (closed 1828).

Aerial photography from 1940 reveals that this area has been extensively overwashed. Subsequently, vegetation recolonized the flats. The area was again overwashed during the early 1950's and during the 1962 Ash Wednesday storm. At the present time, only one narrow channel remains, and aerial overflights indicate that this is occupied mostly from the Sound (west) side. Extensive sand flats are exposed on the south side at low tide from the former overwashing.

Algal mats are beginning to form in the supratidal area. Note also the small (< 1 m), shallow (< 15 cm) depressions present at the throat of the overwash on the Sound side. They are caused by feral hogs, rooting in the sand for clams and other molluscs.

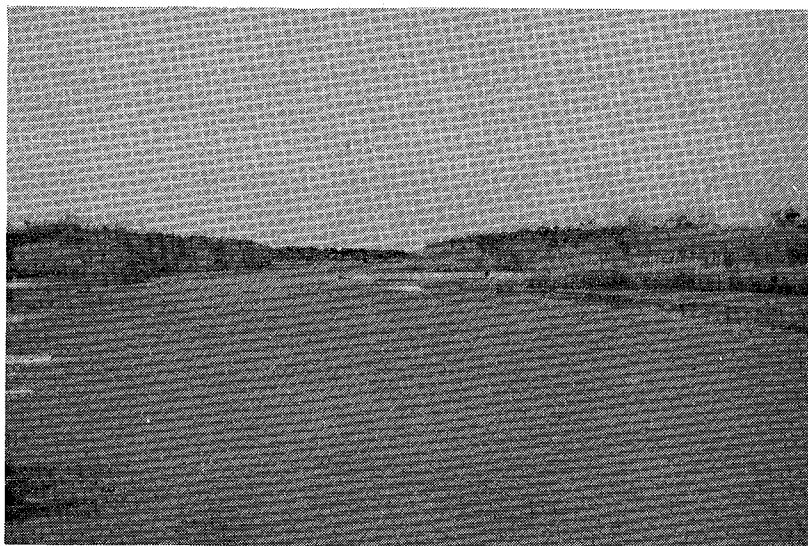
Presently, this portion of the spit would be a prime area for a new inlet.

27.1

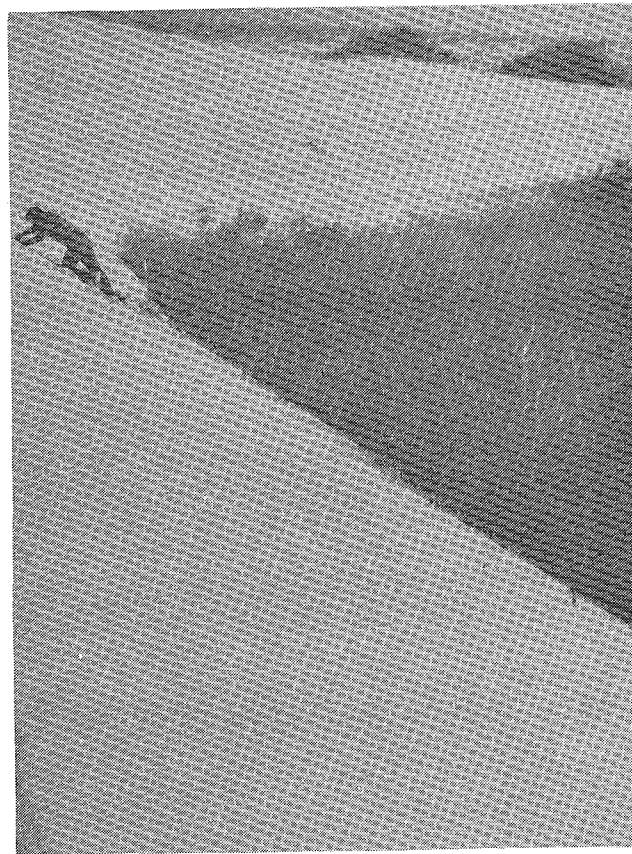
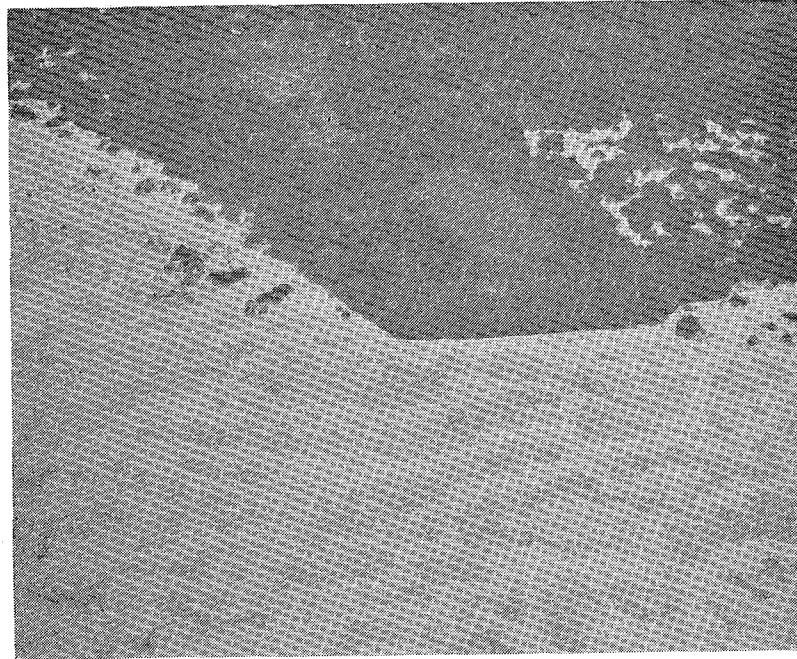
STOP 10.
(optional)

Jones Hill - Will be Viewed and
Discussed from Lighthouse

This medaño has migrated approximately 410 meters in 35 years, for an average of 13 meters per year. The people



STOP 16. Last active, overwash on Currituck Spit, located five Km north of Corolla, North Carolina. Aerial view looking west toward Currituck Sound (top, March, 1976), and ground view looking east through the throat to the beach (bottom, June, 1976). This area was extensively overwashed as recently as 1962.



STOP 10. Jones Hill slipface illustrated by oblique aerial looking southwest (above, October 27, 1976) and ground view looking east (below, December 3, 1974). Note the two distinct slipfaces forming an obtuse angle, typical of many of these medanos.

Mileage

of Corolla deposit their garbage at the slipface and let the sand bury it for them (discussed in this volume).

27.6 Corolla Exit on Currituck Spit
Expressway

28.1 STOP 11. Currituck Lighthouse 46m above
MSL)

Camera stop. Climb to the double balcony at the top (which should provide plenty of room), where a vast panorama awaits.

The anemometer was installed by A. Gutman in January, 1976, and has since provided a continuous record of the local winds in this area (summarized in this volume).

Features to be Observed from the Top of the Lighthouse:

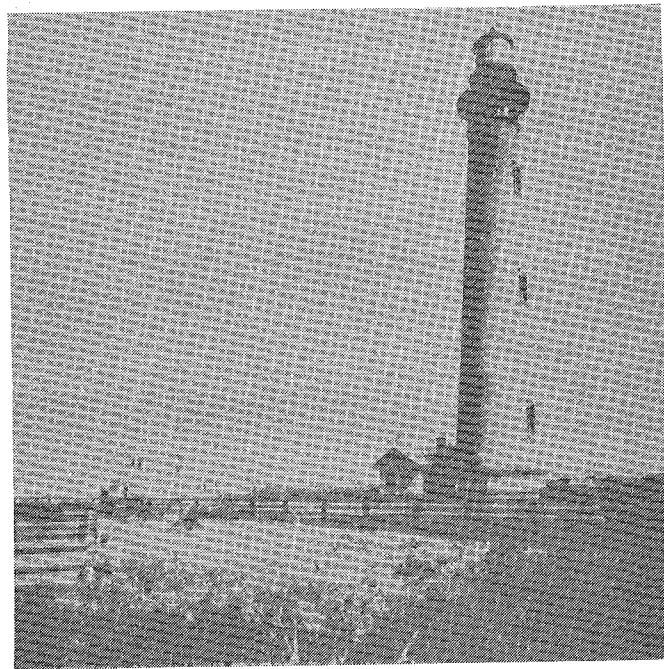
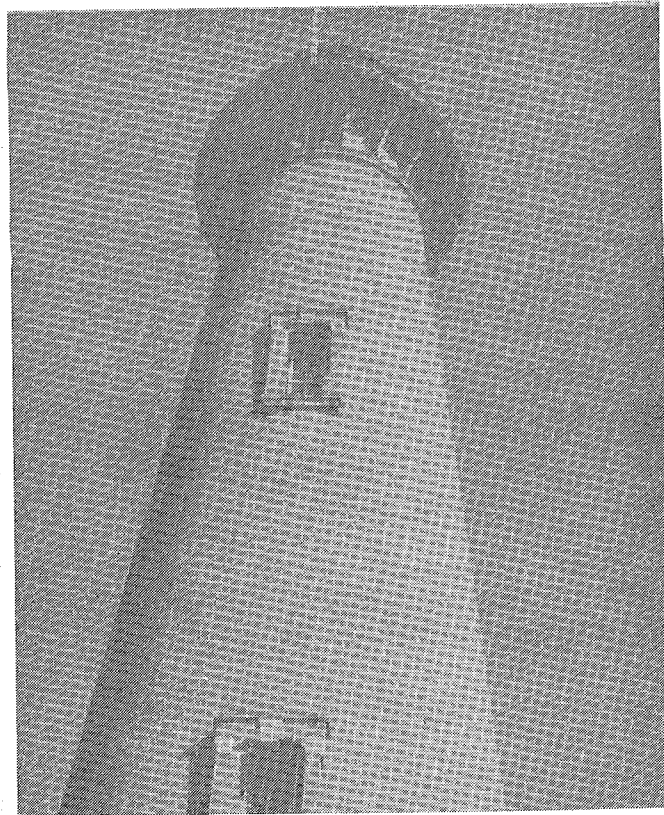
West - Currituck Sound

The large two story building you see was constructed by William Knight during the late 1920's for his child bride at a cost of more than half a million dollars. The dwelling is surrounded by a moat and is one of the few buildings in North America which has one. Both died within two years of each other and the building, along with 6,000 acres, was sold in 1937 for \$25,000. Subsequently, it was used as a school by the people of Corolla. It ceased to function in the early 1960's and presently remains empty.

North

Downtown Corolla

Jones Hill Medaño covering the former main road into Corolla.



STOP 11. Views of Currituck Light House at Corolla, North Carolina, in February 12, 1977 (top) showing anemometer, and June 14, 1889 (bottom). The area that was pastureland for the light house keeper's fresh meat supply, was bare sand in the 1940's, is now being naturally revegetated.

Mileage

East

In the 1890's, there was a fenced-in lawn with grazing animals and close-cropped grass, extending from the Light House to approximately halfway to the beach.

The foredune here is maintained by fencing.

South

En échelon transverse dunes (or medaños), all with slipfaces on the southwest sides.

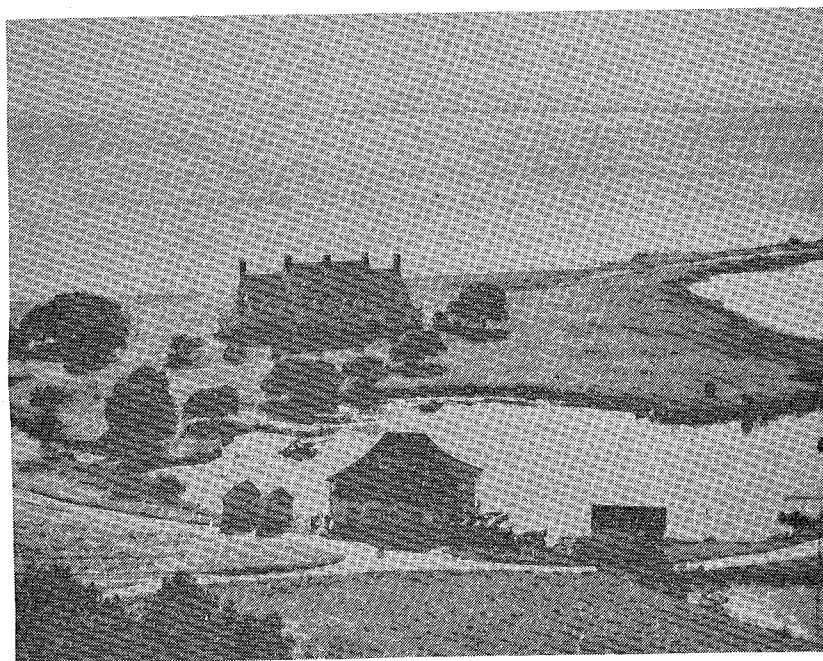
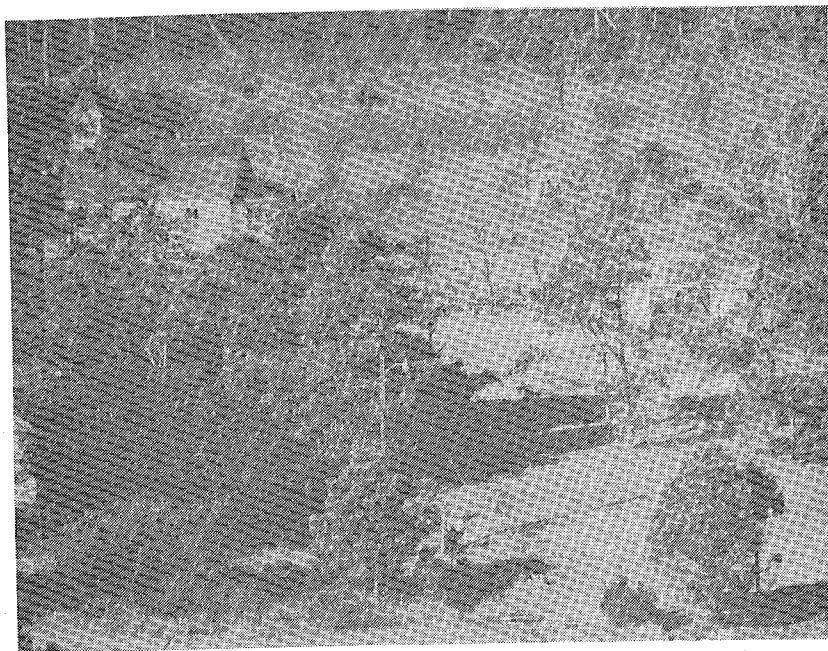
Whalehead Hill, the next stop, is the first dune. The northern end of the privately paved road represents the northern extent of development in this area.

The barrier-spit narrows to the south. The point of widening in the distance is the former site of Caffey's Inlet. This narrow area would have high potential for new inlets, but for the foredune maintained by bulldozing of sand up from the beach.

28.5 STOP 12. Downtown Corolla

Drinks and postcards

Note the red, one-room schoolhouse and old church.



STOP 12. Views from Currituck Light House looking southwest (bottom, May, 1976) at the William Knight House and across Currituck Sound; and looking north (top, February 12, 1977) at downtown Corolla at Church and post office.

Mileage

30.0 STOP 13. Whalehead Hill Medaño and Whalehead Development

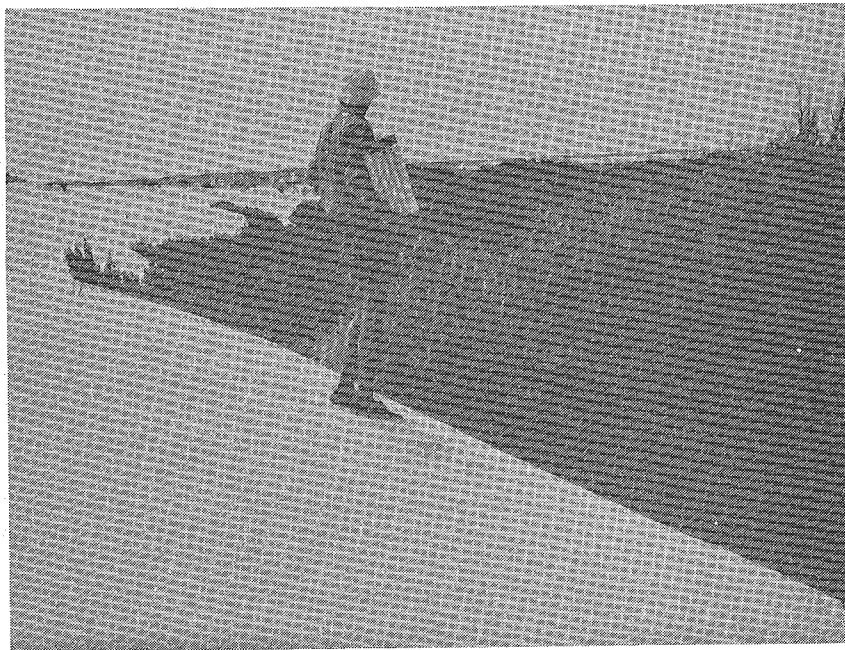
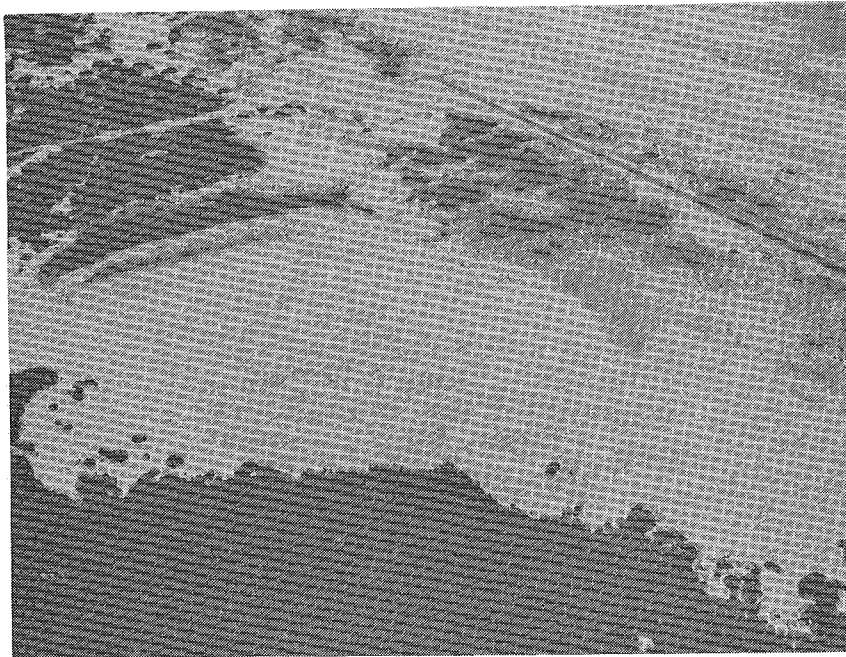
A. Dune Processes

Whalehead Hill, the first in a line of 10 dunes, is very similar in processes and dimensions to the other nine sand hills, all of which can be viewed looking south from the lighthouse. This description is then basically applicable to all the sand hills. Whalehead Hill is about 20 meters high with a 5.5 meter high slipface. Notice, in comparison to Barbour's Hill to the north, there is much less vegetation, and a lower foredune to the east of the sand hill. Unlike Barbour's Hill, there is a flux of wind-blown sand between the beach and Whalehead Hill. Due to this sand drifting, thick vegetation has not been able to colonize the aeolian flat or sand hill. Because these sand hills are still at least partially attached to their source of sand, and there is no anchoring vegetation, Whalehead Hill is migrating to the south-southwest about 6 meters per year, a much faster rate than Barbour's Hill.

Notice the old dirt road that has been covered in the last year by this advance. Twenty years ago these dunes were moving up to 10 meters per year due to the complete absence of vegetation and foredunes in the area. The east flank of Whalehead Hill showed a net lateral accretion of 9 m between 3/76 and 3/77, and thus, may prove a threat to the new (1975) road, 100 m farther to the east. A complete discussion of this sand hill is found in an article in this volume entitled, "Migration of Large Sand Hills, Currituck Spit" (Gutman, 1977).

B. Development

This is the first of two contrasting developments. The area of the Whalehead Development, owned by Kabler and Riggs, in Virginia Beach, is indicated by the privately constructed road running parallel and close to the beach. During construction in 1975 much destruction of vegetation by the road building equipment was observed. Note that there is no attempt to follow the land contours and that the road interferes with the normal beach-dune interaction.



STOP 13a. Whalehead Hill Medano looking southwest (top, October 27, 1976) and southeast (bottom, August, 1975). The slipface, 5.5 m high, has migrated 6 m/year to the south-southwest (1976-1977). Compare with Barbour Hill (STOP 5). Note the north end of the privately-owned, paved road (top).



STOP 13b. Privately-owned, paved road of Whalehead Development looking north (top, February, 1976) and ground view of road looking south (bottom, March, 1977). The series of transverse dunes are reasserting their natural geomorphic form under the effects of the westernly winds, resulting in extensive deposition on the road traversing the dunes.

Mileage

During times of high winds this road is frequently covered by wind-blown sand. Also, the road was built much too close to the beach.

Observations indicate that the main method of AID'ing the foredune at present is by bulldozing of sand up from the beach into the dune gaps. Sand fencing is also very extensive in this area. Our studies indicate that little of such sand stays in place and is usually removed within months. Sand fencing was also employed prior to road construction, but we have not observed any fencing or planting program since road construction.

Most of this area, seaward of the large sand hills is topographically low, and lacks protection from the low foredune. Real estate maps of plots appear to indicate that lots are for sale on some of the migrating medaño dunes, which may result in "mobile homes".

There is a new development plan for Currituck County, which is attempting to encourage well-planned developments. However, its effectiveness is the source of some controversy, and unfortunately can only be judged on a post facto basis.

31.0

Road is frequently covered by wind-blown sand at approximately this location, as it cuts through the trailing edge of the medaño dune.

Note the imbricated trailer.

The bunkers on the west side of the road are from the 1950's when several hundred people were employed here at a government installation.

32.6

Road bends west. Last access onto beach until CERC Research Pier at Duck. Approximately 0.5 miles south of this bend is the north boundary of the Ocean Sands Development, which is marked by a central sewage treatment plant.

Mileage

35.7 Turn left into "cluster" development

35.9 STOP 14. "Treacherous Red Sands", Narrow
Beaches, and Ocean Sands Development

A. Processes and Sediments

The foredunes here are higher than to the north, a result of intensive efforts of fencing and plantings since the 1930's. Coincident with the heightened foredunes, the beaches here are narrower and coarser; both of which increases to the south. Dolan, Godfrey, and others have suggested that there is a direct relation between the artificially heightened and stabilized foredunes along the Outer Banks, and a subsequent narrowing and coarsening of the adjacent beaches. This, they attribute to a concentration of wave energy in an ever narrowing beach zone resulting from a rise in sea level and restrictions on overwash activity. They suggest that overwashing maintains the barrier island during transgressions by causing the barrier to migrate landward.

However, although there are areas along Currituck Spit which have overwashed into the Sound (e.g., Back Bay area in 1962), the widest parts of the barrier-spit appear to be related to old inlets and their associated flood tidal delta deposits.

Since Currituck Spit has displayed both types of features in the past (though neither occur at present), the audience is invited to critically view these features and form their own opinion.

The source of the coarse red sandy-gravel (discussed by Farrell in this volume) is unknown. This sediment is highly anomalous with respect to the associated beach sands. It forms a surface deposit of highly variable extent from Duck as far north as Corolla. Extrapolating the studies of Riggs and O'Connor (1974) in the Roanoke Island area, to this area, it is

Mileage

hypothesized that the "treacherous red sands" are a former river channel deposit, underlying the present barrier-spit, which is now being excavated on the shoreface by the present transgression. This was also suggested by Shideler and Swift (1972, p. 175). These sediments are then being moved onshore, and sporadically alongshore to the north, by the waves.

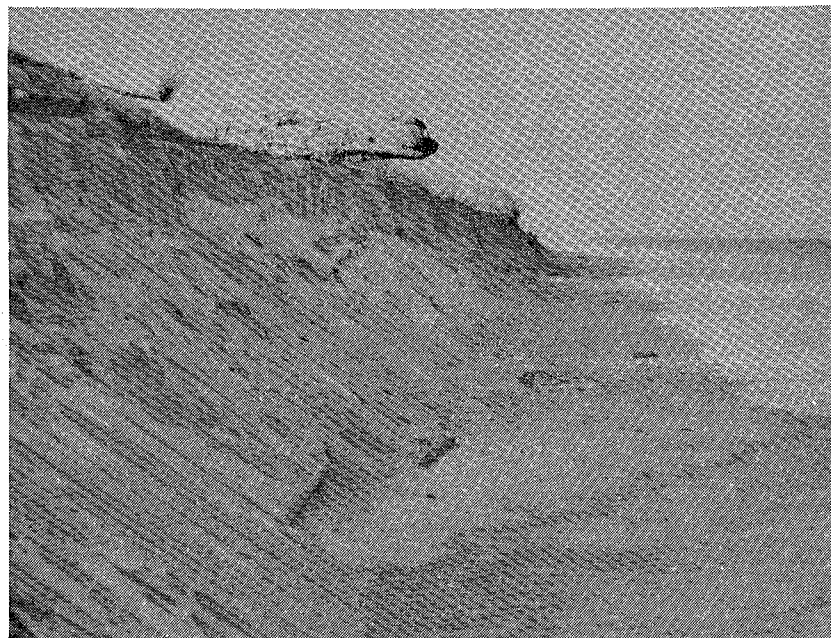
Monitoring of these sediments over a two year period (1974-1976) show no relation between beach slope and the presence of these coarse sediments (discussed in this volume).

B. Ocean Sands Development

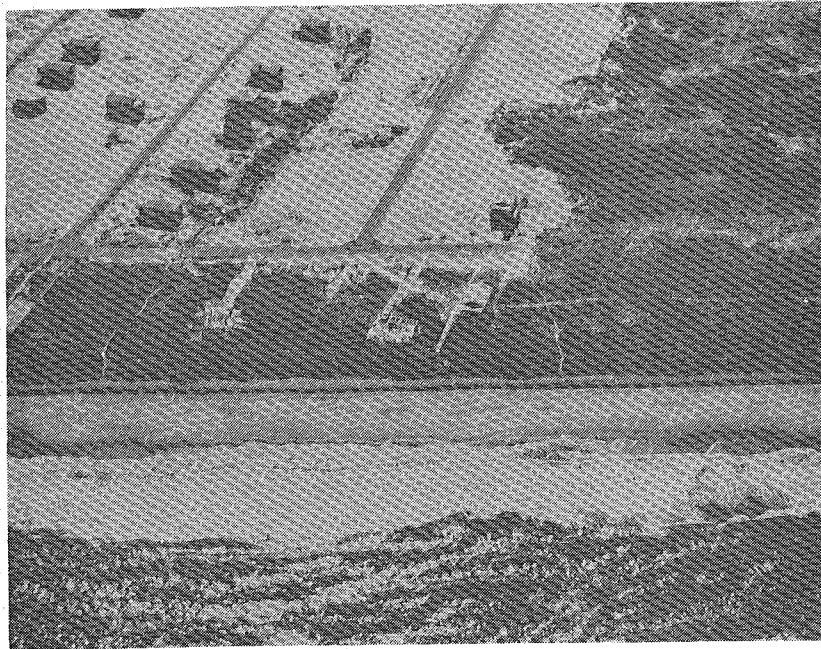
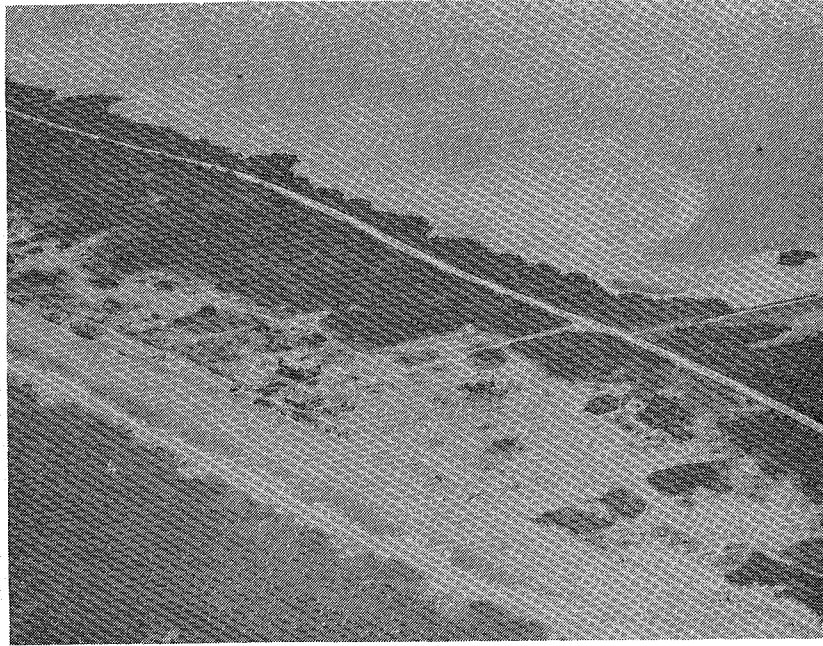
In contrast to Whalehead Development to the north, there is no road paralleling the beach. Instead, there are cluster developments (i.e., cul-de-sacs) with 'trident-shaped' road networks open to the beach and ending behind the foredune, and which are connected by a single road to the main road network within the interior.

The following information relating to Ocean sands was provided by Mr. Doug Douglas, Tidewater director of Coastline Development, which is selling these house lots, and therefore, should be read within that context. This unverified information is presented for information purposes only, because of interest with respect to natural processes:

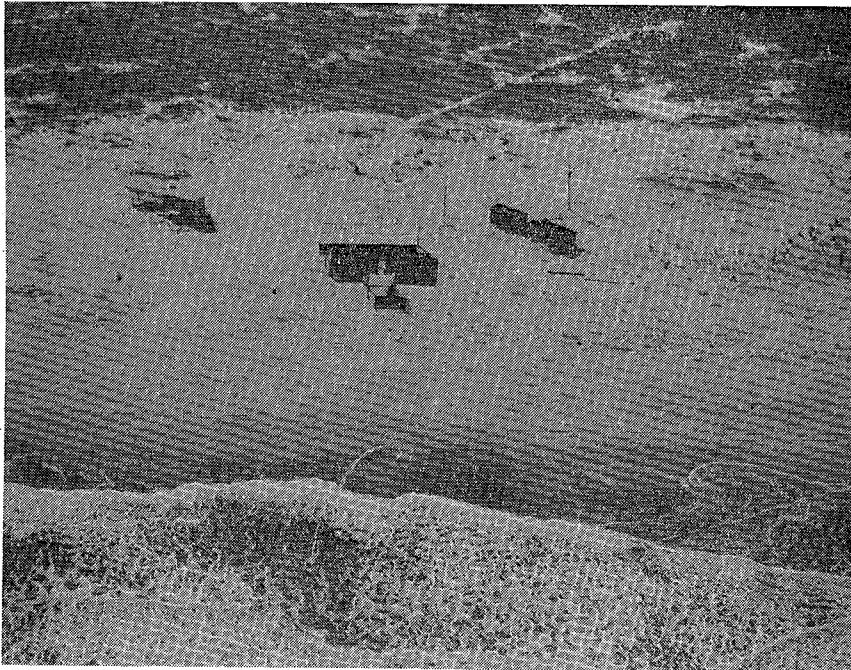
1. House lots cost between \$13,000 and \$55,000 per lot, which average between 60 X 100 ft. and 80 X 150 ft. in size.
2. The area including the "primary dune", between the house lots on the land side and the high tide line (the extent of private ownership in North Carolina), is owned in common by all those along the 3.5 miles of beach encompassed within the development.
3. Direct access to the beach by vehicles along this 3.5 mile stretch of beach is prohibited. However, the foredune is under constant attack by week-enders, who like to see how steep a slope their vehicles can climb.



STOP 14 a. About 10 Km south of Corolla the foredune becomes higher and narrower, and scarped due to beach narrowing and steepening. Aerial view looking north (top, October 5, 1976) and ground view (bottom, November 4, 1975).



STOP 14b. Aerial views of the closed Caffey's Inlet, North Carolina (top, May 4, 1976), one of the narrowest portions of Currituck Spit, and Duck, North Carolina vicinity (bottom) April 5, 1976) illustrating the dramatic effects of development in altering the natural dune ecosystem.



STOP 14c. Contrast the lack of foredune in the aerial view of False Cape profile location number 15 (top) with the artificially-induced foredune (AID) at Ocracoke Island, North Carolina (bottom, November 11, 1972).

Mileage

4. There are central water and central sewage systems, built by the development, and then given to the county to operate. All electrical and telephone cables have been placed underground.
5. Ocean Sands Development adjoins a 6,000 acre game refuge (Pine Island, Currituck Gun Club, etc.), and so much of this area will be left "undisturbed".

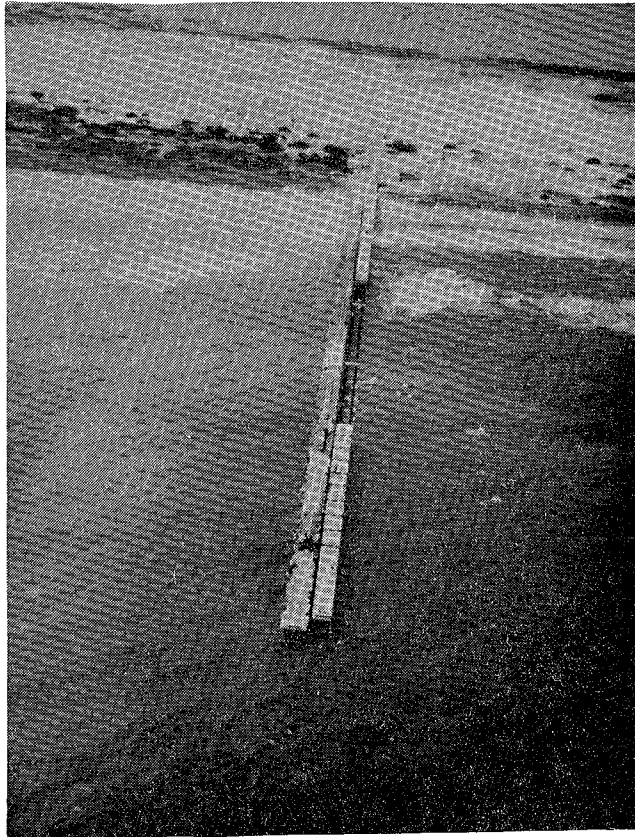
Continue south on main road pass guardhouse controlling access to Ocean Sands and Whalehead Developments.

Dare County, North Carolina

44.2 STOP 15. C.E.R.C. Research Pier Facility at
(optional) Duck, North Carolina.

"CERC's Field Research Facility, currently under construction at Duck, North Carolina, will provide a permanent field base of operations for physical and biological studies of the site, the sound behind the site, and nearby barrier islands, bays, and offshore (ocean) areas. The 1,800-foot pier will provide a rigid platform from the land across the dunes, beach, and surf out to a 20-foot water depth. Continuous data on coastal phenomena (waves, currents, tides, and beach changes) can be measured across the full length of the surf zone during all weather conditions including severe storms. The ensuing information will directly result in improved designs for restoration and protection of eroded beaches and fragile coastal areas.

In addition to the 1,800-foot concrete pier, the facility will include an instrumented research vehicle, a laboratory building, as well as a 3,300-foot section of the barrier island. Built at an approximate



STOP 15. C.E.R.C. Research Pier Facility at Duck, North Carolina (October 5, 1976). The construction pier, to the left (south) is removed after the research pier (right) is constructed.

Mileage

cost of \$6 million, construction of the pier will be completed during mid-1977.²

²From The Quarterly CERCircular, V. 2, No. 2, p. 4.

R E F R E S H M E N T S

Return (north) on beach with intermediate stop at Overwash (located 16.8 miles north of C.E.R.C. Research Pier, 2.8 miles north of Corolla turnoff, and 1.0 mile south of Lewark Hill).

80.2

Back Bay Refuge Parking Lot

REFERENCES

- Dolan, D.R., Godfrey, P.J., Odum, W.E., 1973. Man's Impact on the Barrier Islands of North Carolina, in *American Scientist*, Vol. 61, March-April 1973, p. 152-162.
- Goldsmith, V., Sturm, S., Thomas, G., 1977. Variations in Beach Erosion and Accretion Trends at Virginia Beach, Virginia, and Vicinity: Final Report CERC Contract DACW-72-C-0008 and CERC Tech. Memo No. (in press), C.E.R.C., U.S. Army Corps of Engs., Ft. Belvoir, Virginia; VIMS SRAMSOE No. 122.
- Riggs, S.R., O'Connor, M.P., 1974. Relict Sediment Deposits in a Major Transgression Coastal System, Sea Grant Publication, UNC-SG-74-04, North Carolina State University, Raleigh, N.C., 37 p.
- Sallenger, A.H., 1974. Mechanics of Beach Cusp Formation, Unpublished Ph.D. Thesis, VIMS, Gloucester Point, Va., 214 p.
- Shideler, G.L., and Swift, D.J.P., 1972. Seismic Reconnaissance on Post-Miocene Deposits, Middle Atlantic Continental Shelf-Cape Henry, Virginia to Cape Hatteras, North Carolina, *Marine Geology*, Vol. 12, p. 165-185.
- Swift, D.J.P., Sanford, R.B., Dill, C.E., Jr., and Avignone, N.F., 1971. Textural differentiation on the Shoreface During Erosional Retreat of an Unconsolidated Coast, Cape Henry to Cape Hatteras, Western North Atlantic Shelf, *Sedimentology*, Vol. 16, p. 221-250.

CONTRIBUTIONS

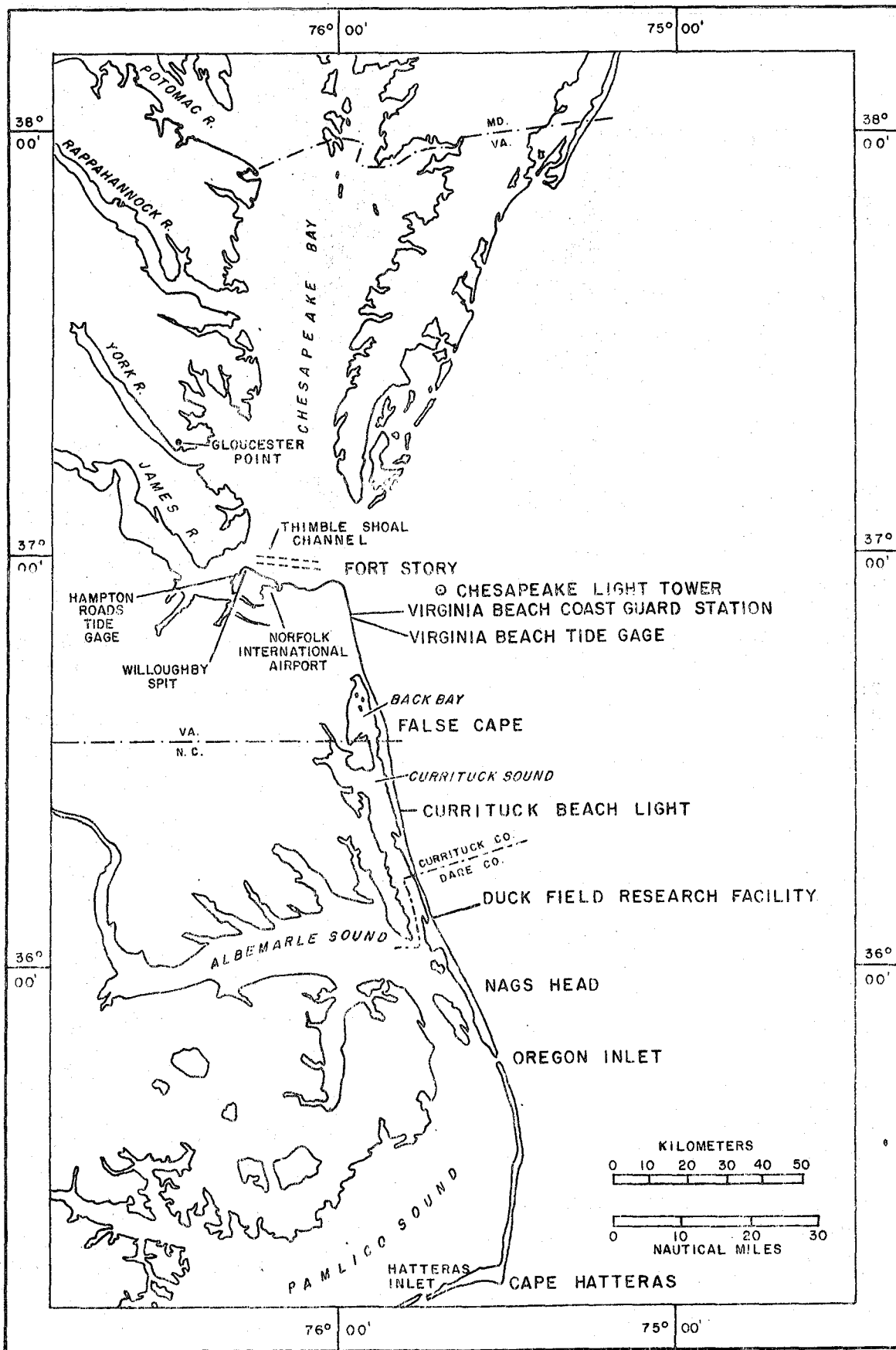


Figure 1. Regional location map of study area.

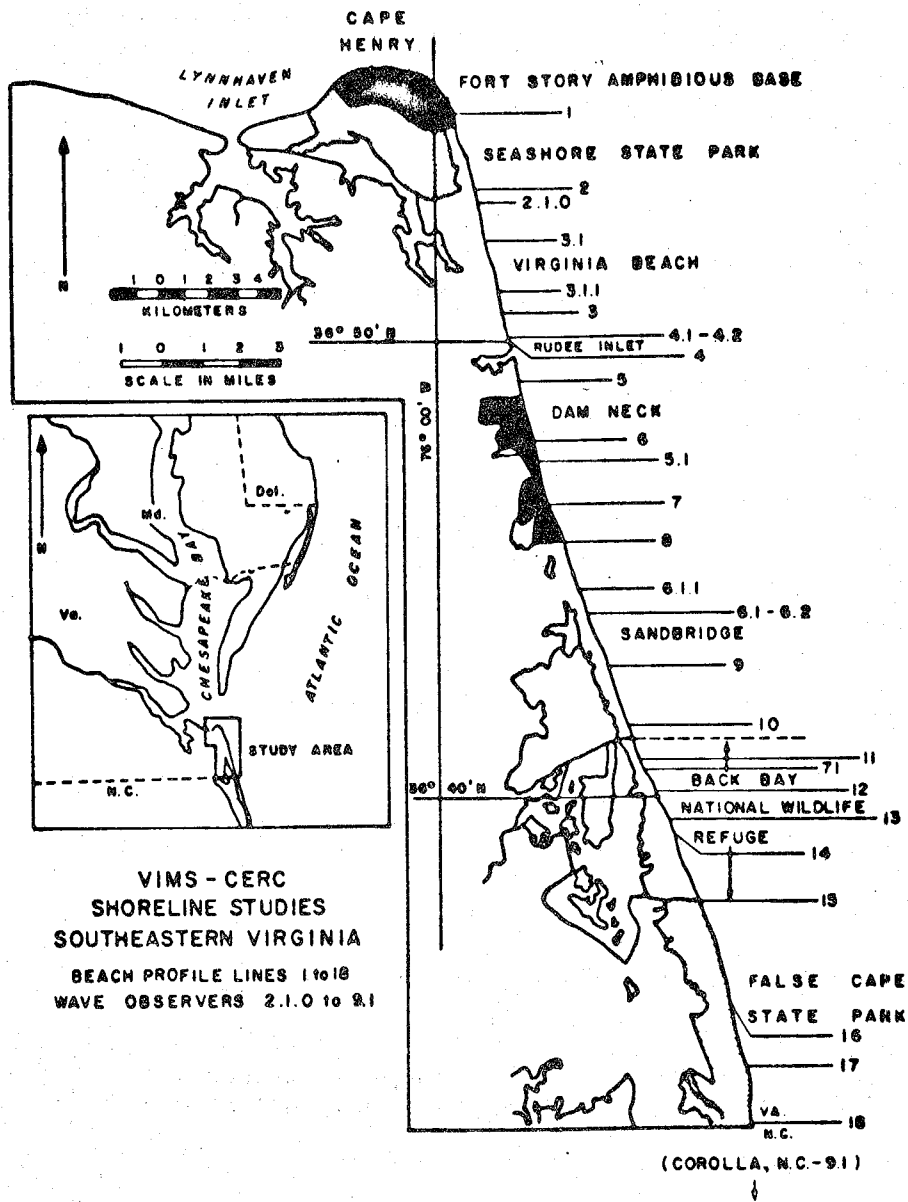


Figure 2. Location map of profile lines, wave observation sites, and areas of varying beach usage.

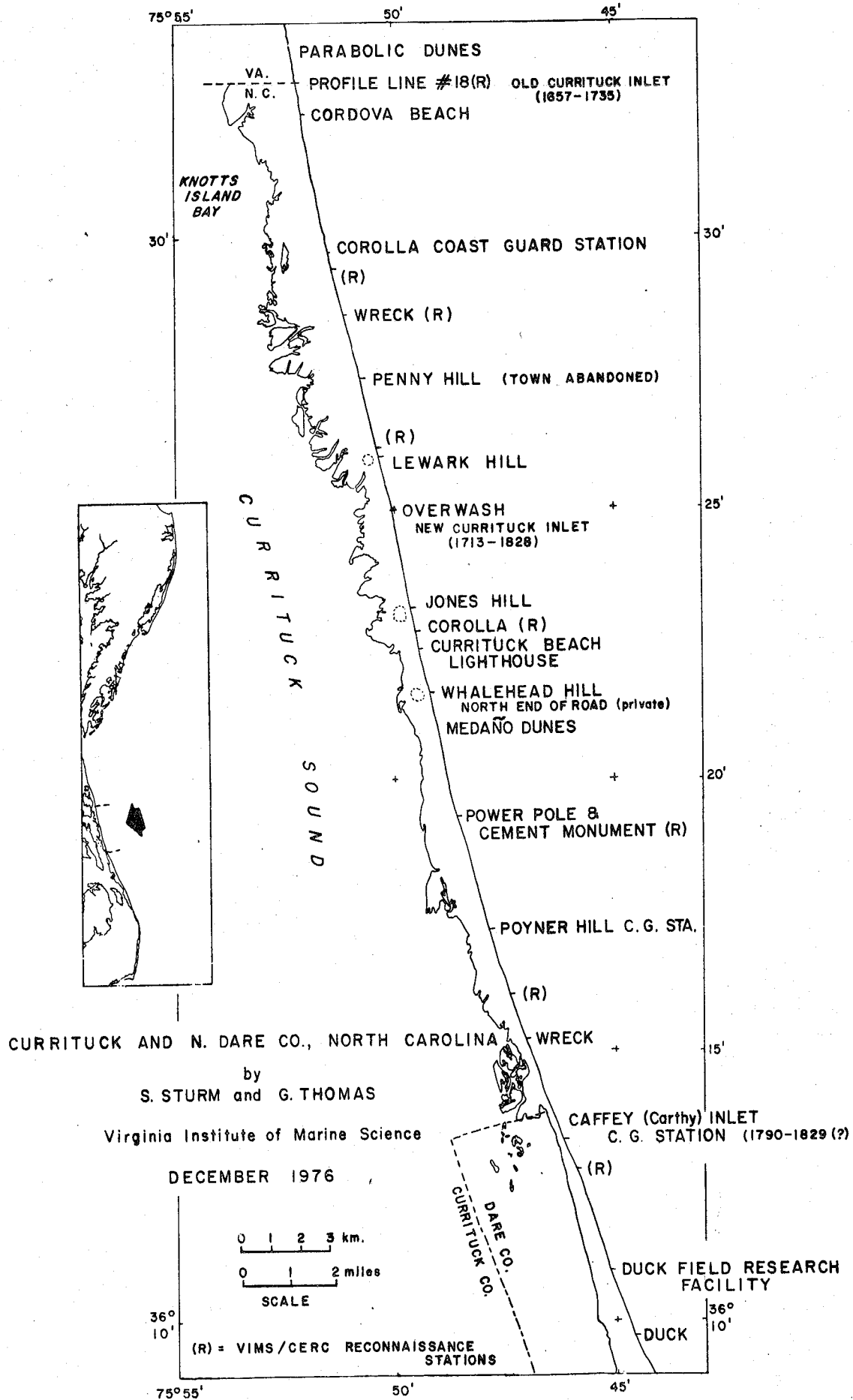


Figure 3. Map of Currituck County, North Carolina.

FROM: MAP OF VIRGINIA & MARYLAND
WITH PART OF PENNSYLVANIA,
NEW JERSEY & NORTH CARO-
LINA.

J. FRY & P. JEFFERSON
1775

FROM: MAP OF THE
UNITED STATES
IN NORTH AMERICA
ACCORDING TO THE
TREATY OF 1783

T. CADELL
1783

FROM: SURVEY OF THE SEA COAST FROM
AND INLAND NAVIGATION

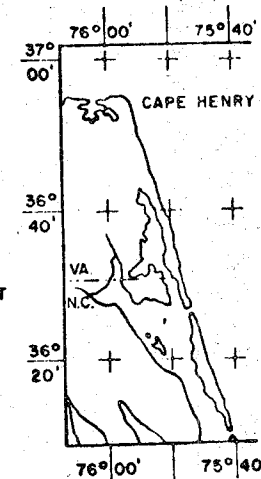
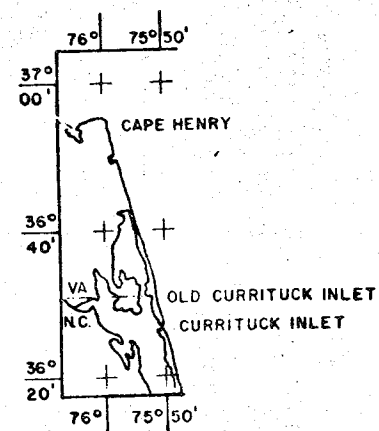
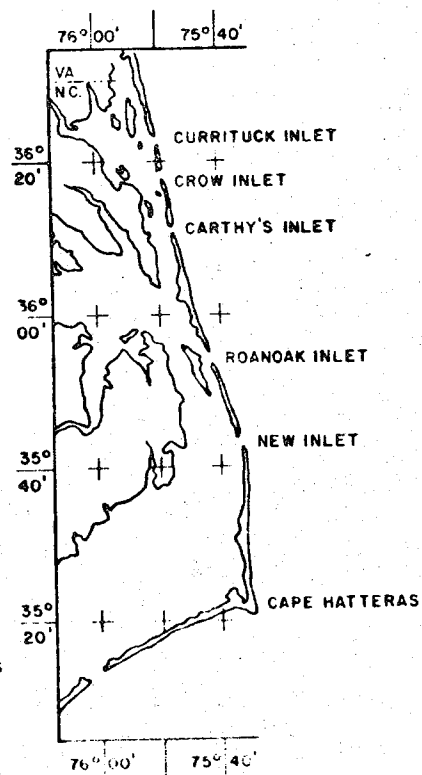
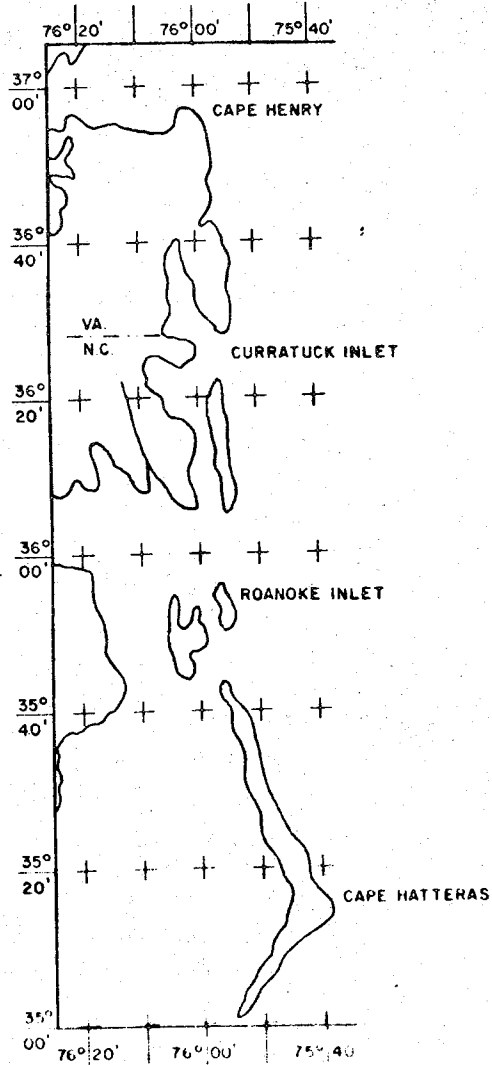
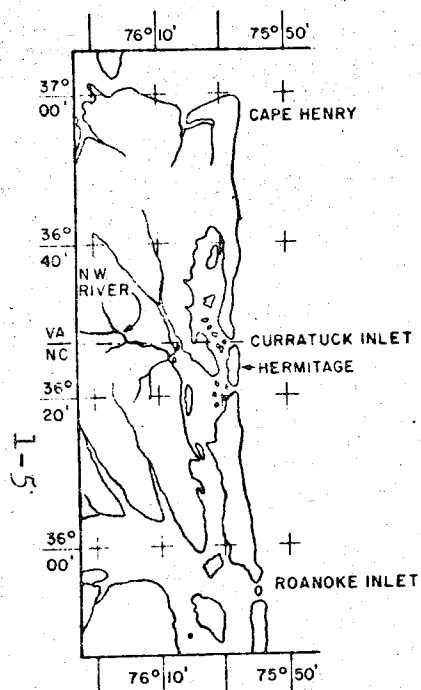
PRICE & STROTHER
1798

MAP OF VIRGINIA &
NORTH CAROLINA COAST

H. BOYE
1826

FROM: MAP OF INTERNAL
IMPROVEMENTS
OF VIRGINIA

C. CROZET
1848



Thus, the study area encompassed by this volume includes the 80 kilometer stretch of coast from Cape Henry at the Chesapeake Bay entrance to the C.E.R.C. Research Facility at Duck, 42 kilometers south of the Virginia-North Carolina State line. However, the area visited on the field trip (and discussed in the STOP descriptions) includes only the area between Back Bay Wildlife Refuge (13 kilometers north of the state line) and Duck, a total shoreline distance of about 50 kilometers.

A literature review of geological and coastal studies is notable by a lack of previous information in the 50 kilometer stretch of coastline visited on this trip. However, there have been several pertinent studies in the two flanking areas, and these shall be briefly reviewed. The physiography and geology, both immediately underlying the study area and at the surface to the west, are directly related to the six or more Pliocene(?) and Pleistocene cycles of emergence and submergence, with maximum submergent sea levels near +45 feet (14 meters) (Oaks and Coch, 1973). The Sandbridge Formation, the youngest Pleistocene (Oaks and Coch, 1973), was observed after storms in the intertidal zone at 44th Street, Virginia Beach. Other aspects of coastal plain geology are discussed by Sanford (1912), Wentworth (1930), Cederstrom (1941), Richards (1950), and the early literature is summarized by Ruhle (1965). Harrison, et al. (1965) presents evidence for a late Pleistocene uplift in the area. Pleistocene sea level changes are discussed by Milliman and Emery (1968) and Oaks and Coch (1963). Holocene geomorphology and stratigraphy at the Chesapeake Bay entrance are detailed by Meisburger (1972) and Nelson (1972), who discussed the relationships between the ancestral Pleistocene Susquehanna River and the present bay mouth configuration. Meisburger (1972) indicates the present gross bottom morphology in the Bay entrance is largely due to Holocene sedimentation (estimated at 1.37×10^9 cubic meters) and bears little relation to the buried Pleistocene topography. Ludwick has made extensive studies of tidal deposition and transport in the Chesapeake Bay entrance (Ludwick, 1974). Hicks (1973) has calculated a 20 cm rise in sea level at Hampton Roads between 1930 and 1970 (Fig. 5).

The Holocene evolution of a part of the Hatteras barrier island chain has been discussed by Pierce and Colquhoun (1970a, 1970b). Based on subsurface core information from Duck, North Carolina to Cape Lookout, North

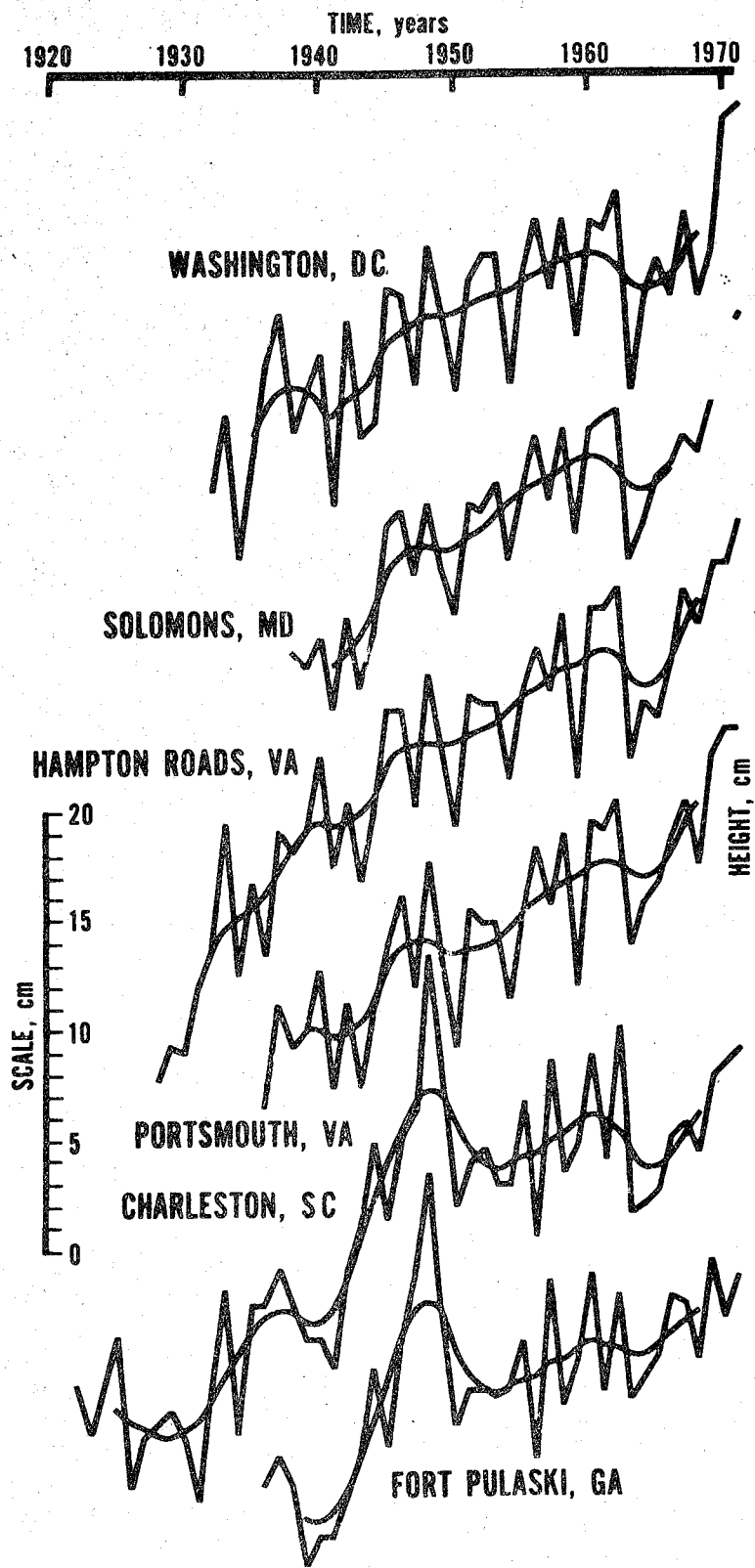


Fig. 5. Historical sea level changes at Hampton Roads, Virginia (from Hicks, 1973).

Carolina, they suggest this present barrier complex has evolved from a combination of primary barrier landward retreat and the development of secondary barriers by spit elongation. White (1966) has suggested these capes formed initially from Pleistocene River deltas.

Since the study area encompasses wide variations in shore usage, this aspect will be discussed in some detail. Table 1 gives a complete description of the study area as given in the U.S. ARMY CORPS OF ENGINEERS "Shore Protection Guidelines", National Shoreline Study, Washington, D.C., August 1971. Names mentioned in Table 1 can be found in Figures 1 and 2. The information is reorganized in the table by reaches and subjects; these reaches are related to population zonation of the coast and not to geological aspects.

The beach survey study area, which includes the 18 profile line locations, encompasses 42 kilometers of coast in Virginia from Cape Henry to the Virginia-North Carolina State line (Fig. 2). Profile line 1 is located at Fort Story, a U.S. Army transportation training center with amphibious vehicles frequently on the beach. Profile lines 2 to 5 are in Virginia Beach, a densely populated (especially during the summer months) residential (above 40th Street and south of Rudee Inlet) and commercial area. Profile lines 6, 7, and 8 are located in Dam Neck, at the U.S. Naval Anti-Air Warfare Training Center. Profile lines 9 and 10 are in Sandbridge, a residential area which has a significantly higher population during the summer months. Back Bay National Wildlife Refuge is the location of Profile lines 11 to 15. The southernmost Profile lines 16, 17, and 18 are located in False Cape State Park.

In a broad sense the study area consists of two basic beach morphology types: wide beaches which may be very active, both accretionally and erosionally from one month to the next; and fairly narrow beaches with little overall accretion or erosion. The wider beaches have lower slope gradients than the narrower beaches. Generally, the narrower beaches tend to show more extensive changes after storms and are usually slower to recover from storm effects. Profile lines 1 and 14 to 18 are generally wide and flat; Profile lines 3 to 12 tend to be narrow and steep, although there are several exceptions. All 629 beach profile surveys (1974 to 1976) are notable by a complete absence of classic ridge and runnel activity.

Table 1. Description of study area (from U.S. Army Corps of Engineers, 1971).

<u>Reach</u>	<u>VINS-CERC profile lines</u>	<u>Physical characteristics</u>	<u>Shore ownership</u>	<u>Shore use and development</u>	<u>Shore history</u>
Willoughby Spit to Cape Henry	None	Characterized by an irregular dune line with a beach width varying from 100 to 125 feet at an average elevation of about 5 feet mean sea level (MSL). The dune elevation is generally about 12 feet MSL.	Encompasses two military reservations--Little Creek Amphibious Base and Fort Story, the Seashore State Park, and the commercial beach of Ocean View. Of the shoreline composing Ocean View, 4 miles are owned privately and 5 miles publicly.	Used extensively for public and private recreation. Several miles of nonrecreational shoreline are devoted to the Little Creek Amphibious Base. Segments of this reach near the western tip have, of necessity, been stabilized with timber groins.	West of Cape Henry to Little Creek, the shoreline has shown alternate periods of erosion and accretion with the overall trend being one of gradual accretion. Between 1891 and 1916 the 4.8-mile section of shoreline between Lynnhaven Inlet and Little Creek eroded at an average rate of 12 feet per year. Since then, the overall trend has been one of gradual accretion. Based on complete shoreline surveys of the 4.9-mile reach between the lighthouse and Lynnhaven Inlet, made in 1962, and the 4.8 miles of beach between Lynnhaven Inlet and Little Creek, made in 1946, the average annual rate of accretion was 1.98 cubic feet, which is equivalent to slightly more than 100,000 cubic yards per year. The 11-mile segment of shoreline from Little Creek Inlet to Willoughby Spit has been relatively static to change in recent years. Erosion has removed material from this reach during storm periods, but natural return has usually occurred. Transport west of Cape Henry to Willoughby Spit is westerly. Rates in this zone are moderate to small. No information on transport west of Willoughby is available.
Cape Henry to 49th Street	1 2	Characterized by an irregular dune line.	The 2.7-mile segment between 49th Street and 89th Street, known as North Virginia Beach, is centered about 3 miles south of Cape Henry and is publicly owned. Fort Story extends along the Atlantic Ocean for about 1.1 miles from 89th Street to a point opposite Cape Henry Lighthouse which is the south point of Chesapeake Bay.	The stretch of shore north of Rudee Inlet to Fort Story is publicly used for recreational purposes. In 1970, the annual visitation at the Virginia Beach commercial areas was 4,320,000 persons. Development is residential and commercial.	Material placed to rebuild the Atlantic Ocean shoreline at Sandbridge, Virginia Beach proper, and North Virginia Beach after the 6-8 March 1962 storm has continued to erode at rates comparable to those experienced historically. Except for a few segments of beach accreting, there has been a general recession of the entire shoreline. Based on the latest complete survey of 1968 for the segment from the State line to the Cape Henry Lighthouse, the 27.0 miles of beach front along the Atlantic Ocean was undergoing an average annual rate of erosion of 0.72 cubic foot, which is equivalent to approximately 100,000 cubic yards per year.

Table 1. Description of study area.--Continued

<u>Reach</u>	<u>VIMS-CERC profile lines</u>	<u>Physical characteristics</u>	<u>Shore ownership</u>	<u>Shore use and development</u>	<u>Shore history</u>
Rudee Inlet to Dam Neck/Sandbridge Boundary	5	The beach narrows and is separated from the mainland by low dunes. Beach grasses have been planted along sections of this segment in an attempt to stabilize the sands.	Largely occupied by the U.S. Anti-Air Warfare Training Center at Dam Neck. A segment of publicly owned beach does, however, exist immediately south of Rudee Inlet.	Development is primarily military.	See Cape Henry to 49th Street Shore History.
	6				
	7				
	8				
Dam Neck/Sandbridge Boundary to North Carolina line	9	Narrow undeveloped barrier strip of land with a sandy beach facing the Atlantic Ocean on one side and several bays on the other extends a distance of 9 miles before approaching the rapidly developing commercial area of Sandbridge Beach. This relatively undisturbed segment varies in width from 0.25 to 1.5 miles and is frequently breached by both sound and ocean waters during storm periods. Access to this area is limited to vehicles capable of traveling on sand since no paved roads exist.	The 12 miles of beach is divided among Federal, public, and private interests. Sandbridge Beach, a segment of 3 miles, is publicly owned.	The shoreline south of Sandbridge is generally undeveloped and publicly used for recreation. The Back Bay National Wildlife Refuge and the Little Island Municipal Park are located in this segment. Sandbridge Beach is privately used for recreational purposes and developed for summer residence. Summer residential development south of Sandbridge is expected to continue. Some additional development as parks and conservation areas is likely.	Observations indicate that south of False Cape, an area approximately 25 miles south of Cape Henry, the transport is southerly. North of False Cape, the transport has a net northerly component. The rate and volume of transport in this zone are relatively large.
	10				
	11				
	12				
	13				
	14				
	15				
	16				
	17				
	18				

(From U.S. Army Corps of Engineers, 1971)

Table 1. Description of study area.--Continued

<u>Reach</u>	<u>VIMS-CERC profile lines</u>	<u>Physical characteristics</u>	<u>Shore ownership</u>	<u>Shore use and development</u>	<u>Shore history</u>
49th Street to Rudee Inlet	3	From Rudee Inlet to Cape Henry, a dis- tance of 7 miles, is a flat, unstable sandy beach, 100 to 200 feet wide and averaging 5 feet MSL in elevation. The 3.3 miles of shoreline between 49th Street and Rudee Inlet is devoid of dunes.	The 3.3 miles of beach between 49th Street and Rudee Inlet is publicly owned and consti- tutes the most significant ocean front area of Virginia Beach, in terms of mass recreational use and commercial development.	The segment of shore north of Rudee Inlet to Fort Story is publicly used for recreational pur- poses. Two piers and a boardwalk have been constructed for public use. In 1970, the annual visitation at the Virginia Beach commercial area was 4,320,000 persons. Development is residential and commercial. This segment of beach is visited annually by more tourists than any commercial beach in Virginia.	See Cape Henry to 49th Street Shore History.
	4				

The beach continues in a relatively "natural" state from Back Bay Refuge, Virginia to Corolla, North Carolina (i.e., Currituck Beach Light). However, south of Corolla, developmental pressures are beginning to be manifest in the form of new roads and houses. Although these are just beginning in the area between Corolla and Duck, the area to the south is a relatively settled and densely populated summer resident and tourist community.

In general, there appears little relationship between shore use (enumerated here) and beach processes. There is, however, a strong relationship between coastal dune dynamics and development and shore use (i.e., via the buildup of the foredunes by fencing and grass plantings).

This volume discusses the beach and eolian processes, and the resulting depositional environments. Since all these areas, even the so-called natural areas, bear the imprint of people, these aspects are explored in some detail, so as to be better able to separate out the natural.

REFERENCES

- Cederstrom, D.J., 1941. Ground-Water Resources of the Southeastern Virginia Coastal Plain, Circular 1, Virginia Conservation Commission, Richmond, Va.
- Dunbar, 1968. Historical Geography of the Outer Banks, LSU Press, Baton Rouge, La., 113 p.
- Fisher, J.J., 1967. Development Pattern of Relict Beach Ridges, Outer Banks Barrier Chain, N.C., Ph. D. thesis, University of North Carolina, Chapel Hill, N.C.
- Harrison, W., Malloy, R.J., Rusnak, G.A. and Terasmae, J., 1965. Possible Late Pleistocene Uplift, Chesapeake Bay Entrance, Journal of Geology, Vol. 73, pp. 201-229.
- Hicks, S., 1973. Trends and Variability of Yearly Mean Sea Level, 1893-1971. N.O.A.A. Tech. Memo. No. 12.
- Ludwick, J.C., 1974. Tidal Currents and Zig-Zag Shoals in a Wide Estuary Entrance. Geological Society of American Bulletin, Vol. 85, pp. 717-726.
- Meisburger, E.P., 1972. Geomorphology and Sediments of the Chesapeake Bay Entrance, Technical Memorandum 38, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Washington, D.C.
- Milliman, J.D. and Emery, K.O., 1968. Sea Levels During the Past 35,000 Years, Science, Vol. 162, p. 1121.
- Nelson, E.G., 1972. Holocene Sedimentary Facies in Chesapeake Bay Entrance, Abstract, Geological Society of America Annual Meeting.
- Oaks, R.Q., Jr. and Coch, N.K., 1963. Pleistocene Sea Levels, Southeastern Virginia, Science, Vol. 140, pp. 979-983.
- Oaks, R.Q. and Coch, N.K., 1973. Post-Miocene Stratigraphy and Morphology, Southeastern Virginia, Bulletin 82, Virginia Division of Mineral Resources, Charlottesville, Va.

- Pierce, J.W. and Colquhoun, D.J., 1970a. Holocene Evolution of a Portion of the North Carolina Coast, Vol. 81, Geological Society of America Bulletin, Washington, D.C., pp. 3697-3714.
- Pierce, J.W. and Colquhoun, D.J., 1970b. Configuration of the Holocene Primary Barrier Chain, Outer Banks, North Carolina, Southeastern Geology, Vol. 11, No. 4, pp. 231-236.
- Richards, H.G., 1950. Geology of the Coastal Plain of North Carolina, Transactions of the American Philosophical Society, New Series, Vol. 40, Pt. 1.
- Ruhle, J.L., 1965. Geologic Literature of the Coastal Plain of Virginia, 1783-1962, Information Circular 9, Virginia Division of Mineral Resources, Charlottesville, Va., pp. 1-95.
- Sanford, J., 1912. The Underground Water Resources of the Coastal Plain Province of Virginia, Bulletin No. V, Virginia Geological Survey, University of Virginia, Charlottesville, Va.
- Wentworth, C.K., 1930. Sand and Gravel Resources of the Coastal Plain of Virginia, Bulletin 32, State Commission of Conservation and Development, Richmond, Va.
- White, W.A., 1966. Drainage Asymmetry and the Carolina Capes, Vol. 77, Geological Society of America Bulletin, Washington, D.C., pp. 223-240.

THE HOLOCENE GEOLOGY OF DAM NECK, VIRGINIA:

A BRIEF INTRODUCTION

Linda R. Zellmer

ABSTRACT

A series of 35 cores taken offshore of Dam Neck, Virginia show a stratigraphic sequence indicative of a former back-barrier deposit suggesting that the barrier island may have migrated shoreward in response to rising sea level. The sediments in the cores taken from the nearshore area can be divided into five different groups. Tan and gray fine sands represent the present shoreface deposit. Underlying this is a woody peat. Beneath the peat is a unit made up of interbedded dark gray clay, fine silty sand, and coarse lag. This could represent a lagoonal deposit. The other two sediment types are fine, medium, and coarse sands, some of which are iron-stained, and a compact gray clay. These two units may be an early or pre-Holocene deposit. The sedimentary units found in the Dam Neck cores are similar to the sediments found by other workers along the Outer Banks.

INTRODUCTION

The landward migration of barrier islands in response to the late Holocene rise in sea level is well documented for many areas (Hoyt and Henry, 1967; Shepard, 1956). In the Virginia and Currituck Spit region, some work has been done on the Holocene stratigraphy (Pierce and Colquhoun, 1970; Newman and Munsart, 1968; Shideler, Swift, Johnson and Holliday, 1972; Kraft, 1971a & b; Field and Duane, 1976). Generally, these studies suggest that the barrier island complexes on the East Coast of the United States have been migrating landward since they formed (as the rate of sea level rise decreased), approximately 6,000 years B.P. (Milliman and Emery, 1968).

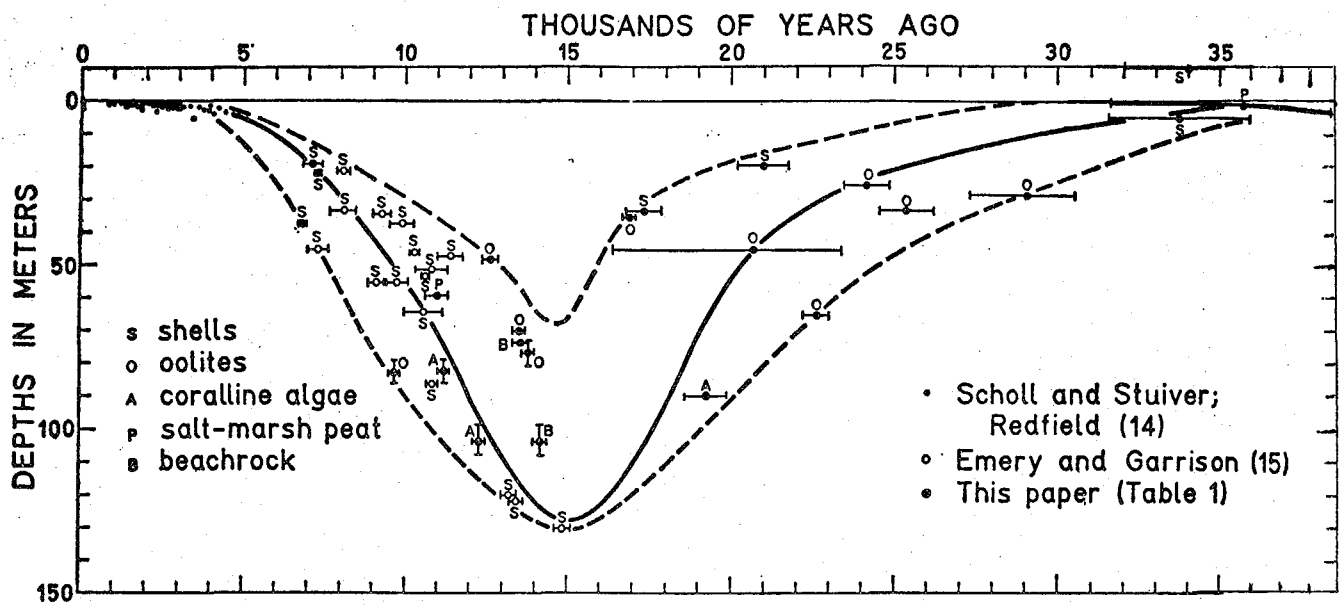


Figure 1. Sea-level curve for the Atlantic Continental Shelf of the United States (From Milliman and Emery, 1965).

CORE SEDIMENTS

The Holocene stratigraphy of the Outer Banks of North Carolina has been well-studied by coring in the Sounds, on the barrier islands themselves, and on the continental shelf (Pierce and Colquhoun, 1970; Riggs and O'Connor, 1974; Shideler, et al., 1972; Moslow and Heron, 1977). In 1976, a series of 35 cores were taken in the area of Dam Neck, Virginia. These cores were taken along the proposed pipeline route for the Atlantic Outfall (Fig. 2) from onshore to an area approximately 3.0 km offshore; the maximum water depth was 10.0 m, while the maximum core depth was about 18.3 m. Upon examination of the cores, a number of sediment types were found. The sediments can be divided into the following groups (Fig. 3):

1. Tan and Gray Fine Sand - these sands make up the foredunes, beach and the shoreface area.

2. Woody Peat - the peat found is of three types. There is a woody peat with a high amount of organics, a clay-rich peat, and also sand with interbedded peat.

3. Interbedded Dark Gray Clay, Fine Sand, and Coarse Lag - this sand is highly variable across the unit. In some parts, clay and fine sand are interbedded, while in other parts, fine silty sand predominates. The sequence is broken throughout by coarse-grained sand, pebble and shell lag-type deposits (Fig. 4). Examination of some of this material reveals the presence of Foramenifera. This indicates that the deposit was laid down in a saline environment.

4. Fine, Medium, and Coarse Sand - this material varies somewhat across the unit, but is markedly different from overlying material. In two cores, the sands are yellow-brown in color, due to iron staining. Underlying these iron-stained sands in all cores is a pebble-cobble layer (Fig. 5).

5. Compact Gray Clay - this clay was only encountered in a few of the cores. Where it is present, a brown-red oxidation zone of variable thickness is found. This oxidation zone is best developed under the iron-stained sands (Fig. 5).

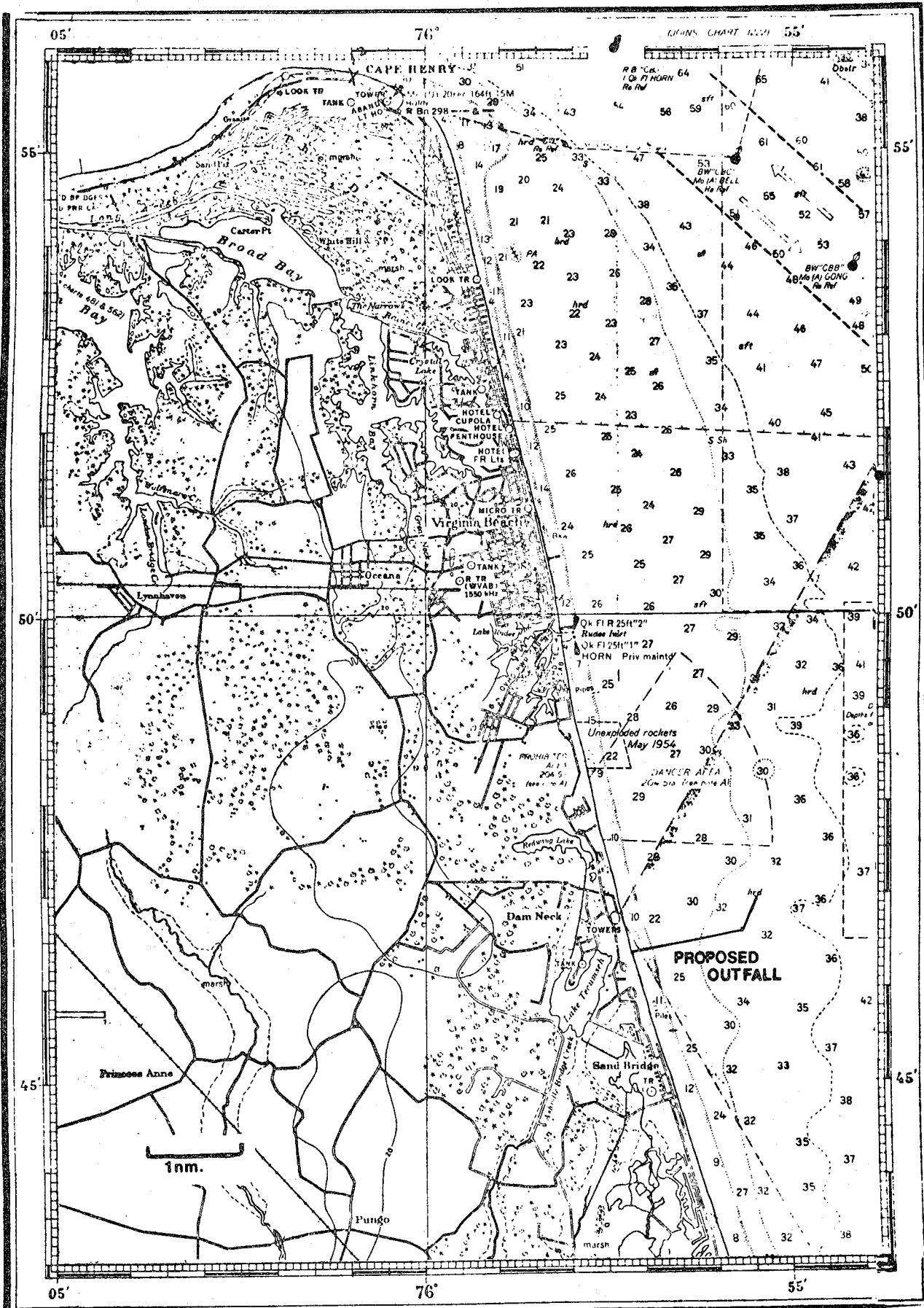


Figure 2. Map showing the location of the Proposed Outfall along which the thirty-five cores were taken in 1976.

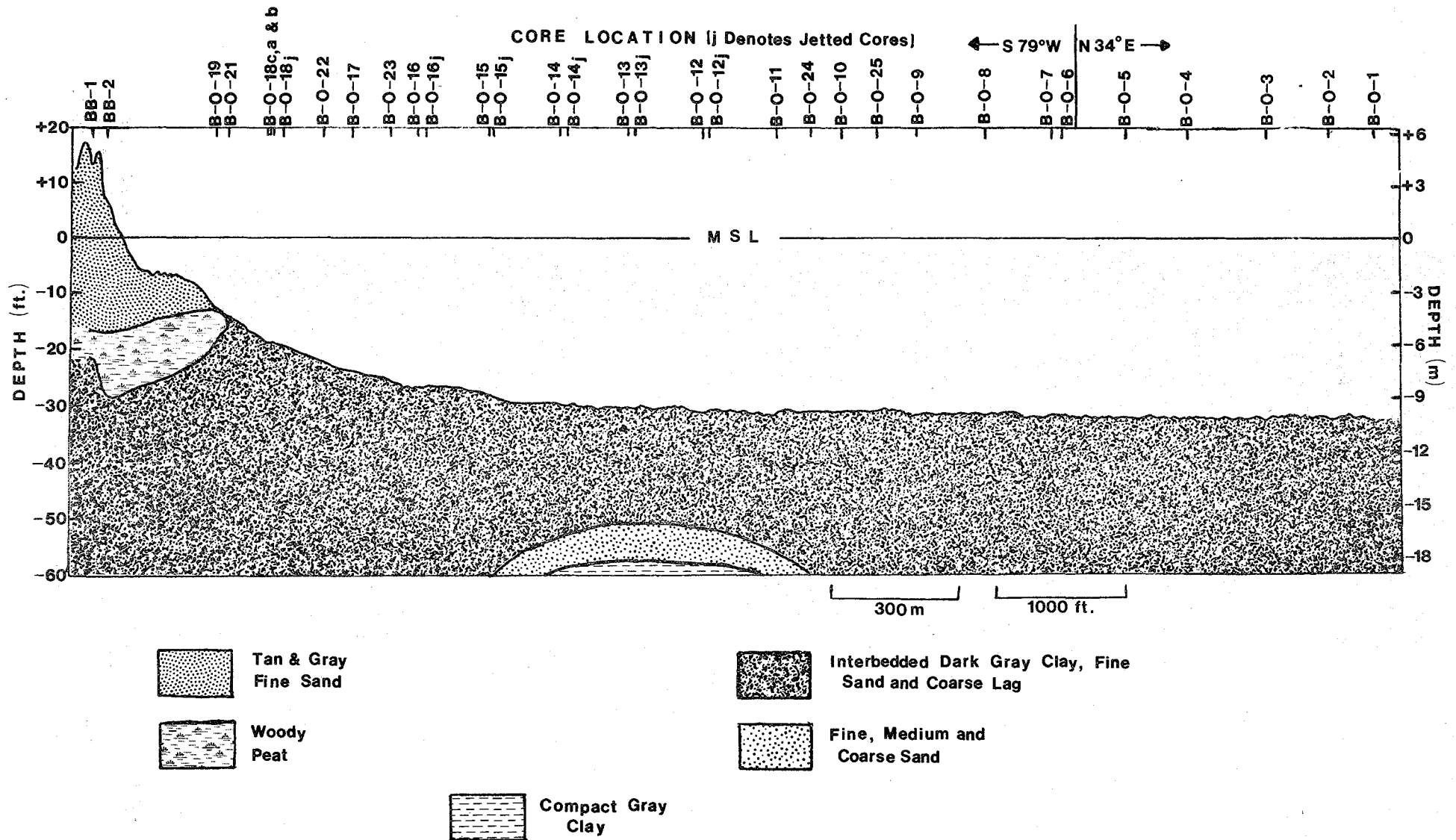


Figure 3. Diagrammatic cross section based on 35 cores taken during 1976 extending offshore from Dam Neck, Virginia (Location shown in Figure 2).

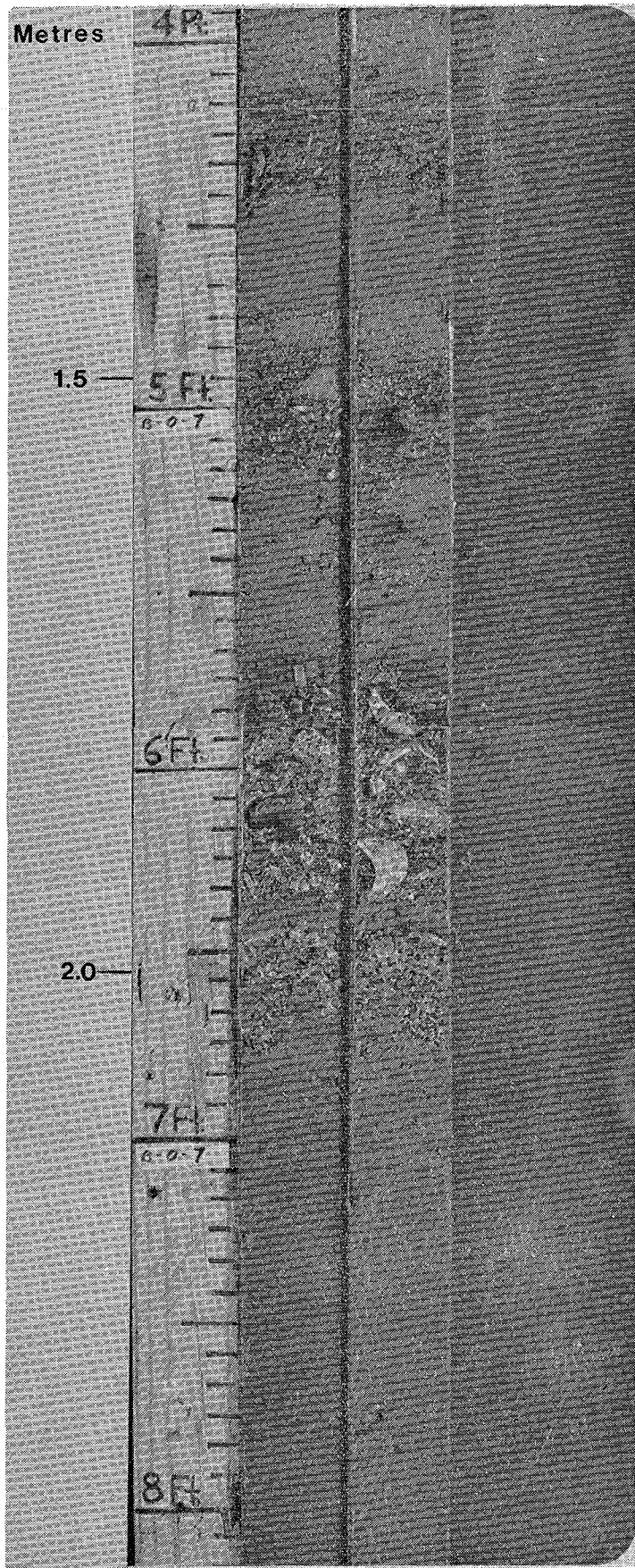


Figure 4. Example of interbedded dark gray clay, fine silty sand and coarse lag from Vibracore B-0-7 taken offshore of Dam Neck, Virginia during 1976 in a water depth of 10 m. Scale shown is in meters below sea floor.

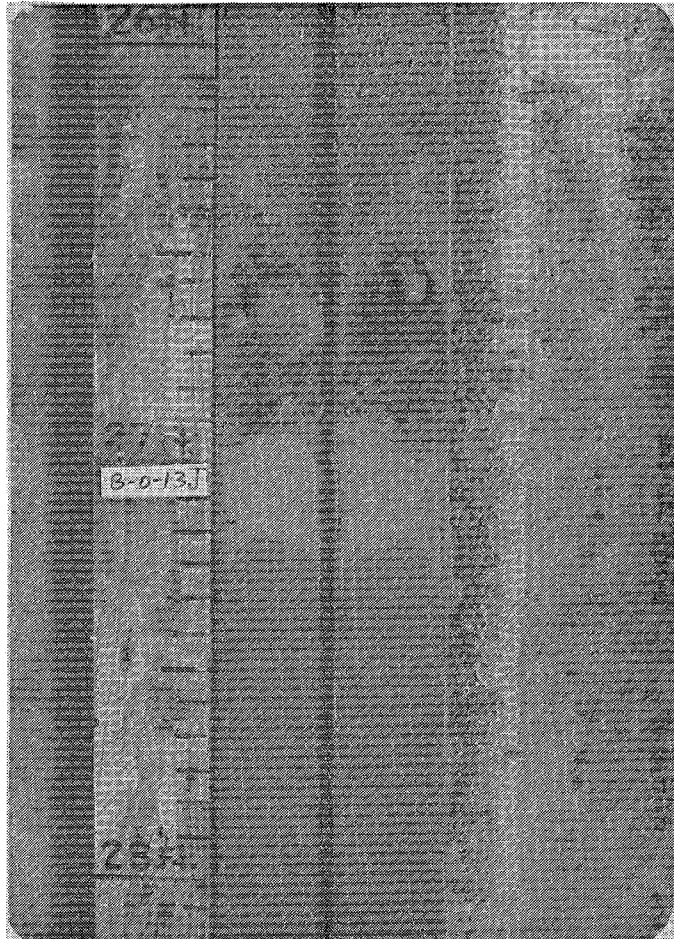


Figure 5. Example of fine, medium and coarse sand overlying compact gray clay from Vibracore B-0-13J (J denotes jetted cores) taken offshore of Dam Neck, Virginia during 1976 in a water depth of 9 m. Note large cobble and oxidation of clay.

CORE STRATIGRAPHY

Core studies have been done in many areas on and near the Outer Banks, and most of them have encountered similar Holocene sequences. A comparison of the sediments underlying the peat can be made with descriptions of Holocene sediments from other areas.

Of the sediments penetrated by the cores, the dark gray clay, fine sand, and coarse lag seems to be most widespread; it occurs in all of the cores from depths of 7.6 to 18.3 m below mean sea level. Other workers on the Outer Banks have found a similar sediment type. Shideler, et al. (1972) found a Recent sediment which they describe as "brownish-gray (5YR6/1) to medium greenish-gray (5GY5/1) mud." They further state that the unit, which they refer to as Unit C, "might represent lagoonal mud of early Holocene age, which has been overridden by the retrograding Currituck Spit during the Holocene transgression." Pierce and Colquhoun (1970) also found a lagoonal deposit in their core studies, but do not describe these sediments. Moslow and Heron (1977) reported a similar deposit, which they labelled as back-barrier, at a similar depth on Core Banks. Field and Duane (1976) describe a shelf sediment sequence for Ocean City, Maryland. Their generalized mid-Atlantic Shelf section also contains a lagoonal deposit and a pre-Holocene deposit in a sequence similar to the one at Dam Neck.

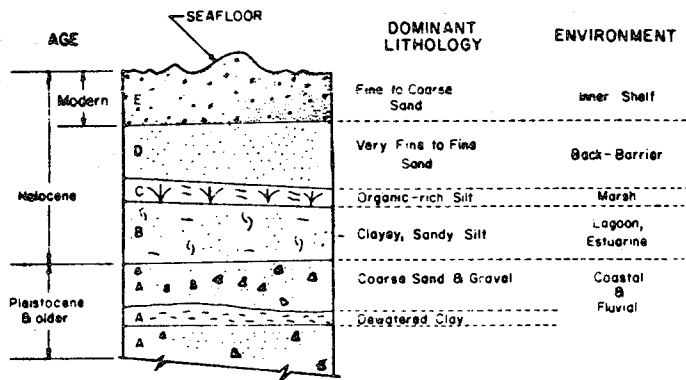
Underlying the dark gray clay and silty sand in cores 11J through 16J (J denotes jettied cores), lies a medium to coarse grained sand. Of special interest in this unit is the fact that the sands in cores 12J and 13J are yellow-brown due to iron staining. Similar iron-stained sands were reported by Pierce and Colquhoun (1970). It is uncertain at this time whether the iron staining of the sands in cores 12J and 13J is due to water table effects, or if the sands actually represent a relict soil zone.

Cores 12J through 14J are also interesting because they contain a hard, compact, gray clay, the top 2.5-23.0 cm of which are oxidized to a light brown-red. In each case, the clay layer is overlain by a gravel-pebble layer. Furthermore, core 13J contains a cobble 7.6 cm in diameter (Fig. 5). This may be an indication that the medium to coarse sands are actually a relict deposit, and the iron staining is due to subaerial exposure, not the water table. Further work will be done to evaluate this problem.

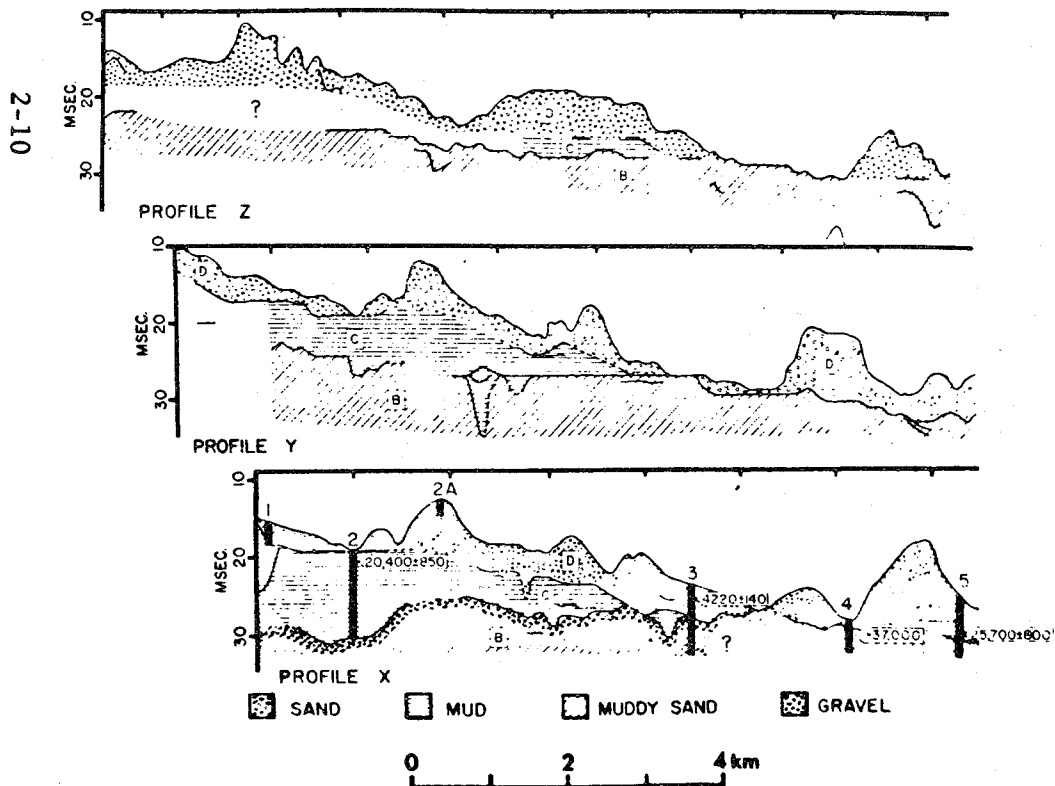
SUMMARY

The Holocene development of the Currituck Spit area has not been studied in depth. Work in evaluating the cores taken at Dam Neck, Virginia will add to the knowledge of the Holocene history of the area. Preliminary results show that most of the subsurface is made up of interbedded dark gray fine silty sand, clay and lag deposits. This may represent a back-barrier or lagoonal environment as interpreted by others (Pierce and Colquhoun, 1970; Shideler, et al., 1972; Moslow and Heron, 1977) (Fig. 6). The sequence in the Dam Neck cores may have resulted from a landward migration of Currituck Spit during the late Holocene. The non-Holocene deposits represented in the cores are the tan and gray fine sands, which are the recent shoreface deposits, and the medium to coarse sands, and compact gray clay. The latter may represent an early or pre-Holocene deposit. The environment of this deposit is uncertain at this stage of the investigation.

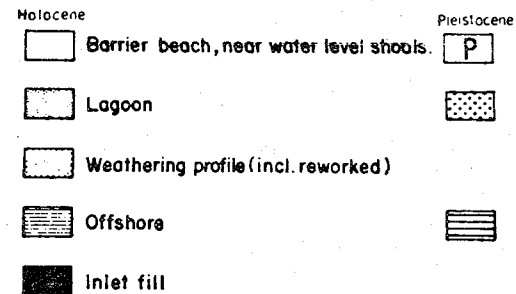
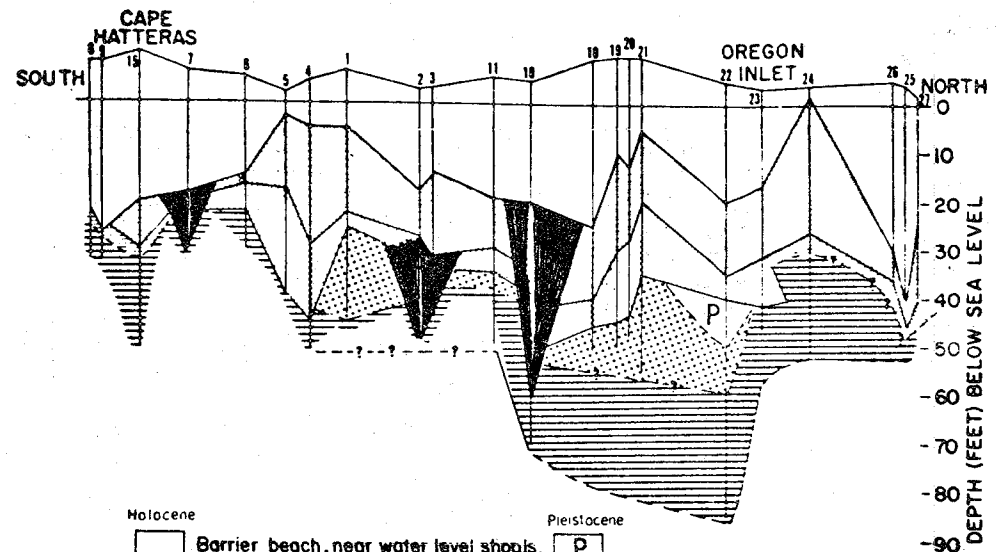
As work progresses, definite environmental interpretations will be made. Hopefully, the results will be able to be compared with the work done on the rest of the Outer Banks, and perhaps on the Eastern Shore of Virginia. From this study, the Holocene geologic history of the Currituck Spit area will be extended.



Ocean City, Maryland
(From Field and Duane, 1976)



False Cape Locality
(From Shideler, Swift, Johnson, and Holliday, 1972)



Along Outer Banks Barrier Chain
(From Pierce and Colquhoun, 1970)

Figure 6. Comparison of vertical sections from the Mid-Atlantic Inner Shelf and the Outer Banks Barrier Chain (From: Field and Duane, 1976, Pierce and Colquhoun, 1970, and Shideler, Swift, Johnson, and Holliday, 1972).

REFERENCES

- Field, Michael E., and Duane, David B., 1976. Post-Pleistocene History of the United States Inner Continental Shelf: Significance to Origin of Barrier Islands: Geological Society of America Bulletin, Vol. 87, No. 5, pp. 691-702.
- Hoyt, John., and Henry, Vernon J., 1967. Influence of Island Migration on Barrier Island Sedimentation: Geological Society of America Bulletin, Vol. 78, No. 8, pp. 2131-2158.
- Kraft, John C., 1971a. Sedimentary Facies Patterns and Geological History of a Holocene Marine Transgression: Geological Society of America Bulletin, Vol. 82, No. 8, pp. 2131-2158.
- Kraft, John C., 1971b. A Guide to the Geology of Delaware's Coastal Environments: Geological Society of America Field Trip Guidebook, Department of Marine Studies, University of Delaware, Newark, Delaware, 19711 p.
- Milliman, John D., and Emery, K.O., 1968. Sea Level During the Past 35,000 Years: Science, Vol. 162, pp. 1121-1123.
- Moslow, Thomas F., and Heron, Duncan, 1977. Evidence of Relict Inlets in the Holocene Stratigraphy of Core Banks from Cape Lookout to Drum Inlet (abs.): Geological Society of America Abstracts with Programs, Southeastern Section, Vol. 9, No. 2, 170 p.
- Newman, W.S., and Munsart, C.A., 1968. Holocene Geology of the Wachapreague Lagoon, Eastern Shore Peninsula, Virginia: Marine Geology, Vol. 6, pp. 81-105.
- Pierce, J.W., and Colquhoun, D.J., 1970. Holocene Evolution of a Portion of the North Carolina Coast: Geological Society of America Bulletin, Vol. 81, No. 12, pp. 3697-3714.
- Riggs, S.R., and O'Connor, M.P., 1974. Relict Sediment Deposits in a Major Transgressive Coastal System: University of North Carolina Sea Grant Publication 74-04.

Shepard, Francis P., 1956. Late Pleistocene and Recent History of the Central Texas Coast: Journal of Geology, Vol. 64, No. 1, pp. 56-69.

Shideler, Gerald L., Swift, Donald J.P., Johnson, Gerald H., and Holliday, Barry W., 1972. Late Quaternary Stratigraphy of the Inner Virginia Continental Shelf: A Proposed Standard Section: Geological Society of America Bulletin, Vol. 83, No. 6, pp. 1787-1804.

A BRIEF HISTORY OF CURRITUCK SPIT

(1600-1945)

Harold F. Hennigar

"... The White Death is a naked, gleaming shifting flood of sand moving ever inland from the ocean shore inch by inch, foot by foot, in huge white waves of glistening grit, inexorable as fate, silent as the grave, swallowing and destroying everything that lies before it in its way. The wind blows the shifting surface up the crest of each towering wave and over the edge in a sparkling mist. Beyond the crest the dry mist falls and so the wave moves steadily, resistlessly forward, enveloping all things in a universal white ..." (Pyle, 1890)

References to the Outer Banks are as old as the European in North America. In fact, the first attempt at an English colony in North America was undertaken by Sir Walter Raleigh at Roanoke during the late 1580's. The colony was a failure, the only clue to its disappearance was the word "CROATAN" carved on a post (White, 1590). Subsequently, colonies were established along this area, and for the next one hundred and fifty years the Outer Banks played an important part in the history of Virginia and the Carolinas (Dunbar, 1958).

The boundary between Virginia and Carolina was long disputed and arose from the charter of King George II, dated March 24, 1663 (Boyd, 1967). A line was to be run, according to the charter, from the north side of Coratuck Inlet (known now as Old Currituck Inlet) west to Weyanoke Creek and thence through the Dismal Swamp. Unfortunately, no one at that time knew the exact location of Weyanoke Creek. Therefore, the governors of both colonies agreed to end the controversy by forming a joint commission to determine the true boundary line. Fortunately, the

surveying of the boundary line was recorded by Col. William Byrd in "The History of the Dividing Line" written in 1728. The following is from Byrd:

"... It was just Noon before we arrived at Coratuck Inlet, which is now so shallow that the Breakers fly over it with a horrible Sound, and at the same time afford a very wild Prospect. On the North side of the Inlet, the High Land terminated in a Bluff Point, from which a Spit of Sand extended itself towards the South-East, full half a Mile. The Inlet lies between that Spit and another on the South of it, leaving an Opening of not quite a Mile, which at this day is not practicable for any Vessel whatsoever. And as shallow as it now is, it continues to fill up more and more, both the Wind and Waves rolling in the Sands from the Eastern Shoals.

However, that we who were punctual might not spend our precious time unprofitably, we took Several bearings of the Coast. We also surveyd part of the Adjacent High Land, which had scarcely any Trees growing upon it, but Cedars. Among the Shrubs, we were shewed here and there a Bush of Carolina-Tea called Japon, which is one Species of the Phylarrea. This is an Evergreen, the Leaves whereof have some resemblance to Tea, but differ very widely both in Tast and Flavour.

We also found some few Plants of the Spiked Leaf Silk grass, which is likewise an Evergreen, bearing on a lofty Stemm a large Cluster of Flowers of a Pale Yellow. Of the Leaves of this Plant the People thereabouts twist very strong Cordage. A virtuoso might divert himself here very well ...¹

"... At Noon, having a Perfect Observation, we found the Latitute of Coratuck Inlet to be 36 Degrees and 31 Minutes.

Whilst we were busied about these Necessary Matters, our Skipper row'd to an Oyster Bank just by, and loaded his Periauga with Oysters

¹Note Byrd's reference to marijuana.

as Savoury and well-tasted as those from Colchester of Walfleet, and had the advantage of them, too, by being much larger and fatter.

About 3 in the Afternoon the two lagg Commissioners arriv'd, and after a few decent excuses for making us wait, told us they were ready to enter upon Business as soon as we pleas'd. The first Step was to produce our respective Powers, and the Commission from each Governor was distinctly read, and Copies of them interchangeably deliver'd.

It was observ'd by our Carolina Friends, that the Latter Part of the Virginia Commission had something in it a little too lordly and Positive. In answer to which we told them twas necessary to make it thus peremptory, lest the present Commissioners might go upon as fruitless an Errand as their Predecessors. The former Commissioners were ty'd down to Act in Exact Conjunction with those of Carolina, and so could not advance one Step farther, or one Jot faster, than they were pleas'd to permit them.

The Memory of that disappointment, therefore, induc'd the Government of Virginia to give fuller Powers to the present Commissioners, by Authorizing them to go on with the Work by Themselves, in Case those of Carolina should prove unreasonable, and refuse to join with them in carrying the business to Execution. And all this was done lest His Majesty's gracious Intention should be frustrated a Second time.

After both Commissions were considered, the first Question was, where the Dividing Line was to begin. This begat a Warm debate; the Virginia Commissioners contending, with a great deal of Reason, to begin at the End of the Spitt of Sand, which was undoubtedly the North Shore of Coratuck Inlet. But those of Carolina insisted Strenuously, that the Point of High Land ought rather to be the Place of Beginning, because that was fixt and certain, whereas the Spitt of Sand was ever Shifting, and did actually run out farther now than formerly. The Contest lasted some Hours, with great Vehemence, neither Party

receding from their Opinion that Night. But next Morning, Mr. M., to convince us he was not that Obstinate Person he had been represented, yielded to our Reasons, and found Means to bring over his Collegues.

Here we began already to reap the Benefit of those Peremptory Words in our Commission, which in truth added some Weight to our Reasons. Nevertheless, because positive proof was made by the Oaths of two Credible Witnesses, that the Spitt of Sand had advanced 200 Yards towards the Inlet since the Controversy first began,² we were willing for Peacesake to make them that allowance. Accordingly we fixed our Beginning about that Distance North of the Inlet, and there Ordered a Cedar-Post to be driven deep into the Sand for our beginning. While we continued here, we were told that on the South Shore, not far from the Inlet, dwelt a Marooner, that Modestly call'd himself a Hermit, tho' he forfeited that Name by Suffering a wanton Female to cohabit with Him.

His Habitation was a Bower, cover'd with Bark after the Indian Fashion, which in that mild Situation protected him pretty well from the Weather. Like the Ravens, he neither plow'd nor sow'd, but Subsisted chiefly upon Oysters, which his Handmaid made a Shift to gather from the Adjacent Rocks. Sometimes, too, for Change of Dyet, he sent her to drive up the Neighbour's Cows, to moisten their Mouths with a little Milk. But as for raiment, he depended mostly upon his Length of Beard, and She upon her Length of Hair, part of which she brought decently forward, and the rest dangled behind quite down to her Rump, like one of Herodotus's East Indian Pigmies.

Thus did these Wretches live in a dirty State of Nature, and were mere Adamites, Innocence only excepted.

²Note that the inlet had migrated 200 yards south in less than 16 years (Boyd, 1967). This southerly migration is typical of inlets in the area.

This Morning the Surveyors began to run the Dividing line from the Cedar-Post we had driven into the Sand, allowing near 3 Degrees for the Variation. Without making this Just allowance, we should not have obeyd his Majesty's order in running a Due West Line. It seems the former Commissioners had not been so exact, which gave our Friends of Carolina but too just an Exception to their Proceedings.

The Line cut Dosier's Island, consisting only of a Flat Sand, with here and there an humble Shrub growing upon it. From thence it crost over a narrow Arm of the Sound into Knot's Island, and there Split a Plantation belonging to William Harding.

We also saw a small New England Sloop riding in the Sound, a little to the south of our course. She had come in at the New Inlet as all other vessels have done since the opening of it. The Navigation is a little difficult and fit only for vessels that draw no more than ten feet Water ...³

Sharpe (1961) remarks that the port of Currituck was one of the five original parts of the colony and discussed its' early history. In 1726, the General Assembly appropriated funds to mark the entrance to New Currituck Inlet. By 1731, the Inlet was shoaling and in 1761 efforts were made to improve it. By the time of the Revolutionary War, traffic to the Port of Currituck was faltering, though even as late as 1786, 194 schooners, 43 sloops and 5 brigs entered through the Inlet. The Inlet finally closed in 1828, possibly buried in part by one of the medaños (i.e., sand hills) in the area, as this excerpt from Fletcher and Guild (1947) suggests:

"... Many years ago there was an inlet to the north, and the water of the sound was salt. Then a great dune, probably Lewark Hill itself, had a part in closing the inlet, and the water turned fresh ..."

The completion of the Dismal Swamp Canal in 1805 undoubtedly also played a role in the closing of New Currituck Inlet as this excerpt from Brown (1970) implies:

³New Currituck Inlet. Note that it too was wide and shallow.

"... Apart from commercial jealousy, the company also had its share of litigation over damaged mills, flooded lands, and so forth. The principle objection lodged against it, however, stemmed from the drastic change in the entire drainage pattern of the east side of the Dismal Swamp.⁴ Water which normally would have seeped through this area was diverted into the canal and found its way out at the ends. This caused a desiccation of the land on the east side and a corresponding impounding and flooding on the west. In 1828, the narrow 3 1/2-foot deep inlet from the Atlantic into Currituck Sound became bar-bound and it eventually closed entirely.⁵ This was said to be the direct result of the diversion of the water from the streams which had emptied into the sound and kept the inlet open. With less water to discharge, ocean waves blocked the passage with sand and, once this arm to the sea was closed, Currituck Sound gradually became entirely fresh and so spoiled the once prosperous oyster beds and salt water fishing industry of the area and necessitated a complete reorientation of the commerce of the region. A plan was made immediately to reopen the inlet and improve it, but apparently nothing ever came of this ..."

After 1828, Currituck was no longer a port of entry into the Carolinas. The effects of this closure on determining the subsequent cultural history of Currituck County are still evident today (Massey, 1971). Farming, fishing and hunting support approximately 85% of the population (Sharpe, 1961) and in 300 years the county has not developed an incorporated town, or a community of more than 500 people. Population of the county is less than it was 150 years ago; in brief, it remains a depressed area, a testimony to the important role of inlets, and specifically to the importance of New Currituck Inlet in the early growth of Carolina.

⁴This earlier eastward drainage of the Dismal Swamp has been verified by Lichtler and Walker (1974).

⁵New Currituck Inlet.

Our next glimpse of the Banks comes from Henry Beasley Ansel, who wrote "Recollections of My Boyhood on Knotts Island" (Unpublished) in the early 1900's. While dealing primarily with Knotts Island, one portion in particular described the Banks. The following is his eyewitness description of "The Great Storms of 1846";

"... Along the greater part of the North Carolina coast runs a narrow strip of land, beach, sand hills⁶ and marsh, that separates the ocean from the sounds and serves as a kind of breakwater between the ocean on one side and the beautiful sounds, the low lying islands in them, and the mainland on the other.

This narrow strip is commonly called The Banks, probably because of its enormous banks or lofty dunes of pure sand. Though sparsely inhabited, in places it contains a goodly number of people. Knotts Island is thus protected from the plunging Atlantic by a narrow bay and The Banks which are between the island and the ocean a mile or so to the eastward.

The people living on the mainland of the island did not know what had taken place on its water fronts, but the news flew that the Atlantic was now breaking on the island shores. I with others went down to the bay side. Such a sight had never been seen before. No marsh, no beach. The tops of a few mountainous sand hills were all that could be seen.

The great salt waves were beating, pounding and breaking at our feet. Nothing of land ocean-ward was visible except the tree tops of Wash Woods and Freshpond Island and the tops of the larger sand hills. The ocean ebbed and flowed on the island shore. High water must have been from eight to 10 feet higher than normal. Nearly everything was submerged.

It was not long before a score of people were gathered with us each lamenting the calamitous situation. Hogs, cattle and

⁶Note that sand hills (referred to now as medafos) were present in 1846. However, these are probably not the same ones as are present today.

sheep on marshes, beach and low lands all gone, all fences blown flat, all water fences washed away. Everything, including the dead animals had been carried down the sound The seriousness of it all was apparent

.... Before this storm the beach opposite Knotts Island consisted of lofty sand hills and high sand ridges.⁷ These had in greater part accumulated since the War of 1812. This I learned from the following facts: The tides of these storms cut these hills and ridges away and in their stead, at a certain point on the beach, appeared to the great wonder of the young, a large thicket of dead cedars whose gigantic arms stretched heavenward.

Uncle Johnny Beasley knew all about these cedars for he had boiled salt under these trees in the War of 1812 and their thick foliage had screened him and others from the view of the British as they passed up and down the coast. I believe the salt water from the sea was hauled to this place to make the salt-a slow process.

He said he had left three of his kettles there where they had sanded up with the trees and now he could get them. He got a crew, I with them, and went over. He pointed out the old stooped cedar under which he had once sat, and boiled salt underneath. He pointed out the place where he had left the kettles.

Digging down just below the surface they found two of them but the third one was never found. These kettles were three by six feet and about 10 inches deep. Uncle Johnny carried them home after they had been sanded over for 30 years. These cedars were dug up, cut and split for vessel timbers and for that purpose were sold to Wallis Bray and B.T. Simmons.⁸

.... But Nature had not wreaked full vengeance on the Island. In September of the same

⁷This implies that "high" foredunes may not be attributed completely to the advent of sand-fencing.

⁸Cedar stumps, cut by man, are now found in the surf zone.

year another storm set in, I believe on the 8th day of that month. It blew harder than the previous March storm and it would have done the same damage if its predecessor had left anything to damage. The few cattle and hogs that the people had gotten together from elsewhere during the summer were away as before. This storm, it was said, blew with even greater force than the first one; but since the wind ranged farther north, the tide lacked two feet of being as high as in the former storm. Then, too, the former storm was at spring-tide, the latter neap tide. This September storm had the same staying quality as the former. The sound and bays, normally fresh, kept salt for many years ..."

Sometime during the period from 1850-1880, extensive logging of the maritime forest was undertaken. Large areas of forest adjacent to the beach were cut down,, leaving bare sand which was susceptible to the winds. Shortly thereafter large sand waves began migrating across the island. While there has been some debate over whether the Outer Banks were originally forested, one has only to note the extensive stumps present on the beach between False Cape and Corolla to answer that question. The following excerpts from Cobb (1906) document the effect of logging:

"... This movement of the sand was started just after the Civil War by the cutting of trees next the shore for ship timbers, and the section is still known as The Great Woods, though not a stick of timber stands upon it today.. Pamlico Sound for two miles from the Hatteras shore is growing steadily shallower from the deposit of blown sand

As already pointed out, the movement of these sands was in every case started by the deforesting of a strip of land next the shore On Currituck below Coffey's Inlet Life Saving Station, the sand has advanced completely across the island, and one man, moving before the advancing sand has at last built his house on piles in the Sound ..."

Another excerpt from Spears (1890) describes the same set of events:

"... As was said, the whole island was covered with a great forest years ago. It was in the thickest parts of woods, but nearly always near the Sound, that the people built their homes⁹

.... A distance of over forty miles, was almost completely covered with a prodigious growth of trees, among which live-oak and cedar were chief in size and number

The population was sparse then, but it has been increasing in such ratio as families of from nine to nineteen children may give. The people then, as now, were of simple habits, living on corn-meal, fish, oysters, pork, and tea made from the leaves of the yapon shrub: but they had to have a little money for clothing and tobacco. To obtain this they cut and sold the live-oak and the cedar.

Thus it happened that spaces along the sea-side of the island were denuded by the axe, and then burned over by the fires the fishermen built when the bluefish and the mackerel came swarming into the beach. In time, and especially during the great demand for live-oak, for Yankee clippers, just before the war,¹⁰ these spaces were enlarged, until at last there was a permanent widening of the whole beach north of the cape.¹¹

It was then that the northeast wind, on a bright day, picked up the sand just beyond the edge of the surf, and tossed it back inland in a fine spray, when it fell down, at the feet of the laurel, and the young cedar, and the young live-oak and the pine, and the yapon. With each fine day the pile of sand in the shrubbery grew, until the shrubbery

⁹Note that over 150 years ago, residents had enough respect for the power of the ocean to construct their houses on the sheltered side of the island.

¹⁰The Civil War.

¹¹Cape Hatteras.

withered under the breath that fanned it, and finally died. Where the green trees had stood in a sandy loam, a sand-ridge arose, which, receiving the breath of the northeast gale, started on a mission of death ..."

At about this time grazing took on major importance as this excerpt from Gibbs and Nash (1961) states:

"... Less than a hundred years ago the Outer Banks were covered with trees, shrubs, vines, grasses, and other types of vegetation from the sound almost to the edge of the ocean. Live oak, water oak, dogwood, pine, sycamore, pellitory, holly, persimmon, yaupon, and mulberry were the principal types of trees, growing so thick that one could go from tree to tree on the interlacing vines for a distance of one-half mile or more without touching the ground.

At that time the inhabitants were primarily engaged in fishing and stock raising; small horses known as banker ponies, cattle, sheep, goats, and hogs were all raised in the area. Originally the stock was kept in fenced enclosures and marsh grass was harvested to feed them during the winter months. As the population increased, the stock increased, fences were abandoned and soon the grasses and other vegetation began to disappear, leaving vast areas barren of all types of vegetation (a familiar cycle that has been repeated in many other areas). First, horses, then cattle, then sheep, then goats, until grasses and shrubs were gone. Then followed the hogs that dug up the remaining roots. Can you imagine a more pitiful situation, especially in an area so fragile as the thin sand barrier of the Outer Banks?

As time went on, the accumulation of sand from the beaches was blown across the barren areas and the vegetation not destroyed by overgrazing was covered up with drifting sand. Since most of the people were engaged in fishing, trees were used in the construction of fishing vessels, others were used for constructing buildings, and many others for firewood. So that eventually all of the

sturdy trees, with the exception of a few left around the homes, were used up or swallowed up by the moving sands. As a result, the storm tides began to wash across the barren beaches from the ocean to the sound ..."

Stratton (1943) describes a similar situation:

"... Overgrazing became one of the major causes in the transformation of the area. The grass and shrubs having been uprooted by hogs and the vegetation having been destroyed by woodsmen, or other lumber interests, or by the cattle and ponies, the sands became susceptible to every wind and tide. This condition, together with the occasional very dry seasons in eastern North Carolina, did much to change the physical condition of the area. The inlets to the salt water sounds became partially closed and in some instances were closed, resulting in serious damage to the salt water fishing industry.

The blowing sand resulted in a decrease of elevation of the Banks, causing the ocean tides to flow over into the sounds. The salt water that flowed over into Currituck Sound which had always been a fresh water sound,^{1 2} destroyed not only the food for the millions of migratory water fowl that wintered there, but also ended the fresh water fishing industry, which was a lucrative business to the residents of that section. Thus, a one time haven of rest and beauty had been changed to a barren beach subject to the ravages of sand, water, and wind ..."

The importance of overgrazing and logging as the causes of migrating dunes are also mentioned by Epler (1933), Cobb (1906), Spears (1890), Stick (1958).

During the late nineteenth and early twentieth centuries conditions became so bad that entire villages were abandoned due to their burial by moving sand dunes (Gibbs and Nash, 1961; Stratton, 1943). The banks became desolate,

^{1 2}This is obviously wrong as Currituck Sound had been a body of salt water prior to the closure of New Currituck Inlet in 1828.

grazing diminished and due to the mass emigration from the Banks, the government took action.

"... As far back as 1904, several of the large hunting clubs endeavored to protect their property by carrying out erosion control on a small scale. In 1907 the State of North Carolina called on the United States Forest Service to aid it in saving what little forested areas remained from the moving dunes.

Meanwhile, erosion was taking its toll. The situation had become so acute that in several places along the coast for a distance of three miles or more ordinary high tides were running over the Banks. Residents were fast deserting their homes and moving to other sections of the State

In 1934 the Federal Emergency Relief Administration undertook erosion control along several miles of the beach adjacent to Currituck Sound. Because of lack of proper study and methods, high tides in a few months destroyed the entire effort.

In 1935 The Works Progress Administration recruited some 1500 workers, transporting them to the area where operations were started over more than 125 miles of the coast line.

The first major undertaking was to eliminate the flow of ocean water over the Banks. To accomplish this, it was necessary to construct a barrier sand dune along the crown of the beach. If this could be accomplished, in addition to stopping the overflow from the ocean, it would act as a windbreak to allow transplanting of vegetation in its lee on the sandy flats.

Experiments indicate that if certain types of barriers were placed along the crowns of the beach, nature would build the barrier dunes. Sand fences of all types from wood slats to jute bagging were tried. As there were no materials available along the coast and transportation extremely hazardous and difficult, the idea was conceived to prefabricate sand fences and transport them by trucks and barges to location.

It developed that an ordinary brush panel 8 feet long and 3 feet wide was the most successful type. These were prefabricated inland about 50 miles, where brush was available. It was found that the success of the panel depended on its height and the thickness of the brush. If the panel was too high and too thick, it acted as a windbreak, causing a scouring motion as the base of the panel, digging out the posts to which the panel was fastened, thereby causing it to collapse. If the panel was too low, winds of velocities of 25 miles would carry the sand completely over the fence and was of little value.

A sand fence of the proper height and thickness acted as a partial windbreak, stopping a percentage of the sand at the base of the fence, allowing the balance to go through the brush of the panel, and with the decreasing wind on the other side of the fence, the latter also was deposited on the ground.

When the panel was covered with sand, it resulted in a lineal dune with a very broad base, sloped very much like the natural ocean beach. Thus, the incoming waves during storm and moon tides would roll up on the base of the barrier dune and when their force was spent, rolled back to the ocean. A high fence also caused a slope so steep that the waves instead of rolling up the natural incline would pound at the base and destroy the dune. In some cases it was necessary to build the barrier dune as high as 25 feet above the crown of the beach; in other localities where erosion had not gained as much foothold, only 8 or 9 feet above normal high tide were necessary.

The base of the barrier dune, depending upon its height, was from 40 to 200 feet. The raising and location of the barrier dune could be accomplished by use of additional sand fences erected at the proper location and heights on the already started dune, adding various types of short laterals to hold the collected sand in place. Taking advantage of the prevailing winds and various sand conditions, in approximately 12 months from the beginning of the project, the tides had been stopped from washing over the Banks.

The study of the numerous huge sand dunes along the coast indicated the direction and rate per year of their movement. It was impossible to cover all of the dunes with vegetation and had it been possible, would have ruined their aesthetic value. Again, by experimental work, it was found if the source of supply of sand was cut off, the action of the dune was greatly retarded and in most instances stopped. This was accomplished by transplanting the bases of the dunes and the surrounding sand flats with grasses and shrubs. In several cases where necessary to protect buildings or natural resources, whole sand dunes were moved by drift fences to another location or were combined with another existing dune.

In some places along the coast were shallow inlets which had been cut through to the sounds by ocean tides but were not of value to the fishing industry, or for drainage purposes, and invariably caused transportation difficulties. These inlets were completely closed and the elevation of the beach raised to normal.

Results of the work were evident almost immediately. No longer do the ocean tides flow over the Banks to hinder traveling, wash away the beach, and kill out the vegetation.

The cost of the project ran well over a million dollars. There were many skeptics when the project was undertaken and there are still skeptics as to the ultimate value over a long period of time of the project. Time and time alone will give the answer.¹³ ..."
(Stratton, 1943)

Unfortunately, this condition did not last for long;

¹³Skepticism continues, of course, on the ultimate effect of restricting overwash. However, it appears from this history that overwashing was not a completely "normal" event, but occurred after devegetation of dunes by overgrazing and concomitant decrease in dune elevation.

"... more details on the hurricane of September 14, 1944, about which I had been hearing all down the Coast. With the barometer falling to 27.97 and the onshore winds blowing, the Sea rose and passed completely across the reef, piling up water in Pamlico Sound and flooding the mainland.

Suddenly the wind decreased in velocity with approach of the storm center; then, increasing again, it blew violently from the opposite direction, and the piled up water from the sound surged back and washed across the reef, meeting the seas coming in from the ocean.

.... Much of the extensive grass plantings made in the late '30's has been lost because during the war there was no money or labor for replacing the grass washed out by hurricanes ..." (Guild and Fletcher, 1947)

This is reiterated by Gibbs and Nash (1961):

"... With the outbreak of World War II, the emergency dune stabilization program came to a close.

During the next fifteen years, much of the fine work accomplished by the emergency works program of the 1930's was lost because of the lack of maintenance. Livestock was still running free on some of the area, and again large areas became barren sand flats where the waves washed across from sea to sound during storm ..."

Since the initial deployment of sand fencing during the late 1930's, this portion of Currituck Spit has not been refenced by any governmental agency, with the exception of Back Bay National Wildlife Refuge in Virginia. However, no sand fencing has been installed since 1974 and present management policy calls for no new sand fencing to be constructed. Other areas have been sand fenced during different time periods for varying lengths of time, however, this aspect is dealt with in another article in this guidebook.¹⁴

To summarize the major events in the early history of Currituck Spit, the following table of events is presented:

¹⁴ See Historical Evolution of Coastal Sand Dunes by H.F. Hennigar.

HISTORY OF CURRITUCK BANKS

<u>Year</u>	<u>Events</u>	<u>Source</u>
1657	"Old Coratuck" Inlet opens	Sawyer; 1975
1663	"Old Coratuck" Inlet to be used as boundary for Virginia-North Carolina line	Byrd; 1728
1664	First English settlement on Outer Banks	Stick; 1958
1713	"New Currituck" Inlet opens 5 miles to the south of "Old Coratuck" Inlet	Sharpe; 1961 Byrd; 1728
1726	Funds appropriated to mark entrance of "New Currituck" Inlet	Sharpe; 1961
1728	Virginia-North Carolina State line marked by "stake 200 feet north of "Old Coratuck" Inlet- "Old Coratuck" Inlet closes	Byrd; 1728 Sharpe; 1961
1731	"New Currituck" Inlet shoaling badly	Sharpe; 1961
1738	"New Currituck" Inlet difficult to navigate- "Fit only for vessels that draw no more than 10 feet water	Byrd; 1728
1761	Efforts made to improve "New Currituck" Inlet	Sharpe; 1961
1805	Completion of Dismal Swamp Canal	Brown; 1970
1828	"New Currituck" Inlet closes; Currituck Sound becomes a body of fresh water	Sharpe; 1961

HISTORY OF CURRITUCK BANKS continued

<u>Year</u>	<u>Events</u>	<u>Source</u>
1846	Two Northeasters submerge Currituck Spit; Stump forest appears on beach near False Cape after being buried for 30 years; Wood used for ships' timbers	Ansell; 1905
1850-1865	Extensive logging of maritime forest for ships' timbers	Sears; 1890 Cobb; 1906
1874	Construction of Currituck Beach Lighthouse and Hunting Club; Mention of 9 great medaños to the south- "Move over 20 feet per year"	Sharpe; 1961
1890	"Sand hills move 100 feet in 5 months"	Sears; 1890
1906	Medaños present north and south of Currituck Lighthouse moving southward; Mention of the need for reforestation and controlled grazing	Cobb; 1906
Early 1920's	Decline of grazing; but herds still exist	Epler, 1933
Late 1920's	Mass exodus from Banks	Epler, 1933

HISTORY OF CURRITUCK BANKS continued

<u>Year</u>	<u>Events</u>	<u>Source</u>
1933	Major Hurricane-decimates herds	Epler; 1933
1934	First attempt at dune stabilization; It was a failure	Stratton; 1943
1936-1940	CCC attempts stabilization with sand fencing; It was successful	Stratton; 1943
1940-1945	World War II; Destruction of sand fencing due to lack of maintenance; Grazing resumes in some areas	Guild and Fletcher; 1947 Gibbs and Nash; 1961

REFERENCES

- Ansell, H.B., 1905. Recollections of My Boyhood on Knotts Island, Unpublished Manuscript.
- Boyd, W.K., 1967. Introduction to Byrd, 1728, Histories of the Dividing Line Between Virginia and North Carolina. Dover Publications, New York.
- Brown, A.C., 1970. The Dismal Swamp Canal, Norfolk County Historical Society of Chesapeake, Virginia.
- Byrd, W., 1728. Histories of the Dividing Line Between Virginia and North Carolina, Dover Publications, New York.
- Cobb, C., 1906. Where the Wind Does the Work, National Geographic Magazine, Vol. 37.
- Dunbar, G.S., 1958. Historical Geography of the North Carolina Outer Banks, Louisiana State University Press.
- Epler, B.N., 1933. A Bit of Elizabethan England in America, National Geographic Magazine, Vol. 64, pp. 695-730.
- Gibbs, R.E. and Nash, E., 1961. Beach and Sand Dune Erosion Control, Am. Soc. of Eng. Trans., Vol. 4, No. 1, pp. 122-125-127.
- Guild, E.R. and Fletcher, J.E., 1947. Exploring America's Great Sand Barrier Reef, National Geographic Magazine, Vol. 92, No. 3.
- Lichtler, W.F. and Walker, P.N., 1974. Hydrology of the Dismal Swamp, Virginia-North Carolina, U.S.G.S. Open File Report 92-478.
- Massey, P.A., 1971. Settlement in North Carolina: A Focus on Seaports. Unpublished Paper, Department of Geography, Clark University.
- Pyle, H., 1890. Among the Sand Hills. Harper's New Monthly Magazine.
- Sharpe, W. 1961. Geography of North Carolina, Sharpe Publication Company, Raleigh, North Carolina.

Spears, J.R., 1890. Sand Waves at Henlopen and Hatteras, Scribner's Magazine, Vol. 8, pp. 507-509.

Stick, D., 1958. The Outer Banks of North Carolina, University of North Carolina Press, Chapel Hill.

Stratton, A.C., 1943. Reclaiming the North Carolina "Banks", Shore and Beach, Vol. 11, No. 1.

White, J., 1590. The Fifth Voyage of M. John White Into the West Indies and Parts of America called Virginia; Original Text in History of North Carolina, Vol. I by F.L. Hawks, 1857. Fayetteville, North Carolina.

Back Bay - Currituck Sound Data Report by Bureau of Sport Fisheries and Wildlife; North Carolina, Wildlife Resource Commission; Virginia Commission of Game and Inland Fisheries; Unpublished Report, 1965.

RELICT INLET FEATURES OF THE CURRITUCK INLETS

John J. Fisher¹

INTRODUCTION

Relict inlet features, commonly physiographic in nature, can be found along barrier chains at the sites of former inlets. Figure 1 shows the distribution of the former and present inlets along the Outer Banks coast as determined from historical maps. The two former Currituck Inlets are the northern-most historic inlets of the Outer Banks barrier island chain. The more distinctive relict features of these two inlets are to be found in the relatively quiet lagoonal environments, and the relict flood delta is the most significant feature remaining after closure of these inlets. The former delta shoals still rise above the water and are separated from each other by distinct flood delta channels and distributaries. The shoals are now covered by a grass, shrub and small tree vegetation, but beneath the surficial organic muck soil can be found a sandy subsoil, typical of the sands of the original shoals. Sediments of both the relict flood delta shoals and channels are similar to those of nearby present inlets.

NEW CURRITUCK AND "OLD" CURRITUCK INLETS

New Currituck Inlet opened in the early 1700's, remained open for about one hundred years and finally closed in 1828. The location of the inlet site was determined from a study of old maps and geomorphic evidence.

The most common problem in relation to different names for the same inlet is the use of the term "New Inlet." Often when an inlet first opens it is known for a time

¹Department of Geology, University of Rhode Island, Kingston, Rhode Island.

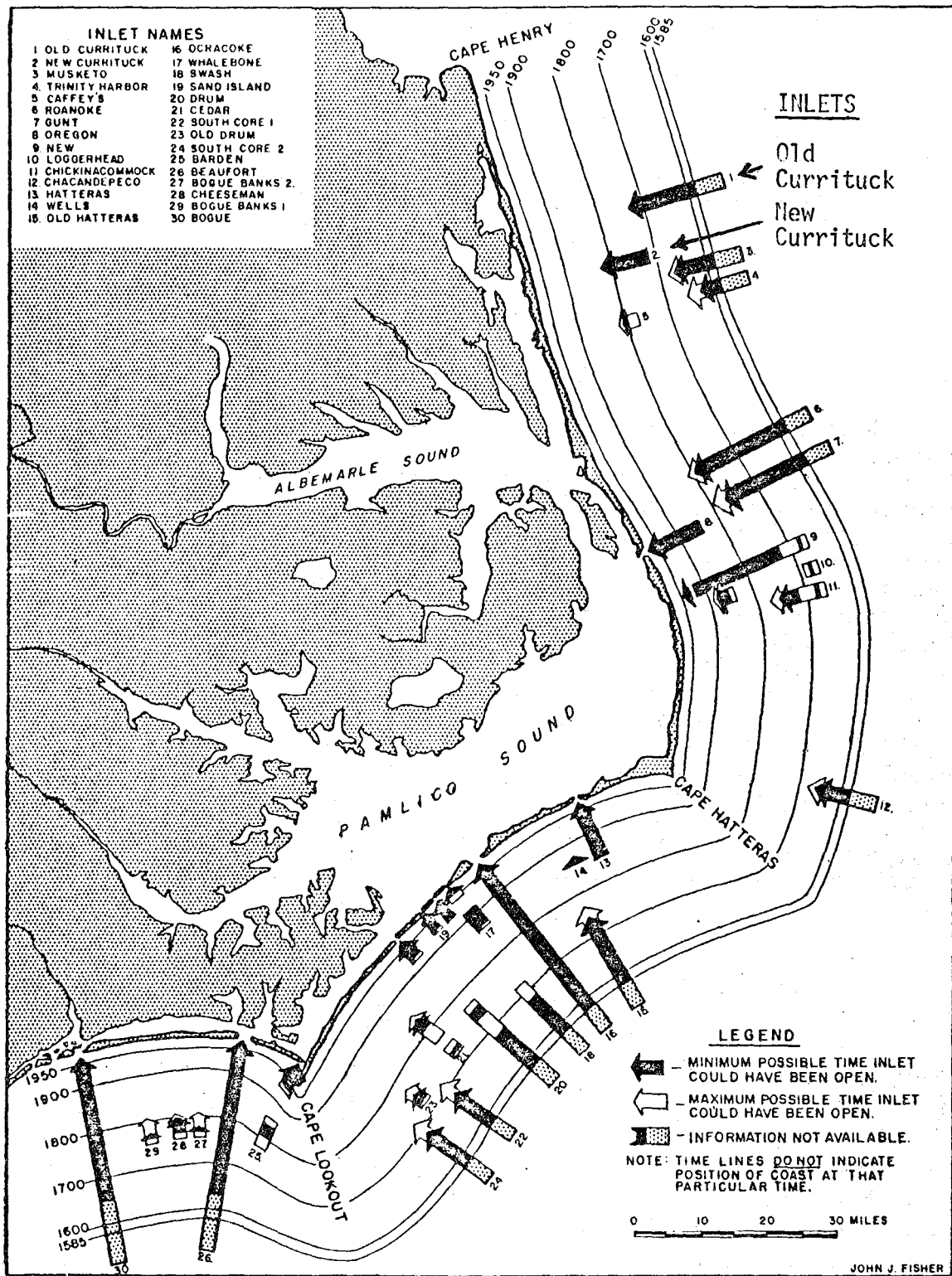


Figure 1. Temporal-spatial distribution of historic inlets along the Outer Banks coast.

simply as the "New Inlet" until it acquires a distinctive name. There have been at least four "New Inlets" noted on maps of the Outer Banks. An example of the complication arising from the name "New Inlet" is illustrated by part of Wimble's 1730 map (C, Fig. 3). The inlet called Currituck at the top of the map is actually New Currituck Inlet. When this inlet first opened it was called "New Inlet" in relation to Old Currituck Inlet just to the north which was still open. Later it was known as "New Currituck Inlet," and when Old Currituck Inlet finally closed, this later inlet was then listed on some maps as simply Currituck Inlet, as on Wimble's map. The original Currituck Inlet ("Old Currituck Inlet") was open from pre-1585 until 1731. The North Carolina-Virginia boundary was surveyed in 1728 and a stake was put 200 yards north of this inlet to mark the point. At that time the inlet was almost shoaled closed. When New Currituck Inlet opened in 1713 this inlet began shoaling. Some reports mistakenly give 1828 as the date of closure of this inlet, but this is actually the date of closing of New Currituck Inlet to the south.²

RELICT INLET FEATURES

The typical flood tidal delta as well as the relict flood tidal delta is a symmetrical fan-shaped shallow water deposit, thickest in the immediate vicinity of the inlet and thinning slowly in all directions towards the lagoon (Fig. 2). Irregular patches of thicker deposits, "flood delta shoals," are found throughout the delta. They normally are above water only during low tide and are built by channel overwash during tide changes. As a result of this overwash, channels of deeper water connecting lagoon and ocean are always found bordering these shoal areas. Lack of wave action in the lagoon allows the flood tidal delta to be more extensive than the corresponding oceanic ebb delta. If the lagoon is large and oriented so there is sufficient fetch, wind-formed waves may also be able to stunt the growth of the flood tidal delta, as well as erode the later relict flood tidal delta. Within the flood tidal delta a number of deep channels branch from the inlet in an irregular meandering fashion. Although normally no distinction is made, the deeper channels which extend from the inlet to the periphery of the flood tidal delta will here

²The history of these inlets is discussed in more detail by Hennigar in this volume.

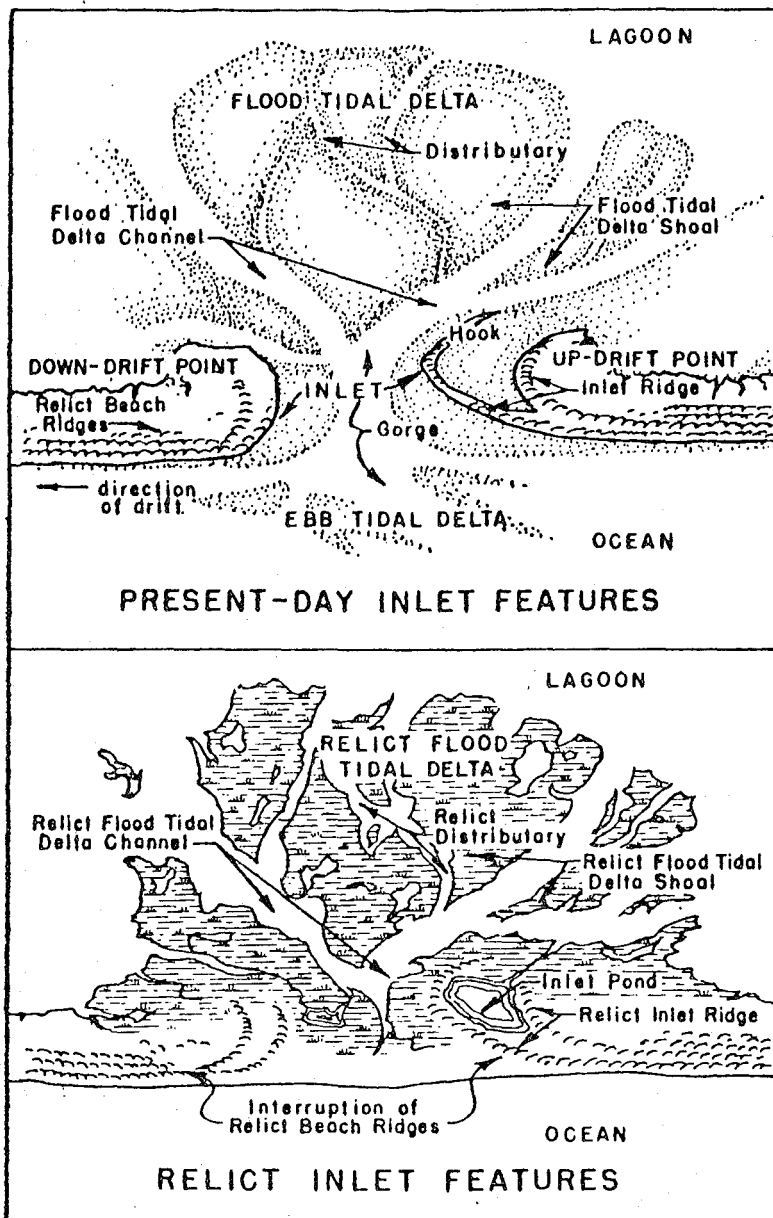
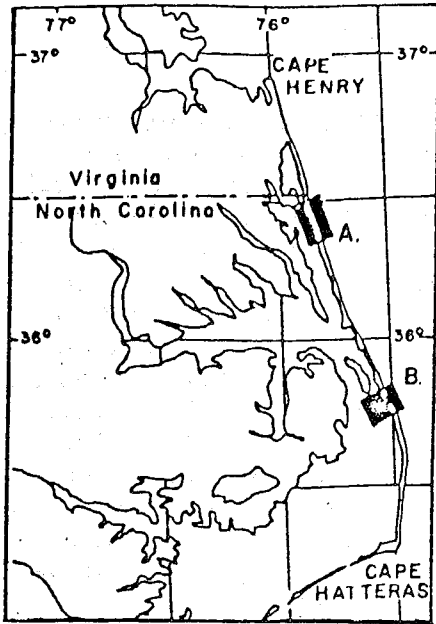
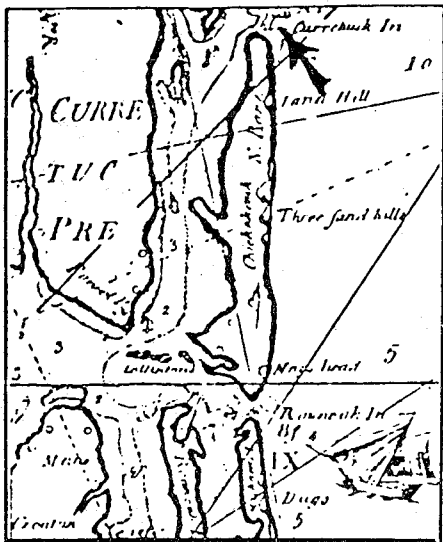


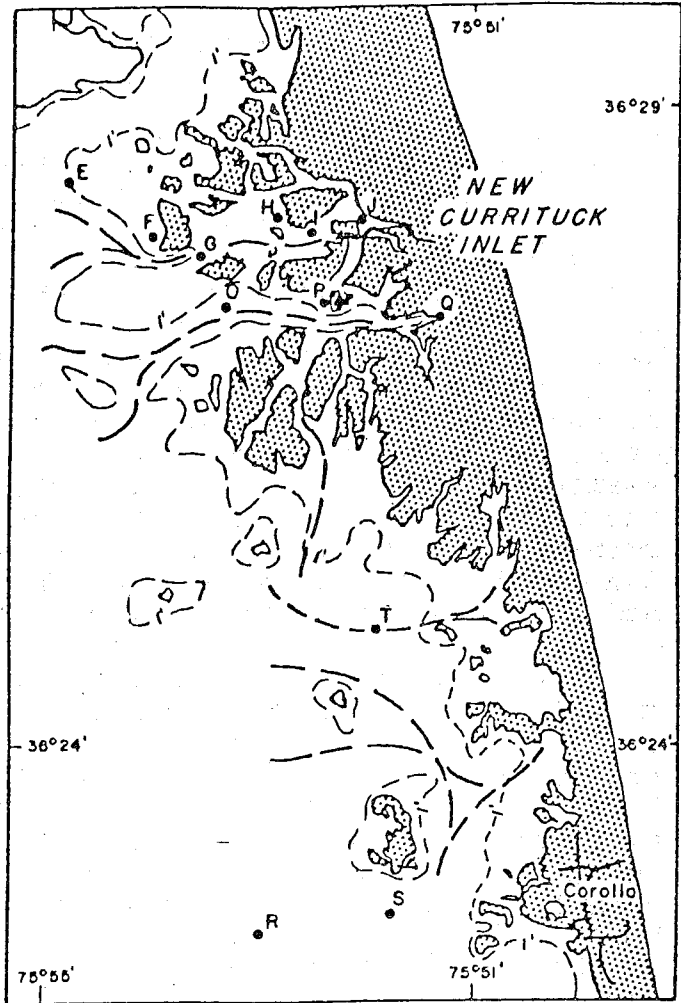
Figure 2. Typical features developed at present-day inlets (upper) and former inlets (lower).



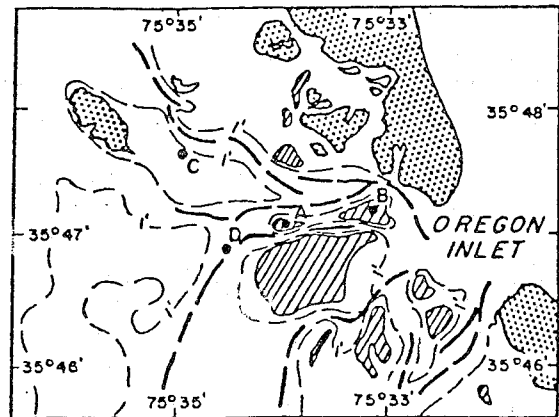
Index Map - Sediment study
Flood Tidal Deltas.



C. Wimble's 1738 map shows a "Currituck Inlet" (arrow) but it is not the original Currituck Inlet which indicated the North Carolina - Virginia boundary. That inlet was 5 miles further north and had closed a number of years earlier.



A. New Currituck Inlet



B. Oregon Inlet

Figure 3. Sample locations for study of sediments of flood tidal deltas.

be called "channels," while the shallower, narrower channels which branch off the main channels will be called "distributaries." Although certain channels in the flood tidal delta can be identified as passageways for either flood or ebb currents, this distinction is not necessary when discussing former inlet features. Relict channels and distributaries leading directly away from the barrier island are recognizable in the relict flood tidal deltas at a number of former inlets along the Outer Banks. Maps of the New Currituck Inlet (Fig. 3A) show the relict channels, distributaries and flood tidal delta shoals. The smallest shoals have retained their original outline and the narrow thread-like distributaries remain open and unchanged in respect to their original sinuous courses. Apparently hurricanes, violent "northeaster" storms, have had little or no effect on these relict features.

Water depths are often greater in the relict channels than in the adjoining lagoons. Although nautical charts indicate those relict channels as having depths of less than one foot, actual field measurements in the New Currituck and Cheeseman Inlet channels showed depths to two feet in channels extending as far landward as dunes on the barrier island. In fact, it was found the relict channels were navigable by a shallow draft outboard motorboat, reflecting the persistence of these deeper channels in the face of lagoonal deposition long after the inlet has closed.

The above-mentioned channel characteristics of relict channels can be recognized in present-day inlets where channels extending from the periphery of the delta to the gorge are usually deeper than the adjoining lagoon or flood tidal delta shoals.

Relict channels usually consist of two main channels separated by a former shoal, now permanently attached to the barrier island. A number of former inlets (e.g., Old Currituck, New Currituck, Musketo, Caffey's and New Inlets) exhibit relict channels with the above characteristics. In the case of New Currituck Inlet local inhabitants consider only the south channel as the site of the former inlet, probably because the south channel was the last to close, especially if the inlet closed by an over-extension of the updrift (north) point.

Present-day inlets show a similar characteristic (e.g., Oregon Inlet, Fig. 3); two main channels extend

from the gorge to the lagoon with a distinct major flood tidal delta shoal between the channels. The shoal has a distinct triangular shape. The apex of the triangle points towards the inlet proper. The same shape can be recognized associated with the relict channels, e.g., Old Currituck Inlet. It should be mentioned relict subaqueous flood tidal deltas in broad open lagoons such as Pamlico Sound tend to exhibit subaqueous relict channels.

When inlets close, gorges and inlet channels are naturally destroyed, but features indicative of the updrift and downdrift points may remain, especially if the inlet migrated. Along the updrift point, less commonly on the downdrift point, low sandy arcuate ridges will form parallel to the inlet. A series of such parallel "inlet ridges" will develop on the updrift point if sand is continuously added during inlet migration, and conversely, ridges formed on the downdrift points will be eroded during migration. What appears to be a series of scattered, irregular dunes just north of the former Old Currituck Inlet site on the topographic map, shows itself to be a series of prominent inlet ridges on aerial photographs. No ridges appear south of the former inlet site. This would be expected if the inlet migrated in a southerly direction as is common along this coast.

FLOOD TIDAL DELTA SEDIMENTS

Samples were collected first from present-day Oregon Inlet for analog comparison (B, Fig. 3), then from the North and South channels of former New Currituck Inlet (A, Fig. 3), and non-inlet lagoonal samples from the Corolla region (A, Fig. 3).

Of the four samples collected in the flood tidal delta of Oregon Inlet for this study (A-D, Fig. 4), all show the same modal class (fine sand), but only the inner shoal is skewed towards the coarser sediments reflecting its proximity to the higher energy environment of the inlet proper. It is interesting to note all the delta shoal samples of Oregon Inlet collected concentrate heavy minerals in the very fine sand class. No heavies were found in this class in the channel sample, although there is sufficient sediment of that particular size.

The relict flood tidal delta of former New Currituck Inlet is a prominent marsh and shoal area in Currituck

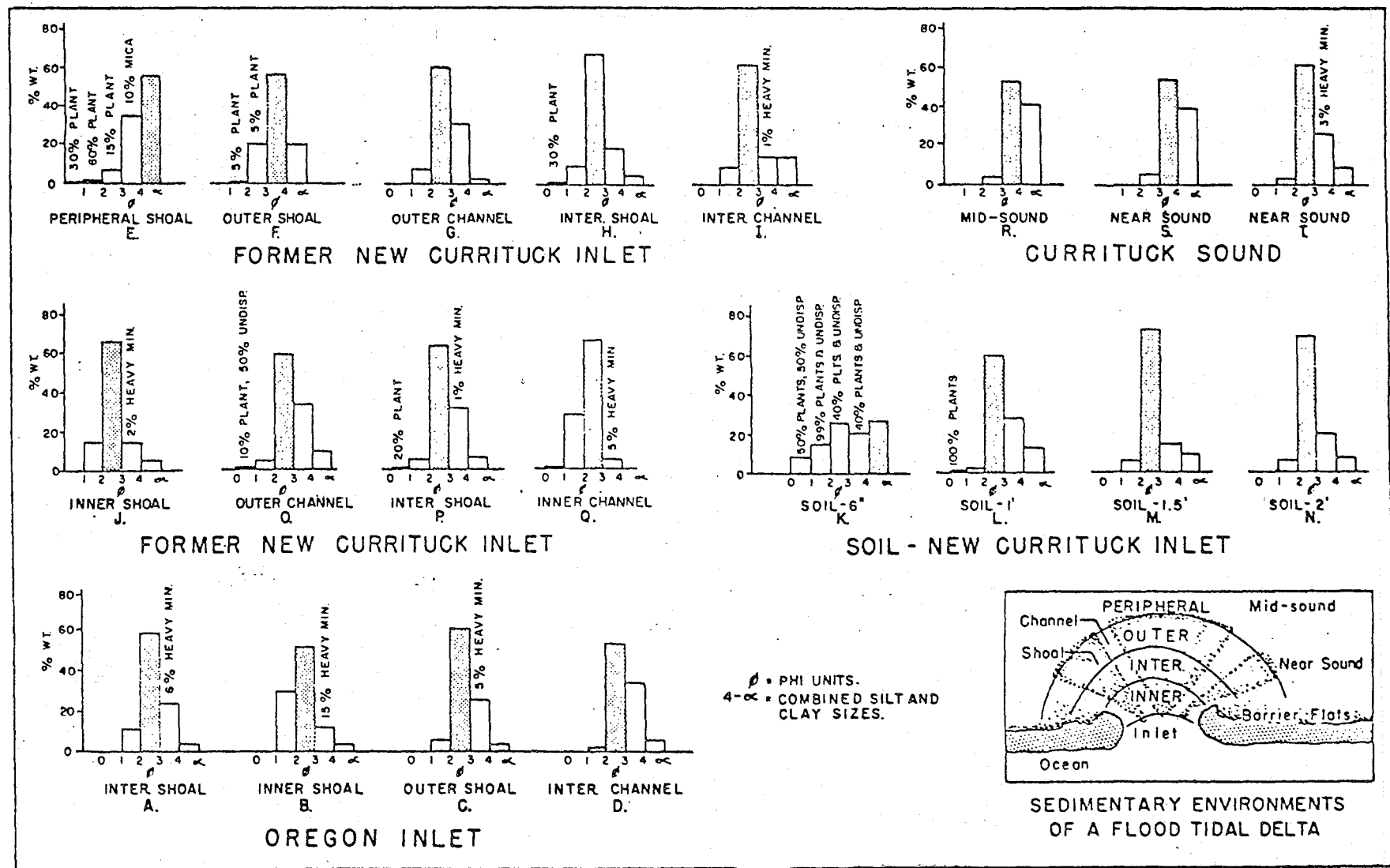


Figure 4. Histograms of flood tidal delta sediments of former inlets. The stippled bar indicates the modal class. The insert (lower right) diagrams the various sedimentary environments of a flood tidal delta.

Sound (A, Fig. 3). Samples from the periphery of this relict flood tidal delta to the former inlet site show an expected decrease in the percentage of fine material (E-Q, Fig. 4). The mode of the peripheral shoal sample is in the combined silt-clay class, while the outer shoal sample has a mode of very fine sand. The intermediate shoal and inner shoal samples both have fine sand as the coarsest modal class. The channel samples show a similar shift towards coarser material as the inlet is approached, but not to the same extent as the shoal samples. All channel samples have the same modal class (fine sand), but the outer channel samples are skewed towards the finer material while the inner channel samples are skewed towards the coarser material.

Plant material shows the expected decrease in total volume from the outermost shoal samples to the intermediate shoal samples, while the inner shoal sample shows no plant material at all. Heavy minerals appear concentrated in both the channel and shoal samples in the very fine sand class, as in the samples from present-day Oregon Inlet, but only in those samples close to the former inlet.

The similarity of the samples from the channel and shoal environments, and the distribution of heavy minerals in both sample types suggests during the closing stages of an inlet the tidal energy becomes similar to the wind-wave energy. As the water shallows, currents become less important in the channels, and the wind-influenced waves dominant the depositional processes in both environments.

The soil profile, developed under a grass and tree vegetation on the flood delta shoal, was sampled at various depths (K-N, Fig. 4). The upper 6" is a dark, sticky clay with abundant plant matter and, although the histogram (K, Fig. 4) indicates a silt-clay fraction on only 26%, it is actually much higher because the coarser fraction contains from 60% to 100% undispersed fine sediments and plant material. At the one foot depth (L) a typical delta shoal deposit of fine sand appears. The samples at the 1' and 1½' depths (M and N) in addition to being typical shoal deposits, are also identical in particle size distribution. This indicates these lower two samples are original unaltered shoal deposits, no soil-forming processes having yet occurred at this depth.

For comparison purposes, samples were collected from non-inlet environments in the Currituck Sound lagoon behind

the Corolla region (see Fig. 3A). Samples R and S (Fig. 4) are perhaps representative of non-inlet lagoonal conditions; both are one modal class finer than most of the flood tidal delta samples in this region. Sample T (Fig. 4) was also collected under the assumption it was a non-inlet sample, but the area in which it was collected was later found to be a former inlet channel. This may account for its one modal class shift towards the coarse material and its similarity to other flood tidal delta sediments. The concentration of heavies in the very fine sand class of this sample is characteristic of flood tidal delta sediments (see Oregon Inlet and New Currituck Inlet) and supports the impression this sample was collected in a former inlet area.

SUMMARY

1. The sediments in both the former New Currituck Inlet flood tidal delta shoal and channel environments show a decrease in size away from the inlet proper. This may be expressed either as a shift in modal class, increase in skewness, or reversal of skewness towards the finer material.

2. Flood tidal delta shoal deposits contain a greater percentage of heavy minerals and plant matter than delta channel deposits. The percentage of heavy minerals is greatest closer to the inlet but the percentage of plant matter decreases or disappears completely closer to the inlet.

3. The most prominent and distinctive relict inlet features are found in the lagoon environment and consist of relict flood tidal deltas and relict flood tidal delta channels. On the barrier island are relict inlet ridges which develop along former inlet spits and relict inlet ponds which develop in the hook of a former inlet spit. Interruption of relict beach ridges along the barrier chain can be in part traced to former inlet action.

4. The spatial distribution of inlets along the Outer Banks (Fig. 1) shows that inlets are a common feature along a barrier chain and have a widespread distribution during the history of the barrier chain. Historic inlets have occurred over approximately 15% of the Outer Banks while evidence of relict inlet features indicates both historic and pre-historic inlets may have occurred over approximately

35% of the Outer Banks. Subsurface barrier island deposits along the Gulf of Mexico indicating a maximum value of 35% for inlet deposits support this line of evidence.

5. In conclusion, the effects of former inlets along the barrier chain are found both on the barrier island in the form of relict physiographic features and in the lagoon in the form of relict flood tidal delta deposits. The widespread occurrence of former inlets along the Outer Banks indicates that effects of the inlet environment are perhaps the most common features, both past and present, of a barrier chain.

REFERENCES

- Fisher, J.J., 1967. Development Pattern of Relict Beach Ridges, Outer Banks Barrier Chain, North Carolina, Ph.D. Thesis, University of North Carolina, Chapel Hill, North Carolina.
- Fisher, J.J., 1962. Geomorphic Expression of Formal Inlets Along the Outer Banks of North Carolina: Unpublished Thesis, University of North Carolina, Chapel Hill, North Carolina.

INTRODUCTION TO COASTAL PROCESSES AT VIRGINIA BEACH, VIRGINIA

by

John C. Ludwick¹

INTRODUCTION

The city of Virginia Beach is bordered on the east by the Atlantic Ocean and on the north by the entrance to Chesapeake Bay. Within the city limits there are 28 miles of oceanfront extending from the Virginia-North Carolina boundary line northward to Cape Henry, the south cape of Chesapeake Bay entrance. The northern beach is backed by sand dunes and farther south by a wooden or concrete bulkhead. South of Rudee Inlet, the shoreline is backed by sand dunes. A public promenade extends 1.9 miles from 35th to 7th Street. From Cape Henry south to Cape Hatteras, a distance of 92 miles, the shoreline is broken by two passes, Rudee Inlet and Oregon Inlet.

The total annual visitation to Virginia Beach is expected to increase from 4.3 million in 1970 to 16.4 million by year 2025. Presently, marine recreation in the City is evaluated at \$80,000,000 annually.

BEACHES AND NEARSHORE ZONES OF VIRGINIA BEACH

In the short sections below, very brief background information is given on local beaches and some related factors. The most complete single technical reference is "Virginia Beach, Virginia - Feasibility Report for Beach Erosion Control and Hurricane Protection", with Appendices 1 and 2, Norfolk District, Corps of Engineers, Department of the Army, September 18, 1970. Other studies dealing with fundamental coastal dynamics problems have also been made in this area including some by Harrison.

CLIMATE: WINDS - STORMS - FLOODS

Monthly wind roses for percentage occurrence of wind direction exhibit a bimodal tendency with major directions mostly from the SSW and secondarily from the NEE. Monthly wind roses for average wind speed exhibit maxima in the NE quadrant during the summer and in the NW quadrant during the winter. The prevailing wind blows in an offshore direction. Average wind speed is approximately 13 mph.

¹Institute of Oceanography, Old Dominion University, Norfolk, Virginia.

Storms in the area occur as northeasters and as hurricanes. North-easters average 2-3 days in duration but may last as long as 10 days. The northeaster of March 6-8, 1962, and the hurricane of August 23, 1933, are recent intense storms that damaged beaches and produced extensive flooding. The northeaster produced tides 6.7 ft. above MSL; the hurricane tides were 8.6 ft. above MSL. In the northeaster, wind gusts reached 56 mph and in the hurricane, 82 mph. Unprotected dunes were cut back 30-50 ft. in 1933, but the beach was not scoured appreciably, the redistributed dune sand apparently offsetting foreshore scour. In 1962, the seawall was extensively damaged. Destruction to property behind the wall was delayed or limited by the protective action of the berm.

WAVE CLIMATE - REFRACTION

Waves that reach the area are predominantly from the NE quadrant in winter and from the SE quadrant in summer. By number there are more waves from ENE than from any other direction. Mean period is 5-6 seconds. Mean height at the Virginia Beach step resistance gage was 1.8 ft. with a standard deviation of 1.0 ft. The gage was located in 19 ft. of water on the 15th Street pier. Modal surf height was estimated at 3 ft. Refraction is such that α opens to the south for NNE and NE swells of all periods. For ENE swells with periods less than 20 sec. α also opens downcoast. For all other directions of deepwater wave approach predicted transport is upcoast.

CURRENT - TIDAL - LONGSHORE

At a point 3000 ft. south of Rudee Inlet, longshore current speed was measured every 4 hours for 26 days in August and September (Harrison, 1968). Mean speed was 1.4 ft/sec to the north. Maximum observed speed was 4.6 ft/sec. At five beach stations between Cape Henry and Camp Pendleton during 7 summer days, breaker angles in 48 of 69 observations opened to the south, but in 55 of 69 observations longshore current direction was to the north.

Tidal currents off the beach are influenced by the proximity of Chesapeake Bay entrance. At three stations between Cape Henry and Rudee Inlet during 7 summer days, surface, mid-depth, and near-bottom tidal current ellipses were greatly elongated parallel to the local shoreline. Residual tidal currents were ebb-directed at Cape Henry at the surface and at mid-depth. At 42nd Street, midway between Rudee Inlet and Cape Henry, residual tidal currents were directed to the north at surface, mid-depth, and near-bottom. At Rudee Inlet, residual currents were negligible.

A clockwise eddy in the net circulation off Virginia Beach was postulated more than 40 years ago but still lacks convincing confirmation. This eddy is believed to extend 3-4 miles south of Cape Henry or perhaps to False Cape and an unknown distance seawards. The present author has shown that in 8-9 m depths from Cape Henry to Sand Bridge, bed sediment transport is almost exclusively to the south and occurs when incompetent tidal currents are augmented by wind- and slope-generated currents particularly in the fall and winter when the water column is essentially unstratified.

SEDIMENT - TEXTURE AND COMPOSITION AND TRANSPORT RATE

Harrison (1968) gives mean grain diameters as 0.22 mm for the zone of shoaling waves, 0.27 mm for the zone of breaking waves, 0.25 mm for the swash zone, and 0.33 mm for the swash-berm zone. Samples from the bottom off Rudee

Inlet range from 0.40 to 0.50 mm. Bunch (1970) gives mean particle size of natural beach sediment at Virginia Beach as 0.31 mm and 0.26 mm for the nourishment sediment in the period 1964-69. Sampling along 5 normal profiles in 1951, 1966, 1967, and 1968 revealed that the median diameters of beach sediment above low water elevation changed from 0.383 mm to 0.326 mm to 0.296 mm to 0.296 mm. Three million cubic yards of sediment were artificially placed on the beach during that period. With distance seaward down the shoreface to a point approximately 1 km offshore, bottom sediment becomes finer in grain size reaching approximately 0.12 mm.

Heavy minerals normally comprise 10 percent or less of the sand. Ilmenite is a common heavy mineral. Shell and rock fragments usually comprise less than 2 percent of the sand.

Littoral sand transport rates are poorly known. Net direction is clearly to the north. Results from a fluorescent tracer study at Rudee Inlet indicated a rate of 70,000 yd³/yr. to the north. A calculation based on repeated beach surveys indicated that the northerly rate past the Inlet was 120,000 yd³/yr. to 140,000 yd³/yr., but much of the sediment was deposited in the forebay area of the Inlet. At a point 30 miles south of the North Carolina border using a wave energy method net transport was calculated at 770,000 yd³/yr. A similar method applied to the area between Cape Henry and the North Carolina border gave a net transport of 980,000 yd³/yr. northward. This value scarcely seems plausible.

BEACH PROFILES AND CHANGES

Comparison of highly reliable shoreline surveys has shown that the high water shoreline at Virginia Beach has retreated at a rate of 2.1 ft/year for the period 1931 to 1946. A more recent figure (1949-1962) for recession is 0.3 ft/year. As of 1958, due to the dumping of 1,563,000 yd³ of sand in the period from 1946 to 1952, the beach was about the same in width as in 1946. An estimated 1,313,000 yds³ of sand had been lost in the same period.

Average berm elevation during the summer is +5 ft; average foreshore slopes are 3°. A flat shore shelf often occurs at -5 to -7 ft below MLW. The width of this feature averages 330 ft. Changing longshore bars occur on this surface.

Some studies of 30-minute changes in swash zone elevation at Fort Story in April showed that a pattern of scour and deposition moved landwards with rising tide. On falling tide, the scoured zone was filled with landwards moving sediment. Sediment stranded during one tidal cycle raised the foreshore level by 0.12 ft. and probably represented initial summer berm building.

RUDEE INLET

Rudee Inlet is just south of 1st Street and connects Lake Wesley and Lake Rudee with the Atlantic Ocean.

Historically, Rudee Inlet has never functioned well as an open inlet. Up until 1952, the inlet served as overflow relief for drainage from Lake Wesley, Lake Rudee, and Owl Creek -- the inlet alternately opening and closing in response

to the hydraulic head developed by interior drainage. For the most part the inlet remained closed by littoral drift. When open, due to overflow action from interior water and/or action of storms, it remained open for only a few days at a time. In its natural condition the interior waters inside the inlet were shallow and the tidal prism, when tidal water flowed in and out, was quite small. Under these conditions very little littoral material was carried into the inlet; practically all sediment bypassed. Accordingly, up until the time efforts were made to improve the inlet, Rudee Inlet had little if any effect on shoreline changes in the area.

Rudee Inlet remained in a natural state until 1927. During this year the Virginia Department of Highways constructed a concrete highway flume, consisting of a structure normal to the shoreline which enclosed an existing inlet channel. The flume served a two-fold purpose of providing a bed for a highway across the inlet area and improving the drainage of Lake Rudee, Lake Wesley, and Owl Creek. Thus, the inlet became a controlled inlet confined to a narrow channel defined by the sides of the flume. In August, 1933, a hurricane destroyed the north section of the flume, washed away the highway and filled the narrow channel with sand, restoring the inlet to its natural condition.

The effect of the flume on the inlet and adjacent beach areas, as documented by photographs, suggests that the flume apparently acted as a groin trapping sediment on the south side. After destruction of the north section of the flume in 1933 noticeable new accretion south of the remaining structure occurred. This accretion and a northward bending of the inlet channel suggests that the drift was predominantly to the north.

Rudee Inlet remained uncontrolled until 1952, when stabilization measures were again taken, in conjunction with a large scale beach restoration program initiated in 1951. The reopening of the inlet, which was then about 18 inches deep at low tide, was done primarily to provide an entrance channel into Lake Wesley for hydraulic dredging equipment. Material removed from this area was to be used for beach nourishment. In the summers of 1952 and 1953 over 1,000,000 yds³ of all classes of material were dredged from Lake Rudee-Lake Wesley bottom and deposited on the 3 miles of beach north of the inlet. Depths up to 35 and 40 feet in the estuary resulted.

To assure an open channel for future passages of the dredge, two short steel-sheet pile and rubble-mound jetties and related bulkheads were constructed in June, 1953. The jetties had a crest at elevation of 8.0 ft., were approximately 190 feet apart, and extended seaward a distance of 150 feet from the back of the existing beach berm. The jetties were designed to be of such a length and so constructed as not to alter radically the effect of the inlet on littoral drift. In addition, the design contemplated future extension of the jetties into deeper water. Soon after completion of the jetties it became apparent that the barrier and forebay impoundment effects created by the stabilized inlet had materially altered the normal northerly drift. This was evidenced by the rapid degradation of the beach immediately north of the inlet.

In July, 1953, a total of 60,000 cubic yards of material was dredged from the inlet and its forebay area and placed on the beach. The majority of this material represented littoral sand which had moved into the inlet between the time it was initially dredged (June, 1952) and the time the dredge returned to sea

(July, 1953). Except for the fact that the inlet had been artificially opened, this material would have by-passed the inlet and replenished the shores to the north. Due to the trapping effect of the inlet the north beaches underwent rapid degradation. Between September and December, 1954, an additional 35,000 cubic yards of material was hydraulically dredged from the forebay area of Rudee Inlet and placed on the beach to the north. In 1954-55, a Commission had constructed a fixed by-passing plant at the seaward end of the south jetty. The plant was designed to by-pass 50 cubic yards of sand per hour. During the several years the plant was in operation, littoral material continued to flow around the end of the south jetty and into the inlet in such large quantities that the forebay area was again filled with sand.

In 1956, an attempt was made to re-open the inlet and dredge the forebay area. This operation continued intermittently with fair to ineffectual results until 1963. The entrance channel was seldom over 10 feet wide and 2 feet deep.

Between 1963 and 1967 the inlet was permitted to revert to its natural state. It remained open for the outflow of drainage from Lake Wesley, Lake Rudee, and Owl Creek. During this period, the majority of the littoral material by-passed the inlet.

Due to the growth of Virginia Beach as a resort area, increased harbor facilities became necessary to satisfy boating interests. In 1965, the City of Virginia Beach decided to further stabilize Rudee Inlet, dredge the forebay area, and establish a boat basin on the north side of Lake Rudee. Expected revenues derived from boating facilities were considered sufficient to justify the costs of construction. The planned jetty improvement began in the summer of 1967. At that time, the north rubble-mound stone jetty extended 800 feet into the ocean. An entirely new structure 320 feet south of the standing south jetty and 510 feet south of the new north jetty was also constructed. This structure, patterned after a similar one built in 1959 at Masonboro Inlet, North Carolina, consisted of a timber weir, 492 feet long joined at its seaward end to a rubble-mound stone jetty, 280 feet long. The stone mound jetty was pivoted to the north to offer some protection for dredging equipment operating in the inlet. The low weir section with top elevation at mean sea level was designed to allow passage of northward moving drift accumulation in a planned deposition basin between the weir and the inlet channel. The weir was also designed to act as a wave break, giving protection to dredging equipment. Due to weather and inadequate equipment the deposition basin was not dredged to design depth.

Construction of the new jetties was completed in January, 1968. Thereafter the Virginia Beach Erosion Commission moved a 10-inch hydraulic dredge to the inlet and commenced dredging a channel into Owl Creek. Other dredging was performed in the forebay area, in the channel between the jetties, and in the sand trap area. Sufficient depth was secured to provide for the navigation of chartered fishing boats in and out of the inlet in the summer and fall of 1968.

In late 1968 and early 1969 the inlet channel was approximately 500 ft. long and 100 ft. wide. Maximum flow occurred in a gorge ranging from 50 to 100 ft. wide and 3 to 10 ft. deep. The lagoon behind the inlet had an area of about 200 acres and a tidal prism of approximately 6 million ft.³

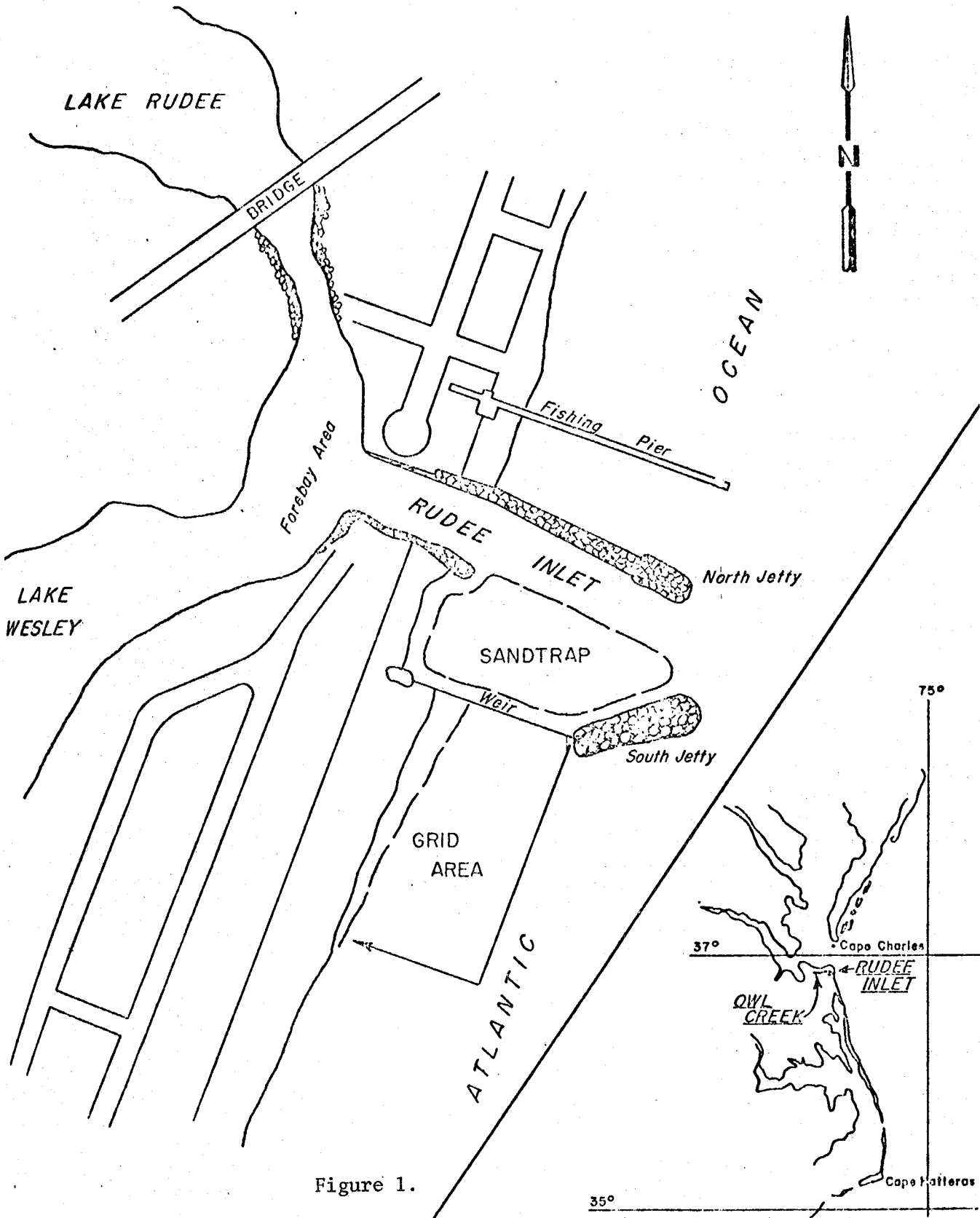


Figure 1.

In mid-June, 1972, commercial dredging of the sand trap finally began in earnest and was brought to the designed depth of 18 ft. The channel was dredged to 12 ft. Future plans include the construction of an offshore breakwater 600 ft. long situated 300 ft. seaward off the south jetty head.

THE POTTER EROSION PREVENTION APPARATUS

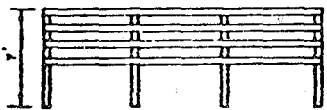
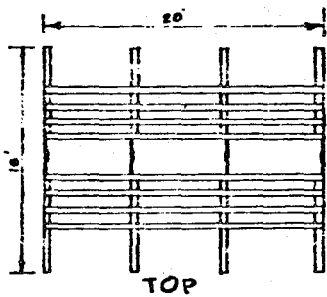
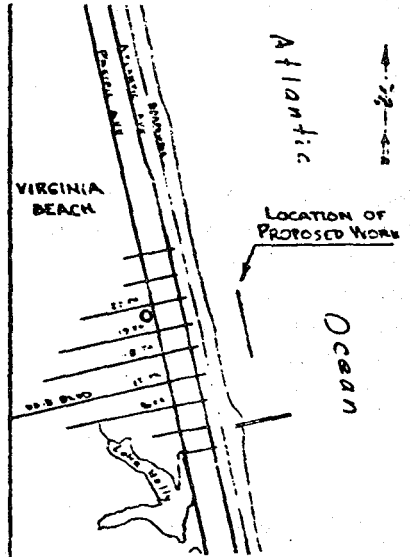
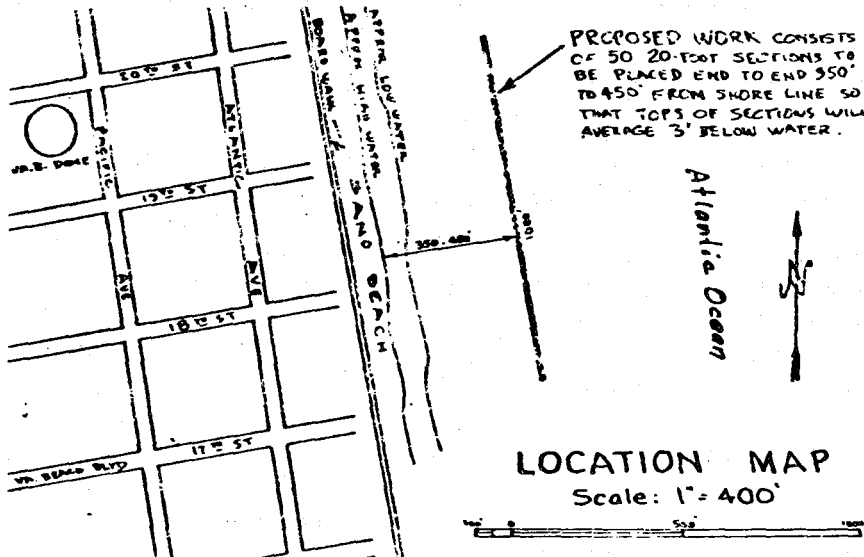
An interesting trial of a semi-permeable offshore breakwater has been made at Virginia Beach. The device is the patented invention of John M. Potter. Individual breakwater sections are 20 ft. in length and weigh 3000 pounds. Fifty of them were placed end-to-end to form a 1000 ft. fence. Individual sections were placed by helicopter. The attached drawing indicates dimensions and geographic location of the fence. The device was ineffective in creating a wave shadow zone owing to the passage of most incident wave energy over and through the device. (Ludwick, et al., 1974; 1976).

SAND STOCKPILING AT CAPE HENRY

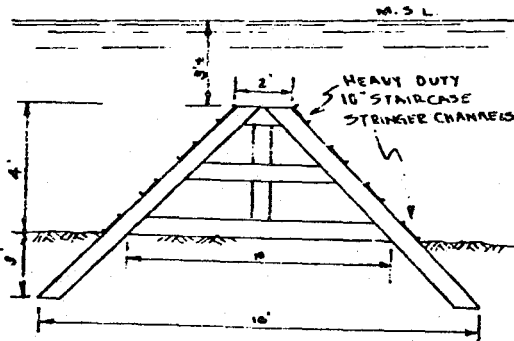
Between October 6, 1974 and November 25, 1974, approximately 700,000 yd³ of sand for Virginia Beach nourishment was pumped ashore from Thimble Shoals Channel to Cape Henry through 1000 feet of submerged 28 inch pipe and an additional 2,500 feet of pipe along the beach. In order to move the sand ashore it was first necessary to connect the 476 foot hopper dredge Goethals (which needs a minimum of 30 foot water depths) to a mooring barge, which in turn was provided an "anchorage" by an 80 x 300 foot DeLong Pier. The pier was floated to the site and then jacked up out of the water.

Once pumped ashore, the coarse channel sand, which was stockpiled by bulldozers at Cape Henry, was periodically trucked to the resort beaches of Virginia Beach several miles to the south. This 28 acre stockpile was expected to last for at least three years, depending on frequency of storm occurrence and associated need. It provides an easily accessible sand source. Also, the coarse channel sand provides better nourishment material than the previous fine-grained sources.

In summary, the use of dredged channel sand, which would otherwise have been dumped at sea or at the site of the Dam Neck Offshore Storage Mound, is being used to nourish the beaches. The major obstacle of moving the sand ashore from the 30 foot depths (shallowest operating depths of the dredge), was overcome with the aid of the Port Construction Company of the U.S. Army, Corps of Engineers.



TYPICAL UNIT
1" = 10'



A FRAME AND ALL BRACES ARE 3/8" x 4" ANGLE IRON BOLTED THROUGHOUT.

TYPICAL CROSS SECTION OF STRUCTURE
Scale: 1" = 5'

PROPOSED EROSION PREVENTION APPARATUS IN ATLANTIC OCEAN AT VIRGINIA BEACH, VA.

Application By SHORELINE EROSION CONTROL CORP., VIRGINIA BEACH VA, J.M. POTTER PRES. Virginia Beach, Va. February 1972

Figure 2.

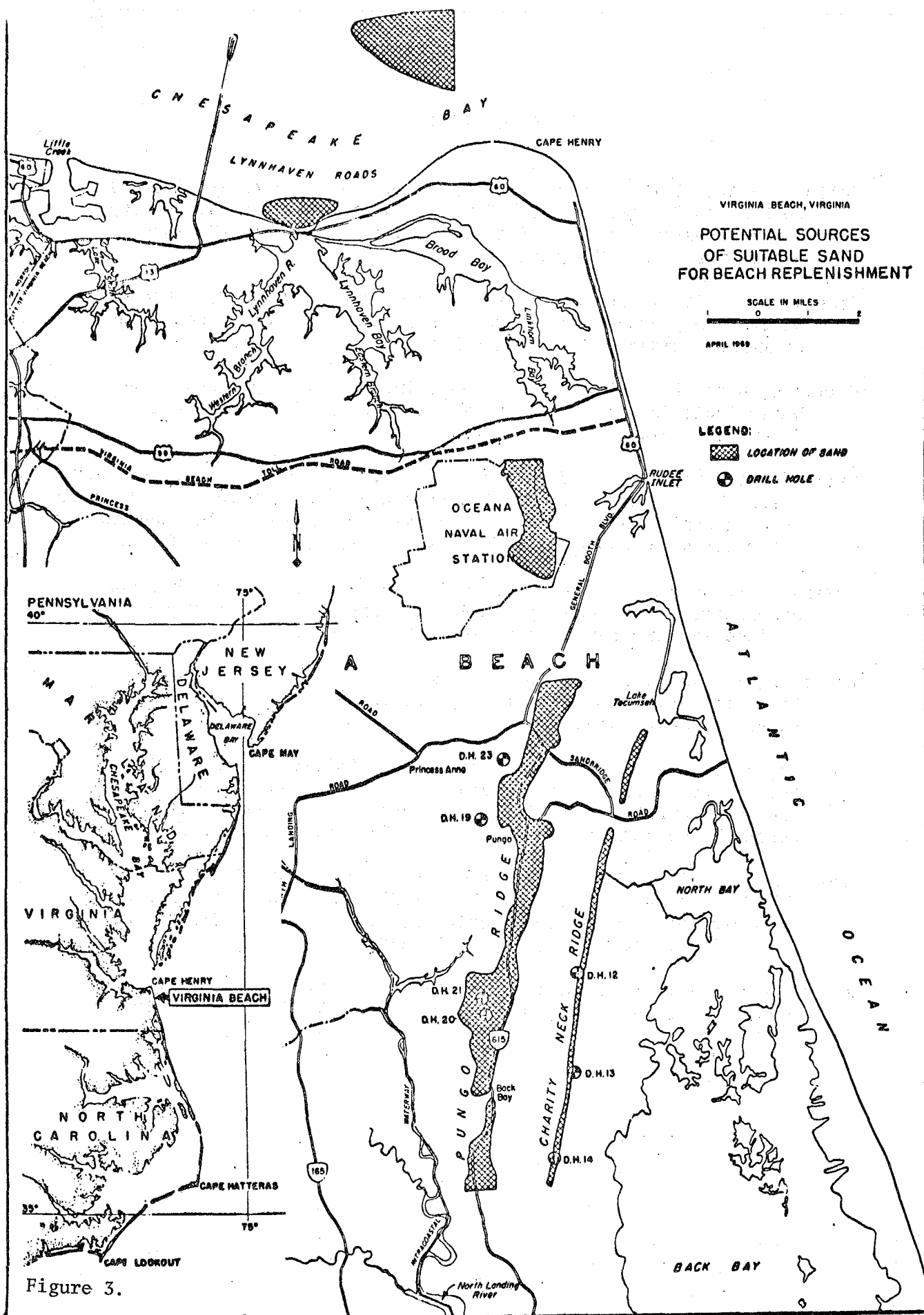


Figure 3.

REFERENCES

- Bullock, P.A., 1971. The Feasibility of Developing Forecast Systems to Predict Changes in Beach Sand Volume on Ocean Beaches During Storms, Masters Thesis, Virginia Institute of Marine Science, Gloucester Point, Virginia.
- Fausak, L.E., 1970. The Beach Water Table as a Response Variable of of the Beach-Ocean-Atmosphere System, Masters Thesis, Department of Marine Science, U.V.A., Charlottesville, Virginia.
- Harrison, Boon, Fang, Fausak, and Wang, 1971. Investigation of the Water Table in a Tidal Beach, S.S.R. No. 60, VIMS, Gloucester Point, Virginia, 165 p.
- Harrison, W., Rayfield, E.W., Boon, J.D., III, Reynolds, G., Grant, J.B., Tyler, D., 1968. A Time Series from the Beach Environment, Atlantic Oceanographic Laboratories, Technical Memorandum No. 1, Land and Sea Interaction Laboratory, Norfolk, Virginia, Contribution No. 12.
- Harrison, W., Krumbein, W.C., 1964. Interactions of the Beach-Ocean Atmosphere System at Virginia Beach, Virginia, U.S. Army Coastal Engineering Research Center, Tech. Memo. No. 7.
- Harrison, W., Wagner, K.A., 1964. Beach Changes at Virginia Beach, Virginia, U.S. Army, Coastal Engineering Research Center, Misc. Paper No. 6-64, November 1964.
- Ludwick, J.C., Fleischer, P., Johnson, R.E., Shideler, G.L., 1974. Beach Processes at Virginia Beach and Their Response to a Beach Erosion Control Device, Inst. of Ocean., Tech. Report 18, ODU Research Foundation, 47 p., 13 Fig., 23 Tables, July 1974.
- Ludwick, J.C., Fleischer, P., Johnson, R.E., Shideler, G.L., 1975. Field Performance of a Permeable Breakwater, Journ. of Waterways, Harbours, and Coastal Engineering Div., ASCE, Vol. 101, No. WW4, Proc. 11703, November 1975, p. 357-368.
- Watts, G.M. 1959. Behavior of Beach Fill at Virginia Beach, Virginia, U.S. Army, Corps of Engineers, Tech. Memo. No. 113, June 1959.

THE WETLAND VEGETATION OF BACK BAY AND
CURRITUCK SOUND, VIRGINIA-NORTH CAROLINA

Gene M. Silberhorn

The marshes of North Bay and Back Bay are represented by typical brackish water marsh plants. The predominant plants are grasses, sedges, rushes and cattails. Big Cordgrass (Spartina cynosuroides) is dominant over much of the area. Also common are Narrow-leaved Cattail (Typha angustifolia) and Broad-leaved Cattail (Typha latifolia). On higher peaty elevations dense meadows of Saltmeadow Hay can be found. Saltmarsh Balrush, Scirpus robustus and Chairmaker's rush, Scirpus americanus occur in scattered colonies. Along the barrier-beach side of Back Bay dark, dense, monospecific colonies of Black Needlerush, Juncus roemerianus are common (Kerwin, 1965).

Saltmarsh Cordgrass (Spartina alterniflora) is common in certain areas although the water is now nearly fresh. Forty years ago when the water was more saline, this specie was nine more abundant than it is now (Harvill).

Other associated species found here are Marsh Hibiscus (Hibiscus moscheutos), Sawgrass (Cladium jamaicense), Smartweeds (Polygonum spp.) Spikerushes (Eleocharis spp.), Giant Bulrush (Scirpus validus), Wax Myrtle (Myrica cerifera), Salt Grass (Distichlis spicata), Walter's Millet (Echinochloa walteri), Bay Berry (Myrica pennsylvanica), sedges (Carex spp.), and others (Kerwin, 1965).

The Back Bay-Currituck Sound area was more brackish when the inlets were open; the last one closed in 1828. Subsequently, extensive overwashing occurred until the 1960's when extensive dune buildup via sand fencing prevented overwashing of ocean waters during storms. The last major overwash event occurred in March 1962 (Hennigar, 1977 and this volume).

An important aspect here is plant succession, which is complicated by the changes from saline to fresh water conditions and by the effects of man. An extensive discussion of plant succession may be found in Boule's (1976) study of Fisherman Island, Virginia, on the north side of Chesapeake Bay entrance.

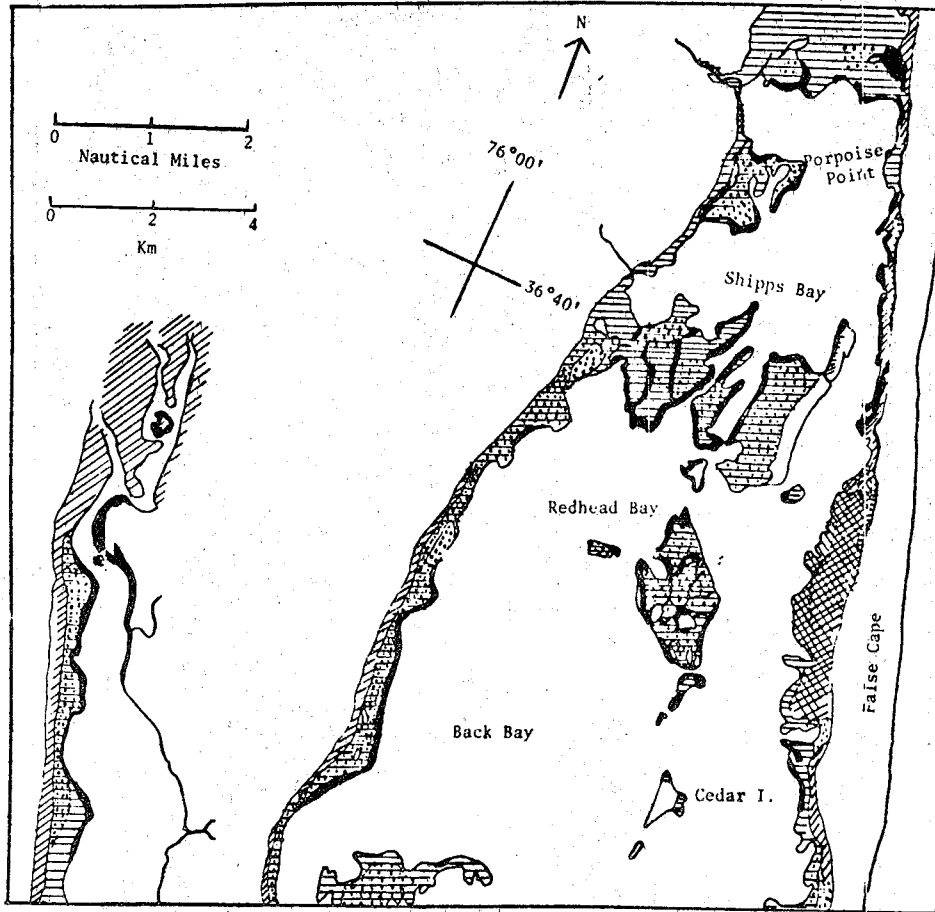









Figure 1. Generalized Cover Map of Marshes of Back Bay and Currituck Sound from Aerial Reconnaissance and Photograph Interpretation, in 1958 (From Sincock et al., 1965).

- | | |
|---|---|
|  Needlerush |  Mixed Waxmyrtle, Needlerush, and Saltgrass |
|  Big Cordgrass |  Heterogeneous Marsh of Cattail, Three-squares, Spikerushes, Marshmallow, and Smartweeds |
|  Cattail |  Three-squares (<i>Scirpus americanus</i> , <i>S. olneyi</i> , and <i>S. robustus</i>) |
|  Sawgrass | |

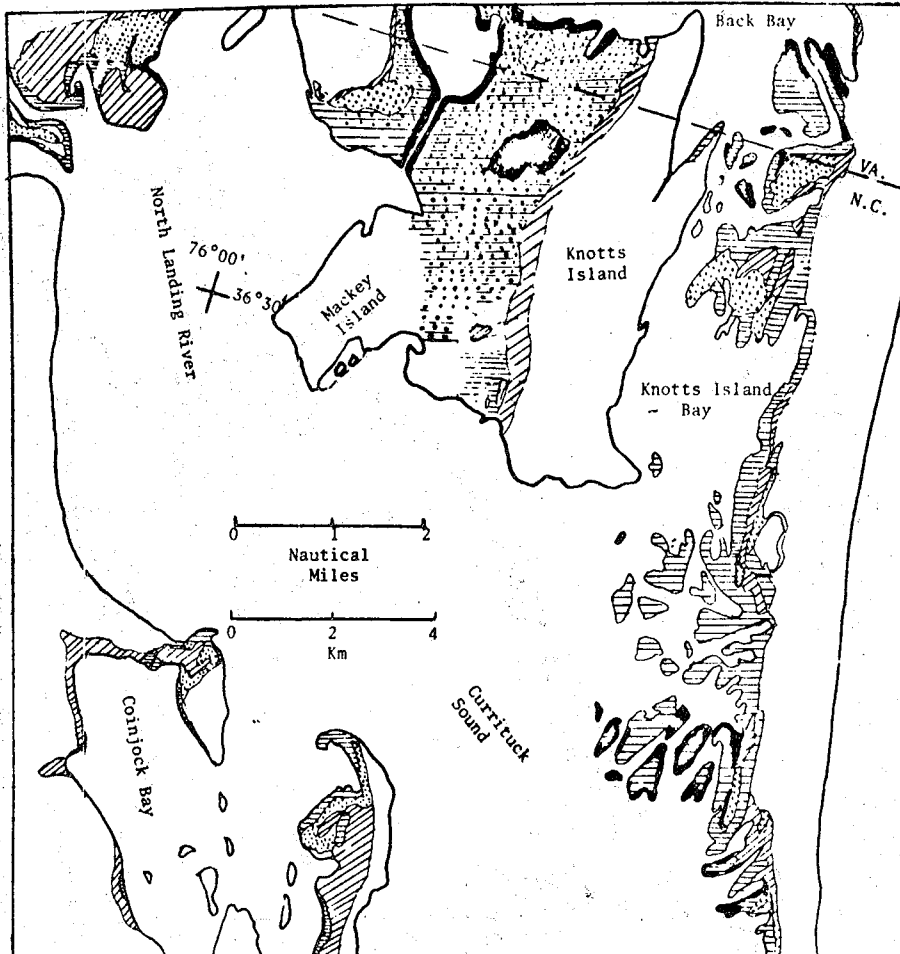









Figure 2. Generalized Cover Map of Marshes of Back Bay and Currituck Sound from Aerial Reconnaissance and Photograph Interpretation, in 1958 (From Sincock et al., 1965).

- | | | | |
|---|---------------|---|---|
|  | Needlerush |  | Mixed Waxmyrtle, Needlerush, and Saltgrass |
|  | Big Cordgrass |  | Heterogeneous Marsh of Cattail, Three-square Spikerushes, Marshmallow, and Smartweeds |
|  | Cattail |  | Three-squares (<i>Scirpus americanus</i> , <i>S. olneyi</i> and <i>S. robustus</i>) |
|  | Sawgrass | | |

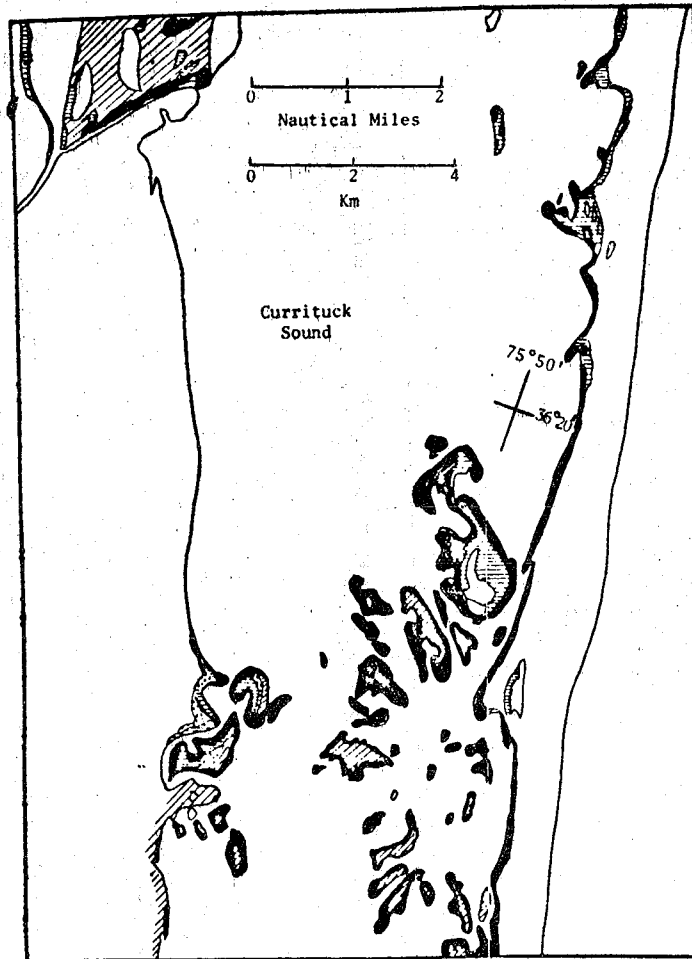









Figure 3. Generalized Cover Map of Marshes of Back Bay and Currituck Sound from Aerial Reconnaissance and Photograph Interpretation, in 1958 (From Sincock et al., 1965).

- | | |
|---|---|
|  Needlerush |  Mixed Waxmyrtle, Needlerush, and Saltgrass |
|  Big Cordgrass |  Heterogeneous Marsh of Cattail, Three-squares, Spikerushes, Marshallow, and Smartweeds |
|  Cattail |  Three-squares (<i>Scirpus americanus</i> , <i>S. olneyi</i> , and <i>S. robustus</i>) |
|  Sawgrass | |

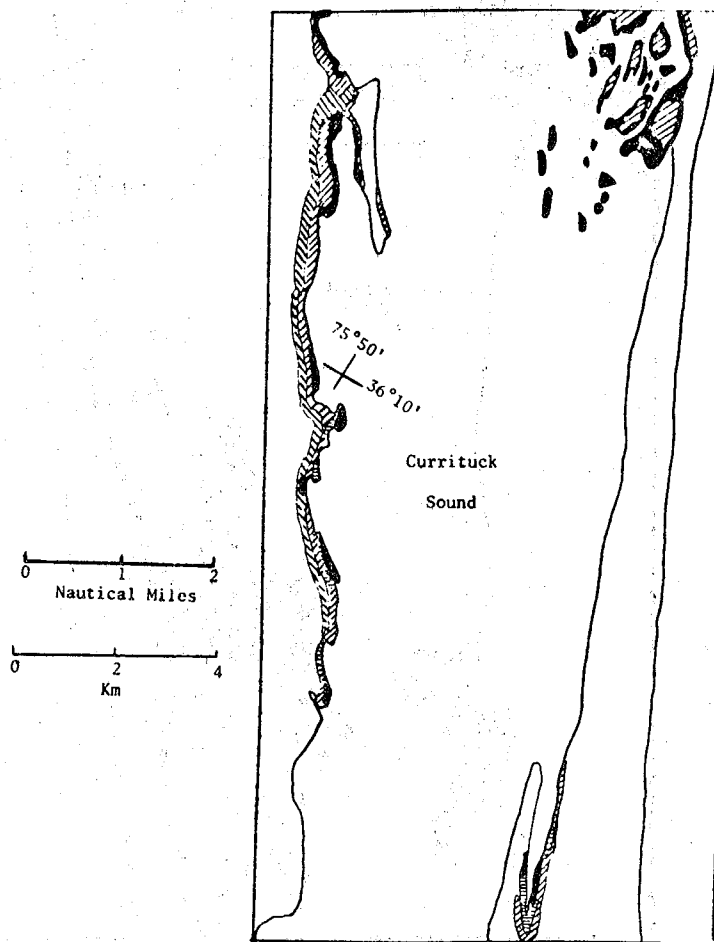









Figure 4. Generalized Cover Map of Marshes of Back Bay and Currituck Sound from Aerial Reconnaissance and Photograph Interpretation, in 1958 (From Singcock et al., 1965).

- | | | | |
|---|---------------|---|---|
|  | Needlerush |  | Mixed Waxmyrtle, Needlerush, and Saltgrass |
|  | Big Cordgrass |  | Heterogeneous Marsh of Cattail, Three-Square, Spikerushes, Marshmallow, Smartweed |
|  | Cattail |  | Three-squares (<i>Scirpus americanus</i> , <i>S. olneyi</i> , and <i>S. robustus</i>) |
|  | Sawgrass | | |

REFERENCES

- Boulé, Mark, 1976. Geomorphic Interpretation of Vegetated of Fisherman Island, Virginia, M.S. Thesis, VIMS, College of William and Mary, 125 p.
- Chamberlain, E.B., 1948. An investigation of certain food plants and a botanical survey of Back Bay National Wildlife Refuge, Princess Anne Co., Va., Unpub. M.S. Thesis, VPI-S.U., 147 p.
- Harvill, A.M., Jr., . The Botany of North Bay and Back Bay, Unpub., 4 p.
- Hennigar, H.F., 1977. Historical Evolution of Coastal Sand Dunes, Currituck Spit, Virginia-North Carolina: M.S. Thesis, Virginia Institute of Marine Science, Gloucester Point, Virginia, in prep.
- Kerwin, J.A., 1965. Marsh Vegetation of Back Bay and Currituck Sound in Back Bay-Currituck Sound Data Report. Bureau of Sport Fisheries and Wildlife, North Carolina Wildlife Res. Com. and Virginia Com. and Game and Inland Fisheries, p. 66-67.
- Sincock, J.L., 1962. Back Bay National Wildlife Refuge in Virginia Acad. Sci. Guidebook in Field Trip, Norfolk Meetings, p. 96-100.
- Sincock, J.L., Johnston, K.H., Coggin, J.L., Wollitz, R.E., Kerwin, J.A., Grandy, J., III, 1965. Back Bay-Currituck Sound Data Report; Introduction and Vegetation Studies, Bureau of Sport Fisheries and Wildlife, North Carolina Wildlife Resources Commission, Virginia Commission of Game and Inland Fisheries, Vol. I, 84 p.

BIRD POPULATION: DISTRIBUTION AND RELATION TO BEACH

USAGE ON CURRITUCK SPIT, VIRGINIA-NORTH CAROLINA

S. C. Sturm

The Southeastern coast of Virginia can be quite productive with many, many species of birds providing interest for both the novice and veteran bird-watcher. Most species may be easily identified with the aid of either Petersen's Field Guide to the Birds of Eastern North America or Robbins' Birds of North America.

Generally, the farther south one travels, the more species and the more individuals can be observed, as shown in the graph in Figure 1. This trend continues south into North Carolina. Also, the farther south one goes (and leaves heavily populated and built up areas), the more likely one is apt to find rarer species of birds. For instance, in the Virginia Beach area pigeons, house sparrows, and starlings may be observed on a regular basis, but the peregrine falcon has been observed on the beach no farther north than Back Bay.

The first and most obvious bird one will see on the beach in the late spring is the gull, of which there are four species: the great black-backed, laughing, ring-billed, and herring. Numerous terns may also be observed either on the beach intermingling with the gulls or diving into the water for food. The terns to look for are the common, royal, caspian, and gull-billed.

In June numerous shore birds may be observed feeding either along the shore or in the swash zone. The most common include the black-bellied plover, semipalmated plover, willet, least sandpiper, and semi-palmated sandpiper. Spring migrants which may still be observed include sanderlings, dunlin, ruddy turnstones, dowitchers, and marbled godwits.

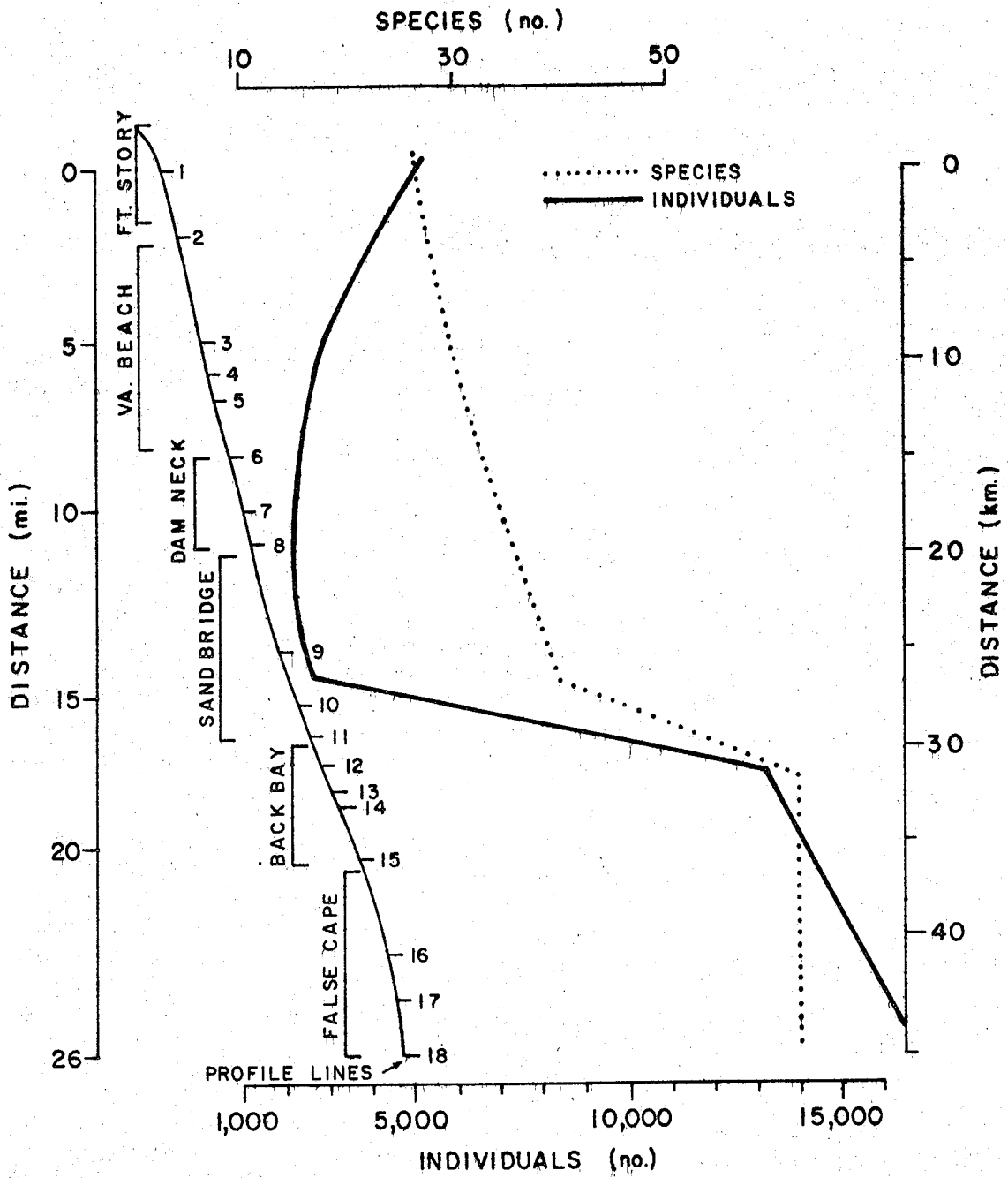


Figure 1. Bird census data, October 1974 to February 1976. (from Goldsmith, et al., 1977)

The most common species found in the dunes are the boat-tailed grackle, yellowthroat, fish crow, Carolina wren, rufous-sided towhee, and song sparrow. Osprey may be observed either flying overhead or diving into the ocean for fish.

In the winter months species to look for include both common and red-throated loons, Canada and snow geese, all three species of scooters and other waterfowl, and birds of prey, such as the marsh hawk and sharp-shinned hawk. During spring and fall migration most of anything can be seen, but the most common species observed include horned grebes, double-crested cormorants, red-breasted mergansers, whimbrel, oyster catchers and black skimmers.

Table 1 is a compilation of birds observed on the Southeastern Virginia coast from October, 1974 to February, 1976.

Table 1.

Bird Census Data

Southeastern Virginia bird observations
(Total number individuals observed October 1973 to February 1976)

Species	Fort Story (military)	Virginia Beach (commercial)	Dam Neck (military)	Sandbridge (residential)	Back Bay (natural)	False Cape (natural)
Common Loon		1	1	12	31	8
Horned Grebe		4	2	8	4	2
Gannet	35	49	50	27	53	189
Double-Crested Cormorant	18	101	5	86	659	671
Canada Goose		19	22		392	6
Snow Goose					762	22
White-Winged Scoter					2	5
Red-Breasted Merganser	20	58	11	43	971	810
Osprey			2		1	2
Black-Bellied Plover	12	2	3	16	145	62
Marbled Godwit					2	
Willet	1	10	33	77	191	118
Ruddy Turnstone		1		1	43	34
Dunlin			23	30	478	1,652
Sanderling	113	146	570	476	1,419	3,677
Great Black- Backed Gull	14	16	65	30	513	696
Herring Gull	1,330	1,507	662	661	2,846	3,772
Ring-Billed Gull	1,949	686	166	534	1,071	1,731
Laughing Gull	45	121	298	66	315	321
Royal Tern	31	28	123	3	96	202
Caspian Tern	25	3	39		55	66
Pigeon		231				
Barn Swallow			2	4	10	36
Carolina Wren	2			1	2	
Starling		12		2	9	1
Yellow-Rumped Warbler				2	37	33
Yellow Throat				3	12	2
House Sparrow		12				
Boat-Tailed Grackle	2	33	29	52	95	105
Song Sparrow		2	3		8	23
Total number individuals	3,611	3,042	2,109	2,134	10,222	14,244
Total number species	14	21	20	21	28	26

EVOLUTION OF THE VIRGINIA, NORTH CAROLINA BOUNDARY

by

Wolf Prow¹

The Commonwealth of Virginia, as other states, is limited in extent and territory by boundaries. The dividing line between Virginia and North Carolina is an example of boundary delineation by compromise and traditional methods of territorial division.

Boundaries are divisions on the surface of planet earth to suit man's conveniences, classifications, controls and frames of reference. Boundaries are either natural or artificial. The former are drawn along topographic, geological, or other physical features. Artificial boundaries are delineated either by latitude or meridians, by lines connecting one reference point with another, or by a geometric pattern. (1)

The evolution of boundaries begins with discovery and exploration, claiming of the area, and allocation by national or international authority. Settlement and problems of jurisdiction compel a more definite delineation of boundaries to end the unstable frontier phase with its indistinct and shifting divisions between entities or interests. Delineation depends upon the state of the art, the skill and techniques of surveyors, ease of access, and reliability and accuracy of existing maps. Demarcation is the final step in boundary establishment and follows surveying and boundary fixing by permanent markers or monuments. (2)

In the case of the Virginia-North Carolina dividing line, amicable solutions were sought and customary procedures in boundary evolution were applied. The original allocation of territory now

¹Geography Department, Christopher Newport College, Newport News, Virginia.

comprising the Commonwealth of Virginia, was granted in 1606 to the Virginia Company of London. Artificial delimitations of territory given as 34° N and 40° N of latitude bounded the earliest allocation. In the year 1609 the Charter was revised and a distance of 200 miles North and South of Old Point Comfort substituted for the earlier astronomic boundaries. The new reference lines embraced nearly the same area that the first Charter had allocated by latitude. (3)

Virginia's territory was more clearly defined by the famous John Smith map of 1608 and many subsequent revisions or "states". This map shows the East coast of North America between approximately $36^{\circ}30'$ N and about $41^{\circ}30'$ N. The grant to Lord Calvert of 1632 was a reference boundary within the same map area and established Virginia's northern neighbor Maryland. The ill-defined or non-existing reference points gave rise to many disputes over the Maryland-Virginia boundary. (4)

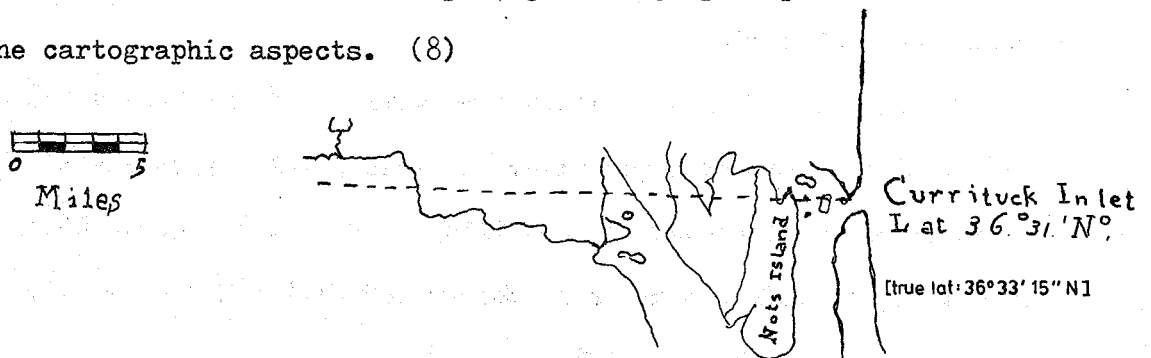
The Charter to North Carolina in 1663 similarly allocated territory by references to islands and rivers, but gave 36° North and 31° North as artificial boundaries by latitude. (5) The second Charter of North Carolina, given in 1665, was the document on which subsequent delineation was based. North Carolina's boundary with Virginia was delimited as follows:

"... extending north and eastward, as far as the north end of Currituck river, or inlet, upon a straight westerly line to Wyonoak creek, which lies within or about the degree of thirty-six and thirty minutes, northern latitude, and so west in a direct line as far as the South Seas..." (6)

The problem with reference boundaries is illustrated by the elusiveness of "Wyonoak creek" which could have been one of several streams. Thus, the 15-mile wide zone between Virginia and North

Carolina was a frontier until the 18th century when problems of taxation, jurisdiction, land titles and voting called for a more precise delineation of the dividing line. Meanwhile, both colonies granted land in the disputed zone. The English crown decreed a temporary stay in land grants. Commissions were to be appointed for a bi-lateral settlement in 1710. However, delays and procrastination on both sides precluded solutions. Since North Carolina blithely continued to grant lands in the disputed zone, controversies flared up and in 1715 the governors of the two colonies, Spotswood and Eden, compromised to accept the crown's ruling and agreed that the Nottoway River would represent the elusive "Wyonoak creek". (7)

Another problem was the prediliction of English rulers to grant the newer colony the opposite shore of waterways. In the case of the Potomac River, bitter disputes marred relations between Maryland and Virginia for centuries. Fortunately, the Virginia-North Carolina case was solved by littoral drift that closed Currituck Inlet and caused the established boundary to cut across beach and berm. At the time of the survey, however, the "north end" of Currituck Inlet served as a convenient starting point for a Virginia-North Carolina boundary delineation. The attached sketch, copied from the map contained with Byrd's Westover Manuscripts, gives a graphic presentation of the cartographic aspects. (8)



The actual survey of the Virginia-North Carolina Line began in 1728. The North Carolina commission was headed by Christopher Gale and the surveyors were Edward Moseley and Samuel Swan. The Virginia commission under William Byrd included College of William and Mary professor Irvin and William Mayo as surveyors. Byrd's "Westover Manuscripts", and especially the long secret diary version of the official report, preserved the details of this expedition for posterity.

(Edmund Ruffin, ed., William Byrd: The Westover Manuscripts: Containing the History of the Dividing Line betwixt Virginia and North Carolina, E. 2. J.C. Ruffin Co., Petersburg, Virginia, 1841)

Assuming the latitude of Currituck Inlet to be $36^{\circ}31'$ North, the commissions began their work in March 1728. The survey made slow progress in the tangled growth of the northern hemisphere jungle which the expedition members named the "Dismal Swamp." Proceeding due West, the expedition reached the confluence of the Blackwater River with the Nottoway 49 miles west of Currituck Inlet. At this juncture an adjustment was made by 44 chains southward to bring the boundary to a latitude assumed to be $36^{\circ}30'N$ as directed by the North Carolina Charter. This is the "Blackwater River Compromise" of 1728 showing as a notch on modern maps. More recent surveys have established the correct latitude to be $36^{\circ}33'15''$ North - or 6 kilometers further North than intended.

Working jointly, the commissions delineated and marked 168 miles or 260 km of antecedent boundary. At this point, approximately 30 miles or 50 km south-east of Danville, Virginia, the North Carolina team left, satisfied that their colony had obtained the territory specified in the Charter. (9)

The Virginia commission measured and marked another 72 miles or 116 km of pioneer boundary. This made it a total of 241 miles or 368 km of North Carolina-Virginia Boundary delineated by the 1728 Byrd Commission. No mean feat in 18th century America when surveys were carried out with Jacob staff and hatchet. (10)

In the ensuing years, the Virginia-North Carolina boundary was continued in successive stages and as population increases called for precise delineation in matters of jurisdiction. The famous surveyor team of Peter Jefferson and Joshua Fry resumed the survey in 1749. Errors of angular measurement caused the extension of the Virginia-North Carolina line to veer further and further north from the base line. The cumulative error was 3° from the $36^{\circ}30'N$ original line. The rugged terrain of the Iron Mountains and possibly some political maneuvers, caused a considerable notch to appear at the juncture of North Carolina, Virginia, and Tennessee borders. This is the "Iron Mountain Notch". Walker and Henderson also conducted surveys which continued the resumption errors and finally placed the westernmost corner of Virginia at $36^{\circ}37'N$ - or 12.9 kilometers disadvantageously North of the intended latitude. (11)

The advent of geodetic surveys and efforts of the federal government in this century established the true locations of Virginia's boundaries. Errors and shortcomings of the past are now demarcated by monumentation and shown on more accurate maps.

Seaward extensions of state boundaries were not a major concern until the present decade. It was not until 1970 that the Virginia-North Carolina line was officially extended seaward just as the land boundary was stealthily extended with man's relentless move westward.

Joint Resolution of the United States Senate 912, Report 92-1299 of 20 September 1972 affirmed the extension of the North Carolina-Virginia line seaward at "the intersection of the low-water mark of the Atlantic and thence due East." To introduce an element of confusion, the earlier house version had provided for "90° due East" and the correction explained that 90° East really means "line of constant latitude." It is interesting to note that the legislators did not specify what this latitude is. However, they provided that the line could be further extended if the need arises. (12) Hopefully, no major disputes over the dividing line will mar relations between states in the future.

While no immediate problems loom in the future, land and riparian boundaries are most seriously challenged when population pressures and clashes of interest occur in valuable areas. Natural boundaries are more tenable in populated areas than artificial ones. (13) A possible source of friction in inter-state relations could be the man-made reservoirs fed by the Roanoke River. The present line cuts across a man-made, but natural boundary with Virginia owning peninsulas and islands on the opposite shores of Buggs Island Lake and Kerr Reservoir while North Carolina projects onto the "Virginia side" in Lake Gaston. An exchange of such promontories and isolated areas may forestall jurisdictional controversies in years to come. A mid-channel division may offer workable solutions.

The Virginia-North Carolina Line offers opportunities for study of boundary lines in microcosm. Historically and geographically, boundaries present a fascinating subject. The Virginia-North Carolina Line is no exception.

REFERENCES

1. J.R.V. Prescott, The Geography of Frontiers and Boundaries, Aldine Publishing Co., Chicago, 1967, p. 37
2. ditto, p. 43
3. F.N. Thorpe, The Federal and State Constitutions, U.S. 59th Congress, 2nd Session, H. Document 357, 1909, p. 3783
4. ditto, p. 1678
5. ditto, p. 2744
6. ditto, p. 2744
7. Linda Jones, The Virginia-North Carolina Boundary, unpublished manuscript, College of William and Mary, 11 January 1972, p. 2
8. Edmund Ruffin, ed., William Byrd, The Westover Manuscripts: Containing the History of the Dividing Line betwixt Virginia and North Carolina, E. 2 J.C. Ruffin Co., Petersburg, Va., 1841
9. ditto
10. ditto
11. Franklin van Zandt, Boundaries of the United States and the Several States, U.S. Government Printing Office, Washington, D.C. 1976, (Geological Survey Paper 909) p. 95
12. Frederick A. Eustis, Lateral Sea Boundaries of the Commonwealth of Virginia, 15 March 1976, University of Virginia Law School
13. Wolf Prow, Virginia's Boundaries, Christopher Newport College, revised March 1977, p. 54

###

SHIPWRECKS ALONG CURRITUCK SPIT AND THE OUTER BANKS

Robert Gammisch

Shipwrecks have long been part of the maritime history of the "Outer Banks" (Fig. 1). These barrier islands, with their treacherous and ever-changing inlets along with the adjacent coastal shoals, have played havoc with sailors and their ships for more than four centuries. Rudders (the secret records of early navigators) and logbooks from the ships of early European, Spanish and Portuguese explorers depict the dangers of what is now Frying Pan, Lookout, and Diamond Shoals. Although the hazards of the route were known, the necessity to utilize the Gulf Stream current for rapid travel made it virtually impossible to avoid these shoals.

Storms which frequent the Hatteras area turn a peaceful sea into the raging savage sea are enhanced by the convergence of the south flow of the Cold Labrador current and the northern flow of the warm Gulf Stream water masses. At the interface of these two major currents, hydrographic and atmospheric phenomenon of great magnitude come into play. Fog, rip currents, sea smoke, and shifting winds plague the coastal seas. The wave refraction occurring over the shallow shoals by long period storm waves can result in areas of complex waves of increased height, and multi-directions, developing destructive forces that can be devastating to maritime traffic. It is these factors that give the Cape its infamous reputation. Ships by the hundreds have been lost to the awesome storms of this Virginia-North Carolina coast. It is for this reason the area has come to be known as "The Graveyard of the Atlantic" (Stick, 1952).

The wrecks of the mid-Atlantic coastline have been an important factor in the history and the culture of the region. It has been found by some researchers that many families on the Banks can trace their ancestry back to survivors of shipwrecks (Dunbar, 1958; Stick, 1952, 1958).

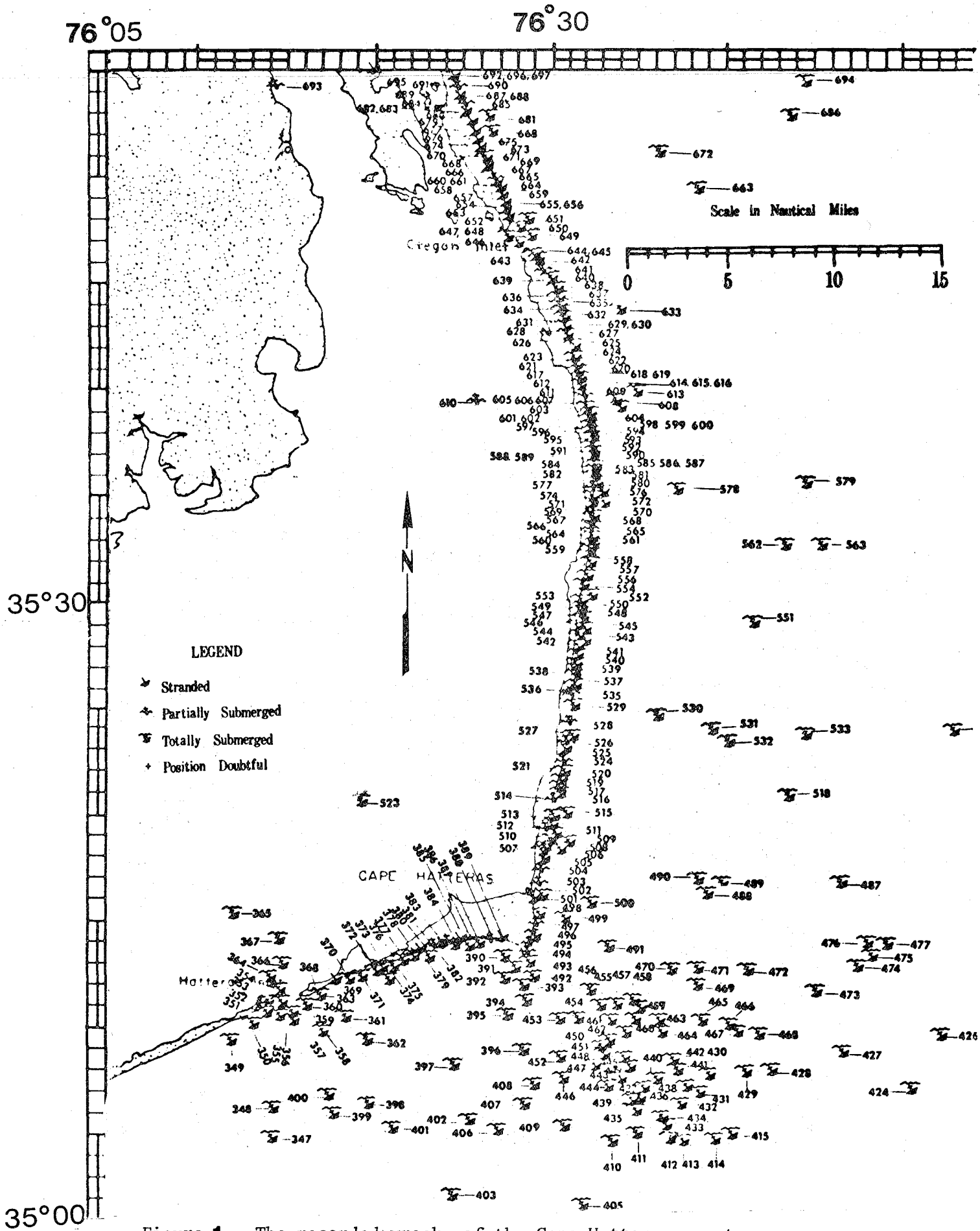


Figure 1. The recorded wrecks of the Cape Hatteras coast (from the Oceanographic Atlas of the Carolina Continental Margin, Duke University Marine Laboratory)

The wrecks of ships were not only responsible for some of the family names, but for names of places and towns. The last example of this must be Nags Head, North Carolina. This area acquired the name through the practice of placing a lantern around the neck of an old horse to lure ships aground. As the horse strolled up and down the beach at night, it gave the appearance of a ship successfully making its way through the treacherous shoals. This routine often caused an unconfident skipper to follow the light and find himself stranded and at the mercy of the breakers.

The names of notorious pirates such as "Blackbeard" (Edward Teach), "Colisco Jack" Rackora, and Anne Bonny echo through the history and legend of the Outer Banks. However, pirates were not the only ones who preyed upon shipwrecked and stranded vessels. Privateering, plundering, and salvage of persons, cargo, and ships stranded on the beach and shoals of the coast has long been a problem for authorities of coastal towns. In order to alleviate the lawlessness at shipwreck sites the federal government set up Wreck Districts along the coast. Each district has a vendue master who was in charge of all merchandise associated with shipwrecks. The vendue master would take charge of cargo and the ship if salvageable, and hold a public auction or vendue. The monies received would pay the salvager and allow the company of the lost vessel to recoup part of their losses.

However, the government still saw the need to prevent the numerous shipwrecks and resulting loss of life occurring on the Banks. The development of lighthouses, such as Corolla light were set up to aid navigation along the hazardous coast. In 1874, the U.S. Life Saving Service expanded their service to North Carolina in hopes of preventing the high loss of life involved with shipwrecks. Although the stations had a record of incompetence in their early going, the men of these stations soon earned a reputation of honor and bravery far beyond the call of duty. Stick (1958) states that in 1876 the Italian Bark, NUOVA OTTAVIA, was wrecked at Currituck Beach when she struck an offshore bar in a March storm. The Jones Hill life-saving station (formerly located about 18 km south of the Virginia-North Carolina State line) launched their surfboat in the darkness of night to assist the stranded vessel. The surfboat capsized and the entire crew was lost to the relentless sea.

Not all lifesaving was this futile. In 1918, Captain John Allen Midgett and a crew of five lifesavers successfully removed 42 persons from the burning British tanker S.S. MIRLO. Midgett and his crew were awarded the Grand Cross of the American Cross of Honor for bravery beyond the call of duty.

The number of shipwrecks have been greatly reduced since the development of modern navigational equipment and storm early warning systems. However, as you travel along the Virginia-North Carolina coast the remnants of ships skeletons and submerged hulks can still be seen on the beach, in the dunes, and the submerged wrecks are still recorded on the charts (Fig. 1). Some of these ships being in their maritime graves are very mysterious with the cause of their destruction unknown. In the wreck of the "Patroit" which suffered minimal damage, none of the crew or passengers were ever found, including the famous Theodosea Burr Alster, daughter of Vice President Arron Burr. The loss of the Monitor after her famous Civil War sea battle, rested on the bottom for nearly a hundred years before its location was established. The Central America sank September 12, 1857 without a trace and to this day neither the ship nor the cargo of two and one half million dollars (1857 dollars) in gold bullion and nuggets have been found. It is all part of the mystery that surrounds the sea and the treacherous coast of the Outer Banks.

During the early years of World War II there was an upsurge in the number of shipwrecks due to German submarine activity. Of great present interest is the fate of the oil lost from these oil tankers. A recent study at the Massachusetts Institute of Technology by D.A. Horn (Hurd, 1977) has investigated the records of the wrecks off Cape Hatteras. Of the 42 oil tankers sunk within 50 miles of the east coast shoreline in 1942, the largest amount of oil was spilled in the Cape Hatteras area, where the Outer Banks shoals forced the tankers into deeper water (Hurd, 1977). Of the 14 spills studied in this area, only three (representing 160,000 barrels of fuel oil and gasoline) were estimated to have been driven on to southern Cape Hatteras and Ocracoke, while the other oil spills were probably driven out to sea. Despite interviews with war-time residents of Cape Hatteras, these researchers were unable to find any information to document proof of the local residents' impressions that the beached oil had only minor environmental impact (Hurd, 1977).

REFERENCES

- Dunbar, G.S., 1958, Historical Geography of the North Carolina Outer Banks: Louisiana State University Press, p. 225.
- Hurd, S.B., 1977, Scientists Find No Effects From Torpedoed WWII Oil Tankers: Sea Grant 70's, Vol. 7, No. 8, p. 4-5.
- Lowdsale, A.L., and Kaplan, H.R., 1964, A Guide to Sunken Ships in American Waters: Compass Publications, Inc., Arlington, Va., p. 189.
- Newton, J.G., Pilkey, O.H., and Blanton, J.O., 1971, An Oceanographic Atlas of the Carolina Continental Margin: Duke University Marine Laboratory, Beaufort, North Carolina, 28516.
- Stick, D., 1952, Graveyard of the Atlantic: University of North Carolina Press, p. 276.
- Stick, D., 1958, The Outer Banks of North Carolina-1584-1958: University of North Carolina Press, p. 352.

*Fare-thee-well, Currituck Banks*¹

article by GARY SOUCIE

The times they are indeed a-changing, faster even than Bob Dylan and his disciples realize. Twelve years ago, when I started going down to the Currituck Banks in North Carolina, I looked forward to sitting around the one-room post office and general store listening to old-timers tell tales of days gone by, when sailing schooners plied the sounds with lumber and kegs of oysters and blocks of ice from New England, when surfmen fought the sea in tiny lifeboats to save the mariners who had come to grief on the treacherous shoals. Then I would regale my friends and acquaintances with retellings of those same stories. There wasn't much use telling people about my own adventures because they weren't anything special. Now, though, with the beach blocked at either end to prevent anyone who isn't a resident or a landowner from driving up or down the Banks, and with most of the land chopped up into little lots that are going for \$10,000 to \$35,000 and up, my own experiences of just a few years ago have become stories of the good old days.

Things are changing rapidly in all the primitive, elemental places around the country, but they seem to be changing even faster down on the Outer Banks. Forty years ago the Outer Banks were still a nineteenth-century kind of place, but each by each the islands and the beaches have been shoved and dragged into the vanguard of the packaged present. I know a fellow in Kitty Hawk who, like the rest of us, watched so many live color telecasts of men walking on the moon they weren't very interesting anymore. As a young boy he drove his family's pony cart down to the ferry landing to carry a couple of bicycle mechanics from Ohio to a boarding house where they were staying, and helped them, the Wright brothers, carry their gliders up Kill Devil Hills. Up and down the Banks I know people who used to be lighthouse keepers, surfmen, market hunters, boat builders, who used to collect and dry eelgrass for mattress and furniture stuffing, who remember when the first automobile came onto their island. And things have changed so rapidly and drastically for these people that television's Waltons seem as quaint and distant to them as they do to those of us who grew up with electricity and telephones.

Fortunately, the Outer Banks from Bodie Island north of Oregon Inlet to Beaufort Inlet at the west end of Shackleford Banks have been preserved in the Cape Hatteras and Cape Lookout national seashores, and on those islands, except for the private lands in the villages and inholdings, the passage of time will be managed more gracefully and with more respect for the past. The southernmost islands and the Nags Head-to-Kitty Hawk beach just north of Cape Hatteras National Seashore have been brutalized and trashed-up with fast-food franchises, bowling alleys, miniature golf courses, fiberglass igloos, asphalt parking lots, and souvenir shops where you can buy the same decalcomaniaed junk from Taiwan and Japan that you can buy in Bayonne or Anaheim.

Of the still-unprotected, privately owned Outer Banks, only the Currituck Banks made it past the midpoint of the twentieth century without much change. As recently as 1964 the Secretary of the Interior could look down from an airplane window and, having just flown over the sardine-packed subdivisions of Virginia Beach, be amazed by the empty wildness of the barrier strand that ran on for mile after roadless mile, the wide flat beaches dark-threaded with flotsam and sea wrack, the surf marching ashore from the diamond-specked cobalt of the Atlantic Ocean in white echelons that foamed over rotting timbers and rusted hulks of wrecked ships.

When an aide told Stewart Udall that the Currituck Banks were all privately owned but mostly uninhabited, he suggested they ought to be preserved in their primitive state, ought to be publicly acquired as a national seashore. But the idea of a Currituck Banks National Seashore was a short-lived one, aborted almost immediately after conception. Udall's remark, reported by the journalists on the flight, made headlines in the area's newspapers and triggered a gale of opposition. Dixiecrats and states'-righters fulminated against government takeovers and federal piracy of tax-ratables. Old anti-park animosities that had been kindled a decade earlier by the federal government's clumsy handling of land acquisition at Cape Hatteras resurfaced. The few

¹Reprinted with permission from Audubon Magazine (1976, v. 78, No. 1, p. 22-35). This article is included here in order to present the recent background and the feelings invoked in one of the visitors to the area. Inlet history, dune development, and processes mentioned here, are described in detail in a series of articles within this volume by Hennigar, Gutman, and others.

residents and landowners on the Currituck Banks renewed their half-century-old clamoring for a hard-surface road to connect the Virginia and Carolina beach resorts. And the land speculators and developers who had been junking up beaches to the north and south discovered a new target of prime raw beachland.

Years later Stewart Udall told me his national seashore proposal had been little more than an off-the-cuff suggestion, the old running of an idea up the flagpole to see if anyone would salute it. It got the down-home version of a twenty-one-gun salute; in the best Tarheel, good-old-boy tradition it was blasted to bits. "No conservation groups came forward with support," Udall explained, "so the idea just died." Trouble was, Udall's idea received almost no publicity outside the immediate area and in 1964 there wasn't an organized conservation group within a hundred miles of the Currituck Banks. Anyway, Udall had other fish to fry that day. He was flying down from Washington to look at Portsmouth Island and the Core and Shackelford banks, islands that were authorized two years later for incorporation in a new Cape Lookout National Seashore, a project that has not yet reached fruition.

But that was twelve years and five Interior secretaries ago—ages the way conservation politics are reckoned—and the Currituck Banks are gone. The barrier islands are still there all right, and most of the land is still empty. But the opportunity has vanished. Where once there were but two dozen landowners and only the most modest of homes and capital investments, now there are several thousand landowners, hundreds of new beach homes ranging from the shabbiest of shanties to multi-kilobuck palaces, and half a dozen developers with investments in the millions and even bigger plans. Lot sales have pushed the average market value up to \$75,000 an acre, land that was assessed a few years back at \$8,000 to \$9,000 an acre. In 1962, I was offered an acre in Corolla for less than \$900. And up in Washington, where once we had a President and an Interior Secretary who cared something about parklands and conservation, now we have an administration which actively opposes investing in such values.

THERE IS NO USE dwelling on dashed dreams, I know, but perhaps there is a lesson somewhere in the story of another wild place that has been lost. And for the next few years, until more of the land that has been sold or is on the block has been developed, until the NO TRESPASSING and KEEP OUT signs are everywhere, the Currituck Banks will still be a good place for terminal beach addicts like me. Now that random mass access is impossible, there is no need to worry about spoiling the place through publicity. You can still go there if you know the right people, if you are willing to buy the right credentials (a lot in one of the subdivisions), or if you have a good boat and a skilled skipper.

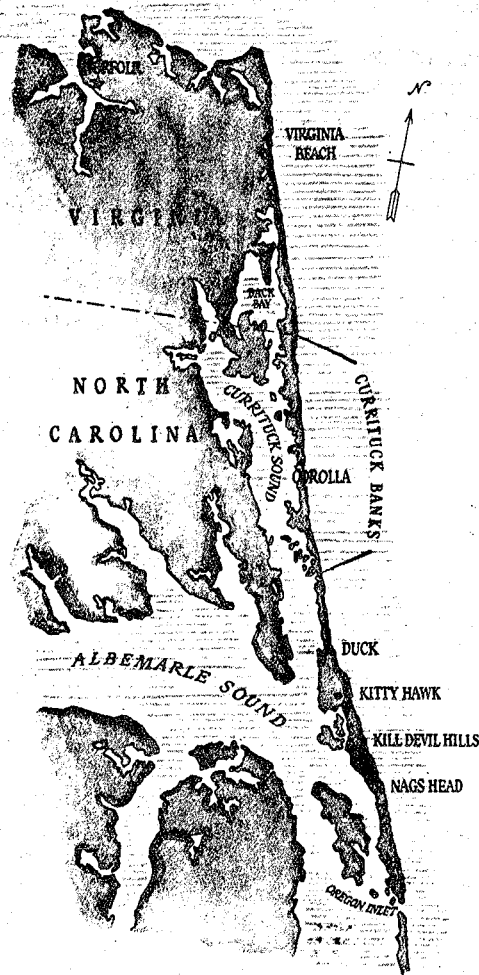
Even before the guardhouses were put up at each end—in Back Bay National Wildlife Refuge to the north, to protect the dunes and beach habitat from the tens of thousands of weekend joyriders who nearly wiped out the ghost crab population, and at the entrance to Pine Island Gun Club to the south, to protect the solitude from the masses and the big-buck developments from the hoi polloi—it was always a little difficult to get to the Currituck Banks. From the north you could drive a car down the beach at low tide, unless an

incoming storm was keeping the water high up on the beach, but you had to have a four-wheel-drive vehicle to get in from the south. Between Kitty Hawk and the old Poyners Hill Coast Guard station the beach was too gravelly for driving, and you could tell how recently anyone had tried. If it had been since the last big storm there would be a car stuck in the sand up to its windows. There is a paved road from Kitty Hawk to the little village of Duck, and beyond Duck there is a graded sand road north to the old Caffey's Inlet Coast Guard station. From there to Poyners Hill you had to drive the "pole road," sinuous, deep-rutted tracks in the sand beneath the old Coast Guard telegraph line. At Poyners Hill you could make a run over the foredune to the beach, and then it was duck soup the rest of the way.

From the late 1940s into the mid-1960s you might have been held up at either end if Navy fighter-bombers were strafing the two beach ranges on either side of the village of Corolla, which was where you were most likely headed. The first time I went up to the Currituck Banks from the south, I had arranged for Norris Austin, the youthful postmaster at Corolla, to meet me at Caffey's Inlet. Before I got there I was stopped by Navy guards because jet fighters were attacking the beach. That didn't deter Norris from driving right through under the hail of 20-millimeter cannon fire to pick me up. "You get used to it," he said. He told me about a time when an unknowing trawler followed a school of fish right into the inner bar just offshore from one of the ranges. When the Navy pilots arrived and found a boat setting nets just a few hundred feet past their target, they made several low passes trying to wave off the boat. All they got in return were clenched and shaken fists. Finally the pilots decided they had wasted enough time and fuel and came down blasting away at the water next to the trawler. From the top of a dune, Norris saw the fishermen hit the deck and the captain crawl into the wheelhouse to throw the throttles full ahead. "They took off straight out to sea, dragging their nets and tearing them up something awful," Norris chuckled. "I never did see that particular trawler around here again." On one of the islands in Currituck Sound, I have heard, the fellow who lived there wore a steel helmet to protect his head against the rain of spent casings when the warplanes were running on target.

The next time I made the trip up from the south, some five years later, the beach ranges were closed, but it was a moonless night with fog so thick that we actually had to navigate into Corolla by the flashing beacon of Currituck Beach Light.

NO MATTER THE TROUBLES, it has always been worth getting to the Currituck Banks. Until the recent spate of development, the whole stretch of barrier beach, from where the paved road ended at Sandbridge Beach in Virginia, down to the end of the paved road at Duck in North Carolina—a roadless distance of nearly forty miles—contained almost nothing but beaches and dunes, woodlands and thickets, marshes and a few freshwater ponds, Coast Guard stations and hunting lodges, a few scattered beach bungalows and fishermen's cottages, Back Bay National Wildlife Refuge at the north end, and the village of Corolla about two-thirds of the way down. Of that



stretch, about twenty-four miles—from the Virginia line south of False Cape to the Dare County line just north of the Caffey's Inlet Coast Guard station—constitute the Currituck Banks, a land that would have made an absolutely stunning national preserve. Even in a state that already has two national seashores, a Currituck Banks National Seashore would not have been superfluous.

Among the many remarkable features which distinguish the Currituck Banks from the national seashores farther south are the great aeolian dunes that native Bankers always call hills, or sometimes ridges, but never dunes. Several of these dunes top out around one hundred feet above sea level, three to four times higher than anything at Cape Hatteras or Cape Lookout. Like the clouds, only more slowly, they are constantly in motion, changing shapes and even positions in response to the caprice of the winds. With the strong winter gales of northeast storms pushing hardest, the migration of these dunes is steadily to the southwest. Old-timers here say that in times past, whenever a dune threatened to bury someone's house, a couple of handshakes was all it took to arrange a casual and sometimes temporary land swap, and the house would be moved on rolling logs with everyone pitching in to help.

In the 1950s the great dune called Pennys Hill started encroaching upon an entire community, the little fishing village of Sea Gull. Without heavy equipment or government aid at their disposal, residents were powerless to do

anything but abandon their community to the advancing sands. In 1964 the last house on the south edge of Sea Gull was just beginning to go under, and the foreslope sands were sifting through the first-floor windows. The roof ridge of another house could still be seen, but barely, through the sand along one flank. Now the wrecked skeletons of houses at the north end of the village are being exposed as Pennys Hill continues marching to the southwest, spilling over into the loblolly and live oak woodlands, burying the myrtle and holly thickets and willow marshes on its way to Currituck Sound. It may never reach the sound, however, for in the process of destroying Sea Gull, Pennys Hill destroyed itself, and the great sand massif that had been one of the most prominent landmarks on the Banks is nothing but an elongate ridge, a dinosaur's back of sand.

Some dunes of fairly recent origin are unnamed, so far as native Currituck Bankers are concerned, even though a few new maps have them labeled with names like Pipers Hill and Fresh Pond Hill. Just when the old dunes got their names—Lewark Hill, Pennys Hill, Jones Hill, Whale Head Hill, the Three Sisters—no one seems to know. But it must have been a long time ago. Anyone who knows the Currituck Banks can locate Poyners Hill with precision on a map or on the ground, but there is no dune there now, and no one alive can recall there ever having been a dune at Poyners Hill.

Between these big dunes of the midbeach and the rising waters of the Atlantic are complexes of smaller dunes and sandy bumps that can send a beach buggy end-for-end if you try to take them too fast, and an almost continuous line of foredunes that were built during the 1930s by laborers of the Civilian Conservation Corps. Geologists, coastal engineers, historians, and old-timers of the beach are in continuous dispute over this dune line. Some say there were similar, natural dunes before grazing cattle ate the stabilizing grasses and the anchorless dunes were flattened by winds and storm tides. Others say that such a dune line never existed before the CCC boys put up nearly three million yards of sand fencing along the Outer Banks and planted more than two and a half million trees and shrubs to catch the blowing sand and hold it in place. At any rate the foredunes are there now, except in a few places where they have been leveled by storm tide surges, and protecting them has become an almost sacramental standard in the budding alchemistic science of coastal zone management.

THE CURRITUCK BEACHES are really something else. They are wide and flat and are not eroding as rapidly as the beaches both north and south. On a summer weekday you can pick just about any spot and have the beach all to yourself, the whole day, for as far as you can see in both directions. Occasionally a jeep or truck may pass, usually a surf fisherman or a local resident, sometimes a couple of sailors from Norfolk or Newport News, Virginia, with the day to kill. Even on weekends you won't be bothered much by other people, unless you are unlucky enough to have picked a spot near one of the developments that already has a lot of cottages on it, or one that is being hustled hard. Then you will have to share the beach with bickering, beer-swilling families, their barking dogs and whooping kids, or you will be interrupted constantly by salesmen carrying prospects up and down the beach to look at lots or trucks carrying building materials.

Generally, though, you can just laze and walk and swim in solitary leisure, watching the gulls and terns and shorebirds strutting and winging along the beach, or the hawks wheeling high above the dunes and thickets of the back beach. You can stroll along and find more whelk shells than you can carry, puddle in the surf for tiny, rainbow-hued coquinas, or dig at low tide on the inshore bars for surf clams. The last time I was on the Currituck Banks I spent the better part of a morning watching a big herd of porpoises feeding and migrating along the shore. A few years ago you couldn't find a brown pelican anywhere along the North Carolina coast, but they are coming back now, and to my mind one of the great pleasures of the beach is watching these birds fishing and wondering how they survive their ungainly plunges into the sea without breaking their wings or necks. (I could look up the answer, but I like the wondering better. It helps preserve the mystery that is the attraction of the sea.)

Up at Wash Woods (renamed Carova Beach by its developer) near the Virginia line, or on the beach in front of the old Monkey Island Club property (on the market now, if you have about \$3 million), you can see plenty of evidence of beach erosion in the hundreds of tree stumps, rooted in peat, right out on the beach and in the swash. Coastal geologists and ecologists I have talked to tell me these stumps have been dated at 400 to 800 years, part of a woods on what was then the sound side of the Banks. Pessimists among them say this shows how serious the erosion problem is, while the optimists cite the stumps as proof that the islands and barrier beaches are not eroding away but merely retreating westward from the rising sea. A few years ago I found an old beach jalopy literally wrapped around one of these stumps. I've heard various accounts of how it got there, ranging from a tragically fatal story of two night beach riders' plowing into it while drunk, to its having been aimed intentionally at the stump by a driver who dived out a la James Dean in "Rebel Without a Cause."

Fifty years ago you would have met a Coast Guard surfman anywhere along these shores. In the 1870s the U.S. Life Saving Service (which merged with the Revenue Cutter Service in 1915 to form the Coast Guard) was established to cut the loss of life and property in coastal shipping. Manned lifeboat stations were established every six miles along the Outer Banks, which were called the graveyard of the Atlantic by mariners who regarded this as the most treacherous stretch of shoreline in the country. On the Currituck Banks there were life-saving stations at Wash Woods, Pennys Hill, Corolla, and Poyners Hill. The surfmen would walk the beaches between the stations to watch for grounded or foundering vessels, meeting at little shelters midway between the stations to exchange numbered brass checks to prove that the whole beat had been pounded. When a vessel in distress was sighted the surfmen would haul their heavily laden beach cart through the deep sand, set up their Lyle guns and faking boxes, and fire projectiles out to the distressed vessels to set up a breeches buoy to haul off the passengers and crew. When the wrecks were too far offshore, the surfmen would set out against even the fiercest of seas in their little surfboats. Their motto, taken in dead earnest, was, "You have to go out; you don't have to come back." Many of them didn't, and the largely unremembered valor of these surfmen was one of the finest episodes in American history.

As coastal shipping declined and as the Merchant Marine and the Coast Guard turned to radio and radar and even

more sophisticated electronics for navigation, communications, and coastal surveillance, the stations were closed one by one, and now there isn't a Coast Guard station between Norfolk and Oregon Inlet. The Wash Woods station, now within the development called Swan Beach, has become a summer beach house. At Corolla there are three old stations. The Currituck Beach station, built in 1905 to replace the original station at Jones Hill, is being outfitted as a beach house, as is the original 1878 Poyners Hill station that was hauled up the beach after its decommissioning. The old Pennys Hill station, similarly moved to Corolla, sits neglected and decaying within the compound of the old Whale Head Lodge hunting club, now owned by the developer of Whalehead Beach. In the whole United States I know of only one of these old life-saving stations that has been preserved and restored to its original condition—the New Shoreham station that was moved in 1969 from Block Island to Mystic Seaport, the marine museum in Connecticut.

ACROSS THE BARRIER BEACH is Currituck Sound, a large shallow lagoon fringed with marshes and marshy islets, choked with water milfoil and hardly a pale image of its former self. In the eighteenth and nineteenth centuries Currituck Sound, like the other North Carolina sounds that separate the Outer Banks from the mainland, bustled with shallow-draft schooners and the little sharpies of the watermen who worked the teeming waters. Shipping disappeared with the coming of railroads and highways, and fishing succumbed to a whole train of events. In 1828 New Currituck Inlet, the last of the direct links between Currituck Sound and the Atlantic, closed, and within two years the whole sound, more than a hundred square miles, was changed from saltwater to freshwater. The shellfish grounds and the traditional fisheries that sustained the Currituck Banks villages were destroyed. With no outlet from their little soundside harbors to the sea, Currituck fishermen were unable to develop an offshore fishery like the ones farther south in Carolina or up in the Chesapeake Bay area. For a while a marginal fishery in the sound for shad and other anadromous fishes and for black bass was pursued, but the pound netters were driven out by the pollution and damming of the mainland rivers that were the breeding grounds of the anadromous fishes and by game laws that reserved the bass for sport anglers.

The closing of New Currituck Inlet was a major geological event; but it was a socioeconomic *force majeure* as well. It ended the physical insularity of the Currituck Banks, made the Bankers more dependent upon and therefore vulnerable to outside influences, and it turned these watermen into people of the land.

After the freshening of Currituck Sound, waterfowl and swans and wading birds came in great numbers and for a time supported a new industry, hunting. In the last half of the nineteenth century and into the twentieth, Currituckers who had always hunted for the table started gunning for northern markets. A man who owned a good gun and who was a good shot could support his family for a year on income from the waterfowl wintering season. But with birds selling for just two bits to four bucks a pair, you had to kill a lot of birds. The wildlife toll during the market-gunning days was unbelievable. Millions of birds fell to market hunters from Jamaica Bay, New York, to Currituck Sound. In 1905 two

Currituck gunners, Van and Russell Griggs, killed 892 ruddy ducks in a single day. The gunners' tolls and the destruction of nesting wetlands far to the north was more than the fowl could bear, and populations fell off rapidly. Finally, in 1918, Congress passed the Migratory Bird Treaty Act, which established hunting seasons and bag limits and outlawed market hunting.

The best gunners could still get a meager living by guiding for wealthy sport hunters who had been coming down from New York and Philadelphia and Washington since at least 1857, when the first of the Outer Banks hunting clubs, the Currituck Shooting Club, was established. But the clubs could only support a few guides, and the profession withered away as the geese started short-stopping in the Chesapeake cornfields and the "sports" started losing interest in clubs that were costing more and more to maintain and repair and as the cost of a day's hunting climbed past a hundred dollars.

You don't see many ducks and geese on Currituck Sound these days. The duckweed and eelgrass they favor have been decimated by the ravages of hurricanes, disease, and competition from the water milfoil that grows so thick. The waterfowl that still come south of Chesapeake Bay seem to know that food and habitat are most plentiful in the national wildlife refuges at Back Bay in Virginia and at Pea Island, Mattamuskeet, and Swanquarter in North Carolina. But whistling swans are fairly abundant in winter, and nothing quite so brightens a gloomy January day as watching these graceful birds lighting up the dark waters under the gray overcast. Wading birds still stalk the sound's shallow waters, and there is a major rookery of herons, egrets, and ibis on Monkey Island north of Corolla.

WITH EACH EBB AND FLOW in the economic tides, people moved onto or off the Currituck Banks, but in this century the trend has been inexorably downhill. Once there were several hundred people living in the fishing and Coast Guard villages, or in little family clusters of cottages in the soundside woods. But these villages disappeared one by one as it became more and more difficult to earn a living and support a family. Several of the old communities died with the decline of fishing in Currituck Sound or when open grazing of cattle was banned in the 1930s as the price of getting an Outer Banks road, a road that never pushed north into the Currituck Banks. Wash Woods disappeared when its Coast Guard station was closed. Sea Gull was buried almost a generation ago. Pennys Hill, the little community northeast of the migrating dune from which it got its name, hung on after the closing of its Coast Guard station, but the vestigial village was utterly destroyed in March 1962 by the tidal surge of the Ash Wednesday storm. Now only Corolla remains, and the 35 people still living there hardly know what is in store for them with the subdivision and development of their lonely barrier beach.

Norris Austin's father, John W. Austin, the doyen of the whole Currituck Banks community, came to Corolla from Cape Hatteras as a month-old infant in August 1891 when his father became keeper of Currituck Beach Light. He has lived through a life of change on the Banks and is of two minds about what he sees happening. He hates to see so much of the lonely Banks changed, and he fears that "the money crowd" will crowd out the native people and the old ways of life. But the kind of life he knew and loved is gone

forever, and he hopes that development will bring income and social amenities that will enable his sons and nieces and nephews to stay on the Banks and earn a decent living.

Except that he was never in the Coast Guard—in World War I he joined the Army and went off to fight in France—John Austin's life pretty much tells the story of the Currituck Banks in the first three-quarters of this century. The light his father kept was automated in the 1930s, and the keeper's cottage in which he grew up is rotting away in the woods. Before the war he was a market hunter, and later he guided for some of the hunting clubs. Like all Bankers, John Austin has fished some and trapped muskrats in the marshes, and his family kept cows until open grazing was prohibited. When Corolla had a school he drove the school bus, and his little country store and one-pump gas station did a fair business until everyone left the beach for jobs and security in the Norfolk-Newport News-Virginia Beach area.

His son Norris has seen a lot of change too, for within the thirty-eight years of his lifetime the Coast Guard stations and the hunting clubs have disappeared from the beach, and with them most of the people. Norris Austin has lived his whole life on the Currituck Banks, except for a few months when he lived with relatives on the Currituck County mainland to attend high school and for a brief stint in the Coast Guard. "They turned me out in six weeks with a medical discharge for flat feet," Norris says. "I had never walked on pavement before, and my feet swelled all up."

The part of growing up on the Currituck Banks that Norris recalls most fondly is the period during and just after World War II. Corolla was a proper town then, with a school, church, two stores, a gasoline pump, even a movie theater. When the war broke out Corolla had a population of around three hundred, and that was doubled when the Navy and Coast Guard moved onto the beach in strength to guard against the possibility of an enemy invasion of the landing of Nazi spies and saboteurs. The Coast Guard stations that had been closed were reactivated, the Navy had a radio station in Corolla, and the Coast Guard took over the Whale Head Lodge for a training base.

There was excitement aplenty then for a young boy. There were lots of new people and important comings and goings, the Coast Guard penned the horses that were used on beach patrol in the old lighthouse keeper's dooryard, and there was a K-9 Corps kennel too. In the first year of the war Nazi U-boats operated right off the coast, and Norris recalls that "one Sunday night after church, we all went up on a dune and watched the submarines sink a tanker."

When the war ended and the Navy and Coast Guard pulled out of Currituck, things slowed down drastically and people started drifting away from the beach villages to the mainland. Still, it was an exciting time if you were young and could ignore the economic problems. But there were other problems that could not be ignored. In the mid-1950s so many hurricanes battered the North Carolina coast that the Outer Banks were being called Hurricane Alley. In the fall of 1954, my senior year of high school, I thought I was having a rough time with a couple of girls named Madeleine and Willa, but the Currituck Bankers really had their hands full with ladies named Carol, Edna, and Hazel, to name just the worst storms. The next year it was Connie and Diane and lone, and in 1958 it was great hurricane Helene.

And in the 1950s the bombing ranges were in daily use by

the Navy planes, and Norris and other youngsters scavenged the beaches for the spent brass casings. It took five casings to make a pound, and there was a salvage dealer in Norfolk who would pay 45 to 60 cents a pound for the brass, and in a good week you could make as much as \$70, a not inconsiderable part of the family income. One older fellow tried to beat the kids to the casings by holing up right on the range during target practice in a cave he had tunneled into the side of a dune.

Since its construction in 1921, Whale Head Lodge has been a dominant force in Corolla's affairs. When the club's members were coming down in full force each winter to hunt, the lodge supported a few families by providing guiding and other jobs. After its wartime economic boom, the lodge withered away. Then in 1958 it became a summer academic makeup school for a hundred teenage boys, and that meant a few seasonal jobs. But in 1962 Corolla Academy moved to England. For a few years after that Atlantic Research Corporation used the lodge for testing small rocket engines, and its force of day workers brought new business to the Austins' store and gave Norris employment as a night watchman. But the company fell on hard times when the space program was cut back and sold the lodge and its lands to a developer.

LIKE HIS FATHER, Norris Austin is divided over the impending development of the Currituck Banks, and even more intensely because he will have to live the second half of his life with the results. He hopes that more people will mean new friends, the upgrading of his third-class post office, and a decent business for the little store he and his brother have taken over from their father. Like his father he worries about what will happen to the local people when tens of thousands of rich outlanders dominate the beach with their different life-styles and social goals, their ability with their tax dollars to command the attention of mainland politicians better than a few tens of local people can with their votes. "The money power never has done right by the native people," Norris says, echoing his father, "and what is going to happen to us once they turn the whole beach into a millionaires' row? What's happening to us now is what happened to the American Indian: we're being pushed off our land and crowded into the background."

Norris is hedging his bets. While he complains that the developers are insensitive to local people's needs, and carries his fight to a mostly uncaring county commission, Norris has taken out a real estate salesman's license and is peddling lots along with postage stamps, soda pop, and candy bars. "The way I figure it, the native people ought to get something out of all this development." And just in case, as he fears, being a landowner in one of the developments will carry more political weight than being a lifelong resident, Norris has bought an \$11,000 lot in the Ocean Sands development south of Corolla.

Corolla fisherman Buddy Pontin knows that his time on the Banks is running out. "As soon as you get a lot of people living here in the summer who have not lived around fishing all their lives," he says, "I'll be regulated right off this beach. It happened to me up in Maryland, and it will happen here." Haul-seining from the beach, the only kind of commercial

fishing that is practicable on the Currituck Banks, inevitably runs afoul of tourists and surf fishermen on developed beaches. When the fish aren't biting, the surf fishermen howl that the seiners have caught or scared away all the fish. Swimmers and sunbathers complain about dead trash fish that are inevitably left behind, smelly, unsightly, and attractive to sharks. And once the complaints start, that will be the end of the haul-seiners, for what is the political weight of one little business and four or five families' livelihoods against the serenity of the tax-paying, money-spending thousands?

The Bankers and the Currituck County government never have gotten along very well. Each side distrusts the other, and they call each other names: fish-eaters and pig-farmers. The Bankers resent paying taxes and getting nothing in return: no schools, roads, water, sewers, fire protection. The only county presence on the beach is Deputy Sheriff Griggs O'Neal, a native of Pennys Hill, and until recent years O'Neal worked without pay and had to furnish his own uniform and four-wheel-drive pickup. The county commissioners complain that, for the few taxes the native Bankers pay, they demand too many services and always vote wrong (that is, against the incumbents, who are usually reelected).

People have been living on the Currituck Banks for three centuries, and in all that time have managed not to muck up the place. The new people are different, for they are people neither of land nor of sea, but creatures of the city who think they can buy whatever they need. When developers got their hands on the old Coast Guard and hunt club properties in the late 1960s, the Currituck County government was only too happy to approve anything that was proposed, so eager were they to reap the windfall of all those new tax dollars. The first developments were really god-awful things, \$25 down and \$20 a month, no promises or services included, and the people in the recreation-starved Norfolk metropolitan area gobbled up the lots by the thousands. A few of the new landowners in Carova Beach, the first of the subdivisions, put up tasteful A-frames and beach bungalows and for their care were rewarded with a view of their less-discriminating neighbors' creations: battered old school buses dragged into service in the dunes as weekend retreats from the meaner environments of rowhouses and shipyards, beach shanties clapped together of whatever could be found that was free or cheap, and trailers of every vintage and state of repair. One fellow even put up a twenty-foot-high plastic Kewpie doll in a bikini. In the inner city it takes years or even generations to make a slum, but these enterprising folk did it overnight.

TOO LATE, THE CURRITUCK GOVERNMENT woke up to what was happening. Besides tax money, these people were bringing problems into the county: septic fields wound up polluting the thin lens of freshwater under the sand, trash and solid waste by the ton, beach buggies that were tearing down the dunes and rutting the beaches so the erosive waves and tidal currents could get a better purchase. When Back Bay National Wildlife Refuge decided to close its beach to through traffic, the new lot-owners set up one hell of a howl for access. Aside from its farms and a few grain elevators and other agricultural enterprises, Currituck

County's business community is limited to a handful of gas stations and country stores. If the new beach landowners succeeded in getting a paved road down the Banks connecting the shore resorts in North Carolina and Virginia, the county's only hope for a future economy—the development of businesses along the mainland highways to tap the wallets of the hundreds of thousands of Virginians and northerners on their way down to Nags Head and Cape Hatteras—would disappear. So the county commissioners rushed through a primitive zoning ordinance and slapped a temporary moratorium on new developments and hired a consulting firm, Envirotek Inc., to develop a plan.

The Currituck plan that evolved is about what you would expect from a rush effort ordered too late by a county so primitive that you can't buy a white shirt or get a prescription filled anywhere, a county that in three hundred years has yet to put up its first traffic light or install its first water or sewer system. With nothing that is legally binding on developments already approved, the plan offers heavy densities as inducements for cooperation by the developers, disguised as always as cluster development for environmental protection. The Currituck plan provides the usual planners' panaceas: communal open space, a state park (a proposal that already has fallen by the wayside), and the inevitable elevated monorail option that no one is seriously considering. So far the state has refused to consider even the ferry service to the Banks that is the plan's first-phase access solution, and the bridges proposed for the future may be a long way off indeed.

How people react to the Currituck plan depends upon how closely they are involved with it. Jerry Hardesty, the county agricultural agent who is chairman of the Currituck County Planning Commission, thinks it is "a fine beginning." He admits readily that the plan has some flaws, but one suspects that his general optimism is unwarranted.

Dr. Arthur W. Cooper, assistant secretary for resource management of the North Carolina Department of Natural and Economic Resources, says, "I could start out by damning it with faint praise, because it's the best thing we've got. They had some pretty brutal givens—really shoddy developments platted and approved that should never have gotten off first base. We are terribly worried that we've bought too much density for a little planning, which the developers might have had to do anyway. Anytime you get involved in something like this you are left with a substantial doubt as to whether you are doing the right thing. Wisdom tells me that barrier beach development per se is simply a bad idea. I hate to say that Currituck County is a practice ground for the state's planning efforts, because the Currituck Banks are far too important a resource for learning by mistake, but I'm afraid that's just what it is, the state government's first effort at comprehensive planning. And I know we are going to make a lot of mistakes that will come back to haunt us."

The developers accept the plan because nothing in it forces them to do anything and its design allows them to make at least as much money as they were planning to make without it. Indeed, the suggested services and proposed controls enable them to sell their lots for higher prices to a more well-heeled clientele. "We're ready to do anything the county or the state wants us to," says Sam Riggs of Kabler and

Riggs, the Virginia-based developers of Carova, Swan, North Swan, and Whalehead beaches. "First they wanted our lots made bigger, and we did. Now they want them smaller, and we'll do that too."

Norris Austin speaks for most of his fellow Currituck Bankers when he says, "Before the Currituck plan came along, Ocean Sands had 700 lots platted and Whalehead Beach had 800. Under this so-called plan, Ocean Sands has 3,600 lots and Whalehead Beach has 4,700. And they have thrown in a lot of high-rise condominiums and a lot of other things we don't need or want out here."

James E. Stacey Jr. of Norfolk, a professional city planner who has nothing whatever to do with the Currituck plan, offers these professional judgments: "The Currituck plan impresses me as being a normal city or county plan with a lot of environmentalism thrown in to make it seem like something it is not. I dislike development planners posing as environmental planners whether they work for a county or for a consultant such as Envirotek. But this is likely to continue to occur until the American Institute of Planners' Environmental Planning Department agrees on a system of ethics—which is not going to happen in the near future. Without the necessary policy specifics that get right down to the lot and parcel level, this plan is just another Magic-Marker exercise."

Out of a turbulent past and facing an uncertain future, the Currituck Banks exist in a perplexed and perplexing limbo of a present. While people haggle over the various niceties and access options of the Currituck plan, lot salesmen keep selling lots and the situation continues to slide downhill. Whether the "new-federalist" program established by the Coastal Zone Management Act passed by Congress in 1972 might be able to bring any order to this chaos is anyone's guess.

For the next couple of years, at least, the Currituck Banks will remain among my favorite shoreside haunts. For the future, though, I may have to content myself with telling seashore stories of the good old days back in the 1960s when you could go down to the beach at dawn and pick up lunch and dinner from the discards of the fishermen's haul seines—blue crabs, spots, mullet, almost anything you wanted—and when you could plunge naked into the surf and swim as far out as you wanted because there were no lifeguards or beach cops to tell you that you couldn't, or any to save you if you got caught in a rip current or in the path of foraging sharks. You could walk yourself weary along the beach picking up shells or prowl through the woods and dunes botanizing and birdwatching and maybe scaring yourself half to death when you encountered a feral hog with two-inch tusks. You could do all these things and others without any fear, for you knew that in all those hours and miles you would never come across any sign that told you not to do this or to buy that, or encounter any living thing as voracious or as greedy as your fellow man. ☼

CHARACTERISTICS OF THE EASTERN SHORE OF VIRGINIA
(FOR CONTRAST WITH CURRITUCK SPIT)

Thomas E. Rice¹

GENERAL INTRODUCTION

The Eastern Shore of Virginia is the term applied to the geographically isolated Atlantic coastline of Virginia north of Chesapeake Bay. It is a barrier island coastline characterized by relatively short islands and numerous inlets. Figure 1 illustrates the area of the Eastern Shore. This coastline contrasts sharply with the generally straight, smooth, and continuous coastline along Currituck Spit, which more closely resembles the shoreline along Assateague Island in Maryland.

There are three distinct sections of this barrier island coastline. The northern section presents a shoreline that is concave towards the mainland. This section begins at Chincoteague Inlet at the north end of Wallops Island and ends abruptly at Wachapreague Inlet at the south end of Cedar Island. The middle section presents a shoreline that is convex toward the sea. This section begins at Wachapreague Inlet and ends at Sand Shoal Inlet, and includes Cobb, Hog, and Parramore Islands. The shoreline of the southern section also is convex to the sea. The section begins with Wreck Island at the north and ends at Fisherman's Island at the mouth of Chesapeake Bay. The three sections of the island chain have responded in different ways to the coastal processes acting on this shore over the past 125 years.

The coastline of the Eastern Shore is subject to rapid geologic changes, and has been for centuries into the past. The geomorphology of the islands and their marsh areas records a regression-transgression that is apparently post-Holocene in age. Changes in shoreline position in excess of a kilometer in the past century are not uncommon among these islands.

Most of the islands of the Eastern Shore are accessible only by boat. At the north end of the Virginia coastline three islands are tied to the mainland by causeways and bridges. Of these islands, only Wallops Island is part of the barrier island system of the Eastern Shore. Assateague and Chincoteague Islands are part of the southern extremity of the barrier island system that lies offshore of Delaware and Maryland. Chincoteague Island no longer faces the open sea, except at Chincoteague Inlet where the southern extremity of the island is exposed to waves from the south. Assateague Island has grown south, seaward of Chincoteague Island, and now protects that island from the sea. At the southern end of the coastline, Fisherman's Island also is tied to the mainland, by Interstate 13 and the Chesapeake Bay Bridge-Tunnel. However, access to these four islands is restricted to varying degrees. Fisherman's Island is a

¹Coastal Research Center, University of Massachusetts

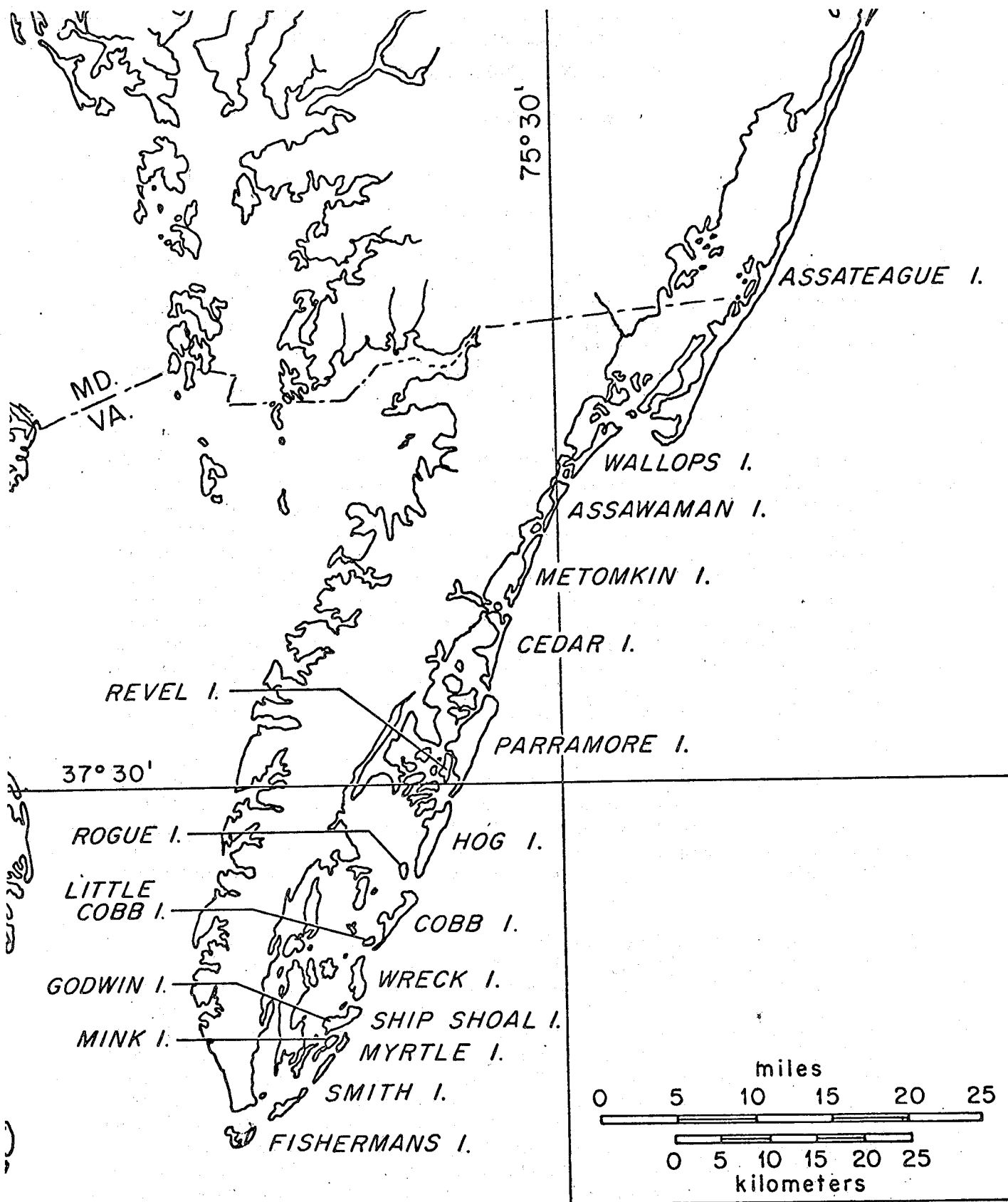


FIGURE 1. LOCATION MAP FOR THE VIRGINIA BARRIER ISLAND GROUP

National Wildlife Preserve. Access is legal only with the permission of the preserve manager. Wallops Island is controlled by N.A.S.A. and access procedures are not known. The southern portions of Assateague Island, including Fishing Point, is part of a National Seashore. Though open to the public, access is controlled by the National Park Service, and to Fishing Point by the Coast Guard which maintains a station there. Only Chincoteague Island is extensively developed and privately owned. However, substantial portions of this island also are restricted by various agencies.

The remaining islands have remained essentially wild. This does not mean that development has not occurred, because it has. But, it means that development has been restricted, and confined to what could be ferried out to the islands. On many islands this limited development has produced impressive results. Until very recently the Coast Guard has maintained a presence on most islands, and in the past on almost every island. This presence has produced beach roads and trails and corduroy roads in the marshes, telegraph and cable networks linking the islands, lights, life-saving stations, watch cupulas, and most recently full Coast Guard Stations. Now, all have been abandoned. Some of the islands have been the sites of posh private hunting clubs. [The area is an important stop-over and wintering ground in the Atlantic Flyway.] The fall and winter shooting made the islands an attractive resort for affluent sportsmen. A native population of deer on some islands, as well as rabbit, hare, and feral populations of goats, pigs, ponies and sheep added to the sporting attraction. Cobb's Island supported a resort hotel which was a popular hostelry until the sea reclaimed the site. Some of the islands were owned in their entirety by a single family, or at least in large part. Other islands had many owners. Consequently, some of the islands display an array of habitations ranging from cottages to old buses, tractors, and semi-trailer bodies.

At present most of the land area of the island system is owned by the Nature Conservancy. In the early 1970's a development company began initial planning for extensive development of Smith, Myrtle, and Ship Shoal Islands near the southern end of the island chain. With the recession of the early 70's the effort waned, and The Nature Conservancy acquired the property. At the present time, the Nature Conservancy owns most of the barrier island system that is not held by State or Federal Agencies. Limited areas still remain in private ownership. The Nature Conservancy has called the area their Virginia Coast Reserve and has designated the area as a research area. They are currently attempting to establish an endowment to support maintenance and research along this coastline. The manager of the Reserve is Mr. Gerard Hennessey, and the Reserve Headquarters is located in Wachapreague, Virginia.

SEPARATE BARRIER ISLAND SYSTEM

The offset of the Delmarva coastline which occurs at Chincoteague Inlet divides the barrier islands along this coast into two parts. The more continuous northern part which extends into Virginia, and the southern part which constitutes the Eastern Shore. Each of the parts functions as a separate barrier island system at this time. In the past the offset did not exist and the coastline ran smoothly from an ancestral Assateague Island along Chincoteague Island and on to Wallops Island. At some past time Assateague Island began to grow southward, and seaward of the north end of Chincoteague Island. That growth continued until by 1852 the southern end of Assateague Island lay about 1.25 km northeast of the southern end of Chincoteague Island. A beach across the southern end of Assateague Island ran northeastward for more than 4 km to meet a sandspit that extended nearly 3 km to the south. The offset of the coastline was developed, and the two parts of the coastline were functioning as separate island systems well before 1852. Since 1852 Assateague Island has continued to grow southward, and the long recurved spit named Fishing Point has also formed.

Much of the area added to Assateague Island and Fishing Point has been built into an area of the sea that previously averaged 7 meters in depth. Elevations throughout the new land area are generally less than 2 meters above sea level, but numerous beach ridges and dune areas rise considerably above that elevation. The highest elevation in the new land area is 15.8 meters. Thus, the new area represents a very large volume of sediment that has been removed from the longshore drift system during the years that it has taken to form that land mass. At the present time approximately 380,000 cubic meters (0.5 million cubic yards) (Byrne, 1975) of sediment is lost each year from the drift system at Fishing Point and Tom's Cove. It is clear that the circumstances which initiated the southward growth of Assateague Island created a sediment trap which enabled the growth of the island to continue to the present. The creation of that sediment trap divided the Delmarva Coastline into two separate barrier island sections.

The southern barrier island section, though related and connected to the northern section through Chincoteague Bay and Inlet, began to function as an independent system. The north end of this system was deprived of the sediment supply of the drift system which had previously maintained its dynamic equilibrium. Consequently, sediment was moved into the drift system to reestablish its equilibrium; the consequence was accelerated erosion of the north end of the southern section. The landward concavity of this northern part of the Eastern Shore was already established by 1852, and the considerable shoreline retreat since that time has not changed the shoreline curvature. That shoreline curvature is most likely residual, being inherited from the shape of the coastline prior to the growth of the south end of Assateague Island. Parallel shoreface retreat has simply moved it back, and changes in current patterns associated with the growth of the offset do not seem to have affected it.

There are twelve islands in the southern system which group into the three sub-sections, previously described. The two inlets

(Wachapreague and Sand Shoal) which separate the three sub-sections have been remarkably stable throughout the past 125 years, and presumably for some previous time span. The other inlets along the system have shown varying degrees of stability. Some have migrated and others have shifted back and forth without much net change in position. Since 1852 none of the existing main inlets have been abandoned, and no ephemeral inlet has become an established inlet.

Some of the inlets are described as off-set inlets, most notably Wachapreague Inlet and Great Machipongo Inlet. The significance and possible cause of the offset of the shoreline at these inlets has been considered by others (Hayes, et al., 1970). Both of these inlets have been stable; Great Machipongo Inlet channel has shifted approximately 1 km south then back to the north without any appreciable net movement for the past century. At both inlets the down drift lobe of the ebb tide delta becomes emergent and is joined to the down drift island. At Great Machipongo Inlet and Little Machipongo Inlet (Quinby Inlet), the offset has developed since the late 1870's as the ebb tide deltas have migrated south until their southern lobe has merged with and become part of the north ends of Cobb and Hog Islands (Rice, et al. 1977). At Wachapreague Inlet, which has been more stable (Byrne, et al., 1974) the offset has grown steadily, but not uniformly, since 1852, as bar after bar on the south lobe of the ebb tide delta has come ashore to form a large ridge and runnel which later merged nearly completely into Parramore Island (Rice, et al., 1976). A similar offset has developed at Metomkin Inlet since the late 1950's following the breaching of Metomkin Island. An offset at Ship Shoal Inlet, which is migrating southward, has waxed and waned since 1852 as the ebb-tide delta migrated first to the south and then to the north: i.e., downdrift then updrift (Rice, et al., 1976).

SHORELINE RETREAT

Three factors, interruption of the longshore drift system, eustatic rise in sea level, and tectonic events which are producing differential subsidence have combined to produce a high rate of shoreline retreat along the Eastern Shore. Subsidence rates vary from 1.2 mm/yr. at the south end of the barrier island system to 2.0 mm/yr at the north end of the system (Holdahl & Morrison, 1974). Thus both the greater subsidence rate and the interruption of the drift system coincide with the north end of the barrier island system.

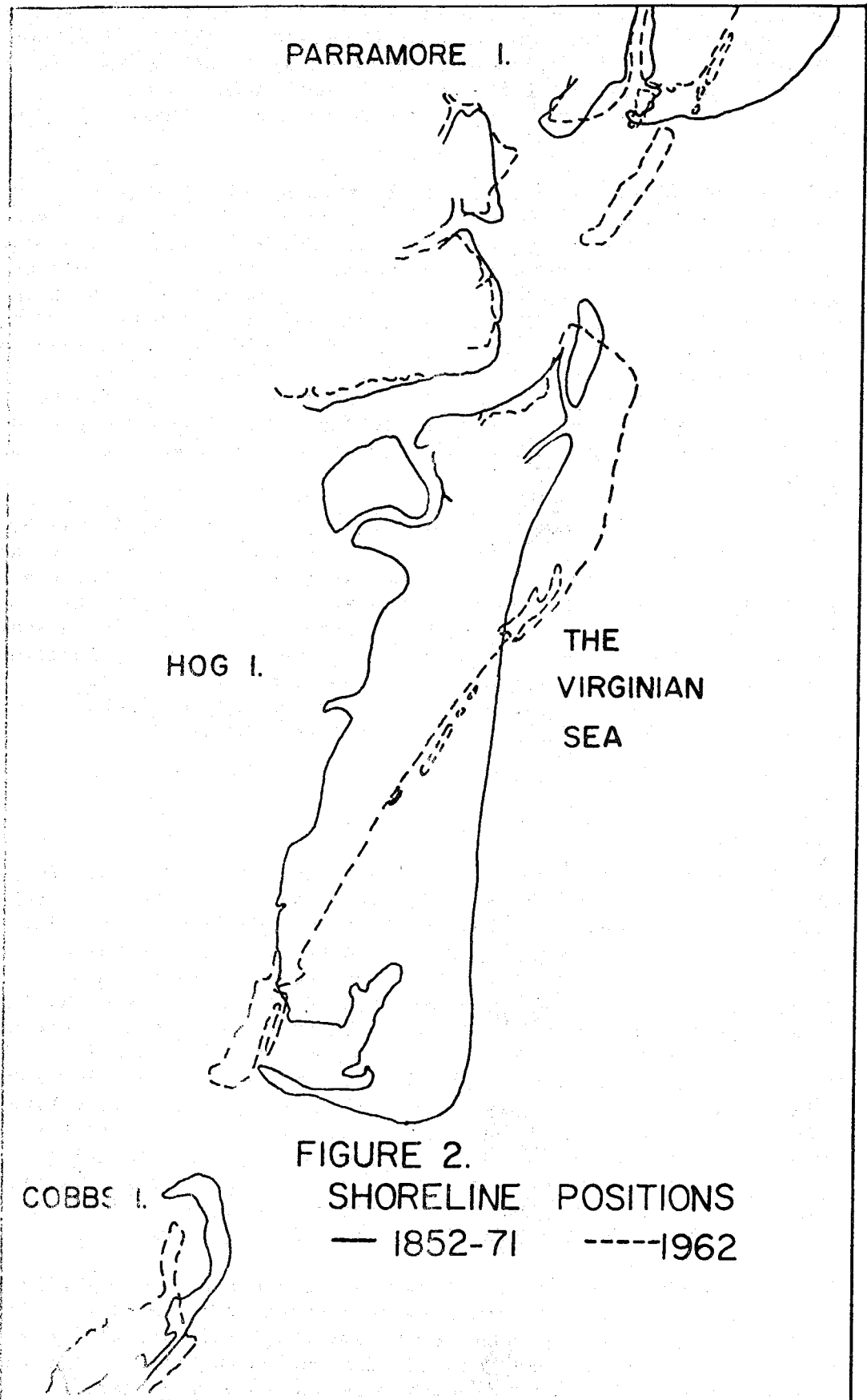
The shoreline of the Eastern Shore is retreating at a rapid rate. A time averaged retreat rate for the past century of 5.5 meters per year can be calculated for the reach of shoreline. But, the significance of that rate is less meaningful for shorter sections of the coastline or for individual islands. Different sections of the coastline have behaved differently during the last 125 years. As mentioned earlier, the northern section of the coastline, south to Wachapreague Inlet, has experienced parallel shoreline retreat on the order of 4.9 meters per year.

The middle section of the coastline has retreated but little in the same time period; but Parramore, Hog, and Cobb Islands have all experienced extreme geographic changes. A mid island position can be found for each of these islands that today differs little from the 1852 position. Each island has experienced severe erosion of its southern beaches and accretion of its northern beaches. Figure 2 shows the changes which have occurred to Hog Island. Maximum retreat on Hog Island has been slightly more than 2.5 km and accretion at the north end has averaged about 0.7 km for more than 3.0 km along the beach. The net effect has been a general reversal of the geographic shape of the island. Parramore Island has experienced a similar change, although neither retreat nor accretion has been as great as on Hog Island. The changes on Cobb Island have followed a similar pattern. The southern half of the island has been reduced to a narrow island varying in width from 45 to over 100 meters. Retreat of this southern half of the island has averaged 6.3 meters per year for the 125-year period. The northern half of the island has alternately accreted and retreated more than once, but has remained at approximately the same position. The northern tip of the island particularly has exhibited that pattern of accretion and retreat, at times adding more than 1.0 km to the island's width only to have it eroded away again.

The southern section of the coastline presents a mixed picture of shoreline change. Wreck Island at the north end of the section has experienced a large decrease in area, radical changes in geographic shape, and retreat of its south end. Yet, the north end of the east facing beach has remained essentially unchanged for 125 years. At the south end of this section of the coastline the beach of Smith Island has retreated essentially parallel to its former position. Ship Shoal and Myrtle Islands in between have retreated rapidly and have experienced changes in their geographic shape that are less severe than those at Wreck Island.

Because Wreck Island has changed shape fast and frequently it is difficult to define a meaningful retreat rate for the island. At the north end the position of the base of the sand spit has retreated at an average rate of less than 0.5 meters/year. Between 1853 and 1974 the island was shortened by 1188 meters due to losses from the southern end as New Inlet widened and migrated northwest. In the same period the shoreline of the remaining part of the southern half of the island retreated an average of 1463 meters. The retreat varied during the period, but averaged 12.1 meters per year.

Ship Shoal Island has experienced an average retreat of 5.5 meters per year. However, that retreat has been erratic and highly variable along the island at any point in time. Between 1871 and 1963 approximately 380 meters were cut from the north end of the island by movements of New Inlet. Since then there has been little change. Most of the shoreline retreat at the north end of the island has occurred since 1962 when a phase of rapid rollback of the beach began. The average roll back rate has been 61 meters per year and for 1974-75 reached 107 meters. Peat outcrops complete with marsh canals that connect to those in the marsh behind the



beach extend from the berm to the low water line. From the air the continued exposure of peat beneath the water is visible. Near the mid-point of the island the rate of this recent rollback is about 59 meters per year, but it diminishes rapidly to the south. It is believed that this period of rapid roll back of the middle and northern part of the shoreline is an adjustment to changes at New Inlet.

Myrtle Island has experienced accretion, and thus changes in geometric outline at both ends of the island while also experiencing a general retreat of the entire island. The accretion at the ends of the island have been due to movements and changes in direction of both inlet channels. The average retreat rate since 1853 thus varies along the length of the island. Near the north end retreat has been just less than 2.5 meters per year. Along the mid-part of the island the retreat rate has varied from 2.6 to 4.2 meters per year with the overall average being approximately 3.0 meters per year. The retreat rate increases rapidly south of the mid-part of the island, reaching 6.7 meters per year near the south end of the island.

The shoreline retreat of Smith Island has been influenced by a breach midway in its length. The breach has healed, but average rates of shoreline retreat along the island reflect the effect of the breach. In the time period 1871-1974 the north end of the island retreated at an average of 7.5 meters per year. Southward, the rate increases steadily to 9.8 meters per year at the location where the breach finally closed. It then diminishes steadily to 4.8 meters per year near the south end of the island, where accretion has been occurring since the late 1950's.

INLETS

The inlets found along the Eastern Shore fall into two groups according to inlet stability. Since the mid-1800's the most stable inlets have been Chincoteague, Great Machipongo, Sand Shoal, Smith Island, and Wachapreague. Of these, Wachapreague Inlet has a very deep inlet throat, and clearly has been the most stable inlet. Byrne (Byrne, et al., 1974) has examined this inlet in some detail and attributes its stability to entrenchment into Cenozoic Strata. Of the other stable inlets, Great Machipongo and Sand Shoal also have very deep throats. The channel position at Sand Shoal Inlet has been the second most stable, despite its name which is derived from shifting shoals both on the ebb tide delta, and inside the inlet. The channel at Great Machipongo Inlet, while remaining deep, has shifted south, then north, over a range of approximately 1 km. The channel movement has controlled the morphology of the adjacent islands (Cobb and Hog) for several kilometers distance.

All of the other inlets along the eastern shore have shallower throats and have demonstrated varying degrees of instability. The establishment of the Inland Waterway and the initiation of dredging for the waterway has altered tidal circulation patterns. When that is combined with the factors which have led to a rapid rate of shoreline retreat, dredging has been responsible for changes at some inlets. The most obvious change has occurred at Gargathy

Inlet, where dredging between two marsh channels, and shoreline retreat combined to allow the northern marsh channel to become dominant. The inlet abruptly shifted to the north between 1949 and 1955 and by 1957 the former southern inlet had been sealed. Assawoman Inlet has been effected also. Neither of these inlets attained great depths.

To the south the most interesting of the less stable inlets is New Inlet. Migration and widening of this inlet has led to the decimation of both Wreck Island and Ship Shoal Island. The inlet opening is very wide and shallow. The strongest tidal currents have been confined to a narrow, somewhat deeper channel that has gradually migrated to the northwest.

Extensive flood tide deposits have been built in the bay behind the inlet. In recent years bay channels have been extended in South Bay until they have integrated with other channels connecting South Bay to Ship Shoal Inlet. As a result, tidal circulation through New Inlet has become more constrained to one location. The geomorphic changes to the adjacent islands indicate that this shallow inlet is becoming an established inlet. The name of the inlet strongly suggests that the inlet has opened since the historical occupation of this part of the continent. The geomorphology, particularly the ancient features of the Eastern Shore, in this southern section of the coastline, strongly suggests that Wreck Island and Ship Shoal Island were formerly a continuous island south of Sand Shoal Inlet. Retreat, and breaching of that ancient island appears to have led to New Inlet. Unfortunately, the available and dependable data base does not yield a clear answer.

It has been suggested, most recently by Halsey and Farrell (Halsey and Farrell, 1977), that stream valleys that developed during the low sea level stands of the Wisconsin glaciation are responsible for the abundance and stability of the inlets of the Eastern Shore. Both surface and sub-surface data are available to support that argument for the more stable deep inlets along the coastline. While the position of the deep and stable inlets may be controlled by the location of buried valleys, this may not be the case for the larger number of shallow and less stable inlets. Movement of some of these inlets in the past century suggests that other factors may be at work. The older geomorphic features of some of the islands reveal former inlets that had migrated and finally been abandoned.

ISLAND BREACHING AND OVERWASH

The existence of large bay areas behind some of the islands of the Eastern Shore, and the rapid rate of shoreline retreat has made island breaching a relatively common event in the history of this barrier island system. The ancient geomorphology found on these islands reveals several major breaches that were active near the beginning of the present regression-transgression cycle. Within the present century major breaches have formed through Assawoman, Metomkin, and Smith Islands. The breach in Metomkin Island is still open, but the breaches in the other two islands have healed. The breach in Metomkin Island was opened in the time interval 1955-56 as an ephem-

eral inlet that remained open. The March 1962 storm overwhelmed the narrow part of the island widening the ephemeral inlet and opening a second one. Figure 3 illustrates the changes in island morphology since 1955. The island is still changing rapidly.

The duration of a breaching episode appears to vary widely but does appear to be related to the size and depth of the bay behind the island. Assawoman Island was breached into Kegotank Bay in the same time interval as the breaching of Metomkin Island. Kegotank Bay is small and water depths ranged up to 1.3 meters at the time of the breaching. The breach had closed by 1967. Metomkin Bay is about six times larger than Kegotank Bay, but had about the same water depths. After more than 20 years it has still not healed, and is actively changing its configuration. The breach at Smith Island broke into Smith Island Bay where water depths ranged up to 2.7 meters and to more than 5 meters in the channels. That breach opened between 1911 and 1921 and did not close until 1973. By the time this breach closed water depths in Smith Island Bay had been reduced to less than a meter over much of the area of the bay, giving some indication of the vast amount of sediment that is swept through a breach. Aerial photographs of Metomkin Bay clearly show the large areas of new sandy sediment that are being built as that bay shallows.

Ephemeral inlets have been shorter lived phenomena on many of the islands. Every other island in the barrier island system has had at least one ephemeral inlet open and close since 1852. The duration of these ephemeral inlets seldom has been more than a decade. Large volumes of sand are usually drawn through these inlets into the marsh or bay area behind the island. One ephemeral inlet that opened on Cedar Island about 1956 and closed again by 1963 built a magnificent fan-shaped sand delta that filled about 4 hectares of Burton's Bay.

The rapid rate of shoreline retreat along the Eastern Shore and the very low elevations of most of the islands makes overwashing a common process on every island. The usual expression of overwashing is the formation of multiple small overwash channels that lead back into or through the dunes. Where these lead through to the edge of the marsh it is common to find a narrow, scalloped overwash apron. Separate channels may be only a few meters wide along long sections of beach. Larger multiple overwash channels also occur with channel widths ranging up to ten meters. Broad overwash channels of 50 meters or more in width which survive through several years and build large distinct overwash fans are not very common. In the fall of 1975 there were two that were active on Smith Island and another very large one on Hog Island. The development of multiple small overwash channels seems to allow the islands to accommodate the high rate of retreat and maintain equilibrium.

11-11

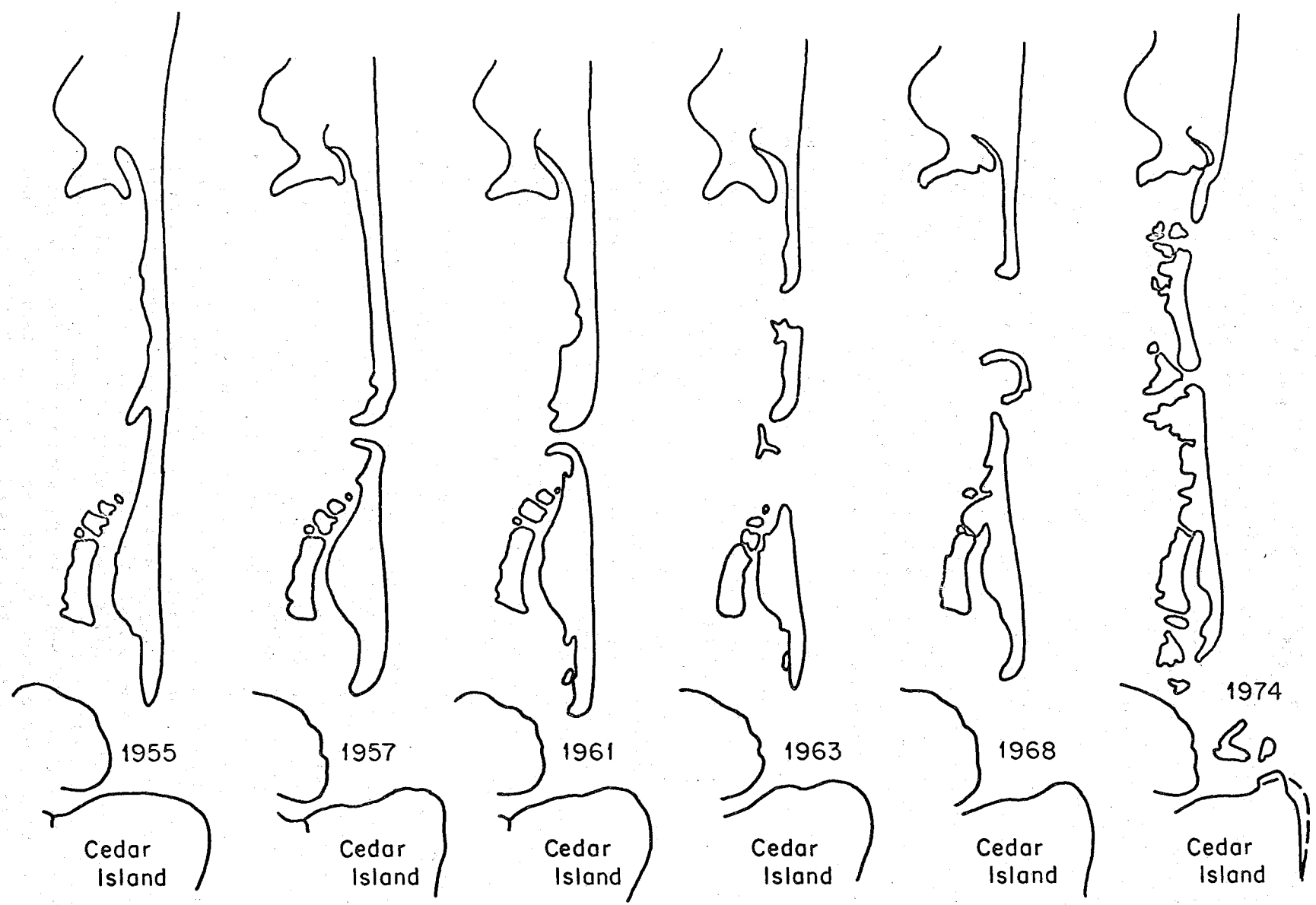


FIGURE 3. SEQUENTIAL CHANGES IN BARRIER ISLANDS EAST OF METOMKIN BAY

BEACH RIDGES AND DUNES

The elevations of modern landforms along the barrier islands of the Eastern Shore are characteristically low: less than 2.0 meters. The areas of higher elevation that are found on the islands are usually associated with older landforms that pre-date the present transgression. Some of these were formed during the earlier regression. The highest elevations are found on Parramore Island where older beach ridges reach heights of 6.1 meters or more over relatively large areas. Many of the islands do not rise above 4.0 meters. The tidal range is slightly more than one meter.

Sand dunes in the fore dune ridge range from less than one meter to an average height of 2.1 meters. Often these dunes are only sparsely vegetated because retreat moves them back too rapidly to stabilize. Few of the islands have modern active dune fields landward of the fore dune ridge. Dune areas of this sort are found on the Cedar Island Sand Spit, at the north end of Parramore, Hog, and Cobb Islands, near the south end of Smith Island, and on Fisherman's Island. These are all areas that are presently accreting. It is believed that the high rate of retreat prevents most dunes from attaining greater heights.

Low circular or elliptical mounds of sand are found rising above a broad interior sandy plain, or swale, on Parramore Island. These features have been named Parramore Island Mounds or Parramore Pimples and have been previously discussed in papers by Melton, Rich, Deitz, and Cross. These features are also found on sandy plains on Cedar Island and on Hog Island. On all three islands these features are found in the interior of the island and the sandy plains around them are now grass covered. The sandy plains originated from steady progradation of those areas in the early stages of a regression. The mounds are believed to be low dune ridges that were partially washed out and reworked during repeated overwash by storm surges and built up in the interim by added wind blown sand. Modern analogues can be observed forming in broad overwash channels on Smith Island. Analogous areas exist today on Assateague Island.

Beach ridges on the islands are either old or are limited to accreting areas on the islands. The older beach ridges fall into groups with different ages. The oldest ridges lie between the islands and the mainland. These ridges are partially drowned and surrounded by marsh areas. Those ridges may fit into the growing body of data for a mid-Wisconsin high stand of the sea about 30,000 years ago. They clearly predate two other groups of old ridges which are found on the mainland side of some of the barrier islands. The latter ridges and geomorphic features associated with them clearly record the end of a prior transgressive period and the onset of a regression. Most of the ridges found on the islands were formed during the regression as the islands advanced seaward. Today these ridges are being eroded as the islands retreat. Modern beach ridges that have formed in relatively short periods of time are formed at the north end of Cedar Island and on the sand spit at the south end of the island. Others are found at the north end of Parramore and Hog Islands. At the south end of Smith Island where accretion began about 20 years ago a young beach ridge has been built across the truncated ends of older beach ridges.

References Cited:

- Byrne, R.J., 1975: Erosion of Virginia Barrier Islands - An Assessment. Virginia Institute of Marine Sciences, (Unpublished communication).
- Byrne, R.J., DeAlteris, J.T., and P.A. Bullock, 1974: Channel stability in tidal inlets: a case study., American Society of Civil Engineers (reprint from Procs. 14th Coastal Engineering Conf., Copenhagen, Denmark, June 1974)., Chapter 92.
- Halsey, S.D., and S.C. Farrell, 1977: Preliminary Investigations of Former Coastal Features Preserved Along the Mid-Wisconsin Shoreline of New Jersey and Delmarva., Geol. Soc. Amer., 12th Ann. Meeting, N.E. Section, Abstracts with Programs, v. 9(3), p. 271.
- Hayes, M.O., Goldsmith, V., and C.H. Hobbs, 1970: Offset coastal inlets., Proc. 12th Coastal Engr. Conf., v. 75, p. 1187-1200.
- Holdahl, S.R., and N.L. Morrison, 1974: Regional investigations of vertical crustal movements in the U.S., using precise relevelings and mareograph data., Tectonophysics, v. 23, p. 373-390.
- Rice, T.E., and A.W. Niedoroda, 1977: Changes in Ebb Tide Deltas and Shoreline Morphology of Barrier Islands., Geol. Soc. Amer., 12th Ann. Meeting, N.E. Section, Abstracts with Programs, v. 9(3), p. 312.
- Rice, T.E., Niedoroda, A.W., and A.P. Pratt, 1976: The Coastal Processes and Geology - Virginia Barrier Islands., Ecosystem Description - Virginia Coast Reserve Study., The Nature Conservancy. L.C.N. 76-21164.

Acknowledgement:

The author wishes to express his gratitude for the encouragement and support lent by many friends and acquaintances who have long worked with the geology of the Eastern Shore, and who have freely shared their knowledge and experience in the area. It is hoped that this contribution may aid their efforts.

DELINEATION OF A WAVE CLIMATE
FOR VIRGINIA BEACH, VIRGINIA

Andrew L. Gutman¹

INTRODUCTION

A total of 78,449 wave observations from six sources, which vary widely in format duration, biases, and quality are compiled in this report (Figs. 1 and 2):

a) Shipboard wave observations for a 1° Marsden Square 116-subsquare 65 (14,580 observations during 12/48-12/73).

b) Chesapeake Lightship wave observations (3977 observations during 1/70-12/72).

c) Coastal Engineering Research Center-Coast Guard Cooperative Surf Observation Program (25,338 observations during 4/54-12/65).

d) Virginia Beach wave gage (6,354 observations during 4/64-10/69).

e) Virginia Institute of Marine Science-Coastal Engineering Research Center Voluntary Wave Observer Program (1882 observations during 6/74-8/76).

f) Hindcasted waves (SMB by Saville, 1954) for Chesapeake Light (26,260 wave computations during 1/48-12/50).

The principal descriptor of wave height used here is the "significant wave height", which is defined as the average height of the highest 33% of the waves occurring during a particular sampling period.

¹A complete discussion of this topic can be found in Delineation of a Wave Climate for Dam Neck, Virginia Beach, Virginia, Virginia Institute of Marine Science SRAMSOE No. 125.

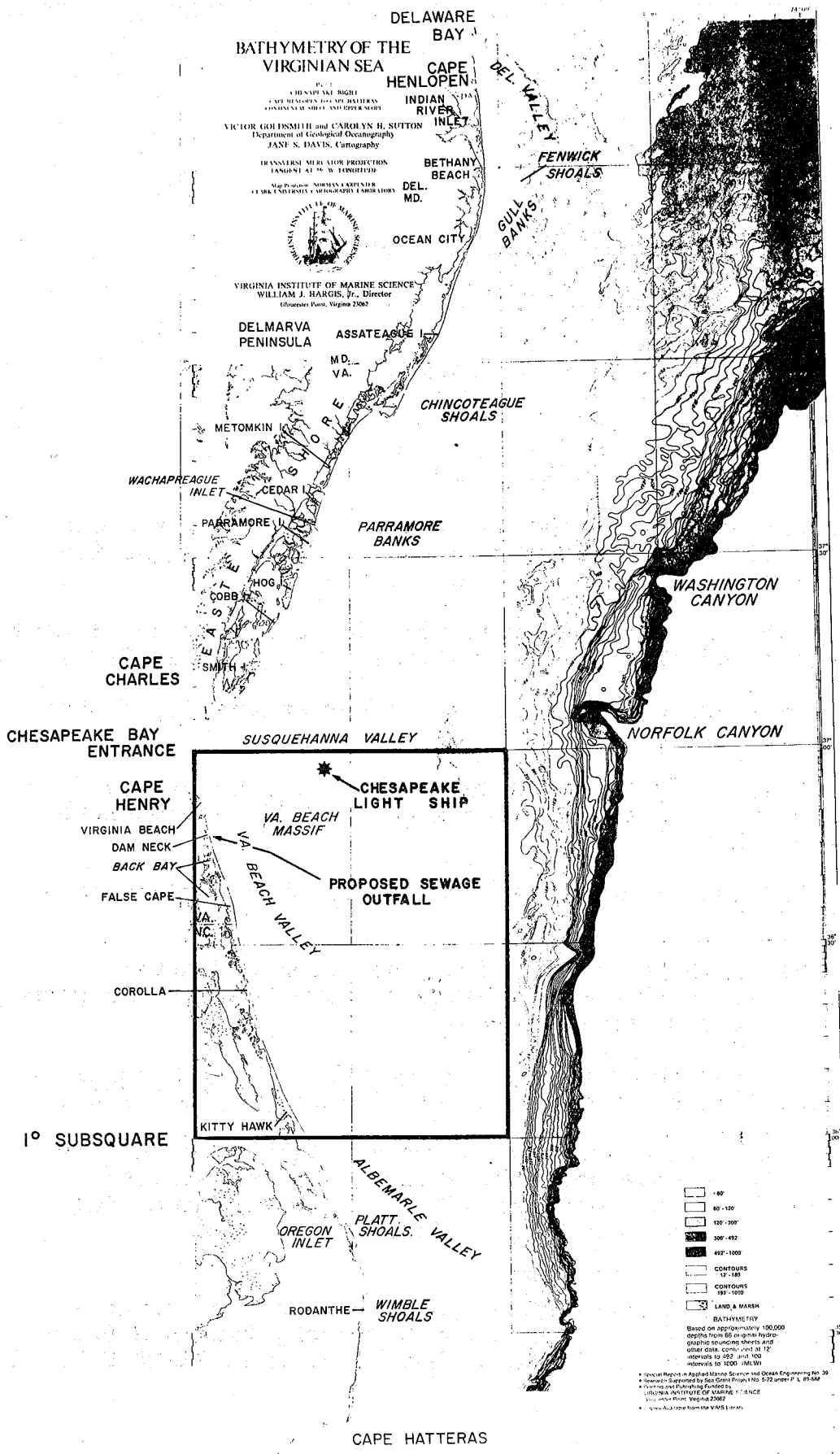


Figure 1a. Location Map

Figure 2.

DAM NECK WAVE CLIMATE SOURCES

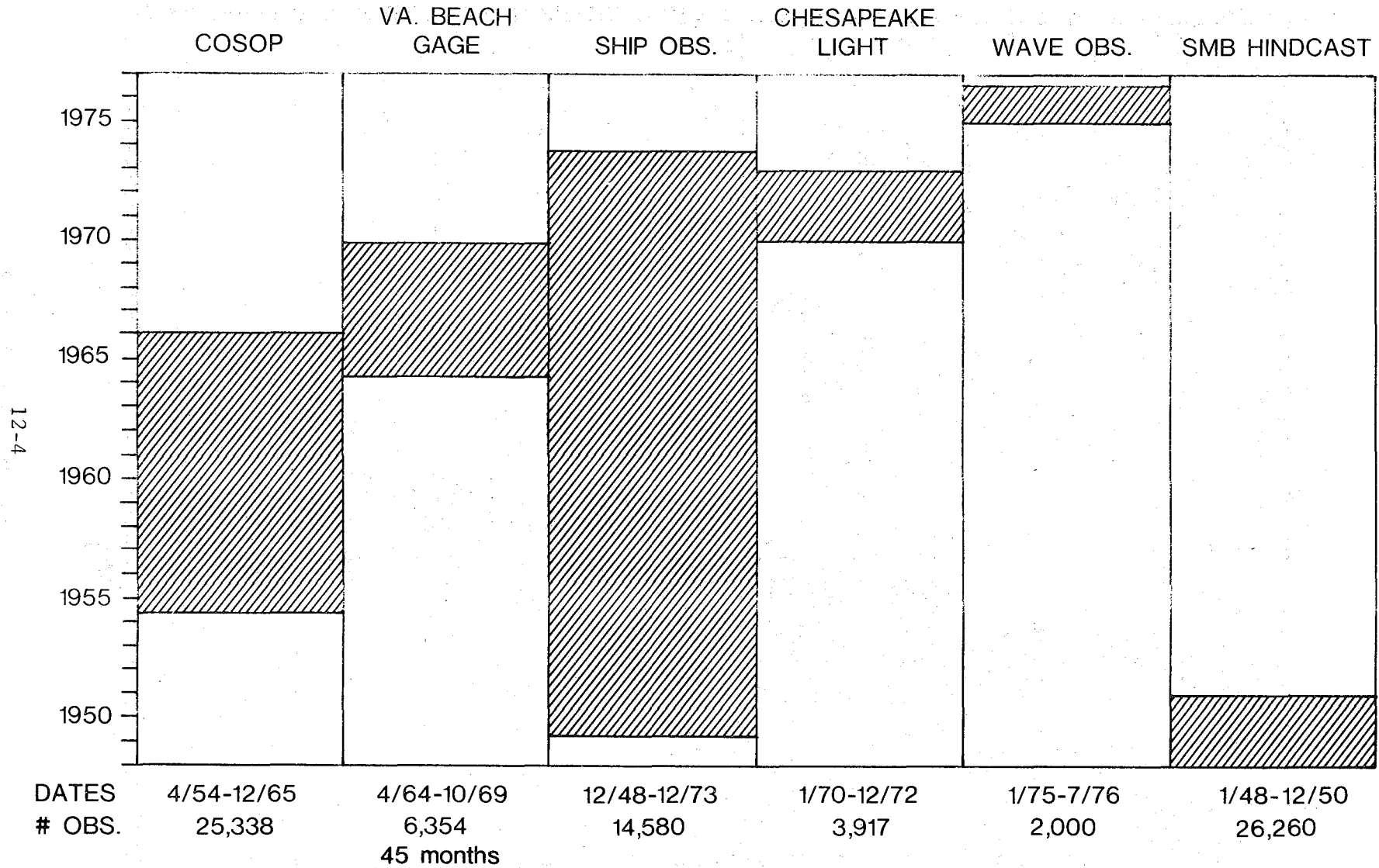


Table 1 lists the limitations and biases of each of the above data sources. Since only the recording wave gage data are formally treated to determine the significant wave height and period the Virginia Beach wave gage data are determined to be the most reliable, useful, and representative source for delineating a nearshore wave climatology.

VARIATIONS ACROSS THE ADJACENT CONTINENTAL SHELF

This wave climate synthesis represents data derived from surf, shallow water, mid-water, and deep water wave conditions. As waves travel across this very wide and high relief shelf into shallow water they are primarily affected by refraction, shoaling and bottom friction. Due to these effects, monitoring stations should detect at least two general changes in wave characteristics for waves traveling from deep to shallow water: 1) The angle of wave approach relative to the shoreline should progressively reduce (wave crests become increasingly parallel to the coast). 2) Wave heights will greatly decrease from friction, and either decrease or increase from refraction. Given all of the variability, unreliability, nonuniform sampling periods, and a large error associated with wave observers, it is completely surprising, but very gratifying to note comparisons of wave sources which reflect different depths along the shelf actually do indicate these changes in wave characteristics (Figs. 3, 5, 6, and 7).

Wave Height

The following conclusions, regarding changes in wave height distributions across the shelf in the Virginia Beach area, were derived from comparisons of the various data presented in this report.

- 1) Deep water average significant wave heights are generally about two feet higher (SMB Hindcast, Chesapeake Lightship and Ship Observations) than the averages for shallow water conditions (COSOP and Virginia Beach Gage).
- 2) The largest average significant wave (see Figure 3) heights are associated with the hindcast data. Note also that the percent greater than or equal to 3 meters is 6.8 for SMB hindcast while only 2.1% for ship and 1.4% for the Chesapeake Lightship observations. These higher averages

TABLE 1.

WAVE SOURCES

ERRORS & LIMITATIONS

COAST GUARD-CERC COOPERATIVE
SURF OBSERVATION PROGRAM at
Virginia Beach C. G. Station

- 1) Surf zone conditions only
- 2) Waves fully affected by:
 - a. Refraction
 - b. Bottom friction
 - c. Wave breaking
- 3) Site specific with respect to longshore variations of wave energy
- 4) Data often lacking for extreme events (CERC, 1973)
- 5) Observer bias and errors
- 6) Observations at unknown tidal stage

APPLICATION SITE SPECIFIC AND SHOULD NOT BE USED FOR SPECIFIC STRUCTURAL DESIGN

VIMS-CERC VOLUNTARY WAVE
OBSERVER PROGRAM at 10
Locations along the Coast

- 1) Surf zone conditions only
- 2) Waves fully affected by:
 - a. Refraction
 - b. Bottom friction
 - c. Wave breaking
- 3) Data usually lacking for extreme events
- 4) Observer bias and errors
- 5) Short duration of record
- 6) One observation per day and 5/week
- 7) Untrained observers
- 8) Many sites along coast
- 9) Observations at unknown tidal stage

APPLICATION ONLY TO ESTIMATE LONGSHORE VARIATION OF WAVE ENERGY

VIRGINIA BEACH WAVE GAGE

- 1) Nearshore conditions
- 2) Wave affected by:
 - a. Refraction
 - b. Bottom friction
- 3) Non-directional record
- 4) Overestimate of height due to gage type
- 5) Incomplete record
- 6) Two methods of recording and analyses
- 7) Site specific

MOST RELIABLE AND PRECISE INFORMATION SEAWARD OF BREAKERS UNDER ALL CONDITIONS FOR NEARSHORE DESIGN AND PLANNING PROBLEMS

Table 1. (cont.)

WAVE SOURCES

ERRORS & LIMITATIONS

CHESAPEAKE LIGHTSHIP
OBSERVATIONS

- 1) Inner shelf (40 ft. depths) conditions
- 2) Ambiguity and errors with coding of data
- 3) Unreliable wave observers
- 4) Evacuated during extreme events
- 5) Short duration of record

PROVIDES A WAVE CLIMATOLOGY, ALTHOUGH NOT
PRECISE FOR MIDDEPTH CONDITIONS

SHIPBOARD WAVE OBSERVATIONS

- 1) Deep water conditions
- 2) Data grouped from many locations and depths
- 3) Ambiguity and errors due to coding of data
- 4) Unreliable, untrained wave observers
- 5) Ships avoid extreme wave events

PROVIDES A WAVE CLIMATOLOGY, ALTHOUGH NOT
PRECISE FOR DEEP WATER CONDITIONS

SMB HINDCAST COMPUTATIONS

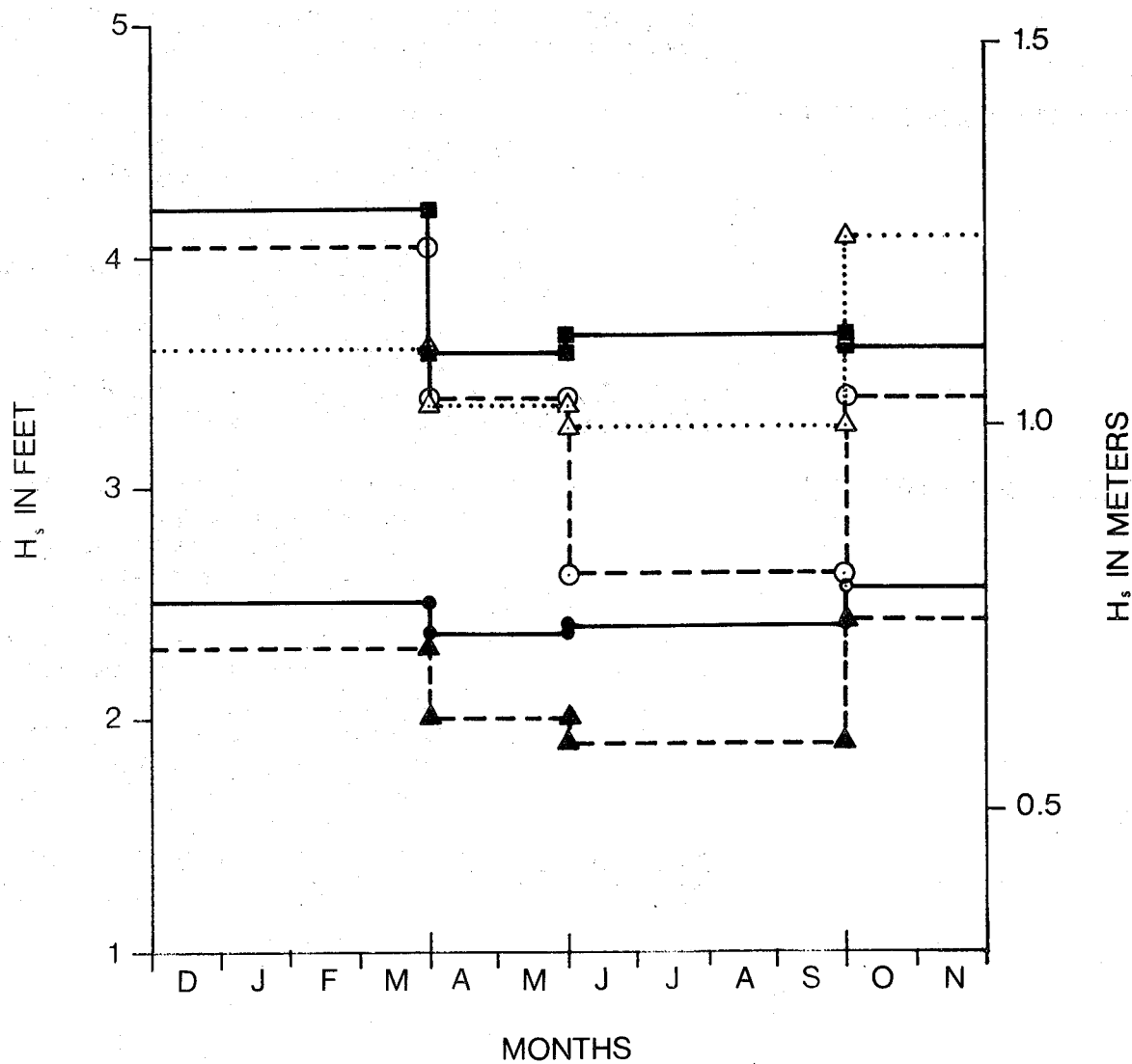
- 1) Assume deep water conditions 360° around site
- 2) Simple model used to generate the wave parameters
- 3) Short period of record
- 4) Changing meteorological conditions since sample period (1948-1950)
- 5) Appears to give highest % of larger wave heights, and therefore may be biased towards extreme events

PROVIDES A SIMPLE, ALTHOUGH NOT PRECISE
ESTIMATE OF WAVE CONDITIONS FOR DEEP WATER

Figure 3.

SEASONAL AVERAGE SIGNIFICANT WAVE HEIGHT (H_s)

SYMBOL	SOURCE
■ ——— ■	SMB HINDCAST
○ - - - - ○	SHIP OBSERVATION
△ ······ △	CHESAPEAKE LIGHT SHIP
▲ - - - - ▲	VA. BEACH GAGE
● ——— ●	COSOP



would be expected because of the simple assumptions of the SMB computations, the avoidance of extreme conditions by ships, and the evacuation of the lightship during extreme wave events, and the fact that only the SMB hindcasted wave observations are for strictly deep water conditions, since the Ship Wave Observations encompassed within the 1° square contain an unknown amount of wave data taken in depths less than "deep" water for the longer period waves.

3) Ship observations in MS 116, SS-65 do not represent only deep water conditions, but instead a range of depths from deep to shallow. Due to this range, the average wave heights from ship data might be expected to conform to more mid-shelf conditions. The Chesapeake Lightship was anchored in the inner-shelf (12 meters) and it is interesting to note that average significant wave heights for both sources are essentially the same, though winter values are higher and summer values lower for the ship observations.

4) Since larger wave heights are associated with breaking waves (which are monitored by the shoreline COSOP program) than with nonbreaking waves, it is not surprising average significant wave heights are slightly higher for the COSOP data than the wave gage, even though the gage is located in 20 foot water depths.

5) The frequency of occurrence of waves greater than a given height is, as would be expected, higher on the shelf than in nearshore water (see Figure 11). For example, waves greater than or equal to 3 meters had a frequency occurrence of only 0.2% in 6 meters of water (Virginia Beach gage), but 2% in 12 meters of water (Chesapeake Lightship) and 7% in deep water (SMB hindcast). The frequency occurrence of waves greater than about five feet is slightly higher for the Virginia Beach gage than COSOP data. This difference is likely due to unequal sampling periods, that is the five years of gage record was unusually stormy compared to the 20 years of COSOP record. In addition, COSOP observations often do not include extreme wave events while the gage does.

Wave Period

Analysis of wave period data receives little emphasis in this report because large differences in average wave periods exist between the data sources, differences which are not induced by waves traveling across the shelf but due

to differences in methodology and observer errors. For example, over 99% of all observations from the Chesapeake Lightship recorded wave periods of five seconds and less, which probably indicates bias and error due to the observers and recording procedure, and not a dominance of 5 second waves. From Figure 4, it is seen the average significant wave periods range from five to ten seconds with no relation to depth induced changes. The only objective wave period information of use to the coastal engineer is available from wave gage records.

There is, however, one trend apparent in Figure 4 which explains the weaknesses in these data. The measured (Virginia Beach Gage) and computed waves (SMB) have the highest wave periods, approximately 8 to 10 seconds, respectively, for all seasons; whereas all other data (observed) is about 5 seconds. This is because when two superimposed wave trains occur, even the trained observer generally sees only the shorter period waves. In this area it is very common to have a local "sea" combined with a longer period swell produced by a distant storm. Evidently, most observers see only the local sea. Thus, only data measured by instruments, and statistically processed, will show the correct percentage of longer period waves.

Wave Direction

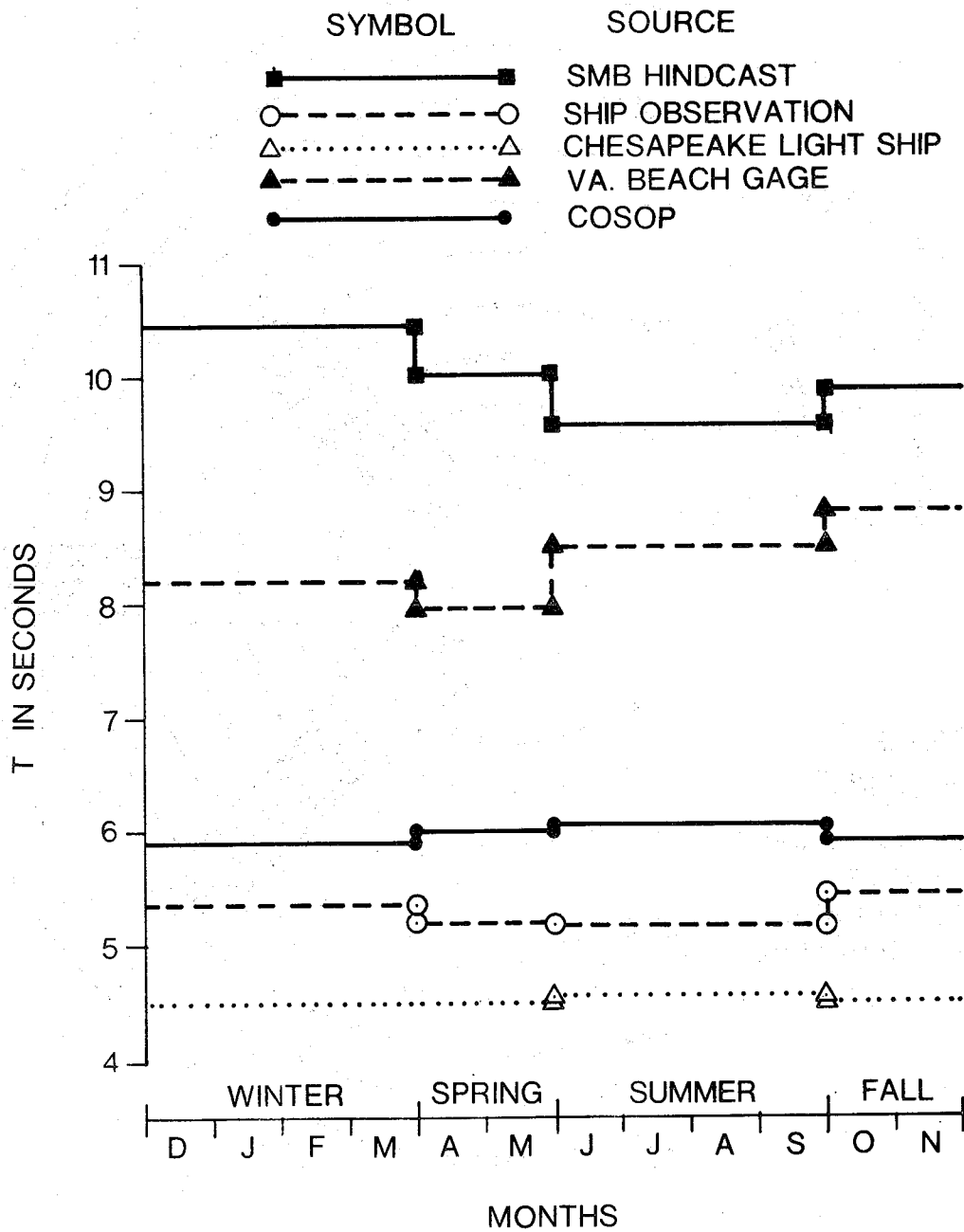
The anticipated changes in direction of approach of waves traveling across the shelf are well documented in this report. The dominant angle of approach relative to the shoreline decreases for monitoring stations in increasingly shallow water. Comparison of COSOP (Fig. 5), Ship (Fig. 6) and Chesapeake Lightship wave roses (Fig. 7) show for increasingly nearshore conditions diminishing northerly and southerly components (wave crests perpendicular to shore) and increasing easterly components (wave crests parallel to shore).

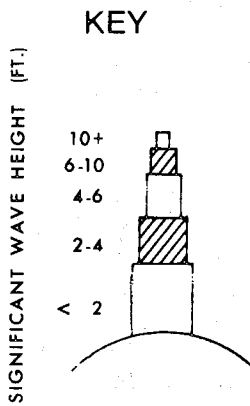
SEASONALITY

Information regarding seasonal changes in wave characteristics is important to coastal engineers trying to efficiently and safely plan the use of construction vessels. The data presented in this report indicate changes, though small, in seasonal wave characteristics. According to Hayden (1975) annual cycles of wave climate exist along the

Figure 4.

SEASONAL AVERAGE SIGNIFICANT WAVE PERIOD (T.)





**COSOP
WAVE ROSE**

PERCENT OF TIME WAVES
OF DIFFERENT HEIGHT
OCCUR FROM EACH
DIRECTION: 4/54-12/65

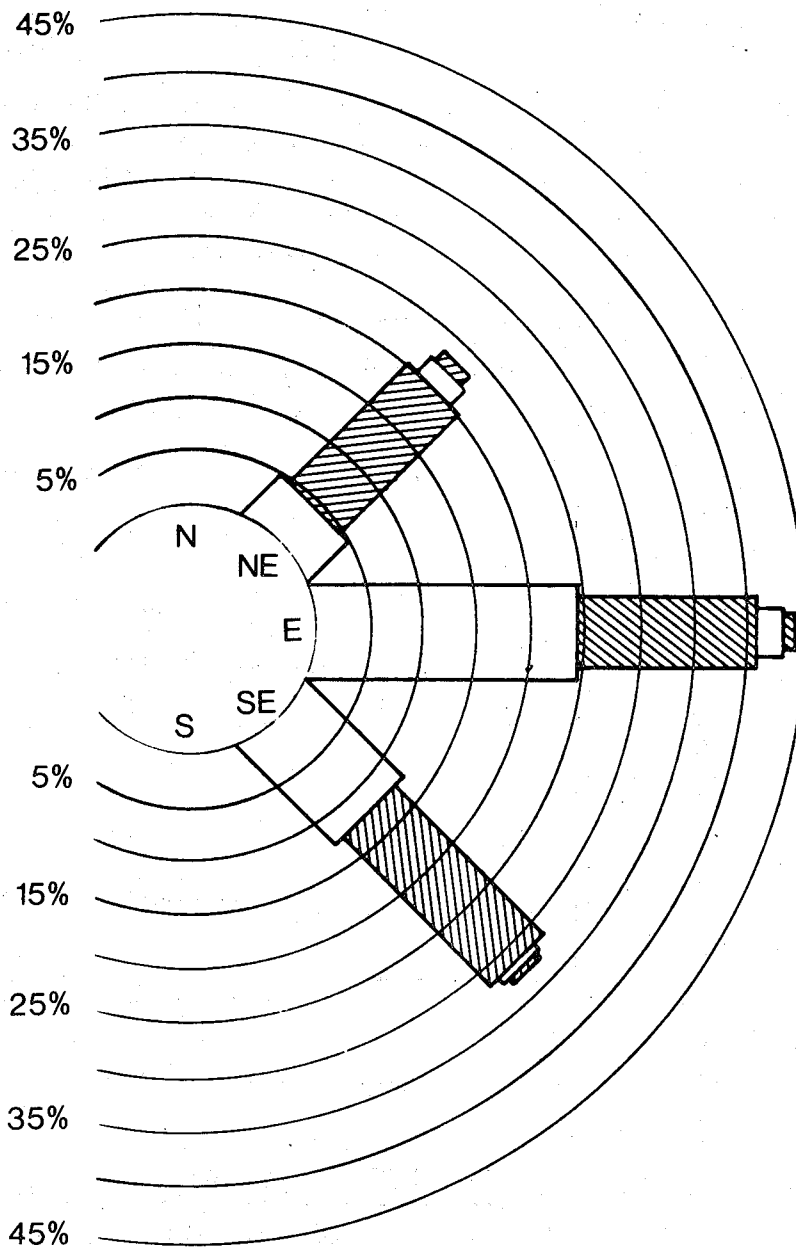


Figure 5.

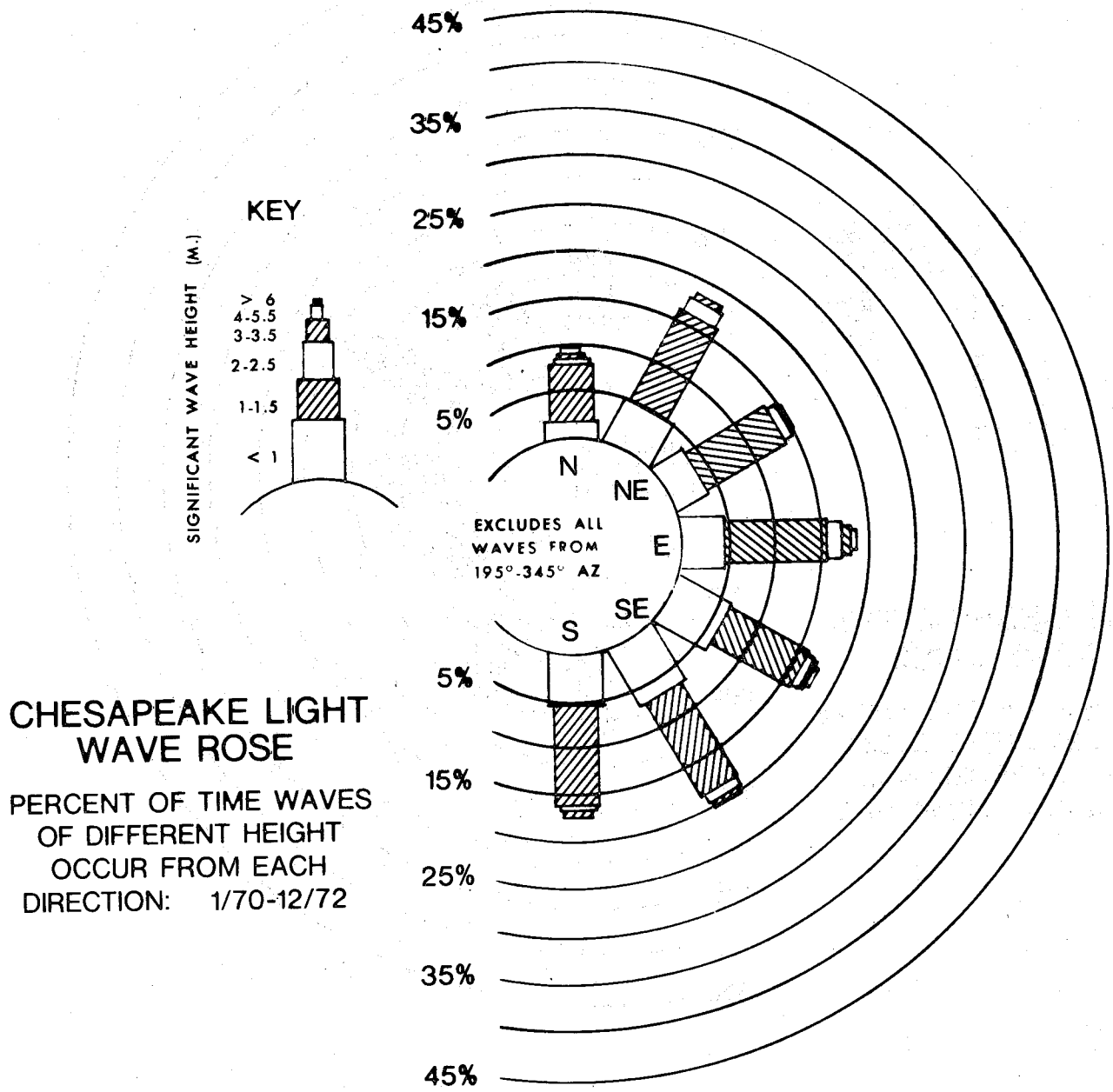


Figure 6.

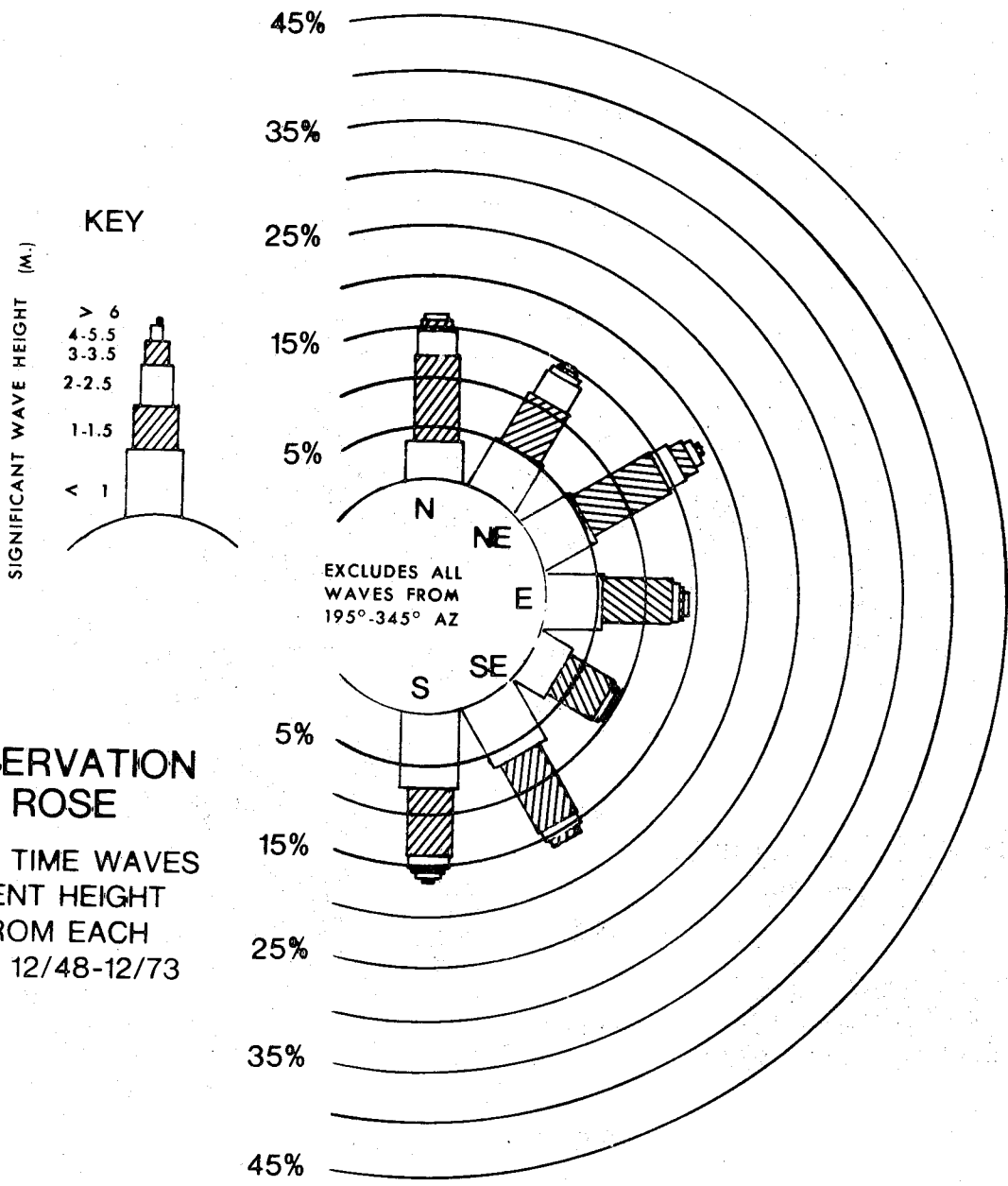


Figure 7.

east coast of the United States. For the Virginia Beach area Hayden (1975) found a winter to summer transition date of April 10, and a summer to winter transition at August 17, based on the same COSOP data presented in this report.

Wave Height

Figure 3 examines the seasonality of significant wave height for all wave sources. It is evident these seasonal height averages are greater during the winter and fall, and lower during the spring and summer. The differences between summer and winter averages range from as little as 3 cm for the COSOP data to 0.4 meters for the ship data. In any case, considering the large standard deviations, most differences are probably not important.

Figure 8 is an analysis of monthly data for the Virginia Beach gage which is the most reliable for nearshore coastal engineering. It is evident the highest significant average heights occur between September-October and December-March with the lowest between April-August. Given a standard deviation (dashed line) of 0.5 meters, this average seasonal difference of 0.1 meter between summer and winter should be regarded as being unimportant. However, twice as many waves over 1.5 meters occurred between December and March (5.4%) than between April-August (2.2%), though in either case, the total number was small.

Figure 3 also compares seasonal and monthly average significant wave heights. The data clearly show the use by NOAA of seasonal groupings which include September as a summer month which is not a good practice for this area. September average significant wave heights (Fig. 8) are as large as those for the winter months. This conclusion confirms Hayden's data of winter to summer transition during August.

Wave Direction

The direction of wave approach changes between winter and summer months. Figures 9 and 10 show the predominance of Southeast and Easterly components during the summer, and Northeast and Easterly components during the winter for nearshore wave conditions (COSOP data).

VIRGINIA BEACH GAGE AVERAGE SIGNIFICANT WAVE HEIGHT (\bar{H}_s)

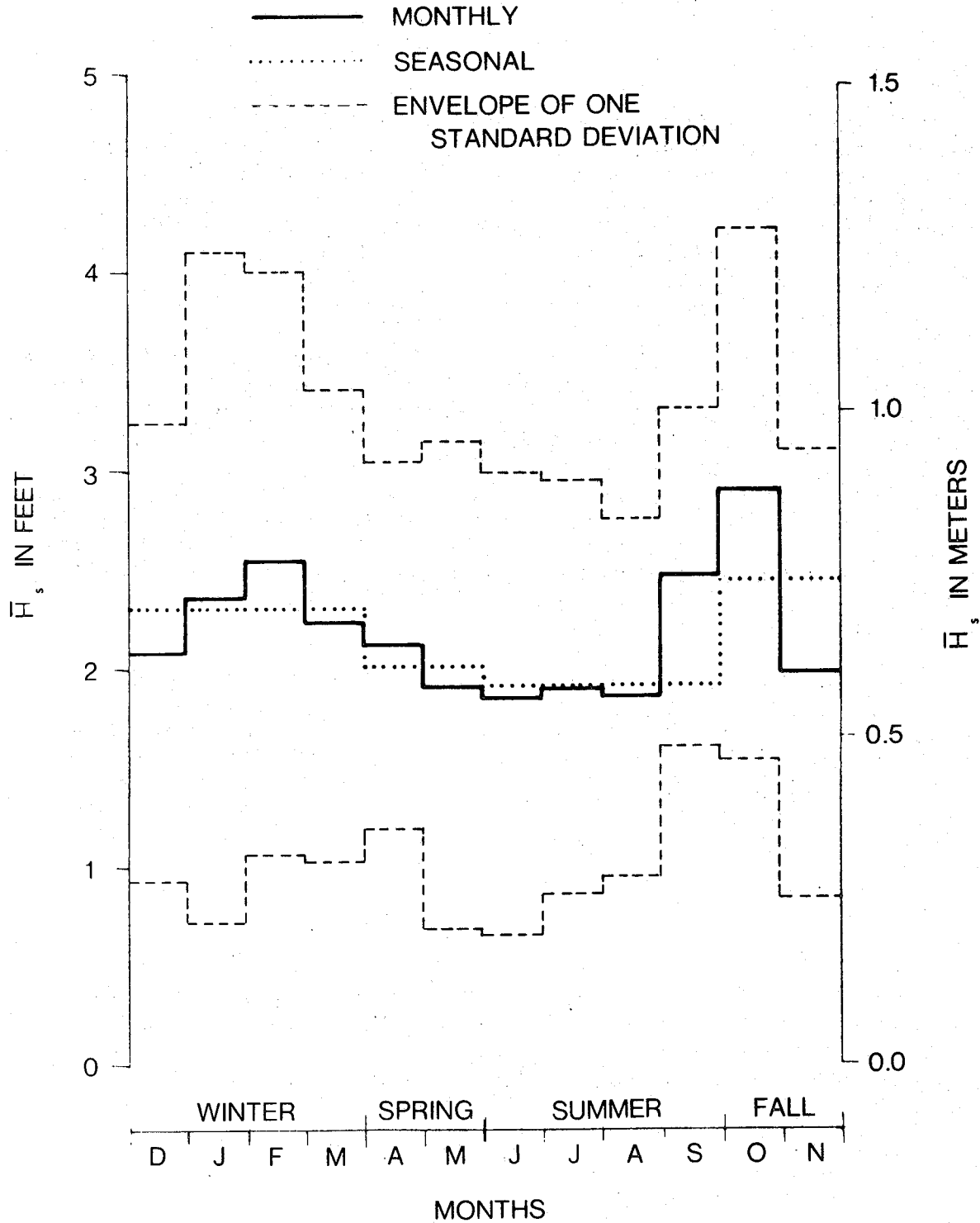


Figure 8.

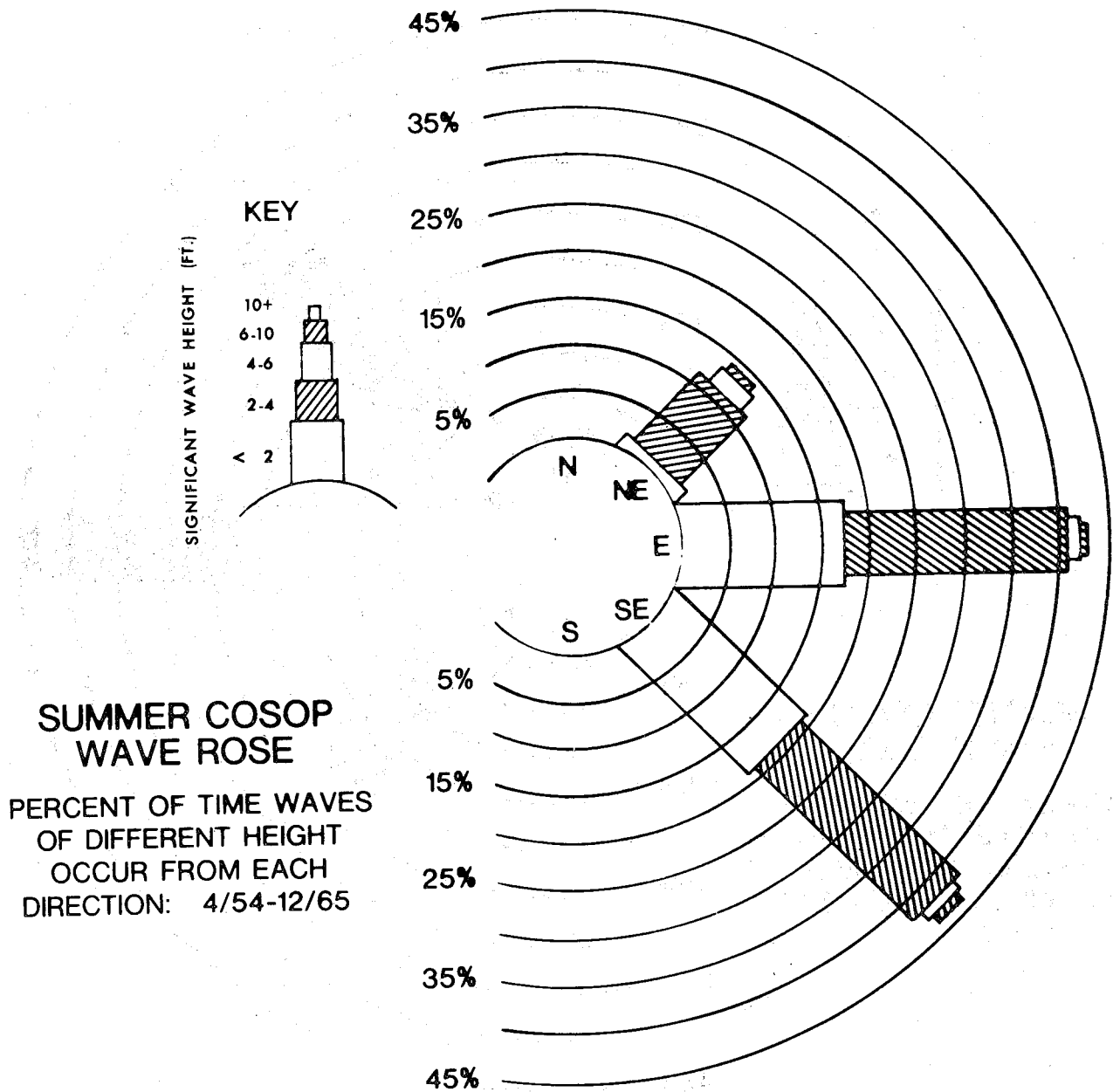


Figure 9.

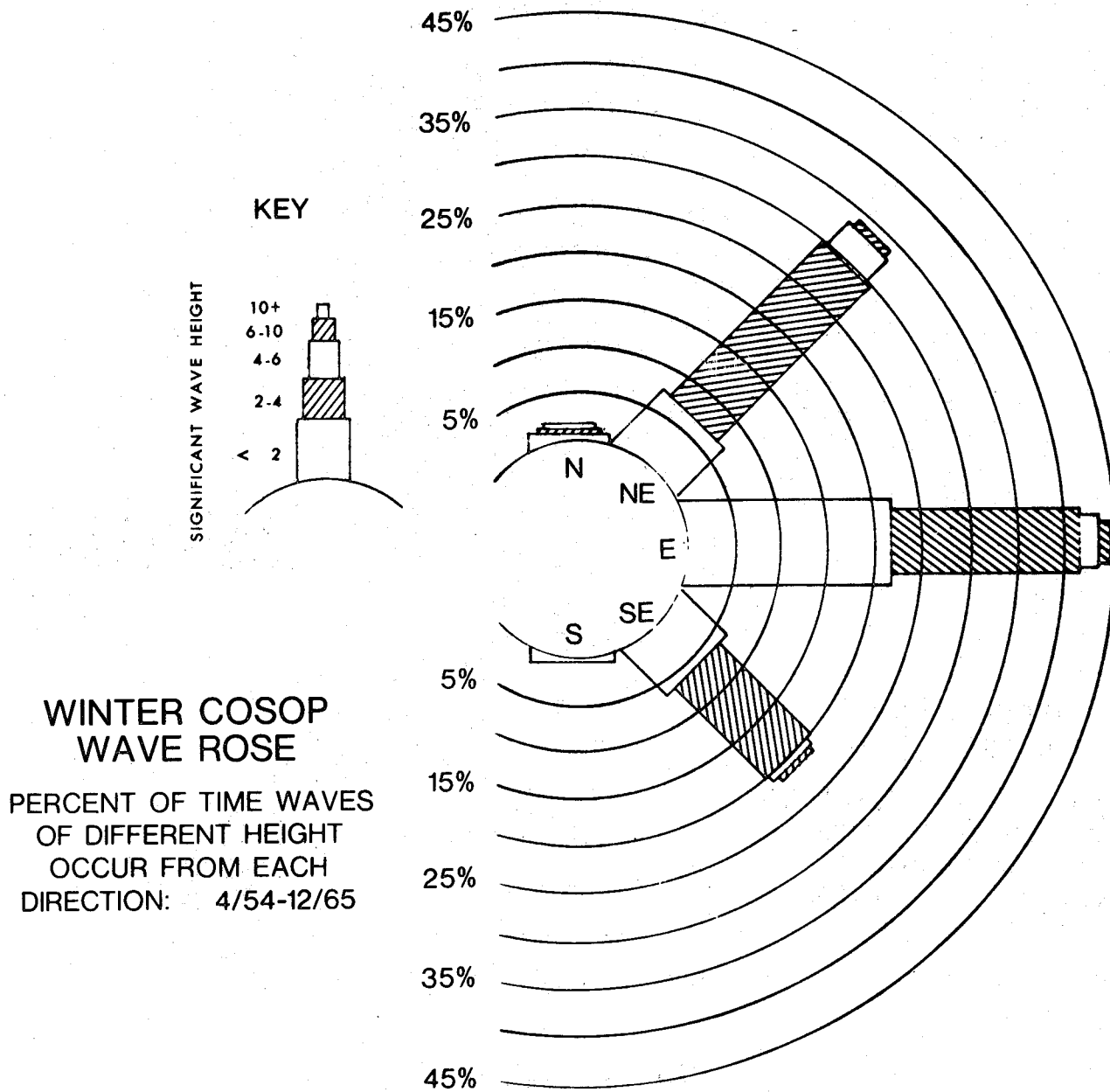


Figure 10.

EXTREME WAVE CLIMATE

The magnitude and frequency of occurrence of extreme wave events determine the design of many marine structures. Nearshore wave gages provide the most reliable recorded data for construction of extreme wave climates. Figure 11 and Table 2 summarize the most pertinent extreme wave data.

The highest significant wave height (H_s) which occurred during the entire period of record of the Virginia Beach was 3.5 meters. However, given the definition of H_s we know waves above 3.5 meters occurred. During the 19 hours of measured $H_s = 3.5$ meters a number of waves up to 4.5 meters ($H_{1/10}$) and a very small number of waves up to 6.2 meters (H_{max}) could be expected. During the entire record of the gage the highest wave likely to have occurred was 6.2 meters, but only very few (less than ten) isolated waves would reach this height.

The extreme wave climate presented in this report is limited by the length of record. Between 1964 and 1969 no waves of H_s over 3.5 meters were observed. This does not necessarily mean no waves with higher significant wave heights will occur at Virginia Beach. For example, a significant wave height greater than 3.5 meters probably occurred during the 1962 Ash Wednesday storm, the 100 year storm.

However, extrapolation of Figure 11 to low frequencies of occurrence seems justifiable from the comparison of the Virginia Beach gage curve with longer record curves such as the ship data. Extrapolated to the .01 percent level, a wave height $H_s = 4.1$, $H_{1/10} = 5.3$ and a $H_{max} = 7.3$ meters might be expected to occur one day in 27 years at the location of the Virginia Beach gage. Therefore this extrapolated wave height distribution should be a better estimate of the extreme wave height likely to occur in the Virginia Beach Dam Neck area than the shorter period measured waves. The fact the gage design itself promotes conservative height estimates supports this conclusion.

Table 2.

VIRGINIA BEACH GAGEOccurrence of Extratropical Storms
During Period of Operation

Name	Date of Storm	Surge	WIND		WAVE HEIGHT			Va. Beach Gage Operating (?)
			Speed (mph)	Direction	H _s	H _{1/10}	H _{max}	
	1/04/64	2.0'	28	W	*	*	*	✓
	1/12/64	2.5'	42	E	11.0	14.1	19.5	✓
	2/12/64	2.0'	32	E	10.0	12.8	17.7	✓
	1/16/65	4.0'	35	NE	12.1	15.5	21.5	✓
	1/22/65	3.0'	36	E				-
	1/29/66	3.5'	37	E	11.5	14.7	20.4	✓
	12/24/66	2.3'	31	NE	6.7	8.6	11.9	✓
	2/07/67	2.7'	33	NE	6.0	7.7	10.7	✓
	12/12/67	2.0'	30	E	1.5	2.0	2.7	✓
	12/29/67	2.0'	31	W	6.0	7.7	10.7	✓
	1/14/68	2.3'	33	E	11.0	14.1	19.6	✓
	2/08/68	2.5'	30	NE	8.5	10.9	15.1	✓
	11/10/68	4.3'	34	N	8.5	10.9	15.1	✓
	11/12/68	2.5'	47	NE	9.7	12.4	17.1	✓
	3/02/69	6.0'	40	N	10.4	13.3	18.5	✓
	11/02/69	2.5'	36	NE	12.0	15.4	21.2	✓

12-20

Occurrence of Tropical Storms
During Period of Operation

Cleo	9/01/64	1.0'	42	ESE				-
Dora	9/13/64	3.5'	61	NE	12.5	16.0	22.1	✓
Gladys	9/23/64	2.2'	44	N	8.5	10.9	15.1	✓
Isabell	10/16/64	2.5'	50	NE	9.5	12.2	16.8	✓
Alma	6/13/66	1.0'	40	N	8.0	10.2	14.2	✓
Doria	9/16/67	4.0'	55	N	8.0	10.2	14.2	✓
Gladys	10/20/68	1.3'	46	NE	8.5	10.9	15.1	✓

*Gage was operating but record not available to author at this time

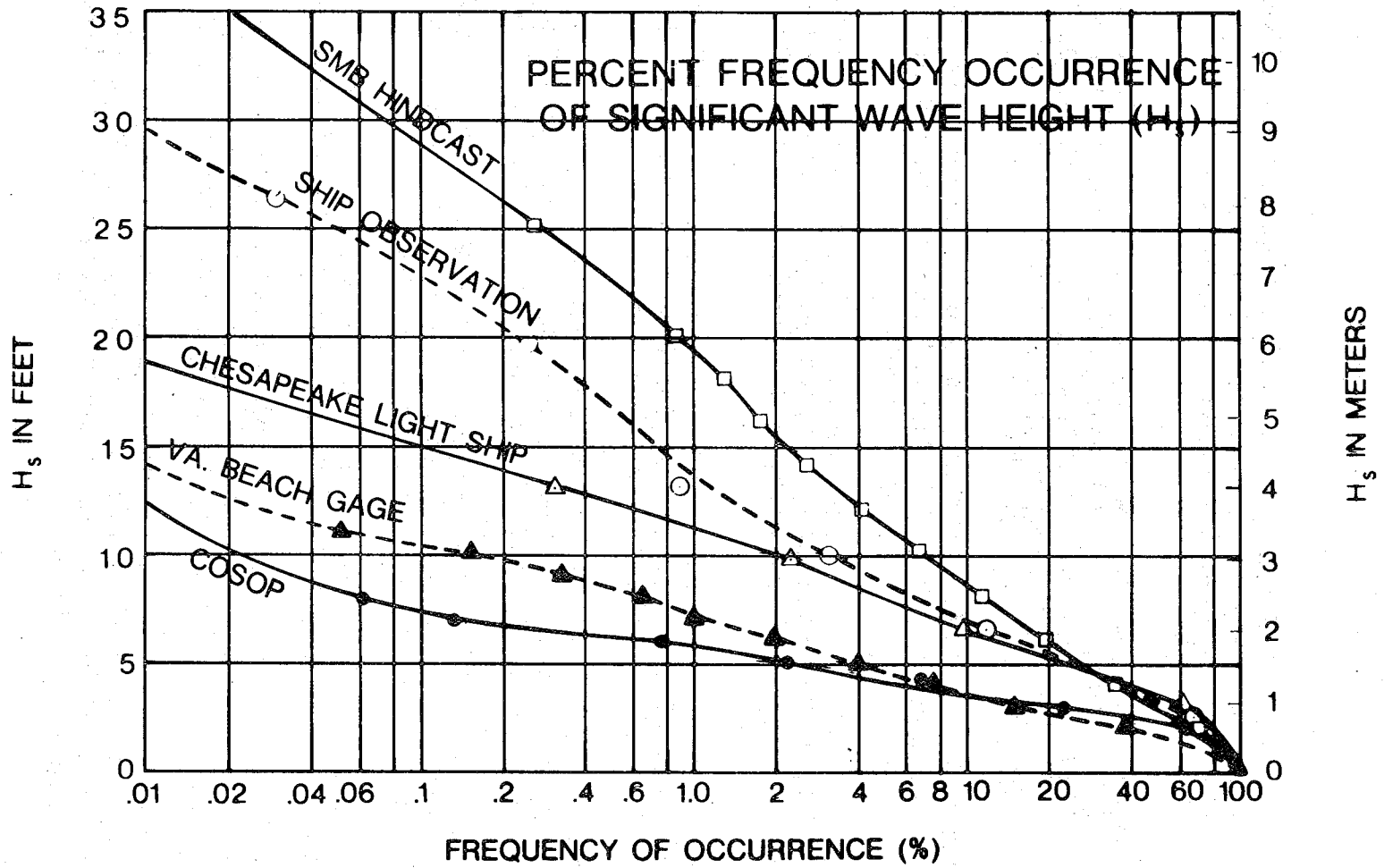


Figure 11.

REFERENCES

- Esteva, D., and Harris, D.L., 1970. Comparison of Pressure and Staff Wave Gage Records, Proceedings of the 12th Coastal Engineering Conference, Washington, D.C., pp. 101-116.
- Goldsmith, V., Morris, W.D., Byrne, R.J., and Whitlock, C.H., 1974. Wave Climate Model of the Mid-Atlantic Shelf and Shoreline (Virginian Sea): Model Development, Shelf Geomorphology, and Preliminary Results: VIMS SRAMSOE No. 38, 146 p.
- Harris, D.L., 1970. The Analysis of Wave Records, Proceedings of the 12th Coastal Engineering Conference, Washington, D.C., pp. 85-100.
- Hayden, B.P., 1975. The Annual Cycle of Wave Climates Along the East Coast of the United States, Proceedings of the First Conference of the Coastal Society, pp. 225-231.
- Longuet-Higgins, M.S., 1952. On the Statistical Distribution of the Heights of Sea Waves, Journal of Marine Research, Vol. II, pp. 245-266.
- Munk, W.H., 1940. Proposed Uniform Procedure for Observing Waves and Interpreting Instrument Records, Wave Project, Scripps Institute of Oceanography, LaJolla, California.
- Munk, W.H., 1949. The Solitary Wave Theory and Its Application to Surf Problems, Annals of the New York Academy of Sciences, Vol. 51, pp. 376-462.
- N.O.A.A., 1964. Weather Service Handbook #1, Department of Commerce National Weather Service, Washington, D.C.
- Saville, T., Jr., 1954. North Atlantic Coast Wave Statistics Hindcast by Bretschneider-Revised Sverdrup-Munk Method, Beach Erosion Board Technical Memorandum No. 55, 18 pp.
- Thompson, E.F., 1977. Wave Climate at Selected Locations Along United States Coasts, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Virginia, 338 pp.

WAVE CLIMATE MODELS AND
SHORELINE WAVE ENERGY DISTRIBUTIONS:
CURRITUCK SPIT, VIRGINIA-NORTH CAROLINA

Victor Goldsmith

INTRODUCTION

During the 1972-1976 period, the Virginian Sea Wave Climate Model (VSWCM) and two other versions of this model, The Chesapeake Bay Wave Climate Model (CBWCM) and The Virginian Sea Wave-Surge Interaction Model (VSWSIM) have been developed and widely applied (Goldsmith, et al., 1973; Goldsmith, et al., 1974; Colonell and Goldsmith, 1974; Sallenger, et al., 1975; Goldsmith, 1975; Goldsmith, 1976; Goldsmith, et al., 1976; Fisher, et al., 1976; Goldsmith, et al., 1977; Carron and Goldsmith, 1977 and Goldsmith, et al., 1976).

These models will be briefly reviewed here, and then their applications towards increasing our understanding of processes along Currituck Spit will be discussed.

MODEL REVIEW

Virginian Sea Wave Climate Model (VSWCM)

In 1947, Munk and Traylor's classic paper clearly showed the importance of shelf bathymetry upon surface wave processes, and linked these processes to shoreline changes to the extent ". . . that wave refraction is the primary mechanism controlling changes in wave height along a beach . . ." (Munk and Traylor, 1947, p. 1). With the application of high speed digital computers in the 1960's, wave refraction diagrams have become commonplace in shoreline and nearshore studies.

The Virginian Sea Wave Climate Model (Goldsmith, et al., 1974) represents a significant advance in the computation and application of "wave refraction diagrams" through the use of new and more sophisticated techniques such as: (1) use of a regional approach in which 52,000 km² of continental shelf (out to depths of 300 m), and 160 km of shoreline, are incorporated into one wave ray diagram; (2) voluminous depths are chosen from numerous original hydrographic sounding sheets and interpolated depths are avoided: e.g., 100,000 depths were acquired for the Virginian Sea Model; (3) these depths are transferred to a common grid using a specially computed transverse Mercator projection "centered" on the study area in order to minimize projection distortion caused by the earth's curvature (i.e., waves travel great circle paths); (4) 19 different ray parameters are computed along each ray including surface wave heights and bottom orbital velocities; (5) an improved understanding of wave behavior in the area of crossed wave rays (Chao and Pierson, 1972) has been applied to the interpretation of such wave phenomena as curved caustics (over the shelf-edge canyons and ridge and swale bathymetry) and straight caustics (over deep channels off the mouths of Delaware and Chesapeake Bays); (6) this information is then used to delineate areas of "confused seas" and bottom "scour" for specific wave and tidal conditions.

Wave ray diagrams, shoreline histograms and shelf contour maps of various wave parameters for various combinations of 122 distinct wave conditions, as computed in the Virginian Sea Wave Climate Model, are being used to increase our understanding of shelf sedimentology, historical shoreline changes, and inlet hydraulics. Figures 1, 2, 3 are three representative wave refraction diagrams.

Chesapeake Bay Wave Climate Model (CBWCM)

As in the VSWCM, the major data input is a detailed grid of depths. The second major input to the Chesapeake Bay Wave Climate Model, wave information, is being fed into the Model within three distinctly different formats. The latter two types of formats represent major changes from the VSWCM.

The first type of wave information was input at the Chesapeake Bay mouth and was computed in the VSWCM. One of the more interesting phenomena observed in our study

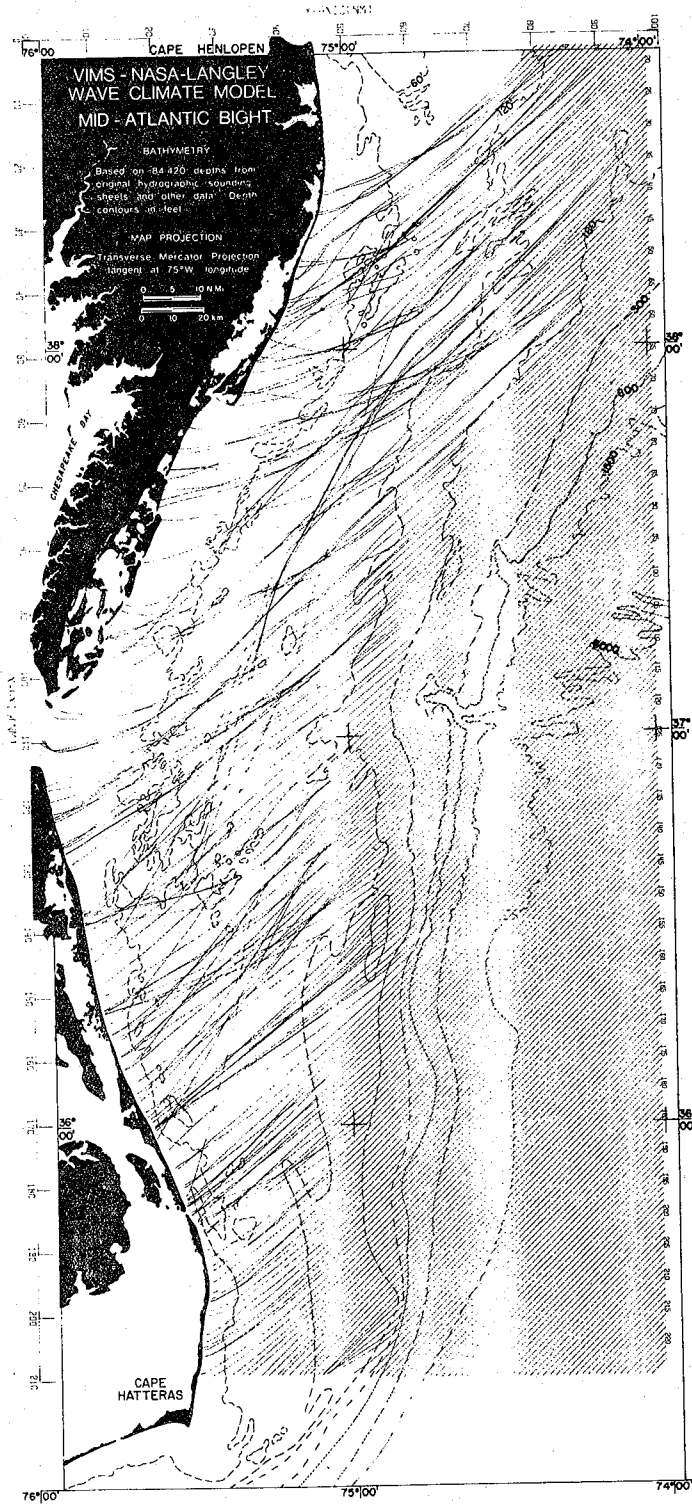


Figure 1. Wave rays computed with following input conditions:
 AZ = 45°; T = 10 sec; Tide = 1.2 m (4 ft).

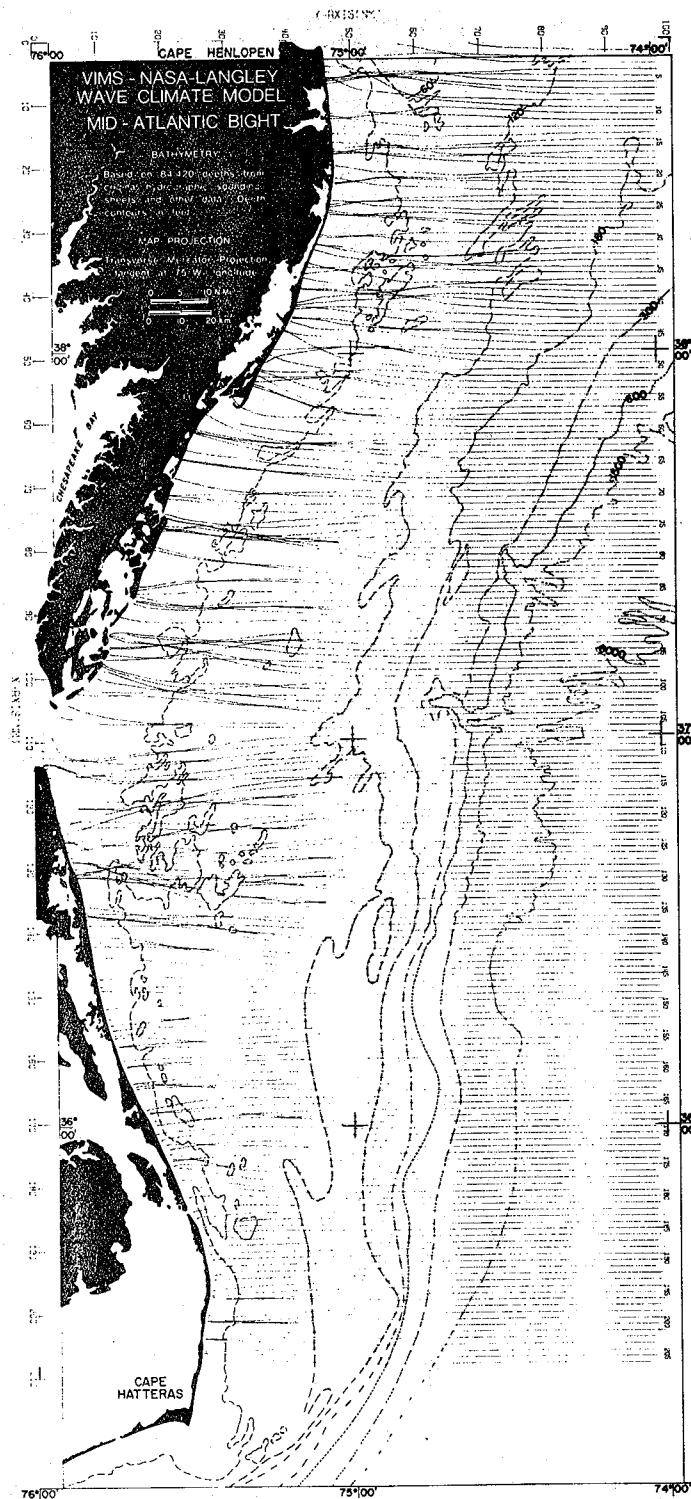


Figure 2. Wave rays computed with following input conditions:
 AZ = 90°; T = 10 sec; Tide = 1.2 m (4 ft).

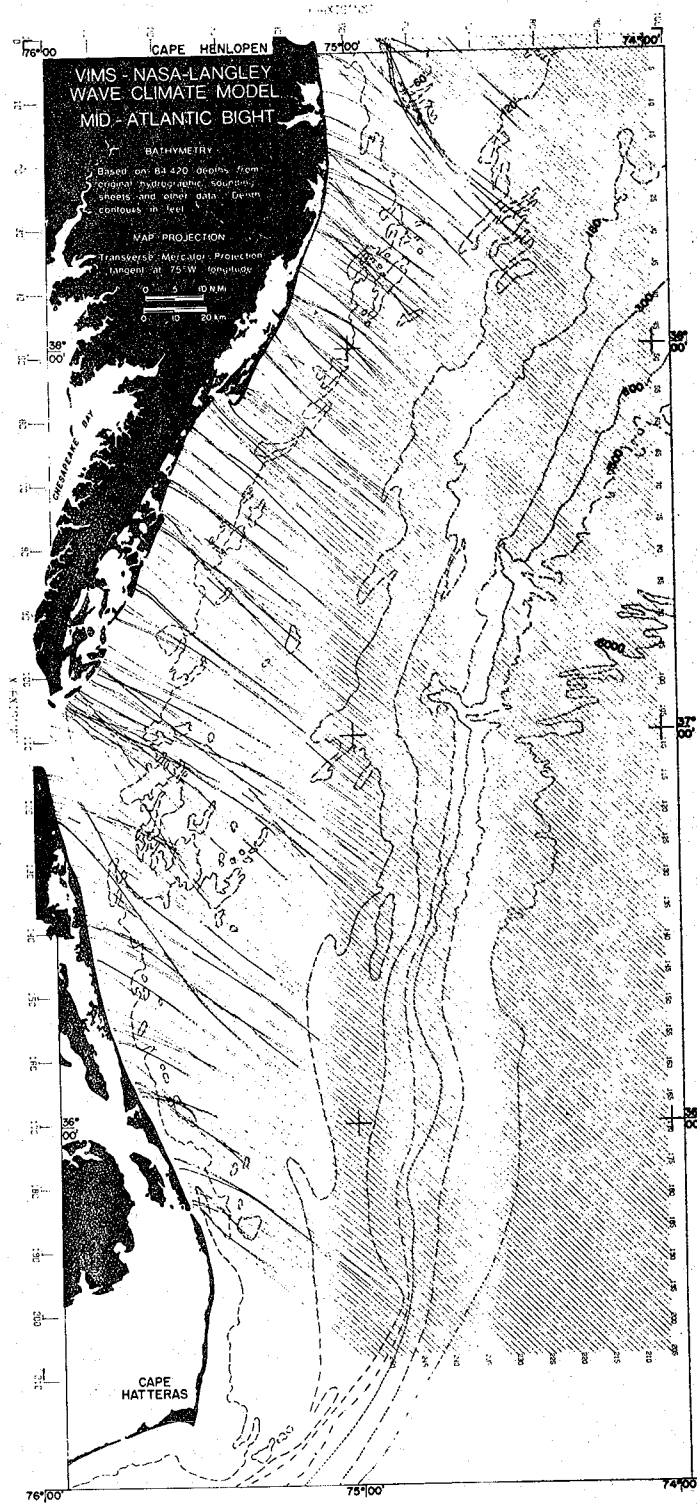


Figure 3. Wave rays computed with following input conditions:
 AZ = 135°; T = 10 sec; Tide = 1.2 m (4 ft).

was the concentration of wave rays at the Bay mouth from nearly all offshore wave approach directions. These output wave data from the VSWCM have been used as input to the Chesapeake Bay Wave Climate Model. Results indicate that most waves refract to the northwest. There are major exceptions, with some waves, for example, refracting around to the eastern shore of the Bay. In general though, the western shore of the Bay receives more wave energy than the eastern shore.

The two other input wave formats involve continuous computation of wave parameters based on the limited fetch conditions that inhibit the growth of overly large "ocean-size" waves in the Bay. The model was made flexible to allow for optional input of two types of wave information. Either (a) wind velocity and wave period, or (b) wind velocity and fetch may be optionally input. The (a) wave input (wind velocity and wave period) is useful at the Bay mouth where entering swell originating in the deep ocean, come under the influence of the local wind regime. The (b) wave input (wind velocity and fetch) is useful at either the north or south ends of the Bay where the size of the waves depends directly on the water surface distance over which the wind blows. In both cases ((a) and (b)), the wave size (period, wavelength and height) will continuously increase under the direct influence of the wind (using Wilson's (1965) equations), while at the same time the waves may decrease under the influence of wave refraction and bottom friction. The particular Bay wave input conditions have been closely coordinated with the Bay shoreline studies of Byrne (Byrne and Anderson, 1973), and the studies of Rosen (1976) on the various Bay shoreline types, their geological development through late Holocene time. Input wave and surge conditions have been carefully chosen from existing data. For example, a typical storm with an approximate one year recurrence interval would have a four foot rise in sea level above MLW and 25 knot winds from either the SW or NNE. A major aim of these two shoreline studies, with which this Chesapeake Bay Model is an integral part, is to increase our understanding of the causes of the severe beach erosion in the Bay (which is equal to or greater than the adjacent ocean shoreline) in order to develop a range of environmentally sound tools that could be prescribed for these erosion problems.

The model demonstrates an increasing deflection of wave orthogonals towards the flanks of the basin with increasing wind velocities, because the larger the waves, the greater

the effects of wave refraction. The larger period components of the spectrum are refracted to shore, while the smaller period components continue down the Bay, increasing in size, until they too are refracted in to shore. Thus, when shallow basins are under the influence of high winds, the wave size is limited less by the boundaries of the basin (geographic fetch) than by wave refraction (i.e., refractive fetch: the distance of water over which the wind acts on a wave without refracting to shore). Greater wind velocities (larger waves) result in a more uniform, but higher, distribution of wave energy along the shore of the basin. Lower wind velocities result in nonuniform wave energy concentrations reflecting primarily geographic fetch. This is the opposite effect from ocean beaches (Goldsmith, et al., 1974), where larger waves result in less uniform wave energy distribution along the shoreline due to shelf refraction.

Virginian Sea Wave-Surge Interaction Model (VSWSIM)

The effect of storm surge on wave refraction patterns along 320 km of shoreline in the Virginian Sea (Mid-Atlantic Shelf) has been investigated. Two types of storm surge patterns based on Bodine (1971) and Jelesnianski (1972 and 1974) are used to alter the ocean surface of the Virginian Sea Wave Climate Model (Goldsmith, et al., 1974). The first pattern, based on Bodine's (1971) Bathystrophic Storm Surge Model, is of circular shape (with the maximum sea level rise in the center) and in real situations results mostly from the inverted barometric pressure effect associated with intense low-pressure storm systems, wind setup and the astronomic tide. The center of this surge was located at two places in 30 m water depths on the shelf in order to determine if a general wave response pattern could be established, and to delineate a sequence of wave responses.

The second type of surge model, based on the general pattern shown by Jelesnianski (1972 and 1974), develops as the storm moves towards shore, and the effects of shoaling, wind stress, and inertia change the shape and height of the surge. At landfall the surge is a long, narrow strip impinging against the shore with a seawardly exponential decay, and with a higher surge height to the right of center.

Based on a comparison of two sets of wave ray diagrams, and shoreline wave energy and wave height distributions

computed for (a) the two surge types and (b) no-surge conditions, using similar initial wave input parameters, the characteristics of the general wave response models are briefly summarized for both surge types as follows:

Shelf Surge: Changing wave refraction patterns result in: (a) maximum increases in shoreline wave energy located to the north and south of that point of land downwave of the storm; and (b) decreases in shoreline wave energy in a shadow zone directly downwave from the storm surge.

Shoreline Surge: An increase in longshore drift caused by lesser wave refraction. The deeper water close to shore results in a greater shoreline breaker angle than that observed during no-surge conditions. Thus irrespective of the wave height, any type of surge will cause significant changes in the shoreline wave refraction patterns resulting in local increases in longshore drift. The tendency for increases in longshore transport, and concomitant decreases in offshore-onshore transport, is thus promoted by water surges, irrespective of wave size and direction and results in permanent local losses of sediment.

SHORELINE WAVE ENERGY DISTRIBUTION

Goldsmith, et al., 1974a states that:

"An example of the effects of these offshore shoal areas on nearshore circulation patterns can be seen in the vicinity of Virginia Beach, Virginia, which is greatly affected by the adjacent, extensive Virginia Beach Massif. Here, the waves with periods of 10 seconds or shorter from the north-northeast, northeast, and east-northeast are, for the most part, refracted away from the resort area by the Virginia Beach Massif to the Chesapeake Bay entrance and the Back Bay-False Cape area. In a similar manner, waves from the east-southeast, southeast, and south-southeast are concentrated in the Virginia Beach and adjacent offshore area. These phenomena result in the dominant northward longshore transport observed in the Virginia Beach area; this might be because greater wave energy reaches the area from the southern quadrants than from the north, resulting in a net nearshore sediment transport to the north. Harrison, et al., 1964 suggested that the observed northward sediment transport in the Virginia Beach area was due to a large nontidal eddy

related to the circulation originating at the mouth of the Chesapeake Bay. It should therefore be noted that both effects may be occurring and that neither the wave or current-induced circulation patterns are mutually exclusive."

Of the 70 wave conditions computed in the VSWCM, data from 30 of these conditions were used to compute shelf contour maps of wave height and maximum bottom orbital velocity, and shoreline histograms of wave height, wave energy and wave power gradient. These are listed in Table 1.

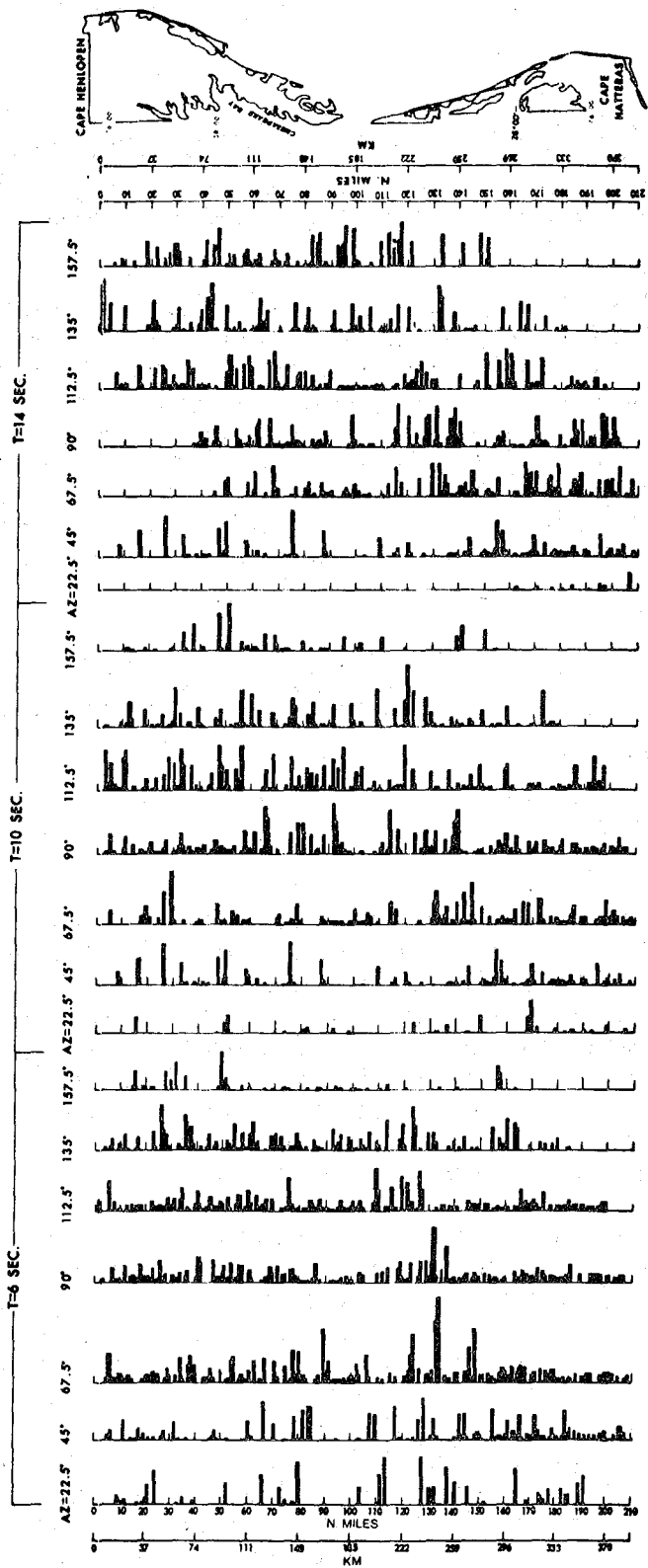
Table 1

<u>Direction of Incoming Wave</u>	<u>Wave Period</u>	<u>Tide Height (ft.)</u>	<u>Wave Height (ft.)</u>
45, 90, 135	6, 10, 14	0., +4.0	6.
22.5, 65.5, 112.5	6, 10, 14	0.	6.
157.5			

Figure 4 is a compilation of shoreline wave height distributions for 21 of these conditions (all the low tide). Note that for each of the three sets of wave periods (6, 10 and 14 sec.), the areas of higher wave heights (i.e., wave energy) move north as the direction of incoming wave energy changes from north-northeast (22.5°) to south-southeast (157.5°). This is to be expected as the incoming waves "pivot" around the shelf area causing the focusing of wave energy on the downwave shoreline.

In general, areas of wave energy concentration on Currituck Spit are from Back Bay, Virginia to Duck, North Carolina. However, the intensity varies considerably along this area with a particular wave condition, and varies also with the wave direction and period. The specific areas along Currituck Spit which receive comparatively larger wave energy from specific wave conditions, are clearly delineated in Figure 4. The important point is that shoreline wave energy distribution is highly variable, both spatially and temporally and that site-specific studies are needed for understanding local coastal processes.

SHORELINE WAVE HEIGHT DISTRIBUTION FOR 21 WAVE CONDITIONS (DIRECTION AND PERIOD) COMPUTED BY THE VIRGINIAN SEA WAVE CLIMATE MODEL
 From Goldsmith, et al., 1974



PRESENT AND FUTURE RESEARCH

These complex wave energy distributions are reflected in the highly variable shoreline changes (Goldsmith, 1976 and in this volume). Present efforts involve relating these computed wave data to real shoreline changes over three temporal scales: (a) Historical changes; (b) Beach profile changes over 4-8 years; and (3) Beach changes resulting from a single storm event (Fisher, et al., 1976).

If statistically valid relationships can be established, then an increased understanding of the nature of shoreline changes and sand budgets will be achieved, as well as a tool for predicting, and thereby managing these shorelines.

REFERENCES

- Bodine, B.R., U.S. Army Coastal Engrg. Research Center, 1971. Storm Surge on the Open Coast: Fundamentals and simplified prediction, 65 p.
- Byrne, R.J., and Anderson, G.L., 1973. Shoreline Erosion in Virginia's Tidal Rivers and Chesapeake Bay (abs.): Va. Jour. Sci. v. 24, n. 3, p. 158.
- Chao, Y.Y., and Pierson, W.J., 1972. Experimental studies of the refraction of uniform wave trains and transient wave groups near a straight caustic: Jour. Geophys. Res., v. 77, p. 4545-4554.
- Colonell, J.M., and Goldsmith, V., 1974. Results of ocean wave-Continental Shelf interaction: 14th International Conf. on Coastal Engineering, Copenhagen, Denmark, June, 1974, p. 586-600. VIMS Contrib. No. 597.
- Fisher, J.S., Gulbrandsen, L.F., and Goldsmith, V., 1975. Analytical prediction of erosion and overwash: An appraisal: Ocean Engineering III, ASCE, Specialty Conference, Newark, Delaware, June 1975, VIMS Contribution No. 706, pp. 161-178.
- Goldsmith, V., 1975. Shoreline Waves, Another Energy Crisis: Presented at the Coastal Society, First Annual Conference, Arlington, Virginia, The Present and Future of Coasts, Proc. Vol., pp. 49-58. VIMS Cont. 734.
- Goldsmith, V., 1976. Continental shelf wave climate models: a critical link between shelf hydraulics and shoreline processes: AAPG An. Mtg., Dallas and SEPM Spec. Publ., Nearshore Processes - Physical and Biological; VIMS Contrib. No. 708, in R.A. Davis, Jr. (ed.) SEPM Special Publication No. 23, Beach and Nearshore Sedimentation, p. 39-60.
- Goldsmith, V., Byrne, R.J., Sallenger, A.H., Jr., and Drucker, D.M., 1973. The influence of waves on the origin and development of the offset coastal inlets of the Delmarva Peninsula: 2nd International Estuarine Conference: Recent Advances in Estuarine Research Geology Section - Coarse-grained sediment transport and accumulation in estuaries: Myrtle Beach, S.C., 15-18 Oct., 1973. Vol. II, p. 183-200. VIMS Contrib. No. 579.

- Goldsmith, V., Morris, W.D., Byrne, R.J., and Whitlock, C.H., 1974. Wave Climate Model of the Mid-Atlantic Shelf and Shoreline (Virginian Sea): Model Development, Shelf Geomorphology, and Preliminary Results: VIMS SRAMSOE No. 38, 146 p. (also available from NTIS for \$5.75).
- Goldsmith, V., Morris, W.D., and Sutton, C.H., 1977. Distribution of wave heights, bottom orbital velocities, wave energy and wave power over the shelf and along the shoreline - Part II-Wave Climate Model of the Mid-Atlantic Continental Shelf and Shoreline (Virginian Sea): VIMS SRAMSOE No. 48, in prep.
- Goldsmith, V., Rosen, P.S., Gammisch, R., Hogge, E., Sutton, C.H., and Carron, M.J., 1977. VIMS-BLM Wave Climate Model of the Baltimore Canyon Trough Shelf--- Shelf Wave Height and Bottom Velocity, Shoreline Wave Height and Energy: Evaluation and Results VIMS SRAMSOE No. 106.
- Goldsmith, V., Rosen, P., Richardson, W.S., and Sutton, C.H., 1976. Wave Modelling in Limited Fetch Basins: Making Waves in the Chesapeake Bay: Presented at G.S.A., NE-SE Conference, March, 1976, Washington, D.C.
- Goldsmith, V., Sutton C.H., Richardson, W.S., and Rosen, P., 1976. The Chesapeake Bay Wave Climate Model for Limited Fetch Conditions: Model Description, Verification and Application to Interpretation Shoreline Geomorphology: VIMS SRAMSOE No. 89 (in press).
- Jelesnianski, C.P., 1972. SPLASH (Special Program to List Amplitudes of Surges from Hurricanes): 1. Landfall storms: NOAA Tech. Memo NWS TDL-46, 52 p.
- Jelesnianski, C.P., 1974. SPLASH (Special Program to List Amplitudes of Surges from Hurricanes): Part Two- General track and variant storm conditions: NOAA Tech. Memo. NWS TDL-52, 53 p.
- Munk, W.H., and Traylor, M.A., 1947. Refraction of ocean waves; a process linking underwater topography to beach erosion: Jour. Geology, v. 55, p. 1-26.

Sallenger, A.H., Goldsmith, V., and Sutton, C.H., 1975.
Bathymetric Comparisons: A manual of methodology,
error criteria and techniques: VIMS SRAMSOE No. 66,
36 p. plus 12 figs.

Wilson, B.W., 1965. Numerical Prediction of Ocean Waves
in the North Atlantic for December, 1959: Deutsche
Hydrographische Aeitschrift, Heft 3, p. 126.

TIDES AND NEARSHORE CURRENTS NEAR CAPE
HENRY AND ALONG CURRITUCK SPIT

Christopher S. Welch

INTRODUCTION

From a hydrodynamic point of view, the state of the ocean between Cape Henry and Currituck Spit is well specified if the height of the free surface, density stratification, and currents are known. In the nearshore region, mixing generally eliminates density stratification, so currents and sea surface heights become the primary quantities of hydrodynamic interest. Changes in sea surface height are caused primarily by tides and storm surges. These latter are discussed in another section of this guidebook.

TIDES

The mean tidal range in the local region, 3.6 feet, is a near minimum value for the East coast north of Florida (Redfield, 1958). The range increases both north and south of the local region. The time of high water along the open coast is nearly simultaneous from Virginia Beach to Currituck Beach, although there is a progression in times of twelve minutes from south to north over this region. As a contrast, a jump in time of almost an hour occurs across the mouth of Chesapeake Bay. These data, and tidal heights in general, are well documented in the National Ocean Survey Tide Tables (NOS, annual a). As the jump in high water times across the mouth of Chesapeake Bay indicates, the Bay itself has a profound influence on the local tidal patterns (Fig. 1).

The nearshore currents are less understood than the tidal heights at present. This is partly because the structure of the currents is more complex than that of the heights, and partly because some of the non-tidal currents

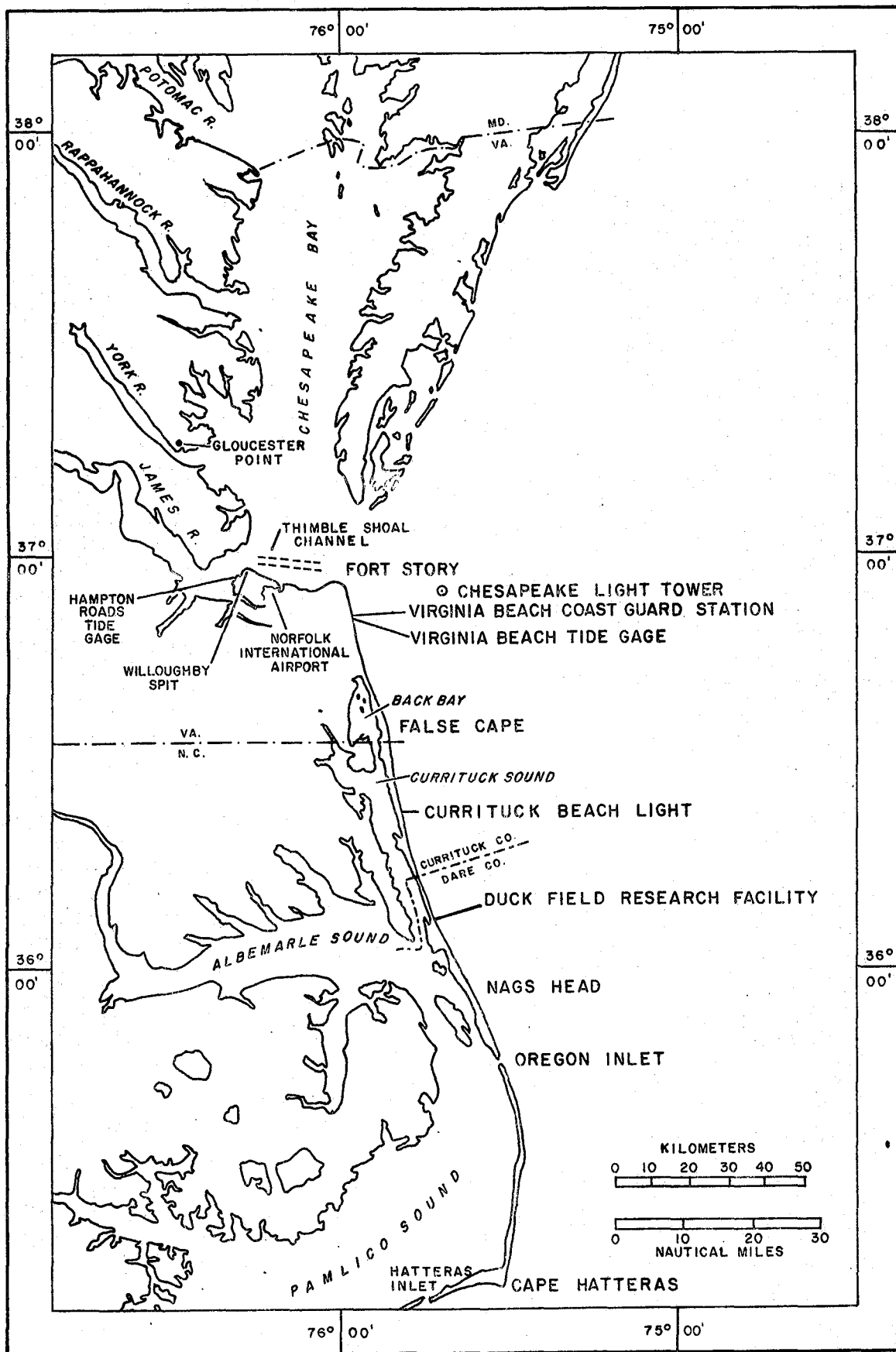


Figure 1 Regional location map

are associated with very small changes in height, so that the height signature is generally disregarded with respect to tidal height variations and storm surges. Also, most tidal current records are obtained from inlets and port areas, which are in general not representative of the larger current patterns.

The tidal current in the local region is dominated by the interaction between the tide on the continental shelf and the response to that tide in Chesapeake Bay. Some indication of the general current pattern is obtained from the Tidal Current Tables (NOS, annual b). The mean amplitude tidal currents near the mouth of Chesapeake Bay are nearly axial to the Bay with an amplitude of 1 to 1.5 knots. Near Chesapeake Light, about 15 nautical miles from the Bay mouth, the tidal currents are too weak and variable to be predicted. This may indicate the position of that station is near a node of the current due to the bay-shelf interaction. An analysis of current data taken between Cape Henry and Dam Neck, Virginia (Welch and Kiley, in prep.) shows the tidal current is reduced to about 30% of its Bay Mouth value at a distance of 11 nautical miles south of the Bay mouth. Between Virginia Beach and Cape Hatteras there are no published tidal current measurements. In many other aspects, this section of the coast and continental shelf remains unexplored territory.

NEARSHORE CURRENTS WITHIN THE COASTAL BOUNDARY LAYER

Non-tidal currents are, beyond the immediate influence of Chesapeake Bay, at least as important as tidal currents. These are due to a variety of causes. Excluding currents directly induced by surface waves, such as longshore drift and rip currents, currents can be caused by non-linear tidal effects, local wind stresses and atmospheric pressure fluctuations, freshwater input pulses from Chesapeake Bay, shelf wide regional weather forcing, and long-period continental shelf waves. The response to this forcing between the surf zone and approximately 5 nautical miles from shore is different to that for the broad extent of the shelf. For this reason, this narrow strip is becoming known as the coastal boundary layer (Csanady, 1972).

Non-Linear Tidal Effects

In the region between Cape Henry and Currituck Spit, non-linear tidal effects may be significant as far south

as Rudee Inlet ($36^{\circ}50'N$), about six nautical miles south of Cape Henry. These effects are associated with patterns of predominant flood or predominant ebb in records from individual current meters. Harrison, et al. (1964), inferred a mean Eulerian current in the form of a gyre due to these effects near Virginia Beach and Stanley (1976) calculated a similar gyre in a numerical model of the Bay Mouth.

Local Wind Stresses

Local atmospheric forcing effects are not, in general, well correlated to local currents except very near to shore. One such effect of note is the sea breeze associated with the daily rising and setting of the sun. The sea breeze has a response of magnitude equal to the corresponding tidal (S_2) response, and it places a limit on the precision to which tidal currents can be predicted in the local region (Welch and Kiley, in prep.).

Fresh Water Input

Pulses of fresh water sometimes pass through the Mouth of Chesapeake Bay after heavy rains. When this happens, a fresh water tracer is added to the ocean water by which the Bay-derived water can be followed. Boicourt (1974) traced such an influx of fresh water after Hurricane Agnes and noted it formed a narrow coastal jet extending towards Cape Hatteras. It is likely that excess outflow from Chesapeake Bay generally takes such a path.

Regional Weather Patterns

In contrast to local weather forcing, shelf-wide regional weather forcing appears, particularly during the winter season, to drive the currents over the entire mid-Atlantic Bight as a unit. Ruzicki and Welch (1976), using satellite-tracked EOLE buoys in a joint program with NASA Langley Research Center, observed several such responses, in the form of southward moving coastal jets, to winter storms. Beardsley and Butman (1974) noted similar responses in the mid-shelf region to some, but not all winter storms. They speculated that the particular shape of the winter storm as it related to the entire mid-Atlantic Bight had more to do with the response of the system than did the

local winds at any single point. They also found the response seemed dominated by southward flowing currents.

Long Period Shelf Waves

When tidal and short period oscillations are removed from the records of coastal currents, substantial fluctuations remain at periods of about 5 days and longer. These fluctuations are of unclear origin. The candidate causes are weather effects of smaller amplitude and greater ubiquity than those associated with winter storms, and quasi-geostrophic waves called "continental shelf waves" induced perhaps by the meandering of the Gulf Stream.

Coastal Boundary Layer

The response to forcing is, according to recent studies, different in a coastal boundary layer than in the mid and outer shelf regions. Such a boundary layer, extending about 5 miles to sea, has been postulated (Csanady, 1972) in analogy to similar boundary layers observed in the Great Lakes. Within this layer, the depth of the thermocline is subject to rapid variations in response to local wind forcing with an accompanying current structure, the whole process sometimes resulting in coastal upwelling or downwelling. The detailed behavior of this boundary layer has not been fully studied, particularly near discontinuous shorelines such as the Bay mouth.

SUMMARY

The changes of sea level height along the open coast between Cape Henry and Currituck Spit are small compared to other regions of the East Coast. They are comprised mostly of regular tidal fluctuations and storm surges, and fluctuations associated with particular storm events. The currents are less well known and more complex with contributions from sea breeze, shelf-wide weather forcing, non-linear tidal interaction, and radiation of energy from the deep ocean. The response in a narrow coastal band, the coastal boundary layer, is different from that over the mid and outer shelf and results on occasion in coastal upwelling effects.

REFERENCES

- Beardsley, R.C., and B. Butman, 1974. Circulation on the New England Continental Shelf: Response to Strong Winter Storms, Geophysical Research Letters, 1, pp. 181-184.
- Boicourt, W.C., 1973. The Circulation of Water on the Continental Shelf from Chesapeake Bay to Cape Hatteras, Ph.D. Thesis, The Johns Hopkins University, Baltimore, Maryland, 183 p.
- Boicourt, W.C., Hacker, P.W., 1976. Circulation on the United States, Cape May to Cape Hatteras, Memoires Societe Royale des Sciences de Liege, pp. 187-200.
- Csanady, G.T., 1972. The Coastal Boundary Layer in Lake Ontario. Part I: The Spring Regime, Journal of Physical Oceanography, 2, pp. 41-53.
- Harrison, W., M.L. Brehmer, and R.B. Stone, 1964. Near-shore Tidal and Nontidal Currents, Virginia Beach, Virginia, April, U.S. Army Corps of Engineers Technical Memorandum No. 5.
- National Ocean Survey, NOAA, U.S. Department of Commerce, annual a, Tide Tables, High and Low Water Predictions, East Coast of North and South America Including Greenland, published annually.
- National Ocean Survey, NOAA, U.S. Department of Commerce, annual b, Tidal Current Tables, Atlantic Coast of North America, published annually.
- Redfield, A., 1958. Influence of Continental Shelf on Tides, Journal of Marine Research 17, pp. 432-448.
- Ruzecki, E.P., C. Welch, J. Usry, and J. Wallace, 1976. The Use of the EOLE Satellite System to Observe Continental Shelf Circulation, Presented at the Off-shore Technology Conference, May.
- Stanley, E.M., 1976. A Two-Dimensional Time-Dependent Numerical Model Investigation of the Coastal Sea Circulation around Chesapeake Bay Entrance, Ph.D. Thesis, College of William and Mary, 165 p.

Welch, C.S. and K. Kiley. Dam Neck Current Analysis, a report to Malcolm Pirnie Engineering Company (in prep.).

STORM SURGES AT HAMPTON ROADS (SEWELLS POINT), VIRGINIA

N. Arthur Pore¹
William S. Richardson¹

Abstract

Storm surge is the meteorological effect on sea-level and is computed as the algebraic difference between observed tide and astronomical tide. Storm surges which occur along the Virginia coast are of great concern to coastal residents and property owners, particularly if the surge coincides in time with astronomical high tide. These surges and associated wave action which are generated by tropical and extratropical storms have caused tremendous water damage and destruction along the Virginia coast. The highest surge recorded at Hampton Roads (6.2 ft) was caused by the August 23, 1933 hurricane. However, one of the most destructive storms of recent times was an extratropical storm. The March 7, 1962 or "Ash Wednesday" storm generated a 5.6-foot surge at Hampton Roads.

INTRODUCTION

Measured tide data have been recorded at Hampton Roads (Sewells Point) on nearly a continuous basis since 1928. The National Ocean Survey (NOS) tide gage at Hampton Roads is located within the mouth of the Chesapeake Bay (see Fig. 1). Since a storm surge, like astronomical tide, is modified by land masses and offshore bathymetry, the surge which occurs at Sewells Point is quite different from the surge which occurs on the ocean coastline.

Factors which are significant in storm surge (observed tide minus astronomical tide) generation are:

¹Techniques Development Laboratory, National Weather Service, Silver Spring, Maryland.

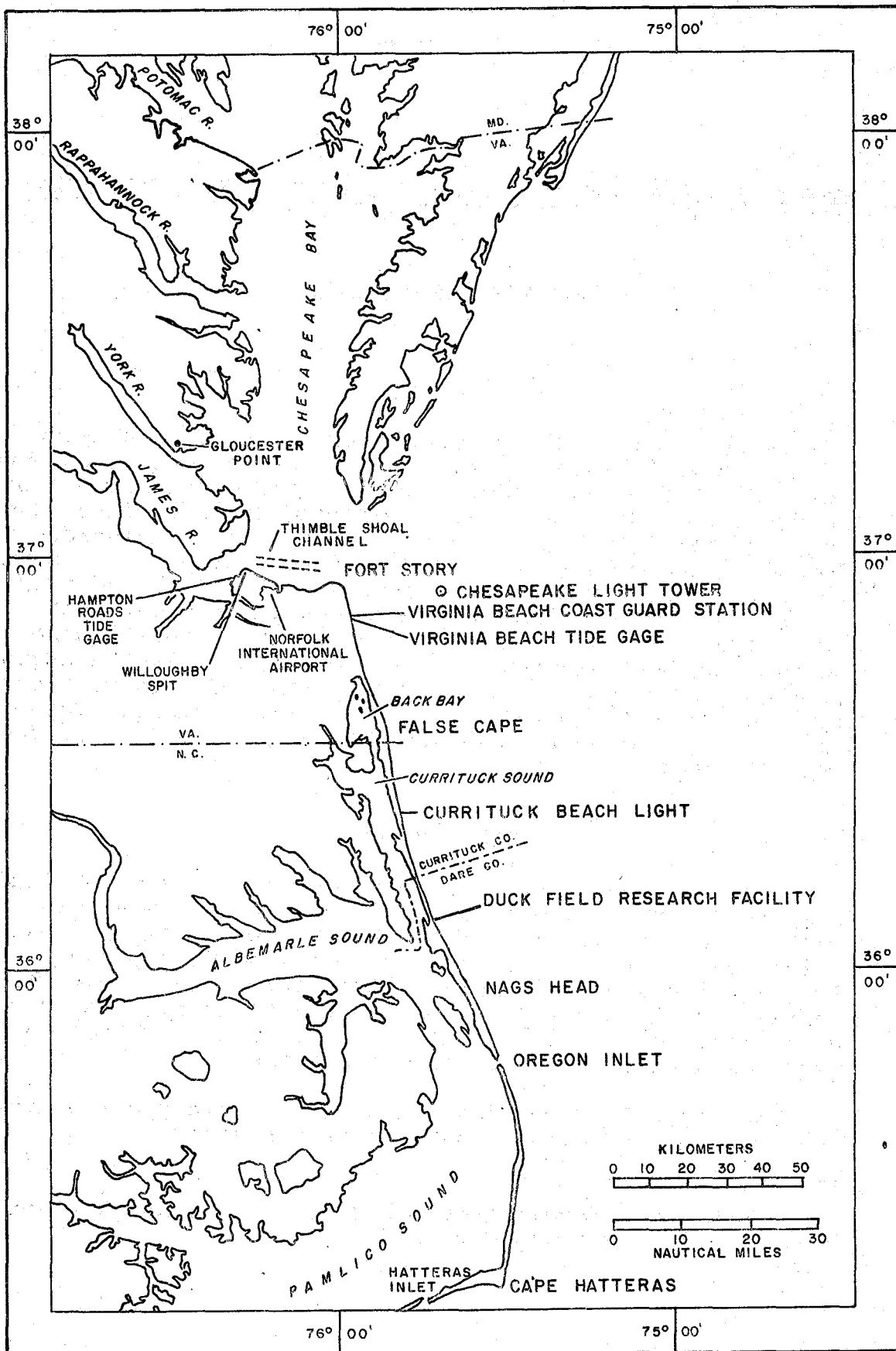


Figure 1. Location of NOS tide gage at Sewells Point in Hampton, Virginia.

- (1) direct wind action,
- (2) coastline configuration and bathymetric condition,
- (3) atmospheric pressure,
- (4) water transport by waves and swell,
- (5) earth's rotation,
- (6) rainfall.

A discussion of these factors is given by Pore and Barrientos (1976).

Methods to forecast storm surges are distributed into three classes by Groen and Groves (1962). They are (1) empirical, (2) semi-empirical, and (3) theoretical. In the first class, direct relationships between meteorological variables at a point or over an area during some time period and the storm surge are formulated. Forecast methods of the second class are based on simplified theoretical calculation, direct correlation, and perhaps smoothing procedures. The theoretical approach is the numerical integration of the basic equations of motion and continuity.

EXTRATROPICAL STORM SURGE

The frequency of significant extratropical storm surge varies from year to year (Table 1a and b, and 2). During the past few years there have been few significant storm surge events at Sewells Point. The average frequency of surges for Sewells Point is illustrated in Figure 2. This graph is based on data for the winter months of October through May. For example, in the winter months, Sewells Point experiences a 4 foot or greater extratropical surge about once every 4.25 years. The dates of extratropical storms which have generated surge heights of 4 feet or greater at Sewells Point and the heights of the surges are shown in Table 3 for the 14 year period, 1956 through 1969. The tide frequency at Virginia Beach, Virginia has been computed by Ho, et al., 1976 (Fig. 3).

Hustead (1955) developed an empirical method to forecast meteorologically produced tide departures from normal astronomical tide for the Norfolk, Virginia tidal basin during northeast winds. This method is applicable to storms moving northward off the Virginia Capes, east of Cape Henry and Cape Charles. Figure 4 shows the tide departure as a function of mean wind movement in a 2-hour period. Instructions for using the method given by Hustead (1955) are: "In practice, forecast the wind movement expected on triple

TABLE 1A

HEIGHTS OF TIDE ABOVE MEAN LOW WATER ASSOCIATED
WITH STORMS AT SEWELLS POINT IN HAMPTON, VIRGINIA

1879-1956

WIND

Date	Maximum Five Minute (kn) and Direction from	Fastest Mile (kn) and Direction from	Lowest Pressure	Height of tide above MLW (ft)
* Aug. 18, 1879		72-N	29.12	7.67
Apr. 6, 1889	55-N at Cape Henry	75-N 105-(actual) 120- (estimated)		8.37
Dec. 5, 1914	42-NE	52-NE	29.89	6.00
* Apr. 3, 1915	62-NE	76-NE	29.32	7.45
Feb. 5, 1920	34-N	37-N	29.69	7.00
* Sept. 29, 1928	53-NE	64-NE	29.51	7.06
Jan. 26, 1933	43-NW	50-NW	29.05	6.48
July 3, 1933	32-NE	34-NE	29.80	6.53
* Aug. 23, 1933	57-NE	70-NE	28.68	9.69- (highest)
* Sept. 16, 1933	56-NE	75-NE EST	29.38	8.16
* Sept. 18, 1936	56-NW	68-NW	29.31	9.19
Jan. 29, 1937	42-N	53-N	29.75	6.25
May 30, 1938	34-NE	36-NE	29.48	6.02
Jan. 24, 1940	43-NE (23rd)	48-NE (23rd)	29.30	6.74

TABLE 1A, continued

WIND

Date	Maximum Five Minute (kn) and Direction from	Fastest Mile (kn) and Direction from	Lowest Pressure	Height of tide above MLW (ft)
Mar. 28, 1942	34-E	40-E	28.85	5.31
*Sept. 14, 1944	56-NW	73-N	29.04	5.90
				Departure +5.2
Oct. 5, 1948	32-E	35-E	29.56	6.80
Nov. 1, 1949	31-NW	35-NW	29.53	5.50
Feb. 22, 1951		33-NW	29.42	4.50
Mar. 13, 1951		29-SE	29.52	Departure average
	+2.3 feet this day due northeast to east winds prevailing Mar. 12 and 13.			
May 18, 1951		23-W	30.01	5.40
Oct. 4, 1951		38-NE	29.61	6.00
Oct. 18, 1951		32-N	30.09	5.60
Feb. 27, 1952		31-N	29.63	5.70
* Aug. 22, 1953		63-NE	29.39	6.00
(Barbara)				
Oct. 22, 1953		26-NE	29.95	5.50
Oct. 23, 1953		18-NE	29.71	5.90
Oct. 24, 1953		16-NW	29.66	5.40
Nov. 6, 1953		30-NE	29.95	5.80 and
				5.60
Jan. 23, 1954		29-N	30.11	5.80 and
(These tides were +3.3 and +3.0 feet above normal.)				5.35
May 14, 1954		35-NE	29.93	5.10
May 20, 1954		27-NE	29.66	5.20
* Aug. 30, 1954		43-NE	29.38	5.60
(Carol)			(31 st)	

TABLE 1A, continued

WIND

Date	Maximum Five Minute (kn) and Direction from	Fastest Mile (kn) and Direction from	Lowest Pressure	Height of tide above MLW (ft)
*Sept. 11, 1954 (Edna)		33-N	29.33	5.1
* Oct. 15, 1954 (Hazel)		78-S	28.99	Less than plus 1.0 greatest
Dec. 6, 1954	(Tide was below normal at height of storm.)	31-N	30.00	departure during approach. 5.90
* Aug. 12, 1955 (Connie)		47-E	28.76	Departure of plus 4.8
* Aug. 17, 1955 (Diane)		42-E	29.69	
*Sept. 20, 1955 (Ione)		47-NE (19th) 32-NE	29.13	Departure of plus 3.0
Apr. 11, 1956		62-N	29.43	7.85

*Indicates that storm was of tropical origin.

TABLE 1B

OCCURRENCE OF STORMS IN HAMPTON ROADS AREA
FOR THE MONTHS OF NOVEMBER THROUGH MARCH¹

Extratropical (1956 to 1969)

Name	Date	Surge (ft)	Wind	
			Speed (kn)	Direction
	11 Jan. 1956	3.4	33	NE
	11 Apr. 1956	4.3	62	N
	3 Nov. 1956	2.0	29	NE
	28 Feb. 1957	2.4	33	NE
	8 Mar. 1957	2.2	27	NE
	1 Nov. 1957	2.7	28	NE
	25 Jan. 1958	2.3	44	E
	1 Feb. 1958	2.2	30	W
	19 Mar. 1958	2.2	21	NE
	27 Mar. 1958	2.6	20	N
	11 Dec. 1958	2.1	27	NE
	29 Dec. 1958	2.3	38	E
	12 Apr. 1959	2.5	45	NE
	19 Dec. 1959	2.1	29	N
	31 Jan. 1960	3.0	42	NE
	13 Feb. 1960	2.3	49	NE
	3 Mar. 1960	2.9	52	E
	12 Dec. 1960	2.0	40	W
	16 Jan. 1961	2.0	13	W
	8 Feb. 1961	2.4	27	NE
	22 Mar. 1961	2.2	33	E
	28 Nov. 1961	2.0	23	NW
	28 Jan. 1962	2.2	37	NE
	7 Mar. 1962	5.6	41	NE
	22 Mar. 1962	2.4	20	N
	3 Nov. 1962	2.5	33	N
	26 Nov. 1962	3.5	41	N
	8 Feb. 1963	2.3	30	NE
	6 Nov. 1963	2.4	38	E
	4 Jan. 1964	2.0	28	W
	12 Jan. 1964	2.6	42	E

TABLE 1B, continued

Name	Date	Surge (ft)	Wind	
			Speed (kn)	Direction
	12 Feb. 1964	2.6	32	E
	16 Jan. 1965	3.9	35	NE
	22 Jan. 1965	3.0	36	E
	29 Jan. 1966	3.6	37	E
	24 Dec. 1966	2.3	31	NE
	7 Feb. 1967	2.6	33	NE
	12 Dec. 1967	2.0	30	E
	29 Dec. 1967	2.0	31	W
	14 Jan. 1968	2.3	33	E
	8 Feb. 1968	2.6	30	NE
	10 Nov. 1968	4.3	34	N
	12 Nov. 1968	2.6	47	NE
	2 Mar. 1969	5.9	40	N
	2 Nov. 1969	2.6	36	NE
<u>Tropical (1964-1968)</u>				
Cleo	1 Sept. 1964	1.0	4.2	ESE
Dora	13 Sept. 1964	3.6	61	NE
Gladys	23 Sept. 1964	2.3	44	N
Isabell	16 Oct. 1964	2.6	50	NE
Alma	13 June 1966	1.0	40	N
Doria	16 Sept. 1967	3.9	55	N
Gladys	20 Oct. 1968	1.3	46	NE

¹Defined as having a surge greater than or equal to 2 feet (0.6 meters) at Hampton Roads tide gage.

TABLE 2

--MAXIMUM OCTOBER-MAY TIDES FROM NORTHEASTERS
1927-1973

(from Ho, et al., 1976)

Season	Hampton Roads Va.			Kiptopeke Beach Va.			Lewes Del.		
	Max ¹	Date ¹	Adj ¹	Max	Date	Adj	Max	Date	Adj
1927-28	2.7	5-08	3.4						
29	3.0	4-16	3.7						
1929-30	3.4	10-01	4.0						
31	4.1	11-04	4.7						
32	3.6	3-06	4.2						
33	3.8	1-26	4.4						
34	2.9	10-06	3.4						
35	2.8	1-24	3.3						
36	3.3	11-17	3.8						
37	3.6	1-29	4.1						
38	3.4	5-30	3.9						
39	3.1	4-29	3.5						
1939-40	4.1	1-24	4.5						
41	3.6	10-01	4.0						
42	3.0	3-28	3.4						
43	-	-	-						
44	2.7	12-29	3.1						
45	3.0	11-18	3.3						
46	3.9	12-05*	4.2						
47	3.0	4-21	3.3						
48	3.7	11-02	4.0				5.2	11-01	5.4
49	4.6	10-05	4.9				4.9	10-05	5.1
1949-50	3.3	10-17*	3.6				4.4	10-18	4.6
51	3.5	5-18	3.8				#7.2	11-25	-
52	3.5	2-27	3.7	3.4	2-27	3.6	-	-	-
53	3.3	11-21	3.5	3.7	11-21	3.9	4.5	12-22	4.7
54	3.9	10-23	4.1	3.9	10-23	4.1	5.5	10-23	5.7
55	3.5	12-06	3.7	3.1	4-25	3.3	4.4	4-24	4.6
56	5.5	4-11	5.7	3.7	1-11	3.9	5.2	1-10	5.4
57	3.5	10-28	3.7	3.2	10-25*	3.4	4.6	11-03	4.7
58	4.8	10-06	5.0	4.7	10-06	4.9	4.6	4-03	4.7
59	4.5	10-21	4.7	3.8	10-21	4.0	4.3	12-12*	4.4

TABLE 2, continued

Season	Hampton Roads Va.			Kiptopeke Beach Va.			Lewes Del.		
	Max	Date	Adj	Max	Date	Adj	Max	Date	Adj
1959-60	3.4	2-01	3.5	3.1	12-29*	3.2	4.3	12-30*	4.4
61	3.1	1-16	3.2	3.3	1-16	3.4	5.1	1-16*	5.2
62	6.4	3-07	6.5	6.1	3-07	6.2	7.4	3-06	7.5
63	4.0	11-27	4.1	3.8	11-27	3.9	5.6	11-03	5.7
64	3.0	1-01	3.1	3.2	1-01*	3.3	5.4	1-13	5.5
65	4.0	1-16	4.1	3.7	1-17	3.8	4.8	1-17	4.9
66	3.5	1-27	3.6	3.1	1-26	3.2	4.8	1-23	4.9
67	3.9	5-24	4.0	3.7	5-24	3.8	5.1	5-24	5.1
68	4.1	5-27	4.1	3.6	5-27	3.6	4.2	1-14	4.2
69	4.1	3-02*	4.1	3.7	3-02	3.7	4.8	11-12*	4.8
1960-70	3.3	11-10	3.3	3.6	11-10	3.6	5.3	11-10	5.3
71	4.2	3-26	4.2	3.6	3-26	3.6	4.7	3-27*	4.7
72	3.7	10-19	3.7	3.6	10-19	3.6	4.6	2-18	4.6
73	4.3	2-11	4.3				5.6	12-22	5.6

Legend:

Max = maximum observed at gage during October-May season, feet above local MSL based on 1941-59 epoch. Hurricanes excluded by inspection of weather maps.

Adj = maximum adjusted to 1970 sea-level conditions, using trends from Hicks and Crosby.

* = same elevation attained on one or more additional dates. Date listed is simultaneous with seasonal maximum at another station as first choice, earliest in season as second choice.

= high-water mark. Gage not in operation.

Table 3. Dates of extratropical storms during the winter months (November through April) in the 14-year period (1956 through 1969) which have generated surge heights of 4 feet or greater at Sewells Point and the heights of storm surges.

Dates of extratropical storms	Heights of storm surges at Sewells Point in feet
April 11, 1956	4.3
March 7, 1962	5.6
November 12, 1968	4.3
March 2, 1969	4.2

Table 4. Dates of tropical storms during 36-year period (1926 through 1961) which have generated surge heights of 4 feet or greater at Sewells Point and the heights of storm surges.

Dates of tropical storms	Heights of storm surges at Sewells Point in feet
August 23, 1933	6.2
September 16, 1933	5.2
September 18, 1936	4.9
September 12, 1960 (Donna)	4.9

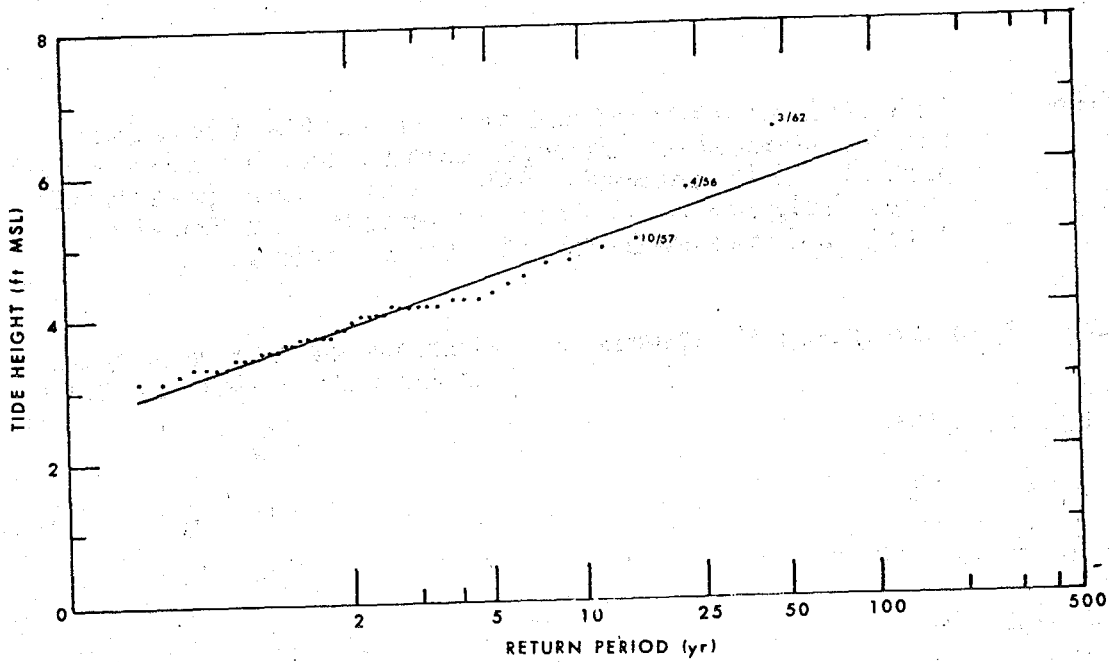


Figure 2. Tide Frequency at Sewells Point in Hampton Roads, Virginia, for October through May (from Ho, et al., 1976).

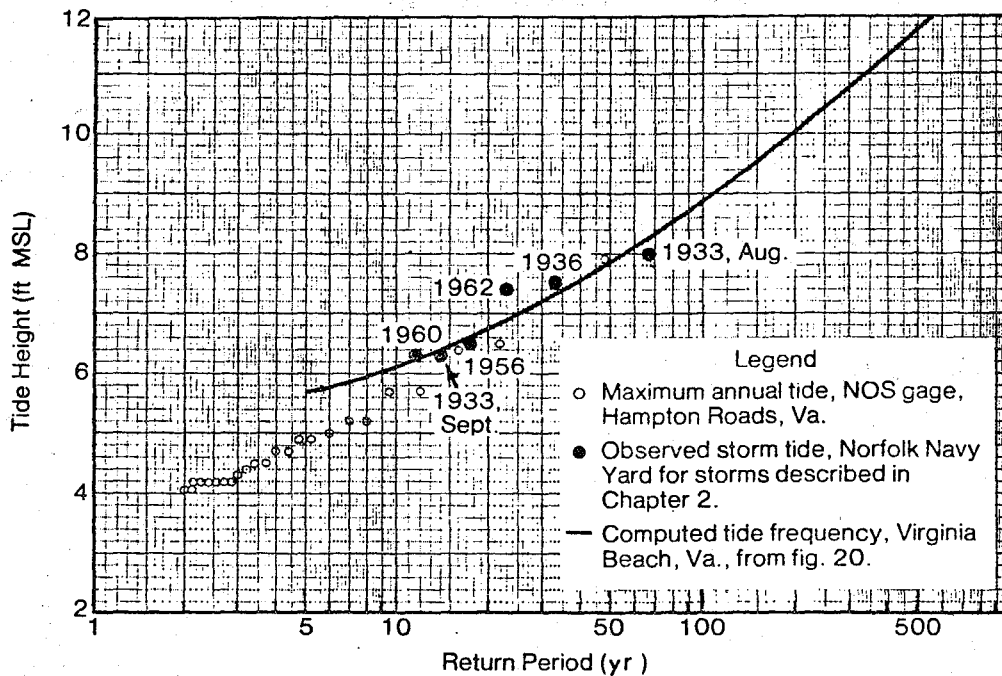


Figure 3. Comparison of tide frequency curve at Virginia Beach, Virginia, with tide observations at Hampton Roads and Norfolk Navy Yard (from Ho, et al., 1976).

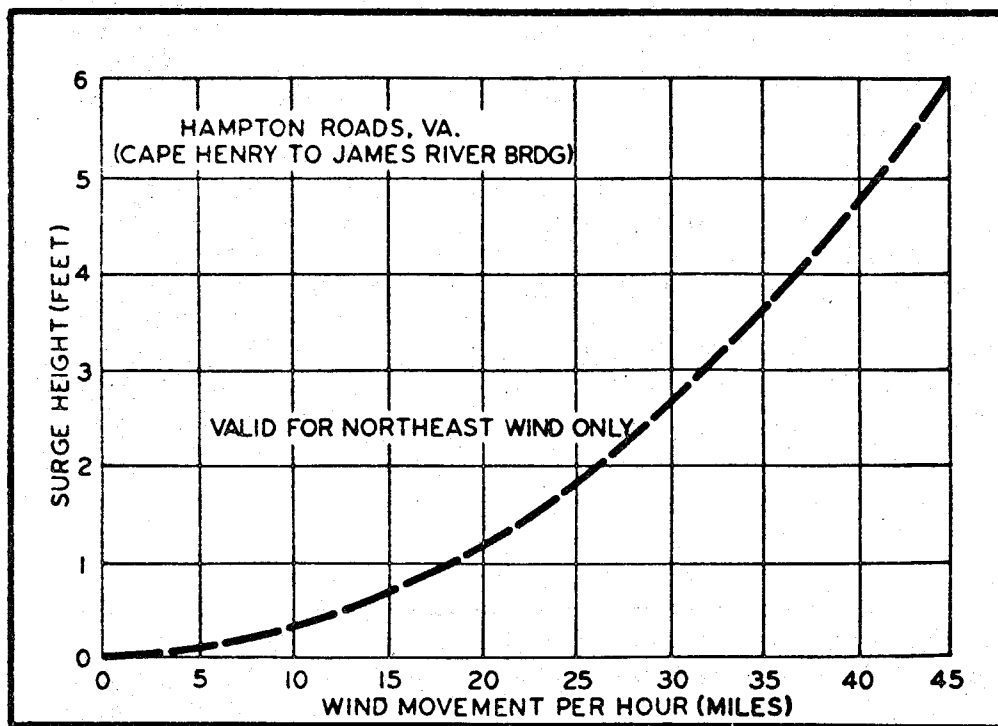


Figure 4. Relation of storm surge at Hampton Roads, Virginia, to 2-hour wind movement for northeast winds at Norfolk, Virginia. Values are based on mean movement for 2 hours prior to indicated tidal departure (Hustead, 1955).

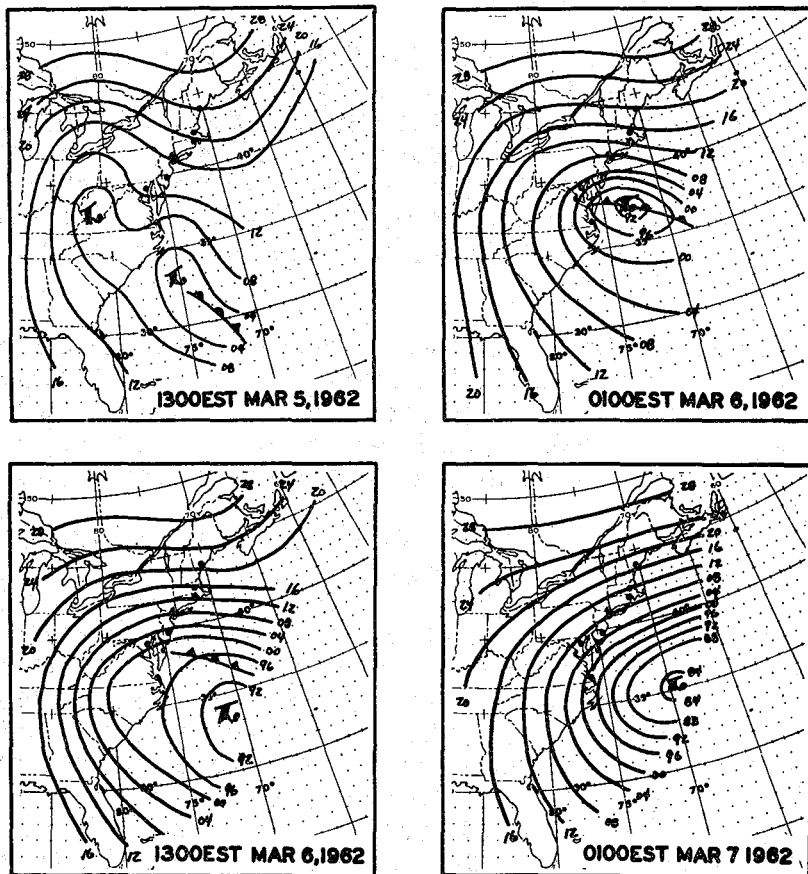
register for the 2-hour period prior to hurricane or coastal wave center reaching latitude 37°N . Then divide this forecast wind value by two. With this value located along the abscissa, read the ordinate value of tidal departure on curve. This tidal departure value if then added to the normal tidal value predicted for the Sewells Point gage for the forecast time of the storm center to reach 37°N . This tidal height and time is the forecast occurrence for Sewells Point and is then modified for any particular point in the tidal basin by using the time and height differences given in 'Table 2 - Tidal Differences and Ranges' as published in Tide Tables East coast, North and South America (including Greenland), U.S. Department of Commerce, Coast and Geodetic Survey."

More recently, Pore et al. (1974) have derived an extratropical storm surge forecast equation for Sewells Point by statistically relating sea-level pressure at various times at 75 grid points to the measured storm surge at Sewells Point. Figure 5 shows the sea-level pressure charts from 1300 EST March 5, 1962 through 0100 EST March 7, 1962. Also shown in Figure 5 are the observed storm surge and the surge computed by a storm surge forecast equation (Pore, et al., 1974) for the March 5-8, 1962 storm.

TROPICAL STORM SURGE

Tropical storms, in general, generate larger surges, but on a much smaller coastal segment, than extratropical storms (Jelesnianski, 1977). In regard to the measurement of the peak storm surge associated with tropical storms Jelesnianski (1977) states the following:

For tropical storms, the small coastal segment with surges may not contain gaging stations. Gages are not generally designed to measure the extreme surges generated by tropical storms and will become inoperative; on the periphery of storms, where surges are much lower, the gages give continuous readings. It is highly unlikely that the peak surge on a coast generated by a tropical storm will be measured by a gage.



HEIGHT IN FEET

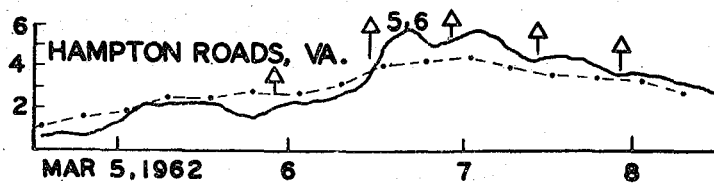


Figure 5. Sea-level pressure charts (in millibars) from 1300 EST March 5, 1962 to 0100 EST March 7, 1962 and observed storm surge and computed storm surge for the March 5-8, 1962 storm. Solid curves are observed storm surges. Dashed lines join calculated values of surge. Arrows indicate times of astronomical high tides. The date of each day is placed at the 1200 EST position. Maximum value of observed surge is placed near peak of the curve (from Pore, et al., 1974).

During the 36-year period (1926 through 1961) 4 tropical storms caused surges of 4 feet or greater at Sewells Point. The dates of these hurricanes and their associated surges at Sewells Point are given in Table 4. The track of the August 22-24, 1933 hurricane and the graph of the associated surge at Sewells Point is shown in Figure 6. The surge associated with this hurricane is the highest surge at Sewells Point.

Statistical techniques have been developed to predict only the peak or upper maximum surge on an entire coast for tropical storms that landfall, e.g., Conner, et al. (1957) and Harris (1959). The dominant predictor parameter for these models is a storm's central pressure.

For planning and prediction, more useful surge information can be derived from numerical models. One such model, SPLASH (Special Program to List Amplitudes of Surges from Hurricanes), Jelesnianski (1972, 1974, 1976) has been developed for general operational use by the National Weather Service. This continental Shelf Model is applicable on the eastern U.S. coasts from the Mexican to the Canadian border. Input to this model are meteorological parameters such as central pressure, storm size and storm track. Output from the model is an envelope of maximum surge heights which alerts the forecaster on the length of coast with significant surges. Variation of the output and other output versions are available, such as a time-history of coastal surge.

Bay surge modeling is handled differently than shelf modeling because of additional physics. Bay models have been developed by Reid and Bodine (1968) and Leendertse (1967).

SUMMARY

Storm surges along the Virginia coast are generated by extratropical and tropical storms. Tropical storms, in general, generate larger surges but on a much smaller coastal segment than extratropical storms. Although tropical storms generate larger surges (6.2 feet compared to 5.6 feet at Sewells Point), surges associated with tropical storms occur less frequently than surges associated with extratropical storms. For example during a 36 year period there were only 4 tropical storms which caused a surge of 4 feet or greater at Sewells Point; about 1 storm every

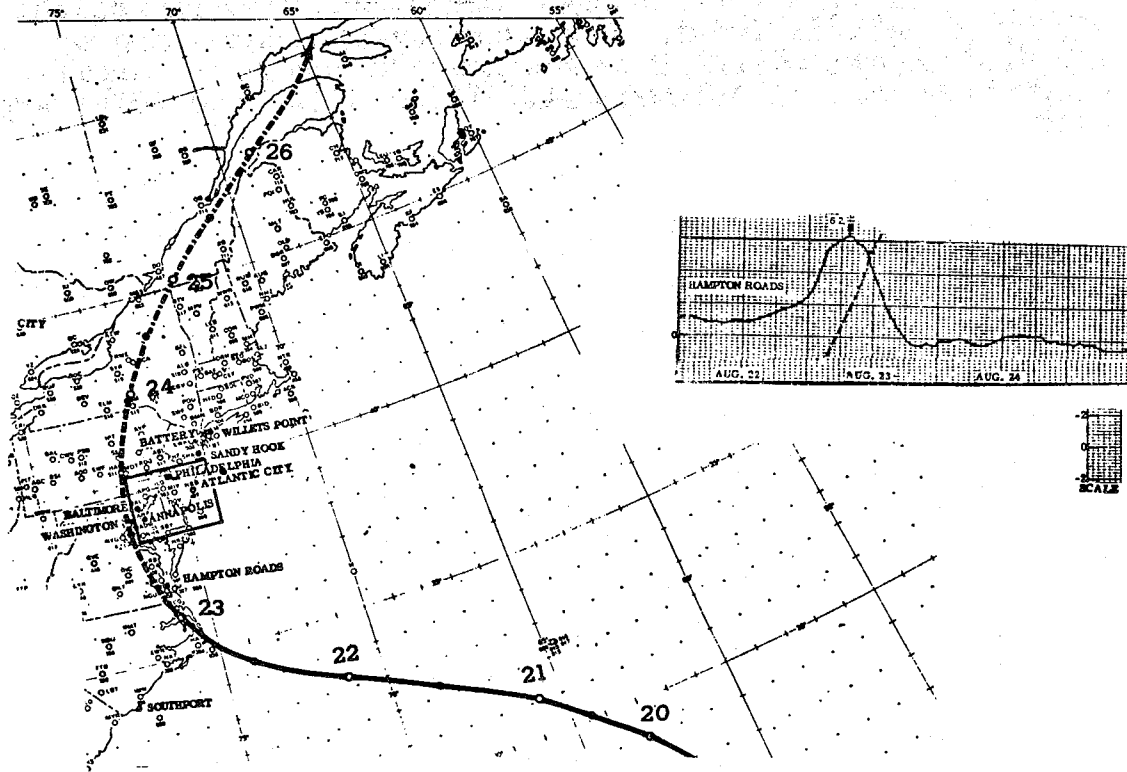


Figure 6. The track of the August 22-24, 1933 hurricane and the graph of the associated storm surge at Sewells Point (Harris, 1963, Fig. 4, p. 37).

9 years. Whereas about 1 extratropical storm every 4 years (using only data in winter months of November through April) generated a surge height of 4 feet or greater. Storm surge forecast guidance is made available to National Weather Service forecasters by computerized models. The National Weather Service uses a statistical method (Pore, et al., 1974) to forecast storm surges generated by extratropical storms at Sewells Point. For storm surges generated by tropical storms along an open coast the numerical shelf models (SPLASH) of Jelesnianski (1972, 1974, and 1976) are used.

REFERENCES

- Conner, W.C., R.H. Kraft, and D.L. Harris, 1957. Empirical Methods for Forecasting the Maximum Storm Tide Due to Hurricanes and Other Tropical Storms, Monthly Weather Review, Vol. 85, No. 4, pp. 113-116.
- Donn, W.L., 1958. An Empirical Basis for Forecasting Storm Tides, Bulletin of the American Meteorological Society, Vol. 39, No. 12, pp. 640-647.
- Groen, P. and G.W. Groves, 1962. Surges, Chapter 17 of The Sea, Vol. 1, John Wiley and Sons, Inc., pp. 611-646.
- Harris, D.L., 1959. An Interim Hurricane Storm Surge Forecasting Guide, National Hurricane Research Project Report No. 32, Weather Bureau, U.S. Dept. of Commerce, Washington, D.C., 24 pp.
- Harris, D.L., 1963. Characteristics of the Hurricane Storm Surge, Technical Report No. 48, Weather Bureau, U.S. Dept. of Commerce, Washington, D.C., 139 pp.
- Ho, F.P., R.J. Tracey, V.A. Myers, N.S. Foat, 1976. Storm Tide Frequency Analysis for the Open Coast of Virginia, Maryland, and Delaware, NOAA Technical Memorandum NWS HYDRO-32, Silver Spring, Md., August, 53 p.
- Hustead, A.D., 1955. An Empirical Method of Forecasting Meteorological Produced Tidal Departures from the Normal Astronomical Tide in the Norfolk, Va., Tidal Basin for a Specific Wind Direction, Manuscript of the U.S. Weather Bureau, Washington, D.C., 5 pp.
- Jelesnianski, C.P., 1972. SPLASH (Special Program to List Amplitudes of Surges from Hurricanes); I. Landfall Storms, NOAA Technical Memorandum NWS TDL-46, 52 pp.
- _____, 1974. SPLASH (Special Program to List Amplitudes of Surges from Hurricanes); II. General Track and Variant Storm Conditions, NOAA Technical Memorandum, NWS TDL-52, 55 pp.
- _____, 1976. A Sheared Coordinate System for Storm Surge Equations of Motion with a Mildly Curved Coast, NOAA Technical Memorandum, NWS TDL-61, 52 pp.

- _____, 1977. An Essay on Storm Surges, for Geophysics Research Board, National Academy of Sciences, to be published.
- Leendertse, J.J., 1967. Aspects of a Computational Model for Long-Period Water-Wave Propagation, The Rand Corporation, RM-5294-PR, 165 pp.
- Pore, N.A., W S. Richardson, and H.P. Perrotti, 1974. Forecasting Extratropical Surges for the Northeast Coast of the United States, NOAA Technical Memorandum NWS TDL-50, 70 pp.
- Pore, N.A. and C.S. Barrientos, 1976. Storm Surge, MESA New York Bight Atlas Monograph 6, New York Sea Grant Institute, Albany, New York, 44 pp.
- Reid, R.O., and B.R. Bodine, 1968. Numerical Model for Storm Surges in Galveston Bay, Proceedings of the American Society of Civil Engineers, Vol. 94, pp. 33-57.

AN INVESTIGATION OF LITTORAL TRANSPORT BETWEEN
VIRGINIA BEACH AND SANDBRIDGE, VIRGINIA

Richard C. Cunningham, Jr.¹

In the period from 1964 to 1967, the City of Virginia Beach spent \$800,000 in attempts to stave off erosion to its beaches. Funds were spent primarily for beach nourishment by dredging and pumping or hauling of sand.

The work summarized here is aimed at direct assessment of the amount of sand transported along the beach at the area of study (Fig. 1). Measurements were made of the cross-sectioned area of the surf zone, suspended sediment concentration, and current velocity. Annual flux of sediment was calculated from these data. Previous estimates of the littoral drift ranged from 980,000 yd³/yr (Weinman, 1970) using a wave parameter technique, 158,000 yd³/yr (Boon, 1969) using a tracer technique, to 70,000 yd³/yr (Bunch, 1969) using tracers and sand loss methods. Most workers concluded the principal transport was to the north in the area studied.

Field data were taken monthly from September 1972 to September 1973 at these stations with some additional sampling at a Dam Neck station in April, 1973.

In addition to visual observation of winds and waves, drogues (oranges or grapefruit) were timed over a 20 m distance 10 to 30 times per station visit and averaged. Drogues were introduced immediately landward of the breaker plunge point line. Suspended sediment concentration was measured by sampling in the water with a plastic cylinder 8 cm by 18.8 cm (800 ml). The tube was held parallel to the beach face by one worker and accuated by a second worker.

¹Institute of Oceanography, Old Dominion University.
Condensed and edited by John C. Ludwick, Old Dominion University, Norfolk, Virginia.

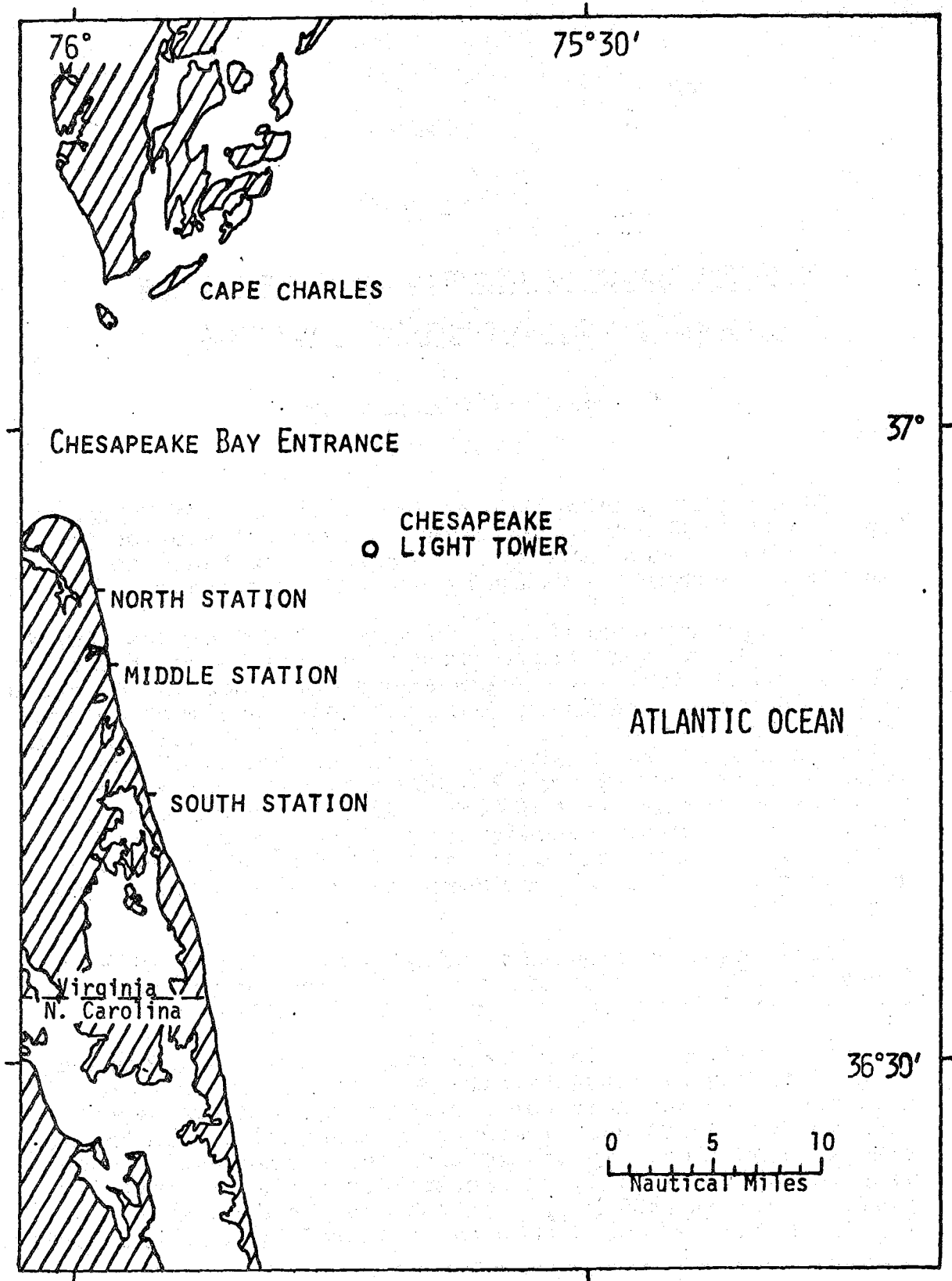


Figure 1. Study area map showing station location and Chesapeake Light Tower.

Both stood clear to reduce obstruction to the flow. Samples were taken at 0, 10, and 60 cm above the bed. The sampling was done at the mid surf zone position. Bottom profiles were obtained using hand levelling rods from a fixed location on the shore.

Sediment concentration was determined by filtration and weighing. A parabolic distribution was fitted to the three data points and an interpolated value was obtained for a 0-10 cm layer and a 10^{cm}-sfc layer. The profile survey data were treated so that a cross-sectional area for the 0-10 cm layer and for the 10^{cm}-sfc layer was obtained. Limits were taken as the mean shoreline and the breaker line.

Current speed in the 0-10 cm layer was taken as 0.75 of the measured surface speed. The product of the layer area by the layer speed by the layer sediment concentration yielded the layer sediment discharge (gm/sec). Total sediment discharge was taken as the sum of the two layer discharges, and finally an annual sediment discharge was calculated (gm/yr).

Average annual rates were obtained separately for southerly transports and northerly transports. Finally, using wave data from Chesapeake Light Tower, it was estimated that southerly transport would occur 40 percent of the year and northerly transport 60 percent of the year.

For northerly transport a figure of 378,000 yd³/yr \pm 24,000 yd³/yr was obtained. For southerly transport an estimate of 54,000 yd³/yr \pm 7,000 yd³/yr was calculated. Net transport was 324,000 yd³/yr \pm 30,000 yd³/yr.

An analysis of errors revealed the three stations gave appreciably different results perhaps owing to differences in beach slope and nearshore bar development. Cusps on the shorelines tended to inhibit the free movement of sediment along the shore. It was shown tidal flows were not correlated with speed and direction of the longshore currents at any of the stations. The assumption of a two-layer system is unrealistic as is the assignment of a uniform concentration of sediment across the entire surf zone. The most serious error is the use of a constant velocity at all points between the wash zone and the breaker line. Almost certainly, the values of sediment transport could be reduced by one-third due to this factor alone. 200,000 yd³/yr might be a better estimate from the data taken.

JULY 6

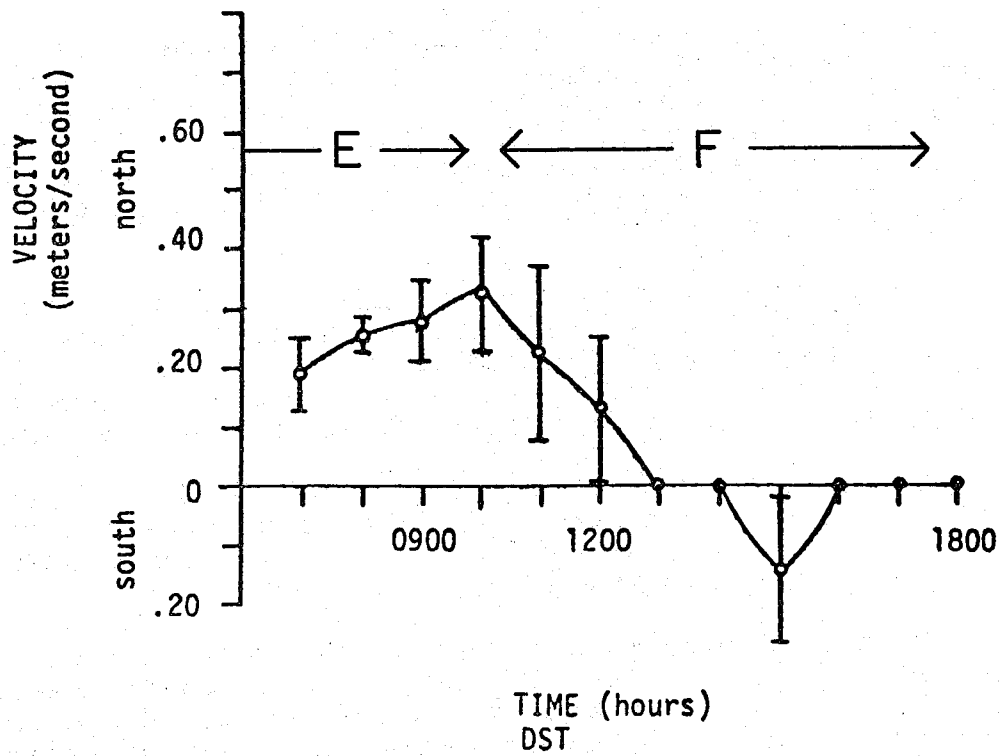


Figure 2. Field results from north station July 6, 1973, graphing littoral current versus time. E and F signify times of ebb and flood tide (Anonymous 1973 A and B). Error bars indicate one standard deviation unit.

REFERENCES

- Anonymous, 1973A. Tide Tables, 1973, East Coast of North and South America. A United States Department of Commerce Publication, 288 pp.
- Anonymous, 1973B. Tidal Current Tables, 1973, Atlantic Coast of North America. A United States Department of Commerce Publication, 200 pp.
- Boon, J.D., 1969. Quantitative analysis of beach sand movement, Virginia Beach, Virginia. *Sedimentology*, 13: 85-103.
- Bowen, A.J., 1969. The generation of longshore currents on a plane beach. *Journal of Marine Research*, 27: 206-215.
- Bunch, J.W., 1969. A fluorescent tracer study at a tidal inlet (Rudee Inlet, Virginia). Thesis, Old Dominion University (unpublished), 51 pp.
- Cunningham, R.C., Jr., 1974. An investigation of littoral transport between Virginia Beach and Sandbridge, Virginia, M.S. Thesis, Institute of Oceanography, Old Dominion University, Norfolk, Va., 58 p., 6 figs.
- Dean, R., 1970. Relative validities of water wave theories. *Journal of the Waterways and Harbors Division, Proceedings of the A.S.C.E.*, 96: 105-114.
- Dean R.G., 1973. Heuristic models of sand transport in the surf zone. *Proceedings of the Conference of Engineering Dynamics of the Coastal Zone, Sydney, Australia*, 208-214.
- Duane, D.B., 1970A. Tracing sand movement in the littoral zone: progress in the radioisotopic sand tracer (R.I.S.T.) study, July 1968 - February 1969. U.S. Army Coastal Engineering Research Center, Miscellaneous Paper 4-70, 46 pp.
- Duane, D.B., 1970B. Synoptic observations of sand movement. U.S. Army Coastal Engineering Research Center, Reprint 5-71, 14 pp.

- Duane, D.B., and Judge, C.W., 1969. Radioisotopic sand tracer study, Point Conception, California, Preliminary report on accomplishments, July 1966 - June 1968. U.S. Army Coastal Engineering Research Center, Miscellaneous Paper 2-69.
- Emery, K.O., 1961. A simple method of measuring beach profiles. *Limnology and Oceanography*, 6: 90-93.
- Galvin, C.J., 1967. Longshore current velocity: a review of theory and data. *Reviews of Geophysics*, 5: 287-304.
- Graton, L.C., and Fraser, H.J., 1935. Systematic packing of spheres with particular relation to porosity and permeability. *Journal of Geology*, 43: 785-809.
- Ingle, J.C., 1966. *The Movement of Beach Sand*. Elsevier, Amsterdam, 221 pp.
- Ippen, A.T., 1966. Sedimentation in estuaries. In: A.T. Ippen (editor), *Estuary and Coastline Hydrodynamics*, McGraw-Hill. New York, New York, 648-672.
- Komar, P.D., 1971. Mechanics of sand transport on beaches. *Journal of Geophysical Research*, 76: 713-721.
- Komar, P.D., and Inman, D.L., 1970. Longshore sand transport on beaches, *Journal of Geophysical Research*: 75, 5914-5927.
- Longuet-Higgins, M.S., 1972. Recent progress in the study of longshore currents. In: R.E. Meyer (editor), *Waves on Beaches and Resulting Sediment Transport*, Academic Press. New York, New York, 203-248.
- Ludwick, J.C., Director, Institute of Oceanography, Old Dominion University, Norfolk, Virginia.
- McGrath, D.G., 1973. Evaluation of two sand-height gage systems for monitoring coastal sediment migration. Thesis, Old Dominion University (unpublished), 68 pp.
- Miller, I., and Freund, J.E., 1965. *Probability and Statistics for Engineers*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 432 pp.

- Pettijohn, F.J., 1957. Sedimentary Rocks, 2nd edition
Harper and Bros., New York, New York, 718 pp.
- Savage, R.P., 1962. Laboratory determination of littoral
transport rates. Journal of Waterways and Harbors
Division, A.S.C.E., 88: 69-92.
- Shepard, F.P., 1963. Submarine Geology, 2nd edition
Harper and Row, New York, New York, 557 pp.
- U.S. Army Corps of Engineers, 1970. Feasibility report
for beach erosion control and hurricane protection.
U.S.A.C.E., Norfolk District, 18 Sept. 1970, 96 pp.
- Watson, T.L., 1973. Littoral drift computations along the
coast of Florida by means of ship wave observations.
Coastal and Oceanographic Engineering Laboratory,
College of Engineering, University of Florida, Tech-
nical Report No. 15, 77 pp.
- Watts, G.M., 1953. A study of sand movement at South Lake
Worth Inlet, Florida, U.S. Army Beach Erosion Board
Technical Memorandum No. 42, 24 pp.
- Weinman, Z.H., 1971. Analysis of littoral transport by
wave energy: Cape Henry, Virginia, to the Virginia
North Carolina border, Thesis, Old Dominion University
(unpublished), 64 pp.
- Zenkovitch, V.P., 1960. Fluorescent substances as tracers
for studying the movement of sand on the sea bed;
experiments conducted in the U.S.S.R. Dock and Harbor
Authority, 40: 280-283.

SHELF GEOMORPHOLOGY ADJACENT TO CURRITUCK SPIT,
VIRGINIA-NORTH CAROLINA - A REVIEW¹

Victor Goldsmith

INTRODUCTION

Ever since Uchupi's (1968) detailed studies of the continental shelf along the east coast of the United States, an increasing number of studies have focused attention on the various shelf relief elements. Much of this work is discussed in Emery and Uchupi (1972). Examples of studies which are of direct interest to the Virginian Sea area are included in the list of references.

Many of these studies are aimed primarily at shedding light on the controversy concerning the origin of the shelf relief elements - that is, are these features relict or presently hydraulically active, or a combination? If relict, how much have they been modified? The purpose here is merely to elaborate on those geomorphic features which are significant to the wave climate of the Mid-Atlantic Continental Shelf and Shoreline. These features are shown in the bathymetric map of the Virginian Sea (Fig. 1) and also in Figure 2, a three-dimensional computer projection of the depth data.

Seven-east west bathymetric profiles at intervals of 30 minutes of latitude taken from the 0.5 n. mi. depth grid is shown in Figure 3. Two important aspects of the profiles for this study are the great width and relatively shallow nature of this portion of the continental shelf. The abrupt increase in gradient at the shelf edge is between depths of 61 and 91 meters (200 and 300 feet) and is located as much as 60 n. mi. from shore. The distance from shore at which

¹Much of this is taken directly from Goldsmith, et al., 1974.

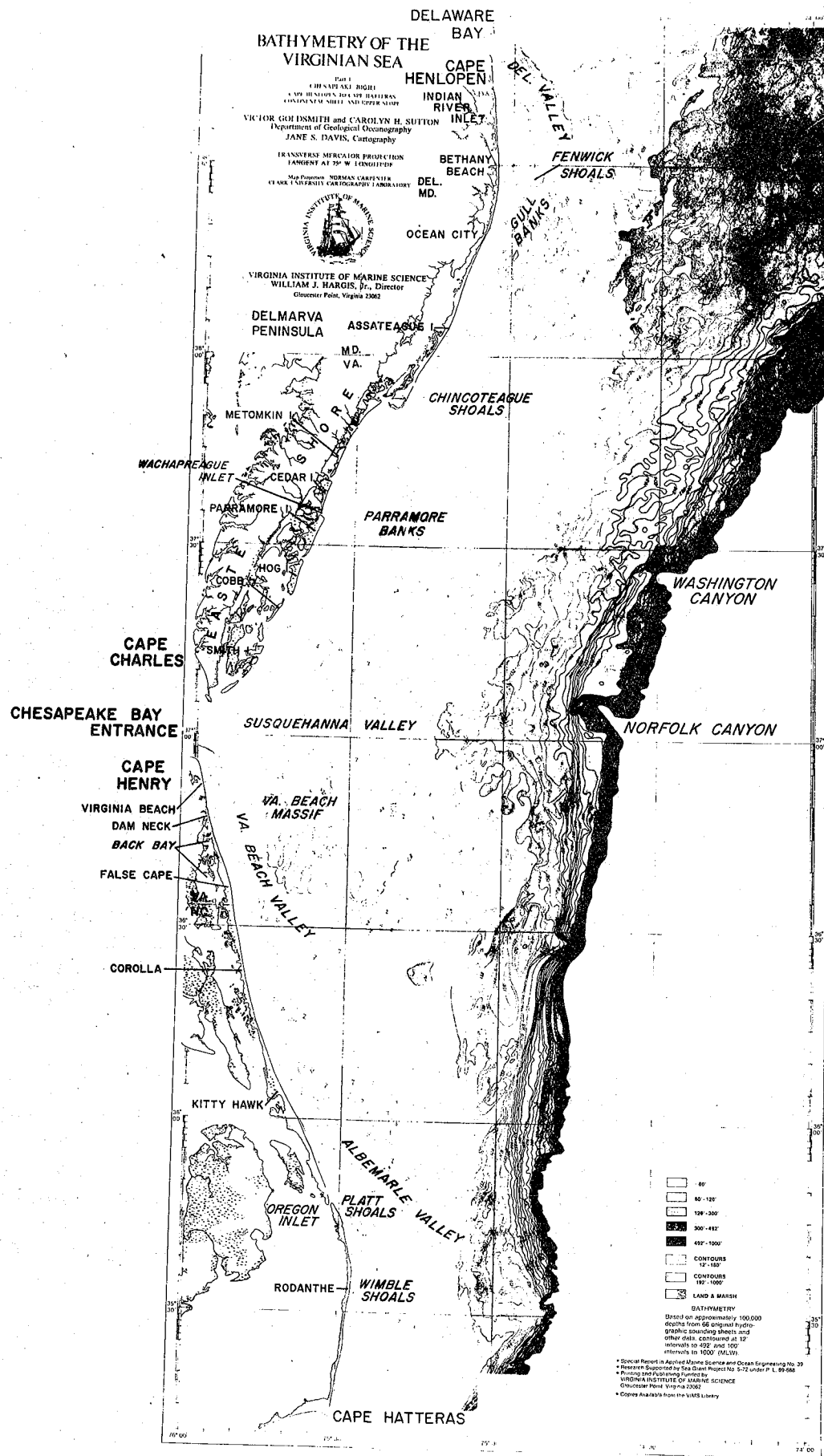


Figure 1. Bathymetric map of the Virginian Sea.

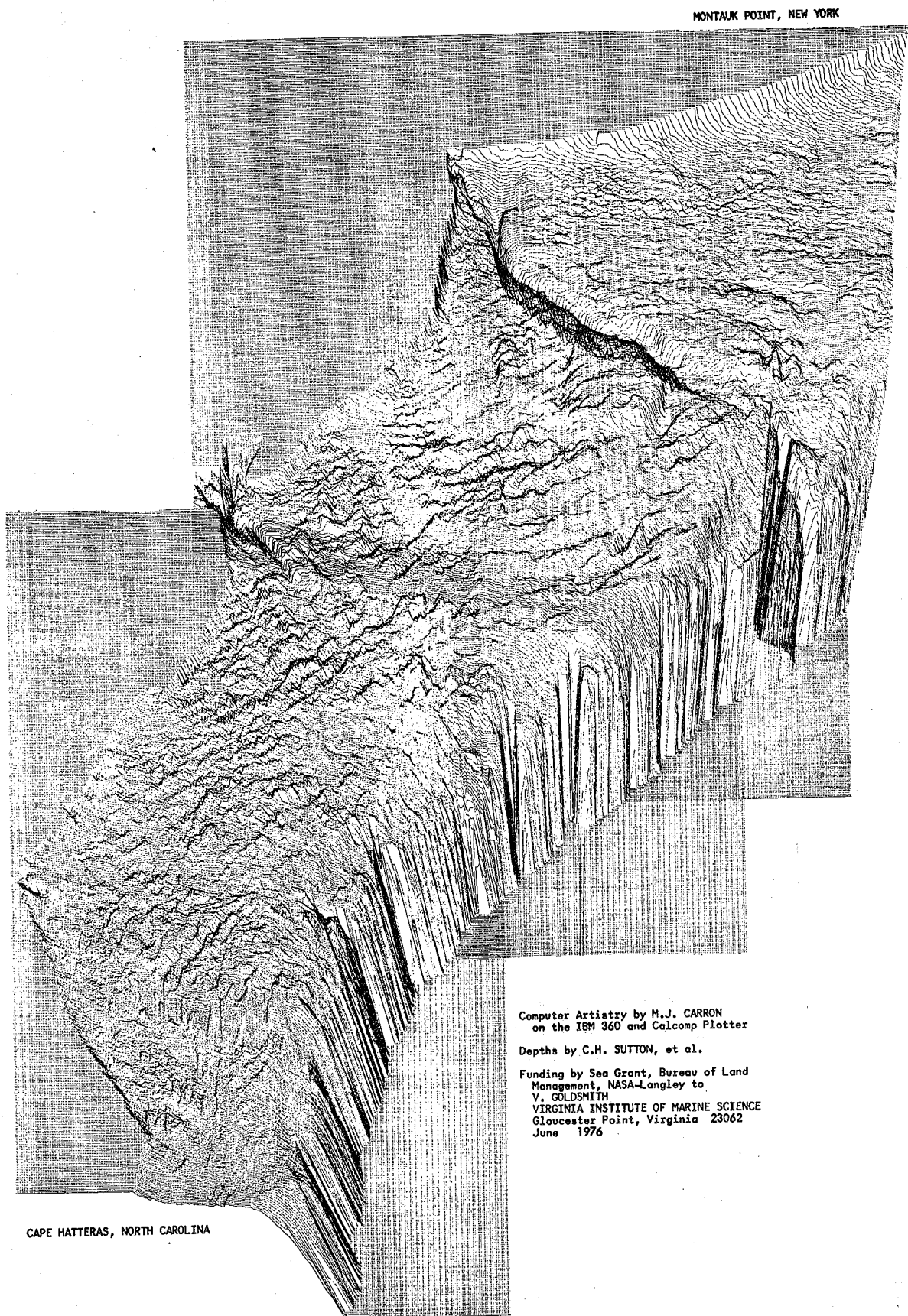


Figure 2. Three-dimensional computer projection of depth data from Montauk Point, New York, to Cape Hatteras, North Carolina.

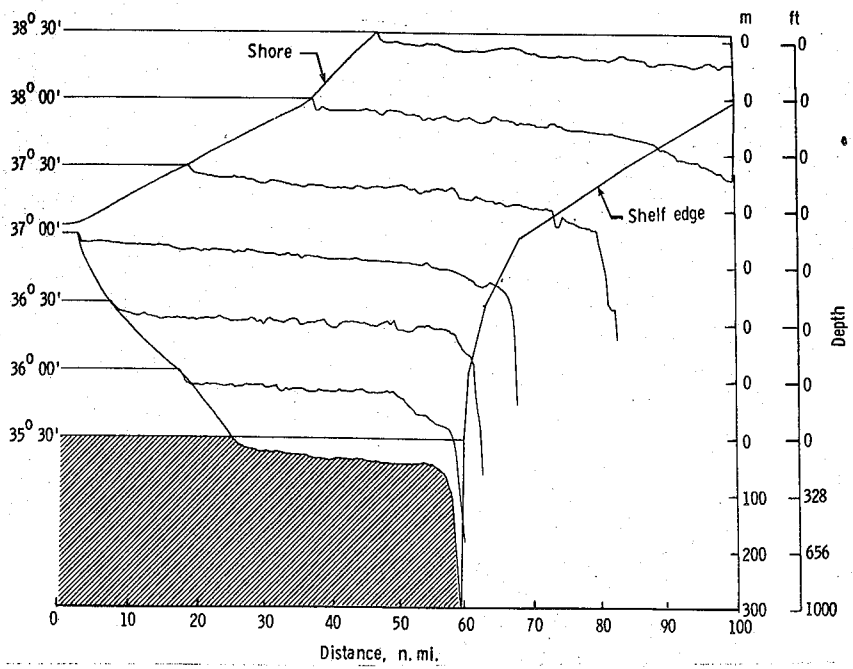


Figure 3. Seven of the 420 computer-plotted east-west bathymetric profiles selected at intervals of 30 minutes of latitude.

the ocean waves of different period begin to be appreciably affected by the sea floor is shown in Figure 4. Thus, a great expanse of the continental shelf, and superimposed relief elements, is available for influencing ocean wave behavior.

A closer examination of these profiles (Fig. 3) and the detailed bathymetric map of the sea floor (Fig. 1) reveals that the shelf surface is not a smooth plain but instead consists of numerous irregularities. These irregularities may be divided into two groups:

(1) Large-scale morphogeometry consists mainly of erosional forms cut into the shelf such as terraces, channels and valleys, and shelf-edge canyons.

(2) Small-scale shelf relief elements consist of low relief features (i.e., less than 9.144 meters (30 feet)) of probable depositional origin, most notably ridge and swale bathymetry and arcuate (e.g., cape-associated) shoals. Whereas the origin of group (1) features is directly related to a lowered sea level, group (2) features probably formed since the last rise in sea level under the present shelf hydraulic conditions. The most recent eustatic sea level lowering reached its maximum extent approximately 15,000 years ago on the Atlantic Continental Shelf. Eustatic sea level has been within 1.8 meters (6 feet) of its present level approximately 30,000 to 35,000 years ago and for the last 4,000 years (Milliman and Emery, 1968). However, tectonic events may have severely altered this sequence of sea level changes in this area (Harrison, et al., 1965; Newman and Rusnak, 1965; DeAlteris, 1973).

LARGE-SCALE MORPHOGEOMETRY

Terraces

The depths of the outer edge of the prominent shelf terraces determined from an east-west profile along 37° latitude from the mouth of Chesapeake Bay out across the shelf to Norfolk Canyon (Goldsmith, et al., 1973) are given in Table 1 and depths of these terraces are compared with the depths of other prominent terraces along the East Coast shelf. The most pronounced terraces adjacent to Chesapeake Bay are at 24, 30, 40, and 86 meters (78, 100, 132, and 282 feet).

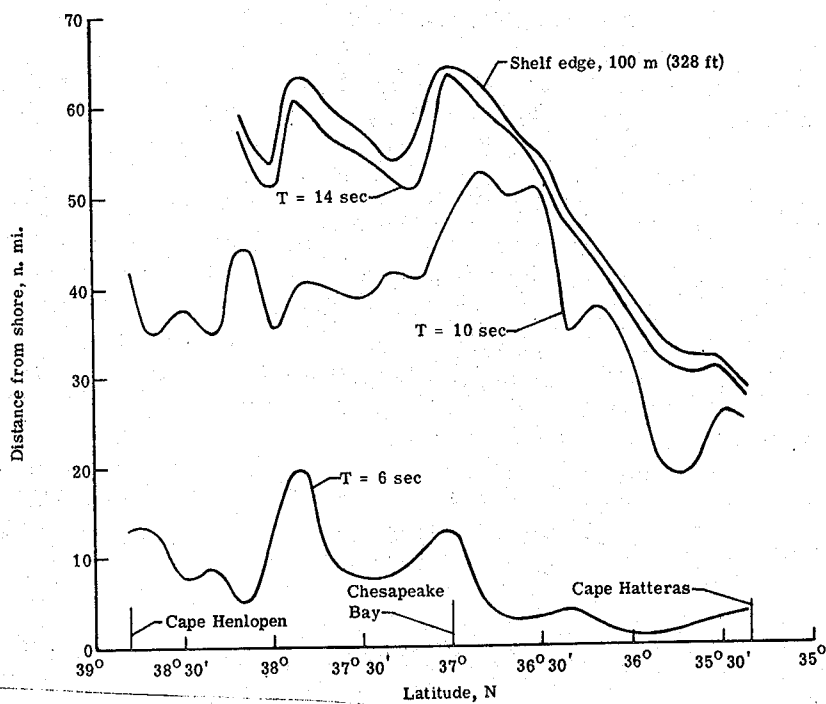


Figure 4. Depths at which waves of different periods begin to be appreciably affected by Virginian Sea Floor.

TABLE I .- DEPTH TO OUTER EDGE OF TERRACES ON
THE CONTINENTAL SHELF AND SLOPE

Depth of outer edge of terraces, m (ft), at -						
Chesapeake Bay, Va. (a)	Martha's Vineyard, Mass. (b)	Atlantic City, N.J. (b)	Onslow Bay, N.C. (b)	Savannah, Ga. (b)	Cape Kennedy, Fla. (b)	Miami, Fla. (b)
-----	-----	-----	-----	-----	-----	10 (33)
7 to 18 (24 to 60)	-----	-----	-----	-----	-----	15 (49)
16 (54)	-----	20 (66)	20 (66)	-----	20 (66)	18 (59)
24 (78)	-----	-----	-----	25 (82)	25 (82)	-----
30 (100)	-----	-----	30 (98)	-----	30 (98)	-----
-----	35 (115)	-----	-----	33 (108)	-----	33 (108)
-----	-----	40 (131)	40 (131)	40 (131)	40 (131)	-----
40 (132)	43 (141)	-----	45 (148)	45 (148)	-----	-----
-----	-----	-----	-----	50 (164)	50 (164)	-----
57 (188)	55 (180)	-----	-----	55 (180)	-----	-----
-----	63 (207)	-----	63 (207)	-----	-----	62 (203)
-----	-----	-----	-----	67 (220)	65 (213)	-----
-----	-----	-----	70 (230)	-----	-----	70 (230)
86 (282)	80 (262)	83 (272)	80 (262)	80 (262)	-----	80 (262)
-----	-----	95 (312)	-----	-----	-----	-----
106 (348)	-----	-----	100 (328)	-----	-----	-----
-----	-----	120 (394)	120 (394)	-----	-----	-----
-----	125 (410)	-----	-----	-----	-----	-----
-----	-----	130 (426)	-----	-----	-----	-----
-----	-----	140 (459)	-----	-----	-----	-----
-----	158 (518)	-----	-----	-----	-----	-----
-----	-----	-----	170 (558)	-----	-----	-----
-----	-----	175 (574)	-----	-----	-----	-----
183 (600)	-----	-----	200 (656)	-----	-----	-----
244 (800)	210 (689)	-----	-----	-----	-----	-----

The presence of these terraces on the sea floor indicate a step-like bathymetric profile. The effect of the steeper portions of the profiles on the incoming waves will depend primarily on the angle of wave approach to these rises. However, even the steepest rises have relatively low-gradient slopes. The slope is $0^{\circ}07'19''$ for the rise between depths of 87.8 and 62.2 meters (288 and 204 feet) as compared with a slope of $0^{\circ}01'58''$ for the total shelf landward of the depth contour of 62.2 meters (204 feet).

Subaqueous stream drainage

Generally oriented perpendicular to the strike of the terraces, the major relief features remaining from the Pleistocene stream drainage are the shelf valleys at the mouths of Delaware and Chesapeake Bays. However, Swift, 1973, has suggested that the Delaware shelf valley is an estuary retreat path and not a drowned river valley. Hunt, et al., 1977, has suggested that Diamond Shoals, North Carolina, has a similar origin. Both these southeast-oriented valleys have a pronounced influence on the wave refraction patterns, with areas of confused seas forming over the seaward rim of the shelf valleys.

Most of the relict Pleistocene river channel network has been filled in with sediments. However, subtle changes in relief in some areas of the shelf surface of the Virginian Sea are suggestive of former channels. Examples of these transverse shelf valleys are found between the mouth of Chesapeake Bay and Norfolk Canyon (Susquehanna Valley), from the Delaware Bay shelf valley to the shelf edge (Delaware Valley), from the Chesapeake Bay shelf valley southeastward to the shelf edge (Virginia Beach Valley), from the Oregon Inlet, North Carolina, vicinity southeastward to the shelf edge (Albemarle Valley), and from the Metomkin-Assawoman Island vicinity east-southeastward to Washington Canyon. The valley names are adopted from Swift, et al., 1972a. The dimensions and gradients of these submarine canyons (from Swift, et al., 1972b) are compared in Table 2 with subaerial canyons.

Virginia Beach Massif

Virginia Beach Massif, between the Susquehanna Valley and the Virginia Beach Valley, is an extensive shallow, relatively level-topped topographic high lying approximately

between the depth contours of 18.3 and 21.9 meters (60 and 72 feet). (See Fig. 1.) This imposing large-scale relict feature, of probable interfluve origin, contains a superimposed irregular ridge and swale bathymetry, which is delineated by the depth contour of 18.3 meters (60 feet). The Virginia Beach Valley, flanked to the northeast by the Virginia Beach ridges on the topographic high and to the southeast by the False Cape ridges, is indeed suggestive of a series of relict ebb-tidal deltas formed as the sea level rose and the estuary mouth retreated, as hypothesized by Swift, et al., 1972a.

This complex topographic high, originating as an interfluve feature, with subsequent superimposed tidal-delta-associated ridges, that have been modified under the present shelf hydraulic regime, has been named the Virginia Beach shoal retreat massif by Swift, et al., 1972a.

SMALL-SCALE SHELF RELIEF ELEMENTS

Linear Ridges

Superimposed on the larger relief elements is an undulating ridge and swale bathymetry composed of shoals with less than 9.1 meters (30 feet) or relief, with the long axis generally extending from 1 to 10 miles and oriented such that they form a small angle (peak at 35°) with the present shoreline (Duane, et al., 1972). These shoals are thought to have formed under the present shelf hydraulic regime because marked seismic and grain-size discontinuities exist between the shoals and the underlying strata which are generally older than 7,000 years (Duane, et al., 1972; Stahl, et al., 1974). Moreover, the mineralogy and granulometric characteristics of many of the shoals are often directly related to the beaches along the adjacent shoreline (Duane, et al., 1972; Field and Duane, 1976).

Linear ridges, separated by valleys called swales, are most prominent opposite the shorelines of Delaware and Maryland, the southern Delmarva Peninsula, the Virginia-North Carolina State line, and Oregon Inlet to Rodanthe, North Carolina.

The depth and orientation of over 200 of the linear ridges on the U.S. East Coast Continental Shelf is shown in Figure 5 (Duane, et al., 1972). Note the bimodal depth distribution with clusters of shoals at depths of 6.1 to 9.1

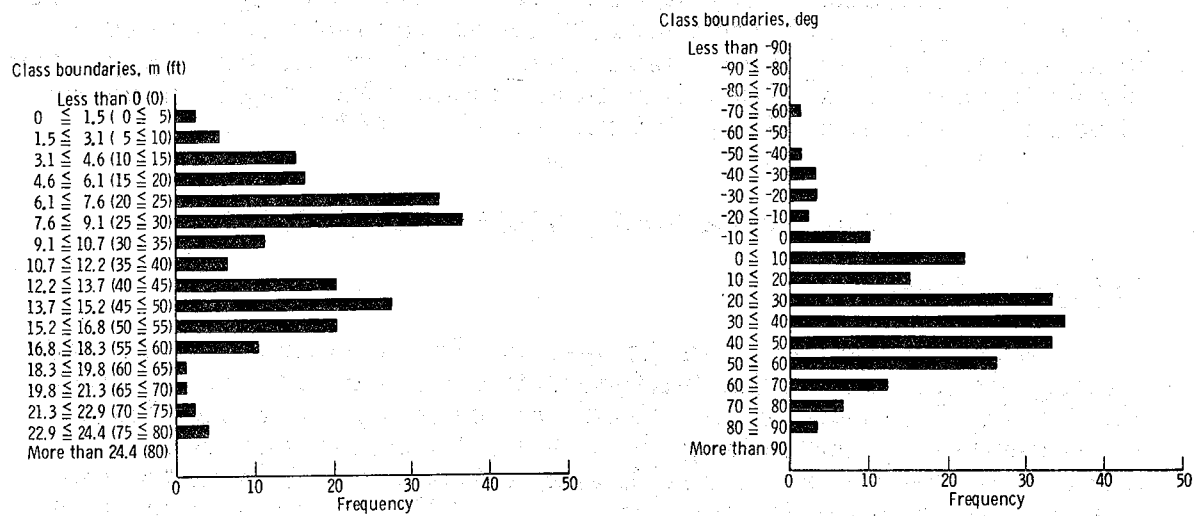


Figure 5. Depth and orientation of shelf linear ridges (From Duane, et al., 1972).

meters (20 to 30 feet) and 12.2 to 16.8 meters (40 to 55 feet) (and possibly a third mode at depths greater than 24.4 meters (80 feet)). These depths do not appear to be related to depths of prominent terraces; instead, they may be related to depths at which the most frequent waves begin to appreciably interact with the sea floor. (Compare Fig. 5 with Fig. 4). The right histogram in Figure 5 shows the azimuth distribution of the same 200 linear ridges, with major axis of the shoals having a mean azimuth (i.e., compass direction) of 32° . Two modes are suggested at approximately 5° and 35° , with a third mode possibly at -30° (i.e., 33°).

Arcuate Shoals

The arcuate shoals are most prominent when associated with capes such as within Chincoteague Shoals opposite the south end of Assateague Island, Maryland. They are even more extensive immediately south of the study area, within Diamond Shoals opposite Cape Hatteras, North Carolina (Hunt, et al., 1977). Arcuate shoals are also located opposite the mouths of nearly all the inlets along the coast of the Virginian Sea. The formation of the inlet shoals (i.e., ebb-tidal deltas) is related to the tidal-current-wave interaction, and they often have an important effect on the nearshore wave refraction patterns.

Probably the largest arcuate shoal in the study area is one associated with the entrance to Chesapeake Bay. Though highly bisected and cut by tidal channels, the distinct convex-seaward arcuate shape of this intermittent sand body, encompassing the mouth of the Bay, can be delineated from the detailed bathymetry. This huge sand body, suggestive of an ebb-tidal delta, may also be directly related to the origin of linear ridges adjacent to False Cape. Indeed, many of the linear ridges, especially those attached to shore, as well as many of the arcuate shoals may owe their origin, in part, to the formation of now relict ebb-tidal deltas.

Extensive studies have been made of the shoals of the Albermarle Valley, North Carolina (Swift, et al., 1977) and Diamond Shoals, North Carolina (Hunt, et al., 1977) involving seismic sediment sampling and current and wave data (Fig. 1). The authors of these studies suggest that these features are relict shoal retreat massifs that are being presently maintained by southward flowing coastal jet

currents formed on the shelf in response to winter north-easter storms. However, there is very little data, as yet, to show this. Of great interest, is the large sand waves associated with these features, that appear to be presently active. The sand wave-forming mechanism is unknown. These ideas are reviewed in Swift (1976a and 1976b).

SUMMARY

The shelf adjacent to Currituck Spit, Virginia-North Carolina, is wide, shallow and contains numerous shelf relief elements of relict Pleistocene and Holocene origin. Many of these features are presently active, though the present hydraulic regime may not necessarily be the same as the initial mechanism of formation.

Some of the features close to shore (e.g., False Cape Ridge System, Albermarle Shelf Valley Massif and Diamond Shoals) may be directly interacting with the adjacent shoreline via sediment transfer through interaction with the longshore drift (see Goldsmith, Shideler, and others, this volume), through inner shelf currents (see Welch, this volume), and through extensive wave refraction (see Goldsmith, this volume). The most important of these interactions, the wave-shelf interaction, results in a shoreline wave energy distribution that is quite complex and variable, and causes the observed variations in shoreline erosion and accretion.

REFERENCES

- DeAlteris, Joseph Thomas, 1973. The Recent History of Wachapreague Inlet, Virginia. M.A. Thesis, Virginia Inst. Mar. Sci., College of William and Mary in Virginia, 1973.
- Duane, David B, Field, Michael E. Meisburger, Edward P., Swift, Donald J.P., and Williams, S. Jeffress, 1972. Linear Shoals on the Atlantic Inner Continental Shelf, Florida to Long Island. Shelf Sediment Transport: Process and Pattern, Donald J.P. Swift, David B. Duane, and Orrin H. Pilkey, eds., Dowden, Hutchinson & Ross, Inc., pp. 447-498.
- Emery, K.O., and Uchupi, Elazar, 1972. Western North Atlantic Ocean: Topography, Rocks, Structure, Water, Life, and Sediments. Memoir 17, American Assoc. Petrol. Geol.
- Field, M.E., Duane, D.B., 1976. Post-Pleistocene history of the United States inner continental shelf: Significance to origin of barrier islands, Geol. Soc. of America Bull., Vol. 87, Doc. No. 60508, p. 691-702.
- Goldsmith, V., Morris, W.D., Byrne, R.J., and Whitlock, C.H., 1974. Wave Climate Model of the Mid-Atlantic Shelf and Shoreline (Virginian Sea): Model Development, Shelf Geomorphology, and Preliminary Results. VIMS SRAMSOE No. 38, 146 p.
- Goldsmith, Victor, Sutton, Carolyn H., and Davis, Jane S., 1973. Bathymetry of the Virginian Sea. Part 1 - Chesapeake Bight (Cape Henlopen to Cape Hatteras, Continental Shelf and Upper Slope). SRAMSOE No. 39 (Sea Grant Project No. 5-72), Virginia Inst. Mar. Sci.
- Harrison, W., Malloy, R.J., Rusnak, Gene A., and Terasmae, J., 1965. Possible Late Pleistocene Uplift, Chesapeake Bay Entrance. J. Geol., Vol. 73, No. 2, Mar., pp. 201-229.
- Hunt, R.E., Swift, D.J.P., Palmer, H., 1977. Constructional shelf topography. Diamond Shoals, North Carolina. Geological Society of America Bulletin, Vol. 88, Doc. No. 70217, p. 299-311 16 figs.

- Milliman, John D. Emery, K.O., 1968. Sea Levels During the Past 35,000 Years. *Science*, Vol. 162 No. 3858, Dec. 6, 1968, pp. 1121-1123.
- Newman, W.S., and Rusnak, G.A., 1965. Holocene Submergence of the Eastern Shore of Virginia. *Science*, Vol. 148, No. 3676, June 11, 1965, pp. 1464-1466.
- Stahl, L., Koczan, J., and Swift, D., 1974. Anatomy of a Shoreface-Connected Sand Ridge on the New Jersey Shelf: Implications for the Genesis of the Shelf Surficial Sand Sheet. *Geology*, Vol. 2, No. 3, Mar. 1974, pp. 117-120.
- Swift, D.J.P., 1973. Delaware Shelf Valley: Estuary Retreat Path, Not Drowned River Valley. *Geol. Soc. of America Bull.* Vol. 84, No. 8 Aug. 1973, pp. 2743-2748.
- Swift, Donald J.P., Kofoed, John W., Saulsbury, Francis P., and Sears, Phillip, 1972a. Holocene Evolution of the Shelf Surface, Central and Southern Atlantic Shelf of North America. *Shelf Sediment Transport: Process and Pattern*, Donald J.P. Swift, David B. Duane, and Orrin H. Pilkey, eds., Dowden, Hutchinson & Ross, Inc., pp. 499-574.
- Swift, Donald J.P., Holliday, Barry, Avignone, Nicholas, Shideler, Gerald, 1972b. Anatomy of a Shoreface Ridge System, False Cape, Virginia. *Mar. Geol.*, Vol. 12, pp. 59-84.
- Swift, D.J.P., Sears, P.C., Bohlke B., and Hunt, R., 1977. Evolution of a Shoal Retreat Massif, North Carolina Shelf. *Inferences from Areal Geology, Marine Geology*, (in press).
- Swift, D.J.P., 1976a. Coastal Sedimentation. Chapter 14, p. 255-310, *In Marine Sediment Transport and Environmental Management*, Stanley and Swift (eds.), Wiley, N.Y., 602 p.
- Swift, D.J.P., 1976b. Continental Shelf Sedimentation. Chapter 15, p. 311-350, *In Marine Sediment Transport and Environmental Management*, Stanley and Swift (eds.), Wiley, N.Y., 602 p.

Uchupi, Elazar, 1968. Atlantic Continental Shelf and Slope
of the United States - Physiography. Geol. Surv. Prof.
Paper 529-C, Dep. Interior.

STABILITY AND LOCAL EFFECTS OF AN OFFSHORE SAND STORAGE
MOUND, DAM NECK SITE, VIRGINIA INNER CONTINENTAL SHELF

William J. Saumsiegle¹

INTRODUCTION

Between 1952 and 1958, 1.5 million yd³ of sand was placed on the beach between Rudee Inlet and 42nd Street at Virginia Beach. The fill came largely from dredging in Rudee Inlet, Lake Wesley, and Owl Creek. Annual required fill is estimated at 120,000 yd³ (Borjis, 1976).

From 1967 to 1974, 18 million yd³ of medium to coarse sand was dredged from Chesapeake Bay entrance channels and stockpiled three miles offshore of Dam Neck, Virginia, in the Atlantic, in 35-45 feet of water. A mound 9000 by 3500 feet was thus created with a maximum relief of 8 ft.

This study was aimed at determining changes in mound shape with time and any effects on beach erosion on the nearby beaches. Three annual bathymetric surveys were made, bottom sediment was sampled, current measurements were made, and calculations were done to estimate the sediment moving power of the local waves. Refraction diagrams were calculated by Dr. Victor Goldsmith of VIMS and generalized by the present author for a hemispherical seafloor mound.

By the end of 1972, more than 99 percent of the 18 million yd³ had been emplaced in the mound (Table 1) by hopper dredges. Thus the bathymetric surveys of the present study were taken after dumping had practically ceased.

The three surveys were taken by the Corps of Engineers using Raydist, and computer plotting. Tide corrections were

¹Institute of Oceanography, Old Dominion University, condensed and edited by John C. Ludwick, Old Dominion University, Norfolk, Virginia.

Table 1. Volume of Sediment Stockpiled at the Dam Neck Disposal Site, Virginia.

Date	Vessel: GOETHALS yd ³	Vessel: ESSAYONS yd ³	Cumulative Total yd ³	Percent
26 Dec 67 - 25 Jan 68	-	153,686	153,686	1
Jun 67 - 25 Feb 68	5, 215,016	-	5,368,702	29
3 Mar 68 - 16 May 68	1,977,161	-	7,345,863	40
30 Jul 68 - 17 Dec 68	2,435,964	-	9,781,827	53
16 Dec 68 - 18 Dec 68	20,430	-	9,802,257	53
5 May 69 - 17 Jul 69	578,750	-	10,381,007	56
30 Oct 69 - 31 Dec 69	-	700,720	11,081,727	60
23 Jan 70 - 11 Mar 70	738,380	-	11,820,107	64
1 Oct 69 - 5 May 70	4,009,903	-	15,830,010	86
30 Jun 70 - 31 Jul 70	314,710	-	16,144,720	88
27 Nov 70 - 6 Jan 71	467,728	-	16,612,448	91
21 Dec 71 - 1 Feb 72	-	452,418	17,064,866	93
1 Jul 72 - 5 Sep 72	1,160,815	-	18,225,681	99
8 Dec 73 - 13 Dec 73	-	93,200	18,318,881	99
20 Mar 74 - 21 Mar 74	-	20,346	18,339,227	100

made by using concurrent observations of water level on-shore. Survey lines were 3000 ft apart in 1973, and 1500 ft in the 1974 and 1975 surveys. In the last survey there were three supplementary north-south lines 1400 ft apart.

Forty-two sediment samples were taken by the Corps and twenty-six by the present author. A textural analysis was made of each sample. Current meter data was obtained for two stations in the vicinity of the mound in an unrelated study: Facilities Plan for the Waste Water Treatment Plant - by Malcolm-Pirnie, Inc., Consulting Engineers for Hampton Roads Sanitation District.

BATHYMETRY

The 1975 bathymetric chart of the mound is shown in Figure 1. An extensive analysis of sounding errors was made including salinity and temperature of the water, wave action, tide, positioning error, roll and heave of the sounding vessel, comparison of depths at the points where survey lines cross, and plotting and reading errors. The average difference between crossing depths was 0.4 ft with a standard deviation of 0.3 ft. Wave action was low on survey days but nevertheless wave-associated errors were appreciable (i.e., up to 1.2 ft), particularly in the 1973 survey.

Apparent depth changes among the surveys are given in Table 2 and show an overall grand mean (1973-1975; 27 months) of 0.8 ft of mound lowering. However, each point comparison contains unavoidable system errors. The topography of the mound has not changed significantly and no loss of material at the disposal site can be proved. Comparison of east-west profiles over the three years is given in Figure 2.

SEDIMENTOLOGY

Sediment analysis showed three major types: 1) indigenous; 2) exotic; and 3) mixed. The indigenous type is a very fine-grained sand with modal grain size of 3.0 to 3.5 ϕ and is characteristically well-sorted.

The exotic type has a mode between 1.0 and 2.0 ϕ and is generally poorly-sorted. This is the sediment dredged from Chesapeake Bay entrance and dumped at the disposal site.

Table 2. Apparent Mean Depth Differences (ft) for Corresponding Plotted Depths for Bathymetric Profile Comparisons.

Line	Surveys Compared		
	1973-1974	1974-1975	1973-1975
45+00	-0.90	-0.01	-0.93
60+00	-	-0.02	-
80+00	-0.94	-0.01	-1.03
95+00	-	-0.19	-
110+00	-1.02	0.17	-0.93
125+00	-	-0.10	-
140+00	-0.66	-0.30	-0.93
170+00	-0.80	0.60	-0.25
Grand Mean	-0.86	0.02	-0.80

Note: A negative value indicates that the more recent year was deeper than the earlier year; a positive value indicates that the more recent year was shallower than the earlier year.

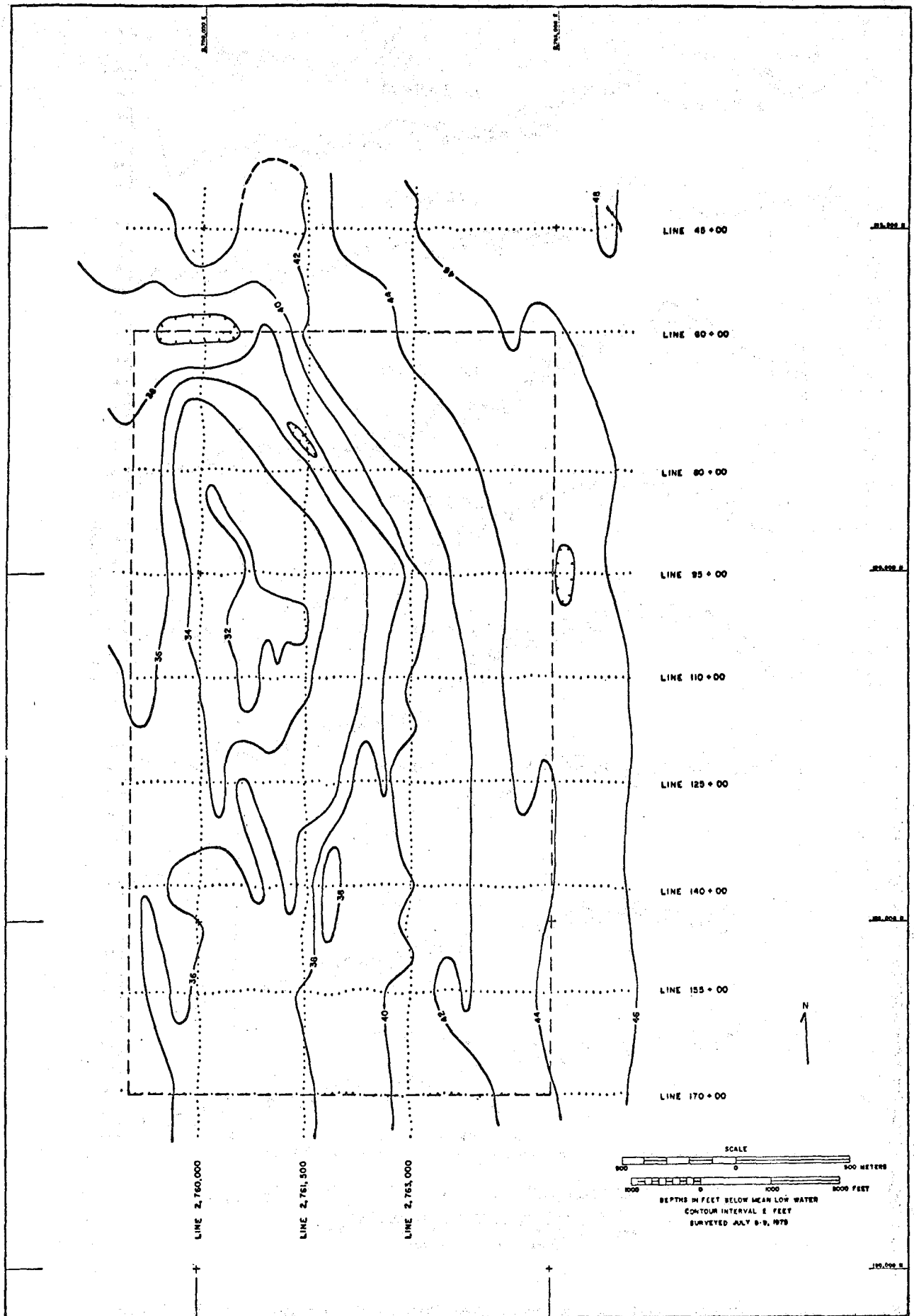


Fig. 1. Bathymetry of the Dam Neck Disposal Site based on the survey of July 8-9, 1975. Survey lines and sounding positions are indicated.

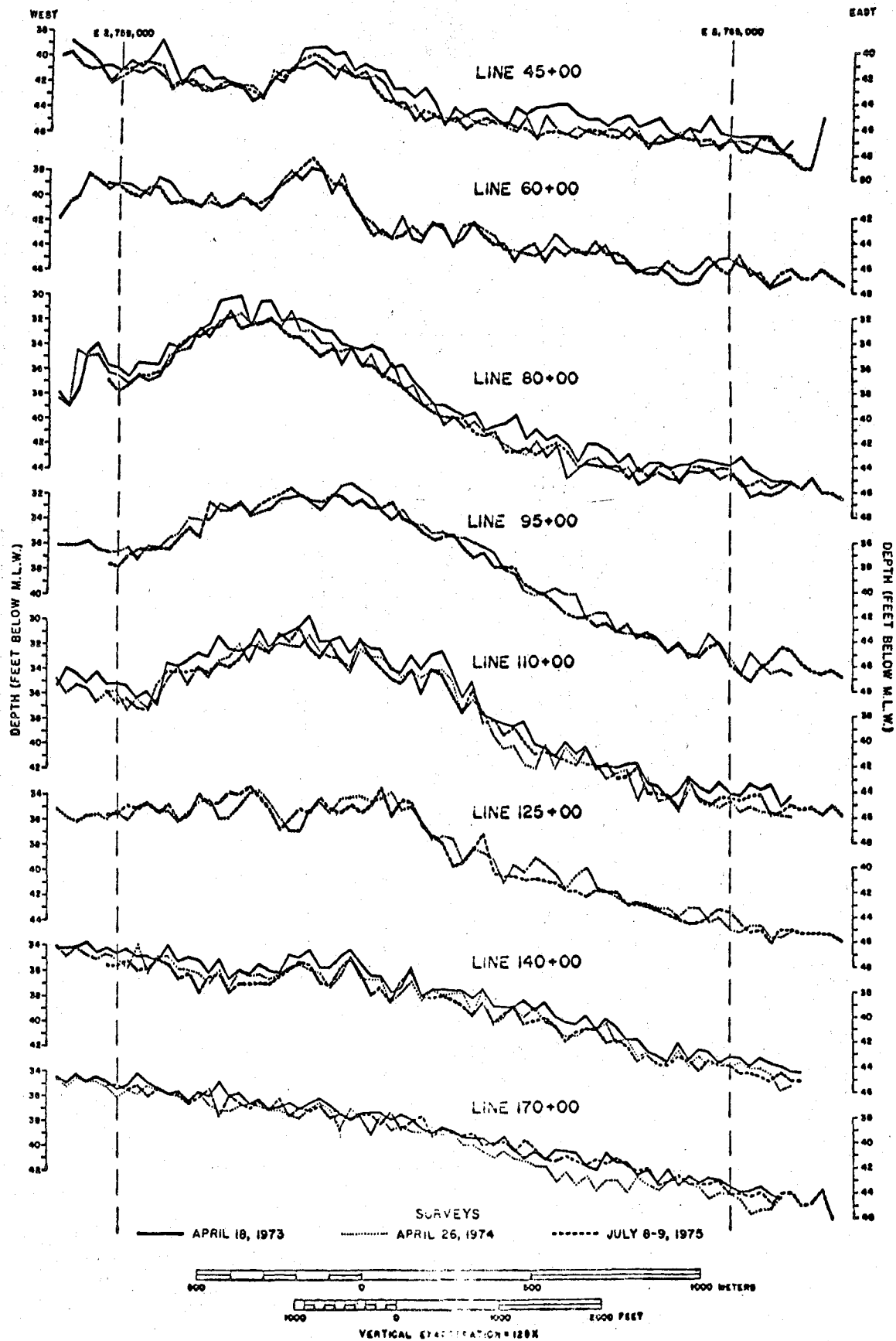


Fig. 2. Bathymetric profiles across the Dam Neck Disposal Site drawn from the plotted depths for the three surveys. See Fig. 2 for locations of survey lines.

The mixed type contains components of both the indigenous and exotic material. This type has modes at 1.0-2.0 ϕ and 3.0-3.5 ϕ and is poorly sorted.

Figure 3 shows the distribution of the sediment types over the surface of the disposal mound.

CURRENTS

Current speed and direction were obtained at two stations near the mound for a period of 30 days. Table 3 shows the distribution of net currents according to speed classes and according to "greater-than" or cumulative groupings. The data are for summer conditions and show competent velocities only a few percent of the time. Two short-term current meter stations near the mound top showed between 12 and 20 percent of observed currents near the bed to exceed 0.67 ft/sec. Flows were generally to the north.

WAVES

Wave refraction diagrams were prepared for NE, E, and SW waves with periods from 8 to 12 seconds. These diagrams were constructed for pre-mound bathymetry and for post-mound bathymetry. Refraction coefficients, i.e., orthogonal spacings, are compared for a point on the beach for the pre-mound and post-mound conditions (Fig. 4). It is seen that north of Rudee Inlet, there is little affect of the mound. But in the vicinity of Dam Neck, under northwest waves, there can be an appreciable focussing of wave energy on the beach. Results for an idealized shoal are shown in Figure 5.

Sediment motion on the mound was studied using the relations developed by Komar and Miller (1973, 1975). The wave height required given the wave period and water depth, to initiate motion of a known particle can be estimated from their equations. These results are given in Table 4.

Using wave climate data (Beauchamp, 1974) calculations were made of the percentage of time during an average year that wave-generated currents are strong enough to move the sediment comprising and surrounding the mound.

Indigenous sediments are entrained 50-77 percent of the time. Exotic sediment can be moved by waves 50-60

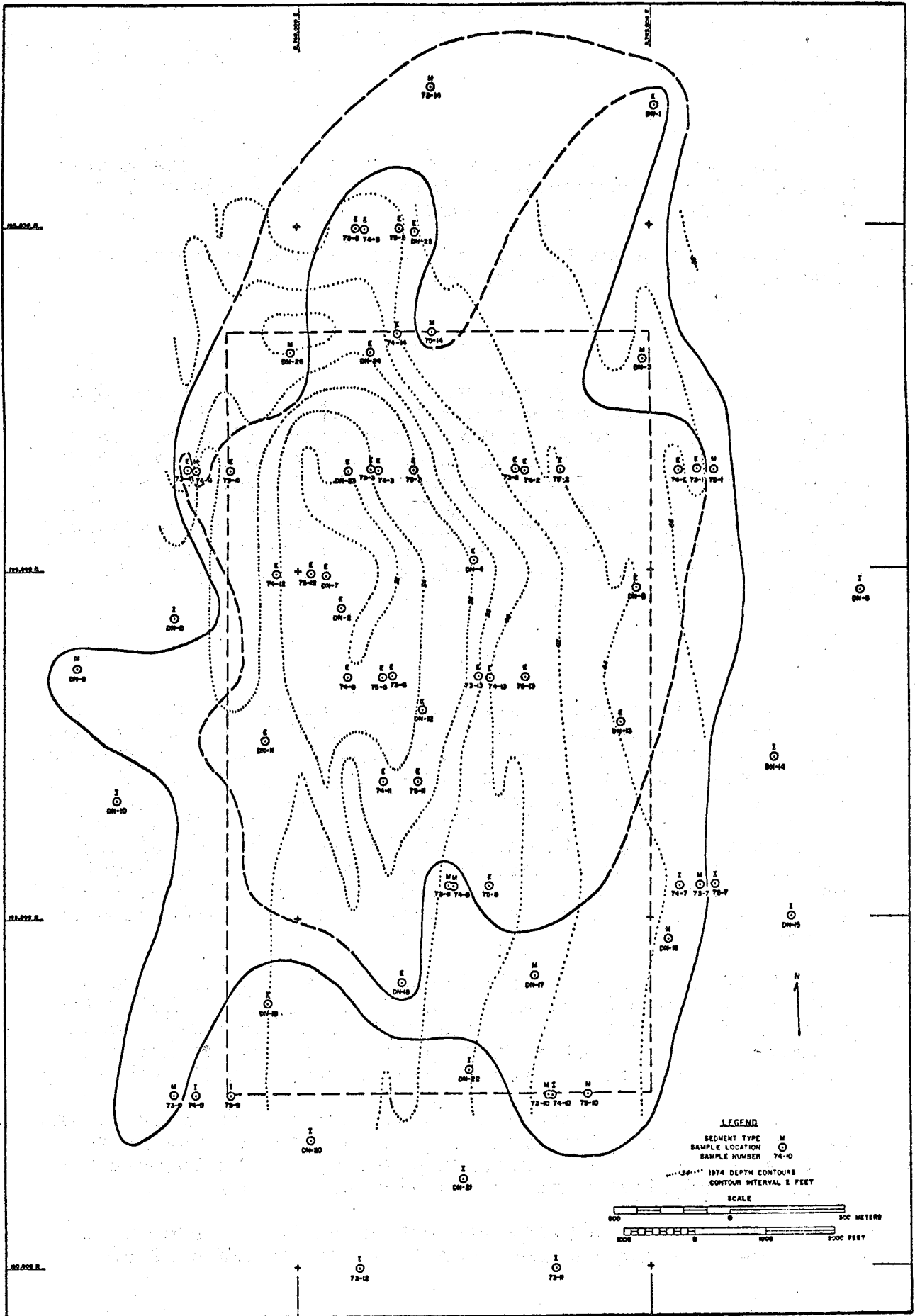


Fig 3. The distribution of bottom sediment at the Dam Neck Disposal Site. Sample location, sample number, and sediment type are shown. E = exotic sediment, M = mixed sediment, I = indigenous sediment.

Table 3. Net Current Speeds and Directions of Near-Bottom Observed Tidal Currents Classified by Speed and Speed Exceedence, July - August, 1973.

Speed ft/sec	Occurrence %		NET CURRENT			
	Location 4	Location 5	Speed ft/sec	Dir °T	Speed ft/sec	Dir °T
> 1.00	0.03	-	1.00	158	-	-
1.00 to 0.82	0.09	0.21	0.90	159	0.86	017
0.82 to 0.67	2.37	1.18	0.47	138	0.33	326
0.67 to 0.50	11.50	11.31	0.20	132	0.13	283
0.50 to 0.33	36.98	32.88	0.03	074	0.08	153
0.33 to 0.16	38.38	39.52	0.04	294	0.04	281
0.16 to 0.00	10.65	14.90	0.03	291	0.03	311
> 1.00	0.03	-	1.00	158	-	-
> 0.82	0.12	0.21	0.92	159	0.86	017
> 0.67	2.49	1.40	0.49	140	0.37	342
> 0.50	13.99	12.71	0.25	135	0.14	297
> 0.37	50.97	45.58	0.08	122	0.09	265
> 0.16	89.35	85.10	0.03	126	0.07	270
> 0.00	100.00	100.00	0.02	128	0.06	272

Maximum Speed at Location 4: 1.00 ft/sec toward 158°T.
 Maximum Speed at Location 5: 0.93 ft/sec toward 012°T.

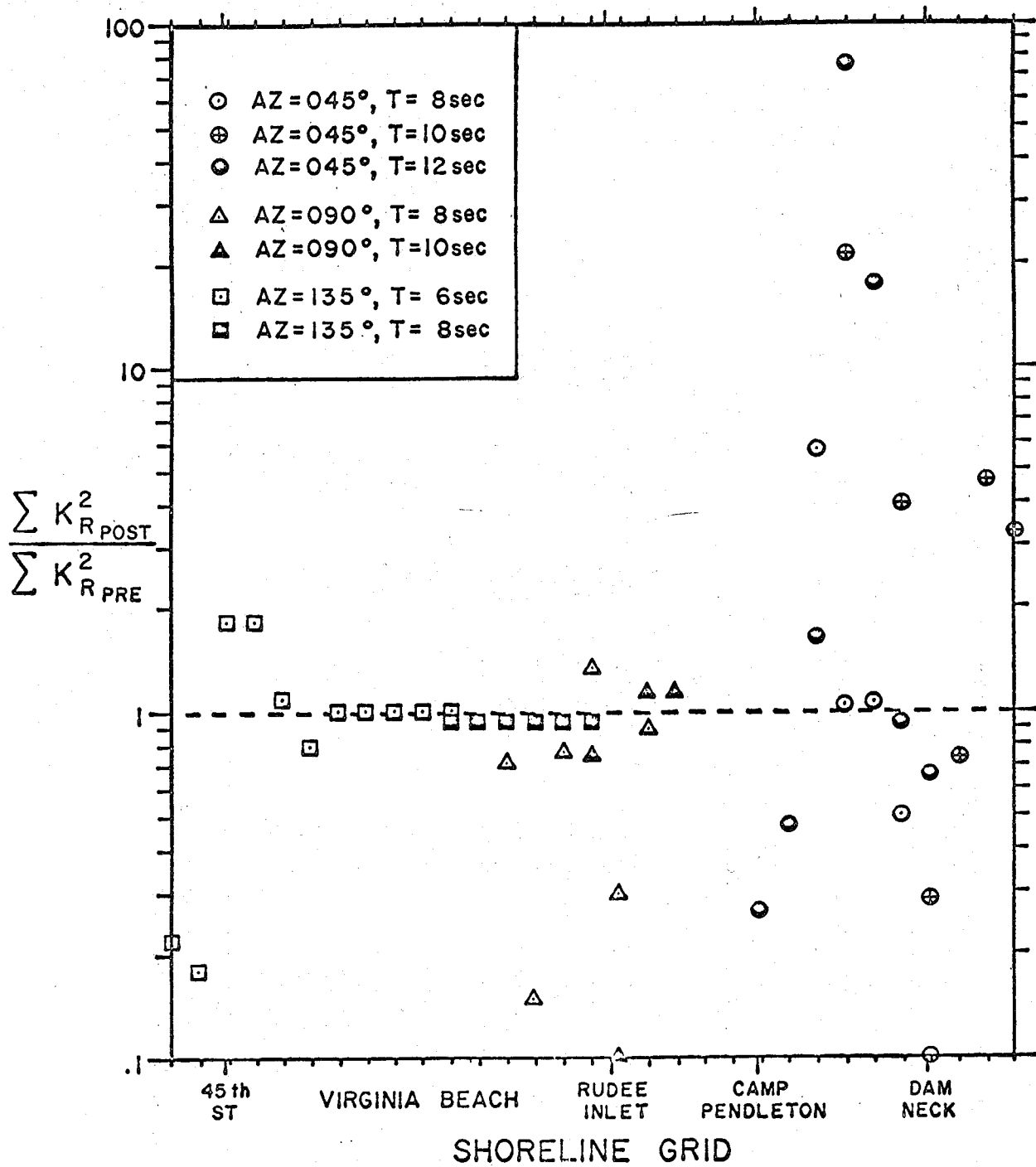


Fig. 4. The relative change in wave energy reaching the shoreline due to wave refraction under post-dump bathymetric conditions relative to pre-dump conditions, based on the ratio of the respective refraction coefficients (K_R^2). The calculated values are presented in Appendix B.

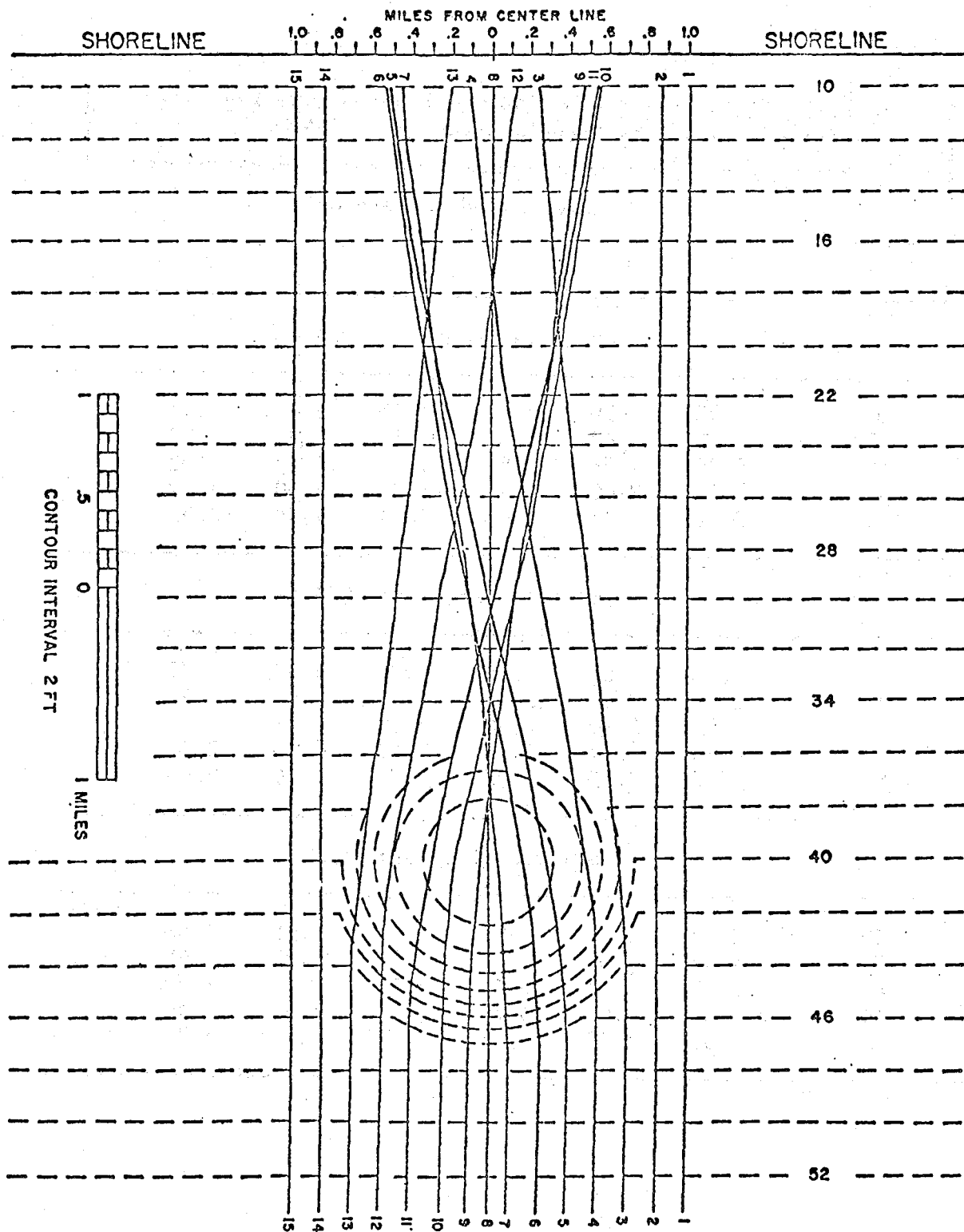


Fig. 5. Sample wave refraction diagram for 10 sec waves approaching perpendicular to the shore and passing over a hemispherical shoal lying on a gently sloping, planar bottom. Note that rays passing outside the shoal area (rays 1,2,14, and 15) are not refracted.

Table 4. Wave Height (ft) and Period Required to Move Sediment Particles of Given Size in Given Water Depth.

Water Depth (ft)	Wave Period In Seconds					
	5	6	7	8	9	10
Particle Diameter: 0.1 mm						
30	1.52	1.26	1.16	1.13	1.11	1.11
35	1.90	1.49	1.33	1.27	1.24	1.23
40	2.40	1.76	1.51	1.41	1.37	1.35
45	3.01	2.06	1.71	1.57	1.50	1.47
50	3.82	2.41	1.93	1.74	1.64	1.59
Particle Diameter: 0.4 mm						
30	2.41	2.00	1.85	1.79	1.77	1.77
35	3.03	2.37	2.12	2.01	1.97	1.96
40	3.81	2.80	2.40	2.25	2.18	2.15
45	4.78	3.27	2.72	2.49	2.39	2.34
50	6.07	3.83	3.06	2.77	2.60	2.53
Particle Diameter: 0.7 mm						
30	3.57	2.87	2.57	2.43	2.35	2.31
35	4.49	3.39	2.95	2.73	2.62	2.55
40	5.65	4.01	3.35	3.05	2.89	2.79
45	7.09	4.67	3.79	3.38	3.17	3.04
50	9.01	5.48	4.27	3.76	3.47	3.29

percent of the time on the mound top but only 30 percent of the time on the mound flanks. The results are given in Table 5.

CONCLUSIONS

It appears from the foregoing and from the sediment distribution chart, dumped sediment has not moved appreciably outside the mound area but, the fine grained indigenous sediment has been moved up onto the mound flanks to produce the mixed sediment type. Wave action has prevented the accumulation of fine-grained sediment on the mound top.

It is concluded from all available evidence loss of sediment from the mound cannot be proven in the two year observation period. Observed currents are too weak most of the time to transport sediment out of the area although lowering of the mound top could be achieved with the sediment being redistributed to the mound flanks.

Wave action can entrain sediment on and near the mound but by itself is not a mechanism for moving sediment out of the mound area. Wave refraction does not concentrate wave energy on the adjacent beaches except under conditions of NE waves. Goldsmith has reported, however, the greatest loss of beach sediment has occurred in the coastal stretch corresponding to where the mound would concentrate wave energy.

Table 5. Percent of Typical Year at Dam Neck Disposal Site That Waves Entrain Bottom Sediment.

Water Depth (ft)	Particle Diameter in mm		
	0.1	0.4	0.7
30	(84.75)*	59.90	47.72
35	77.24	57.65	33.63
40	70.18	45.41	16.18
45	60.64	30.85	10.09
50	48.28	15.73	3.76

* Fine sand is found only in depths greater than 35 ft at the Disposal Site (see Fig. 10).

REFERENCES

- Arthur, Robert S., 1946. Refraction of water waves by islands and shoals with circular bottom contours: Trans. Am. Geophysical Union, v. 27, p. 168-177.
- Beauchamp, Robert G. (editor), 1974. Marine environmental planning guide for the Hampton Roads/Norfolk Naval Operating Area: U.S. Naval Oceanographic Office, Special Publication No. 250, 262 pp.
- Blatt, Harvey, Middleton, Gerald, and Murray, Raymond, 1972. Origin of Sedimentary Rocks. Prentice-Hall, Englewood Cliffs, New Jersey, p. 590.
- Borjes, Russell, 1976. Lower cost for sand replacement at Virginia Beach: Virginian-Pilot, v. 111, no. 72, Feb. 1, 1976, p. B-3.
- Brehmer, Morris L., 1971. Nearshore bottom currents off Virginia Beach, Virginia: Virginia Institute of Marine Science, Special Scientific Report No. 18, 7 pp.
- Bretschneider, C.L., 1966a. Wave generation by wind, deep and shallow water. In Arthur T. Ippen (editor), Estuary and Coastline Hydrodynamics, McGraw-Hill, New York, p. 162-168.
- Bretschneider, C.L., 1966b. Wave refraction, diffraction, and reflection. In Arthur T. Ippen (editor), Estuary and Coastline Hydrodynamics, McGraw-Hill, New York, p. 257-263.
- Brunn, Per, 1962. Sea level rise as a cause of shore erosion: Jour. of Waterways and Harbors Div., Proc. Am. Soc. Civ. Eng., v. 88, No. WWI, p. 117-130.
- Bumpus, Dean E., 1973. A description of the circulation on the continental shelf of the east coast of the United States: In B.A. Warren (editor), Progress in Oceanography, v. 6, Chap. 4, p. 111-157.
- Chao, Yung-Yao, 1974. Wave refraction phenomena over the continental shelf near the Chesapeake Bay entrance: U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Tech. Memo. No. 47, 53 pp.

- Cook, David O., and Gorsline, Donn S., 1972. Field observations of sand transport by shoaling waves: *Marine Geology*, v. 13, p. 31-55.
- Cross, Ralph H., 1974. Hydrographic surveys offshore - error sources: *Jour. of the Surveying and Mapping Div., Am. Soc. Civ. Eng.*, v. 100, No. SU2, p. 83-93.
- Duane, David B., Field, Michael E., Meisburger, Edward P., Swift, Donald J.P., and Williams, S. Jeffress, 1972. Linear shoals on the Atlantic inner continental shelf, Florida to Long Island: In Donald J.P. Swift, David B. Duane, and Orrin H. Pilkey (editors), *Shelf Sediment Transport: Process and Pattern*, Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania, p. 447-498.
- Folk, Robert L., 1968. *Petrology of Sedimentary Rocks*. Hemphill's, Austin, Texas, 170 pp.
- Goldsmith, Victor, Sutton, Carolyn H., and Sallenger, Asbury H., 1973. *Bathymetry of the Virginian Sea: Virginia Beach: Virginia Institute of Marine Science, Gloucester Point, Virginia.*
- Goldsmith, Victor, Morris, W. Douglas, Byrne, Robert J., and Whitlock, Charles H., 1974. *Wave Climate Model of the Mid-Atlantic Shelf and Shoreline (Virginian Sea): Model Development, Shelf Geomorphology, and Preliminary Results*. N.A.S.A., Washington, D.C., 146 pp.
- Hall, J.V., 1952. *Artificially nourished and constructed beaches: U.S. Army, Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 29.*
- Hall, J.V., and Herron, W.J., 1950. *Test of nourishment of the shore by offshore deposition of sand, Long Branch, New Jersey: U.S. Army, Beach Erosion Board, Tech. Memo. No. 17, 32 pp.*
- Harms, J.C., 1969. Hydraulic significance of some sand ripples: *Geol. Soc. Am. Bull.*, v. 80, p. 363-396.
- Harris, Robert L., 1954. *Restudy of test - shore nourishment by offshore deposition of sand, Long Branch, New Jersey: U.S. Army, Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 62, 18 pp.*

- Harrison, W., Brehmer, Morris L., and Stone, Richard B., 1964. Nearshore tidal and non-tidal currents, Virginia Beach, Virginia: U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Tech. Memo. No. 5, 20 pp.
- Harrison, W., Norcross, J.J., Pore, N.A., and Stanley, E.M., 1967. Circulation of Shelf Waters off the Chesapeake Bight. E.S.S.A. Prof. Paper 3, 82 pp.
- Hicks, Steacy D., 1972. Vertical crustal movement from sea level measurements along the east coast of the United States: Jour. Geophysical Res., v. 77, p. 5930-5934.
- Inman, Douglas L., 1957. Wave-generated ripples in near-shore sands: U.S. Army Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 100, 66 pp.
- Inman, Douglas L., 1963. Sediments: physical properties and mechanics of sedimentation: In Francis P. Shepard, Submarine Geology (2nd ed.), Harper and Row, New York, p. 101-151.
- Johnson, J.W. and Eagleson, P.S., 1966. Coastal Processes: In Arthur T. Ippen (editor), Estuary and Coastline Hydrodynamics, McGraw-Hill, New York, p. 404-492.
- Kalkanis, George, 1964. Transportation of bed material due to wave action: U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Tech. Memo. No. 2, 38 pp.
- Karlsson, Thorbjorn, 1969. Refraction of continuous ocean wave spectra: Jour. of the Waterways and Harbors Div., Am. Soc. Civ. Eng., v. 95, p. 437-448.
- Kennedy, John F. and Locher, Frederick A., 1972. Sediment suspension by water waves: In R.E. Meyer (editor), Waves on Beaches and Resulting Sediment Transport, Academic Press, New York, p. 249-295.
- King, C.A.M., 1971. Beaches and Coasts (2nd ed.). Edward Arnold, Ltd., London, 570 pp.
- Koh, Robert C.Y., and LeMehaute, Bernard, 1966. Wave shoaling: Jour. Geophysical Research, v. 71, p. 2005-2012.
- Komar, Paul, D., and Miller, Martin C., 1973. The threshold of sediment movement under oscillatory water waves: Jour. Sed. Pet., v. 43, p. 1101-1110.

- Komar, Paul D., and Miller, Martin C., 1975. Reply: on the comparison between the threshold of sediment motion under waves and unidirectional currents with a discussion of the practical evaluation of the threshold: Jour. Sed. Pet. v. 45, p. 362-367.
- Komar, Paul D., Neudeck, Roger H., and Kulm, L.D., 1972. Observations and significance of deep-water oscillatory ripple marks on the Oregon continental shelf: In Donald J.P. Swift, David B. Duane, and Orrin H. Pilkey (editors), Shelf Sediment Transport: Process and Pattern, Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania, p. 601-619.
- Lavelle, J.W., Brashear, H.R., Case, F.N., Charnell, R.L., Gadd, P.E., Haff, K.W., Han, G.C., Kunselman, C.W., Mayer, D.A., Stubblefield, W.L., and Swift, D.J.P., (in press). Preliminary results of coincident current meter and sediment transport observations for wintertime conditions on the Long Island inner shelf: Geophysical Research Letters.
- Ludwick, John C., 1974a. Tidal currents and zig-zag sand shoals in a wide estuary entrance: Geol. Soc. Am. Bull. v. 85, p. 717-726.
- Ludwick, John C., 1974b. Variations in boundary drag coefficient in the tidal entrance to Chesapeake Bay, Virginia: Institute of Oceanography, Old Dominion University, Tech. Rept. No. 19, 13 pp.
- Ludwick, John C., and Saumsiegle, William J., 1976. Sediment stability at the Dam Neck Disposal Site, Virginia: Institute of Oceanography, Old Dominion University, Tech. Rept. No. 27, 26 pp.
- Madsen, Ole S., and Grant, William D., 1975. The threshold of sediment movement under oscillatory waves: a discussion: Jour. Sed. Pet. v. 45, p. 360-361.
- Magoon, Orville T., and Sarlin, William O., 1970. Effect of long period waves on hydrographic surveys: Twelfth Coastal Engineering Conference, Proceedings, Am. Soc. Civ. Eng., New York, p. 2251-2265.
- Manohar, Madhav, 1955. Mechanics of bottom sediment movement due to wave action: U.S. Army, Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 75, 121 pp.

- Mauriello, Louis J., 1968. Beach rehabilitation by hopper dredge: Jour. of Waterways and Harbors Div., Am. Soc. Civ. Eng., v. 94, p. 175-188.
- McCledden, Charles E., 1973. New Jersey continental shelf near bottom current meter records and recent sediment activity: Jour. Sed. Pet., v. 43, p. 371-380.
- Meade, R.H., 1969. Landward transport of bottom sediments in estuaries of the Atlantic coastal plain: Jour. Sed. Pet., v. 39, p. 222-234.
- Meisburger, Edward P., 1972. Geomorphology and sediments of the Chesapeake Bay entrance: U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Tech. Memo. No. 38, 61 pp.
- Nichols, Maynard M., 1972. Inner shelf sediments off Chesapeake Bay: I, general lithology and composition: Virginia Institute of Marine Science, Special Scientific Rept. No. 64, 20 pp.
- Norcross, J.J., Massman, W.H., and Joseph, E.B., 1962. Data on coastal currents off Chesapeake Bay: Virginia Institute of Marine Science, Special Scientific Rept. No. 31, 5 pp.
- Pierson, Willard J., 1951. The interpretation of crossed orthogonals in wave refraction phenomena: U.S. Army, Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 21, 83 pp.
- Pierson, Willard J., Neumann, Gerhard, and James, Richard W., 1955. Practical Methods for Observing and Forecasting Ocean Waves by Means of Wave Spectra and Statistics. U.S. Naval Oceanographic Office, H.O. Pub. No. 603, 284 pp.
- Roubertou, A.M., 1972. Bathymetric surveying on the continental shelf: International Hydrographic Review, v. 49, p. 37-44.
- Sallenger, A.H., Goldsmith, V., and Sutton, C.H., 1975. Bathymetric Comparisons: A Manual of Methodology, Error Criteria, and Techniques. S.R.A.M.S.O.E. No. 66, Virginia Institute of Marine Science, Gloucester Point, Virginia, 34 pp.

- Saumsiegle, W.J., 1976. Stability and local effects of an offshore sand storage mound, Dam Neck Disposal site, Virginia Inner continental shelf: M.S. Thesis, Old Dominion University, Norfolk, Va., 92 p.
- Saville, Thorndike, Jr., 1954. North Atlantic coast wave statistics hindcast by Bretschneider-Revised Sverdrup-Munk method: U.S. Army, Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 55, 17 pp.
- Shields, A., 1936. Anwendung der Ahnlichkeits Mechanik und der Turbulenzforschung auf die Geschiek Bewegung: Preuss. Versuchsanstalt fur Wassebau und Schiffbau, Berlin, 20 pp.
- Smith, J. Dungan, 1969. Geomorphology of a sand ridge: Jour. Geol., v. 77, p. 39-55.
- Sternberg, R.W., 1967. Measurement of sediment movement and ripple migration in a shallow marine environment: Mar. Geol., v. 5, p. 195-205.
- Sternberg, R.W., 1972. Predicting initial motion and bed-load transport of sediments in the shallow marine environment: In Donald J.P. Swift, David B. Duane, and Orrin H. Pilkey (editors), Shelf Sediment Transport: Process and Pattern, Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania, p. 61-82.
- Stubblefield, William L., Lavelle, J., William, Swift, Donald J.P., and McKinney, Thomas F., 1975. Sediment response to the present hydraulic regime on the central New Jersey shelf: Jour. Sed. Pet., v. 45, p. 337-358.
- Swift, Donald J.P., 1972. Implications of sediment dispersal from bottom current measurement; some specific problems in understanding bottom sediment and dispersal on the continental shelf - a discussion of two papers: In Donald J.P. Swift, David B. Daune, and Orrin H. Pilkey (editors), Shelf Sediment Transport: Process and Pattern, Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania, p. 363-371.
- Swift, Donald J.P., Holliday, Barry, Avignone, Nicholas, and Shideler, Gerald, 1971a. Anatomy of a shoreface ridge system, False Cape, Virginia: Mar. Geol., v. 12, p. 59-84.

- Swift, Donald J.P., Sanford, Robert B., Dill, Charles E., Jr., and Avignone, Nicholas F., 1971b. Textural differentiation on the shoreface during erosional retreat of an unconsolidated coast, Cape Henry to Cape Hatteras, Western North Atlantic shelf: Sedimentology, v. 16, p. 221-250.
- Thornton, Edward B., and Kraphohl, Richard F., 1974. Water particle velocities measured under ocean waves: Jour. Geophys. Res., v. 79, p. 847-852.
- Uchupi, Elazar, 1968. Atlantic Continental Shelf and Slope of the United States - Physiography. U.S.G.S. Prof. Paper 529-C.
- U.S. Army Coastal Engineering Research Center, 1964. Land against the sea. C.E.R.C. Misc. Paper No. 4-64, 43 pp.
- U.S. Army Coastal Engineering Research Center, 1966. Shore protection planning and design (3rd edition). C.E.R.C. Tech. Rept. No. 4, p. 62-72, D3-D29, E1-E2.
- Vesper, William H., 1961. Behavior of beach fill and borrow area at Prospect Beach, West Haven, Connecticut: U.S. Army, Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 127, 29 pp.
- Watts, George M., 1956. Behavior of beach fill at Ocean City, New Jersey: U.S. Army, Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 77, 33 pp.
- Watts, George M., 1959. Behavior of beach fill at Virginia Beach, Virginia: U.S. Army, Corps of Engineers, Beach Erosion Board, Tech. Memo. No. 113, 26 pp.
- Weeks, Colin G. McQ., 1973. Hydrography and the engineer: Jour. of the Surveying and Mapping Div., Am. Soc. Civ. Eng., v. 99, No. SU1, p. 1-14.
- Wilson, W. Stanley, 1966. A method for calculating and plotting surface wave rays: U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Tech. Memo. No. 17, 57 pp.

MORPHOLOGIC TIME SERIES FROM A SUBMARINE
SAND RIDGE ON THE SOUTH VIRGINIA COAST

John F. McHone, Jr.¹

INTRODUCTION

From New York to Florida large underwater sand ridges merge southward into the Atlantic shoreline. A widespread occurrence and a nearly identical morphology suggest a common origin for the ridges.² Although a massive literature has accumulated relating to beaches and surf, relatively little information is available concerning the zone just beyond the breakers. In this study, started in 1968, precision echo-sounding surveys were made revealing ridge changes, sediments were sampled, and currents were measured. The area of study is on the False Cape section of the Currituck Spit barrier system at the Virginia-North Carolina state boundary (Fig. 1).

Small ridge fields have been explained as relict preserved shore features from Quaternary sea level low stands and modern active, hydraulically formed sand bodies. Swift and others (1972) have argued although the sediment is remnant from an earlier environment, the present morphology displays both features from earlier subaerial erosion as well as modern day, active, shallow water bed forms. Moody (1964) discovered 90 m of southeasterly ridge movement off the Delaware coast accompanied by shoreward migration after the Ash Wednesday storm of March, 1962, and reasoned ridges were formed and maintained by modern storm associated currents.

¹Institute of Oceanography, Old Dominion University.
Condensed and edited by John C. Ludwick, Old Dominion University, Norfolk, Virginia.

²This is discussed in more recent references (e.g., Field and Duane, 1976).

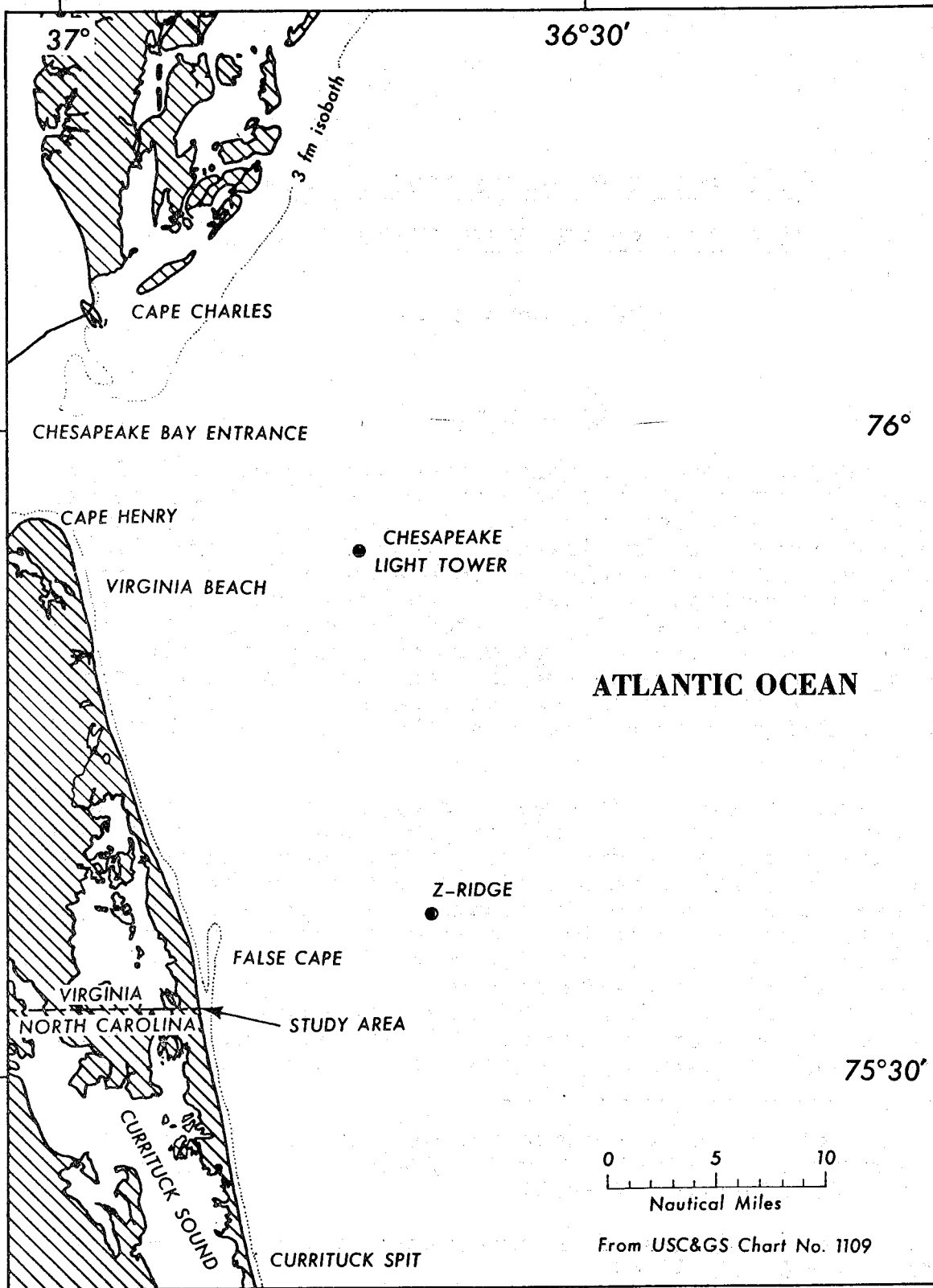


Figure 1. Location Map.

Duane and others (1972) defined arcuate ridges and linear ridges, the latter commonly being shoreface connected and deeper than 10 m, and with opening angles commonly less than 35° with the straight coast.

The ridges and study area are shown in Figure 2. Ridges split into smaller subridges toward their northern distal ends. Flank slopes of nearly all Atlantic shelf ridges are less than three degrees. Relief is less than 7 m and decreases toward the northern ends of the ridges. Troughs expand to become wide and flat with distance to the northeast but the ridges remain narrow and rounded along most of their length. Comparison of 1922 and 1969 charting reveals up to 200 m of ridge movement and the deposition of up to 3 m of sediment on the steepest portion of the shoreface south of the attached ridges (Swift and others, 1970).

HYDRAULIC REGIME

Holliday (1971), after recording bottom currents of the ridge field, suggested a two-fold hydraulic regime; one for fair weather and one for storms. A mild summer climate permits the development of horizontally density-stratified shelf water due to less saline effluent of the adjacent Chesapeake Bay. A northward (bayward) bottom flow, modified by weak tidal and wave-induced currents appears insignificant in moving shelf sediments (see also Harrison and others, 1967; Davies, 1964). During the winter, however, higher winds obliterate the horizontal water structure by wave mixing, thus allowing wind drift surface currents from the north and northeast (Dunn and Miller, 1960; Hayes and Boothroyd, 1969) to extend to the bottom. The result is a wintertime nearshore bottom drift to the south associated with higher wave action as opposed to a summertime, calmer northward drift in the False Cape study area.

GRAIN SIZE VARIATION

Swift and others (1972) have compiled an areal granulometric map of the study area based on the median diameter of the sand-sized fraction of bottom grab samples. Their map reveals a narrow belt of fine sand along the shoreface. The belt widens south of the innermost attached ridge and from here spreads northward on the outer flank of the ridge, suggesting a deposition zone for material transported from

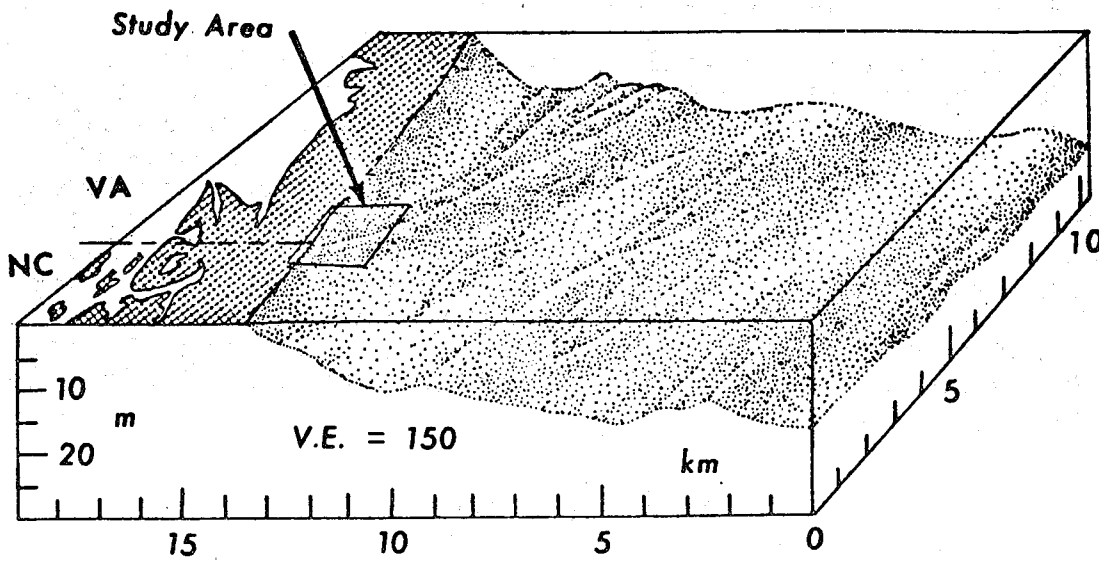


Figure 2

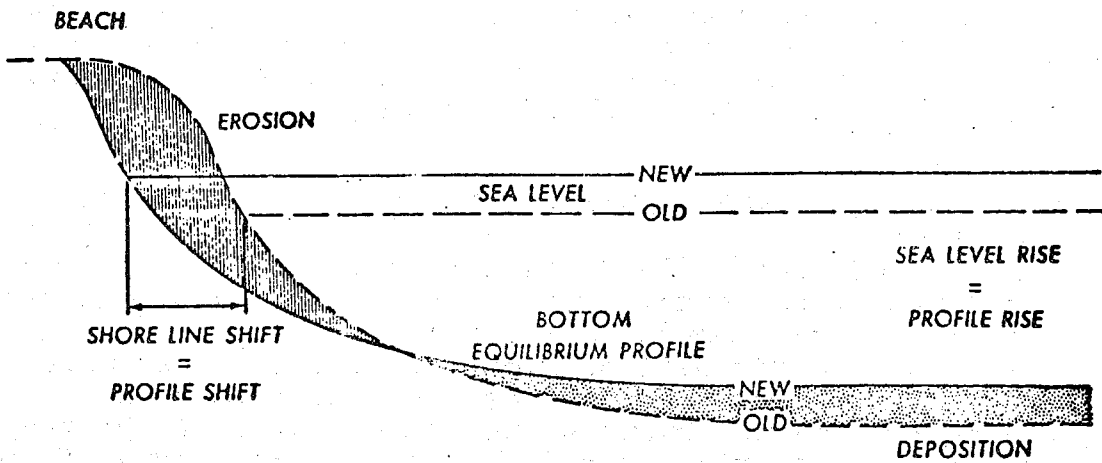


Figure 3

either healing by means of filling with new sediments or at least migrating along the ridge. The two maps which most clearly indicate the presence of ridge saddles (Figs. 5 and 6) also indicate sediment fans seaward and south of the notches.

Profiles were prepared from the contoured charts (Fig. 8) and all profiles were telescoped together into a single diagram showing water depth and distance from shore (Fig. 9). A basic profile is exponential in shape. Limiting lines at $1/3$ less and $1/3$ greater than the local depth to the basic profile constitute envelopes to the bathymetry (King, 1972, p. 360).

It is now well established waves which approach a shore and consistently break at the same depth produce a trough and sand bar pair at this break point (Keulegan, 1948; King and Williams, 1949; Ingle, 1966, p. 53; Johnson and Eagleson, 1969). King and Williams (1949) and King (1972) report that as model break-point bars build to equilibrium, defined by Keulegan (1948) as the condition in which bars display imperceptible motion, their crests approach a height of $1/3$ water depth above the original profile. This behavior was independent of the beach slopes tested. Planimeter measurements of both Figure 9 and of profiles published by King (1972, p. 336) and Keulegan (1948, p. 21) reveal equal areas of trough below the ridge above the basic profile as defined by King and Williams (1949). The implication is, at least in terms of the shore-normal component of sediment transport, ridges are composed of material excavated from troughs.

It has been pointed out most of the Atlantic linear ridges are situated in water too deep to be formed by breakers of the known Atlantic wave climate (Congress, 1953; Saville, 1954; Thompson and Harris, 1972). But bars located in less than 8 m of water, he states, display Keulegan's (1948) criteria for wave-built ridges and certain combinations of deep-water wave height and period are therefore marginally feasible. The relationship of deep-water wave height H_o^1 , period T , and water depth at breaking point d_b has been established from solitary wave theory (U.S. Army Corps of Engineers, 1966) as follows:

$$H_o^1 = \frac{1.873}{T} (d_b)^{2/3}$$

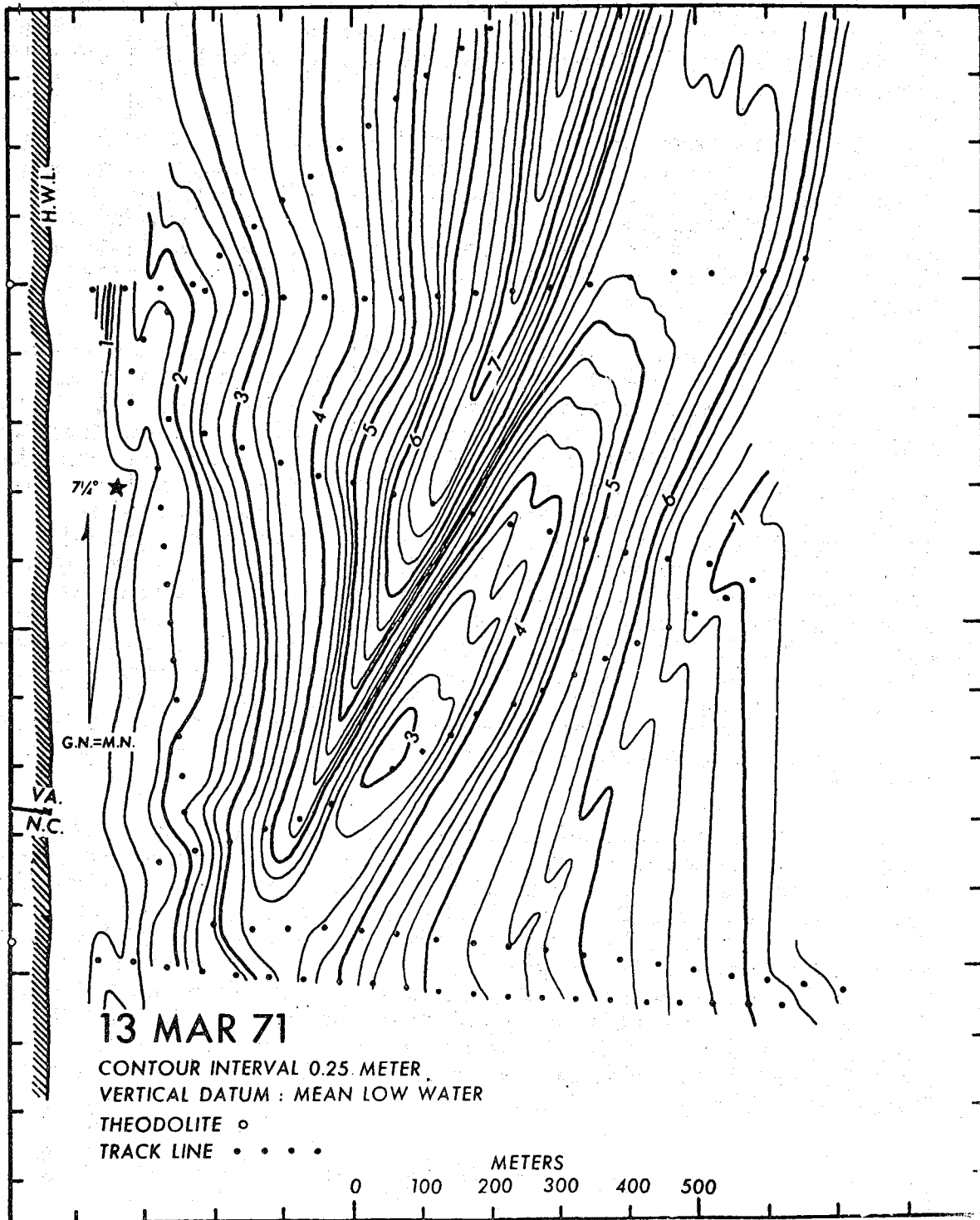


Figure 4

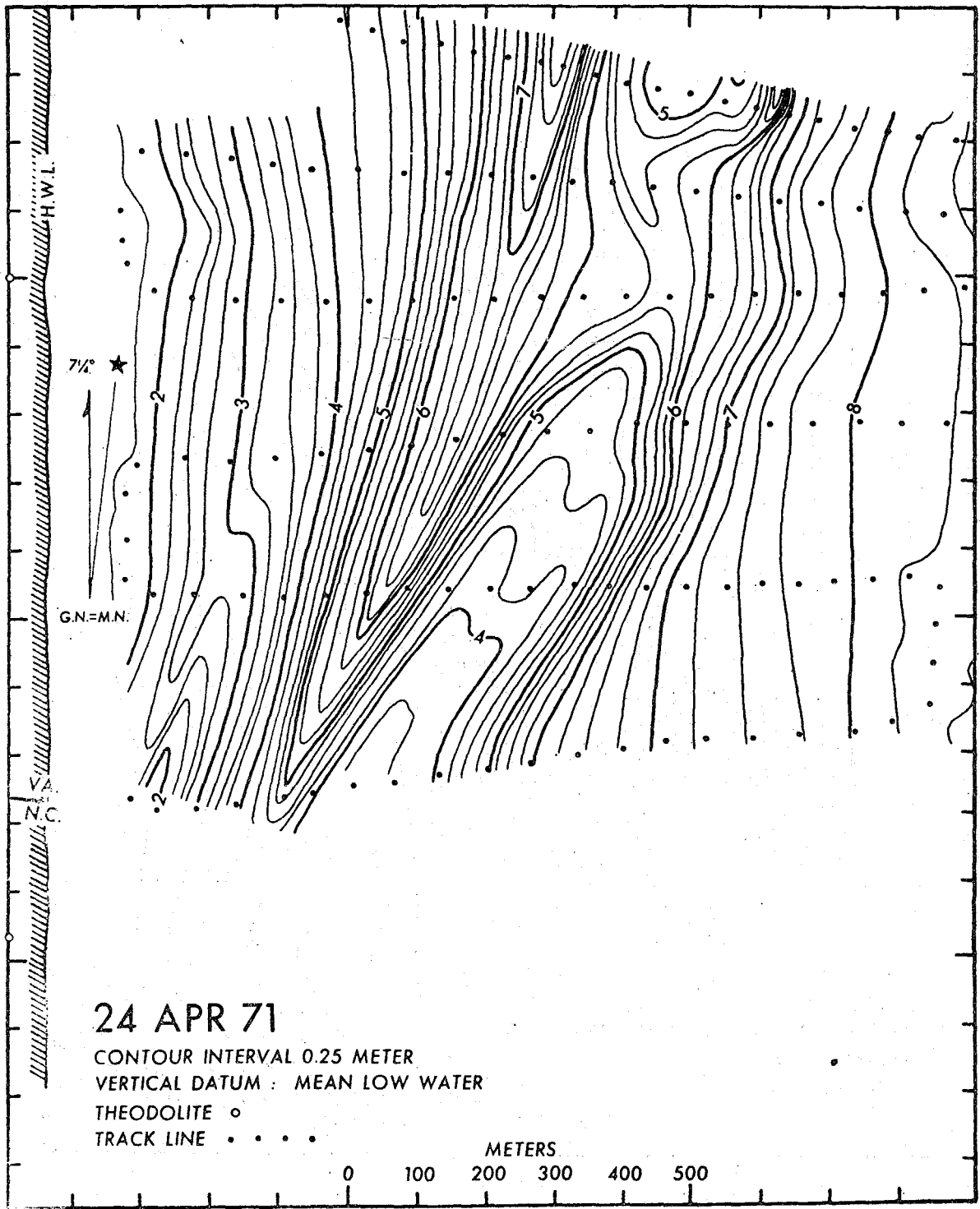


Figure 5

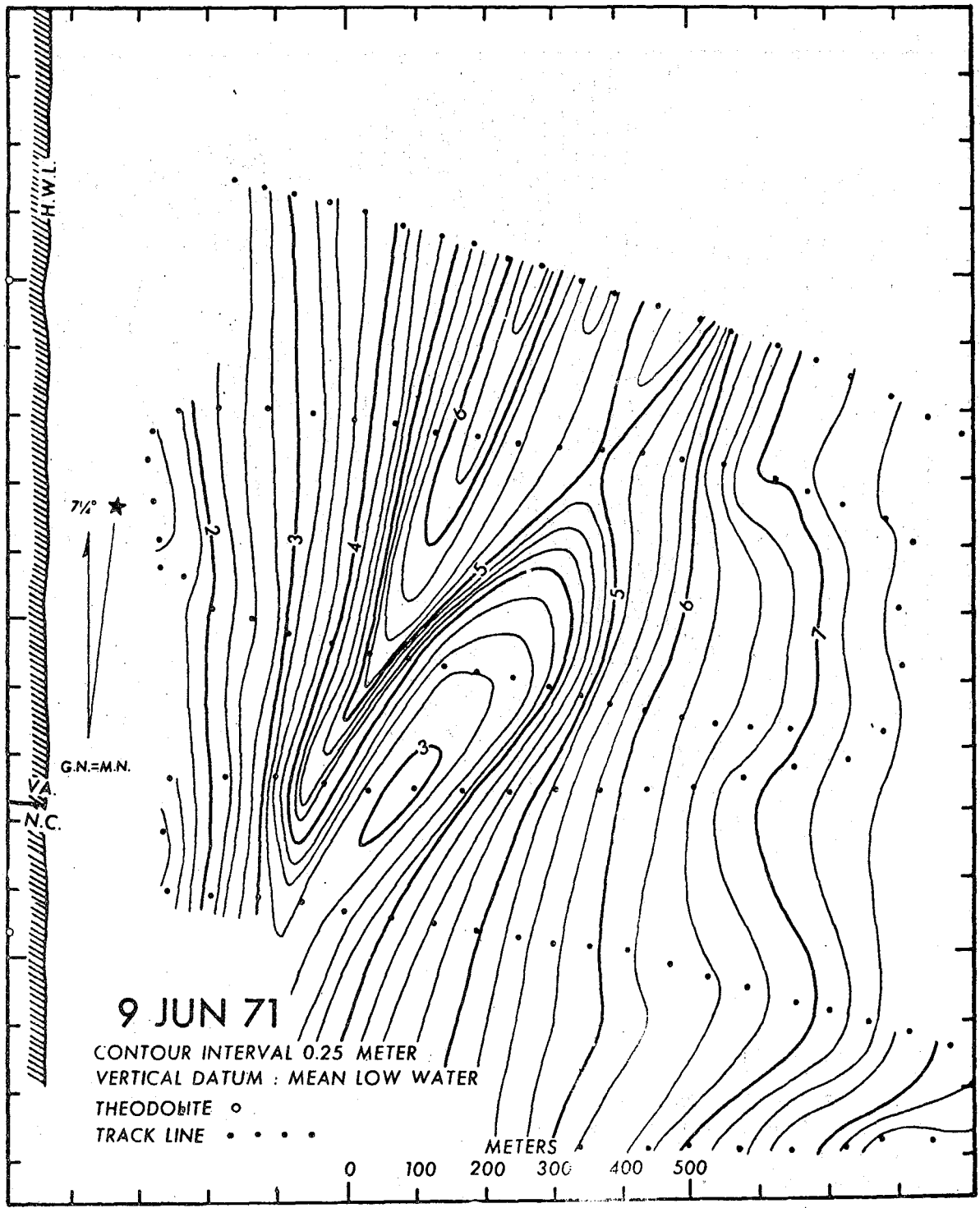


Figure 6

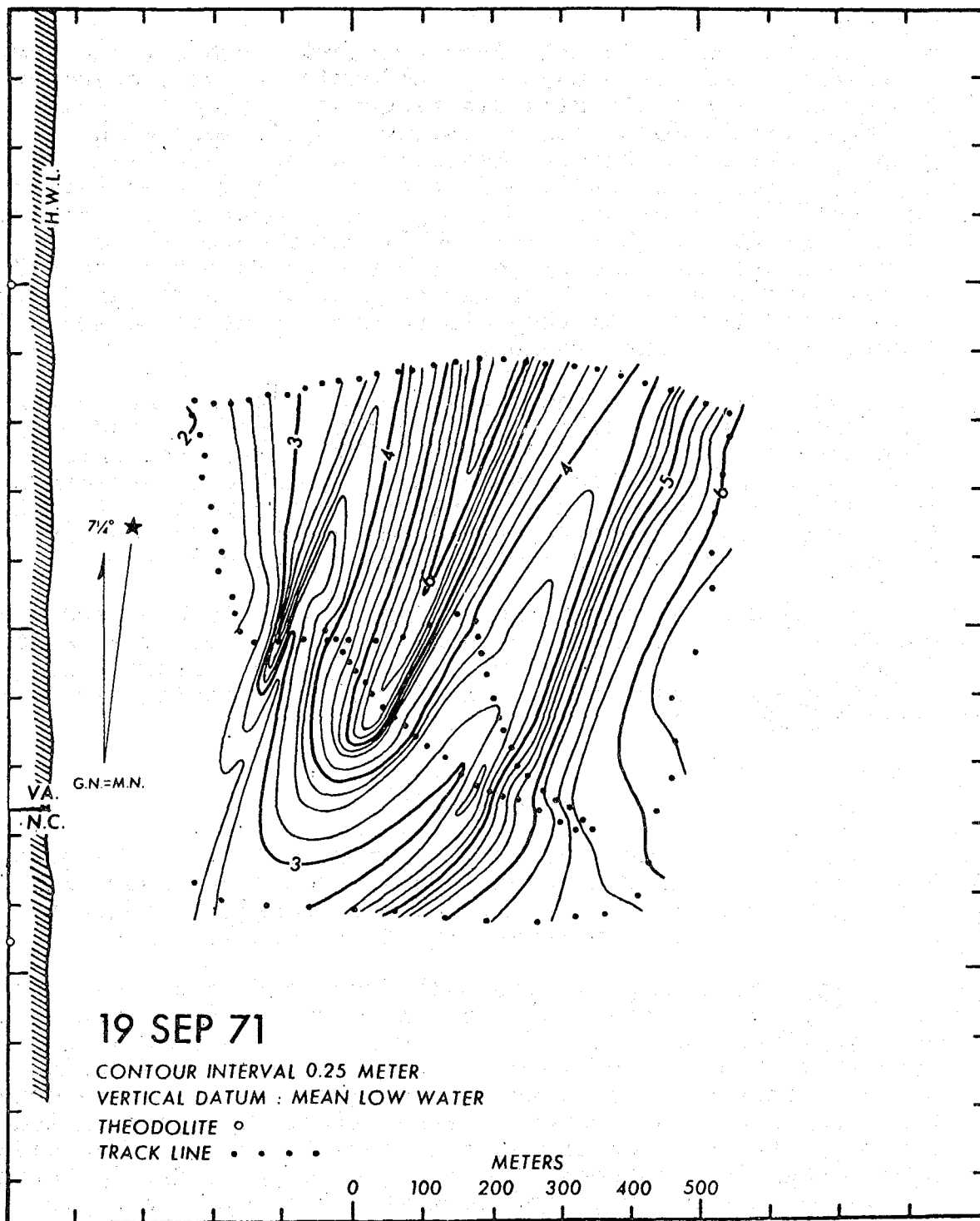


Figure 7

northern regions. Isophi class boundaries exhibit the same northeast trends as bathymetry indicating a correlation of topography with grain size distribution. Using the Folk and Ward (1957) method of comparing graphic mean with graphic inclusive standard deviation as an indication of sorting tendencies, Swift and others (1972) further investigated the sediment sizes. Trough axes consist of a coarse to medium-grained (0ϕ to 1ϕ) pebbly veneer over the stiff clayey Pleistocene substrate. The veneer is better sorted as size increases - a characteristic of winnowed lags (Swift and others, 1972). In the calm summer months temporary mud lenses appear in the troughs.

Ridge flanks and the shoreface consist of fine to very fine-grained (2ϕ to 3ϕ) sands which are better sorted as size decreases. Swift and others (1972) interpret this size distribution pattern as a characteristic of sediments moving from a winnowed area. Ridge crests consist of medium to fine-grained (1ϕ to 2ϕ) sands which, as in the case of the troughs, are better sorted as size increases.

These trends and the resulting implications of sediment movement suggest ridges are constructed from storm-excavated trough material and ridge crests are further winnowed in fair weather by wave action, their tailings moving back down onto the ridge flanks.

BATHYMETRY

The ridge study area was surveyed using transits on a baseline and a sounding boat. Four surveys are shown in Figures 4 through 7. Currents were measured by drogue tracking and bottom current meter (Holliday, 1971).

Bathymetric maps of the shoreface portion of the innermost ridge were successfully compiled for four separate surveys (Figs. 4 through 7). They indicate a narrow trough with a "V" shaped profile which remains in a fixed position but undergoes minor changes at its extreme head. A seaward ridge parallels the trough in a relatively stable position although its shape undergoes considerable change. The ridge has a generally flattened top and has second order features superimposed upon it in the form of a double or multiple crest. Saddles may occur in the ridge. Although track line location and density is not consistent enough to firmly establish the presence of saddles on each map, it is certain that this type of feature is capable of developing and then

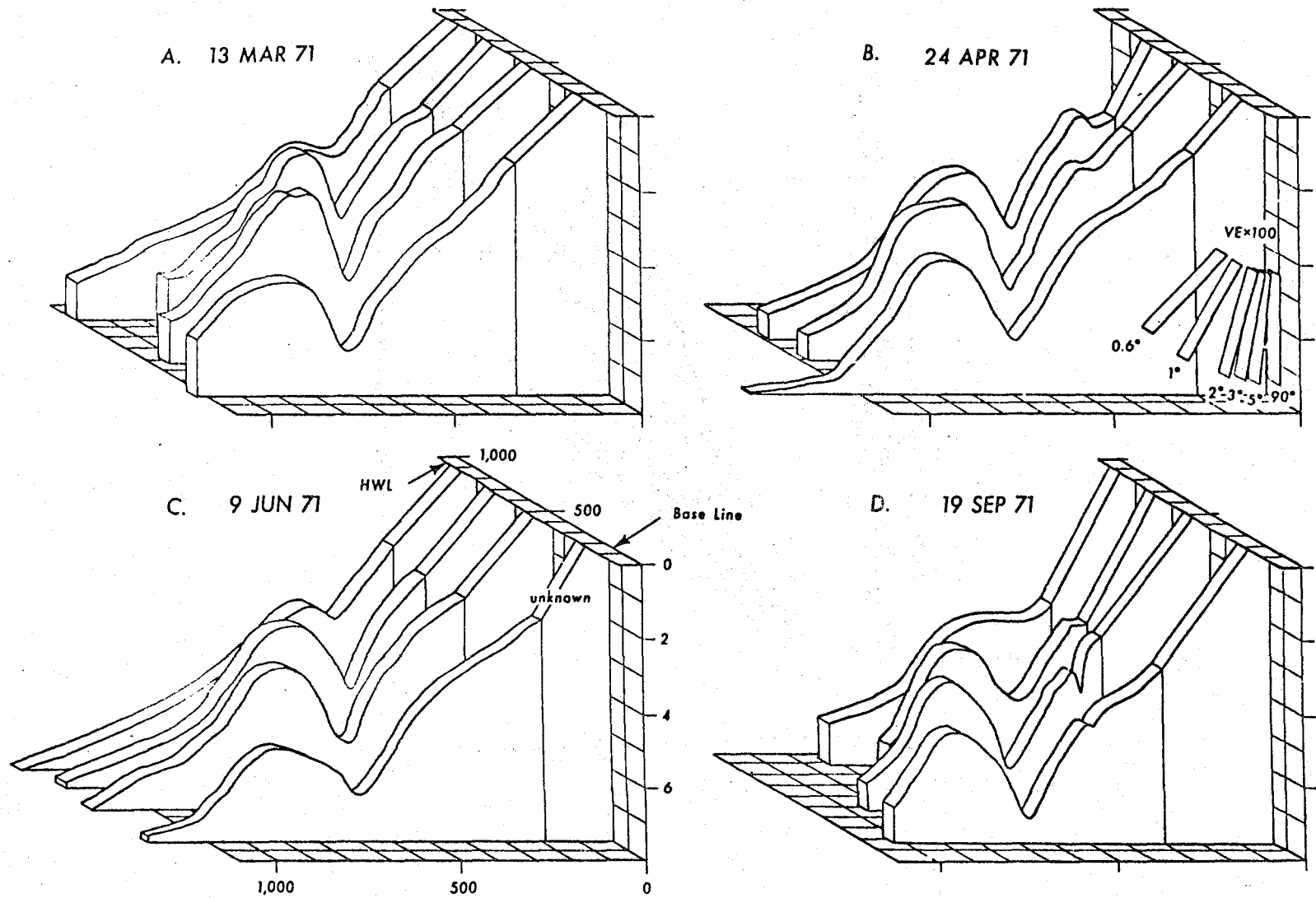


Figure 8. Fence diagrams of profiles from bathymetric maps. Depths uncorrected for tide.
 HWL surveyed 25 September, 1971. All linear measurements in meters.

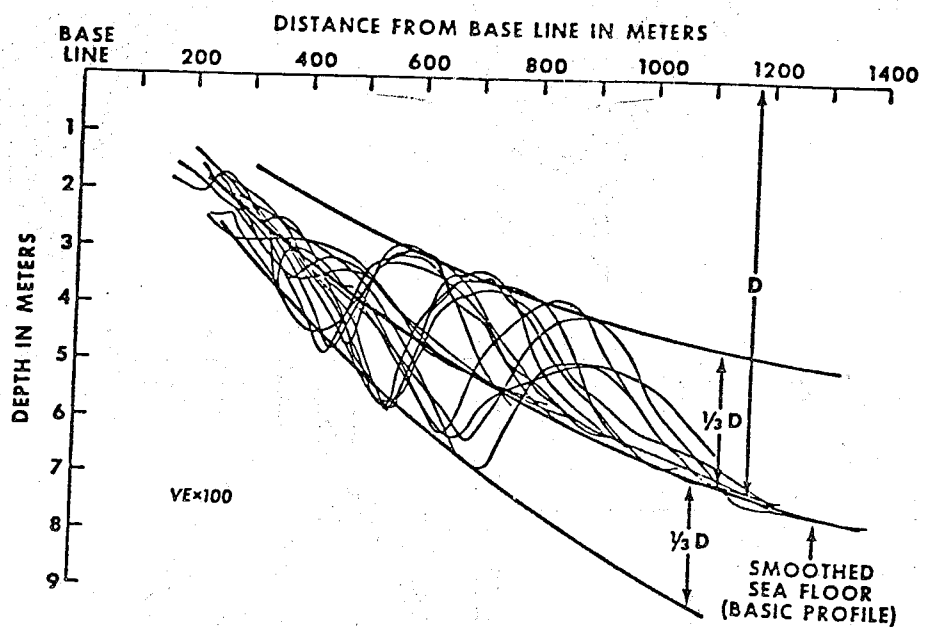


Figure 9 SUPERIMPOSED PROFILES OF THE FALSE CAPE RIDGE & TROUGH.

Figure 10 is a graphical solution for the equation. Wave climates are conventionally reported in tables which display the frequency of occurrence for waves of specified combinations of height and period. Such tables are readily adapted to the graph. Hindsight wave climate figures (Saville, 1954) for a three year period (1948-1950) at the mouth of the Chesapeake Bay have been converted to percent of time for the occurrence of various wave groups and plotted on the graph along with the depth ranges of the study area. By entering the graph from either side, the period (diagonal line), deep-water height (vertical line) and relative frequency (shaded pattern) of breaking waves can be estimated for any given water depth. It can be seen from this illustration large breakers formed during storms are feasible over the entire study area.

Weinman (1971, p. 47) calculated wave refraction patterns for the southern Virginia coast and noted the longer 10-16 second waves converged at False Cape. Wave refraction studies by Goldsmith, et al. (1974) also show eight and 12 second period waves from the northeast converging at False Cape.

Zenkovich (1967, p. 201) used a suspended cable on the Black Sea to measure bottom profiles. During storms the upper portion of the profile became very gentle as the wave energy was spread over a wide breaker zone. Submarine bars formed and moved shoreward as the storm died down. King (1972) observed large bars could be built by heavy wave action and later destructively modified by smaller unbroken waves.

The above considerations strongly suggest it is the bar building characteristics of breaking waves which control the healing of saddles and the maximum dimensions of trough and ridge development in the False Cape ridges.

FAIR WEATHER CURRENTS

The ridges are anomalous however, in their long dimension is more nearly parallel to the northeast direction of prevailing wave approach than perpendicular to it as is typically the case with shore-oblique wave-built bars (King, 1972, p. 365). Therefore it is advisable to consider the other major component of the hydraulic regime, namely the unidirectional coast-parallel currents. In order to assess this component, three drogues were tracked in the study area

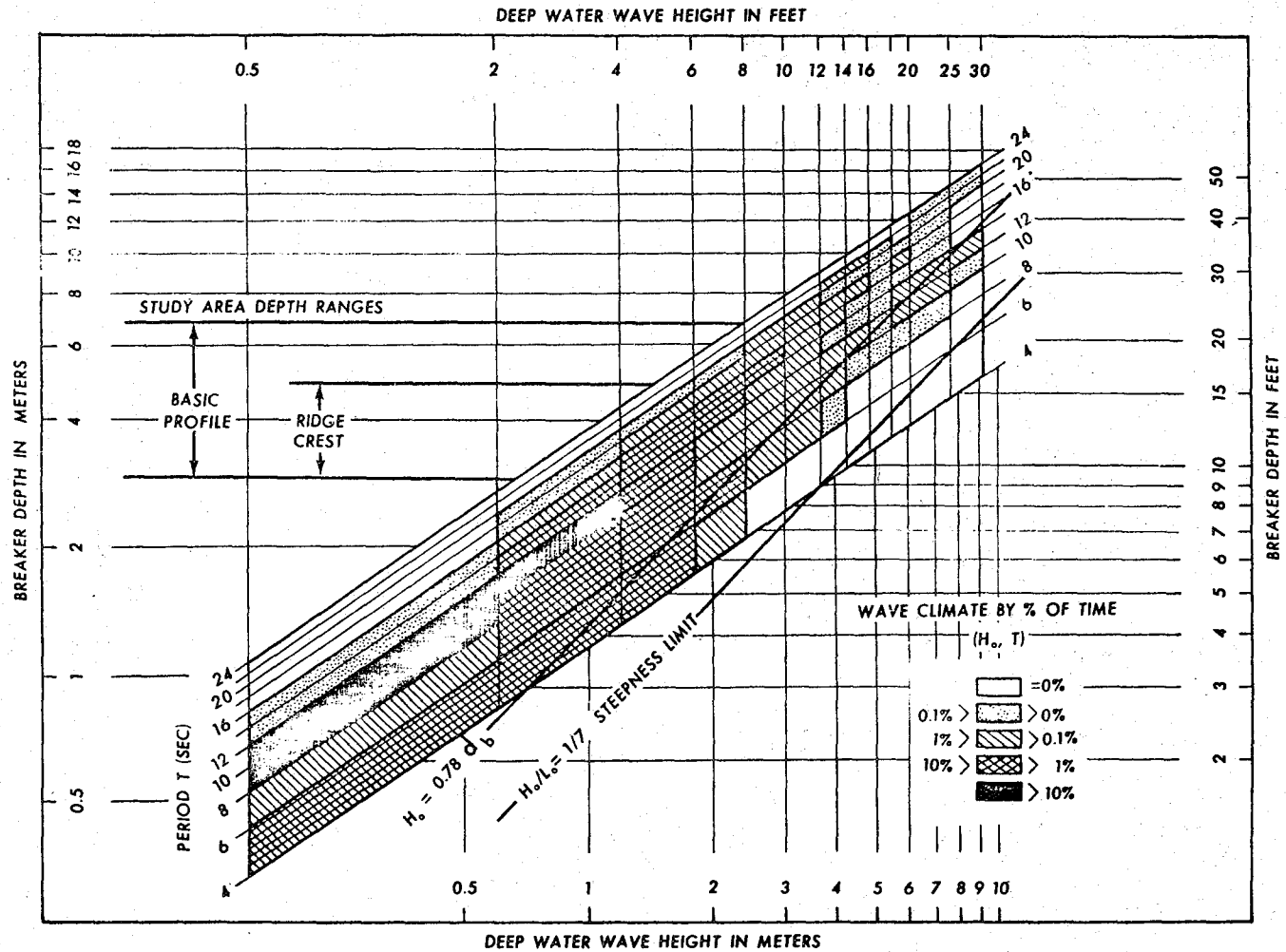


Figure 10 INFERRED BREAKING WAVE CLIMATE FOR THE FALSE CAPE INNER RIDGE.

on August 1 and again on August 21, 1971. On both days the surf was less than 1/-m and southerly winds were less than five n mi/hr. Results (see Fig. 11) indicate fair weather bottom currents which parallel the ridge and trough system and reverse with the tide. The most rapid movement measured 3.6 cm/sec, was directly over the axis of the trough. Over the crest and seaward of the ridge currents are erratic, possibly due to ridge saddle eddies. The exact location of the saddle was not determined during the drogoue study. A full week after the second bottom drifter run, drogoue No. 2 was recovered on the beach at the head of the trough.

Since these currents are not of sufficient intensity to move sand it does not seem they can be responsible for ridge building. Rather than controlling the ridges, the currents appear to be controlled by the ridges during calm weather. In particular, the delayed on-shore recovery of one of the drogues suggests a very weak net headward transport of trough bottom water during the tide dominated fair-weather hydraulic regime. Bottom drifter recoveries by Norcross and Stanley (1967) also support a year round south-westerly, onshore bottom drift in the vicinity of the study area. Local inhabitants report the stranding of large fishes, whales, and drowning victims has occurred more commonly at False Cape than elsewhere along the Virginia-North Carolina coast.

STORM CURRENTS

Unidirectional shelf bottom currents of sufficient velocity to move sand have been observed only during times of brisk wind activity. Eleven-day records from Savonius rotor instruments implanted at Z-ridge (Holliday and others in press) reveal a wind-dependent bottom drift which is modified by a low-magnitude semidiurnal tidal component. The north and east trending components of one of these records are displayed in Figure 12 along with Light Tower wind data for the same period. It can be seen that a gentle tidally reversing current becomes overridden by stronger bottom currents which follow the winds by a few hours. It is these wind-set bottom currents which attain unidirectional velocities capable of moving sands of the False Cape ridges.

The differences observed in the direction of surface and bottom currents strongly support the existence of the helical flow cells proposed by Swift and others (1972). Holliday (1971) and Duane and others (1972) have proposed

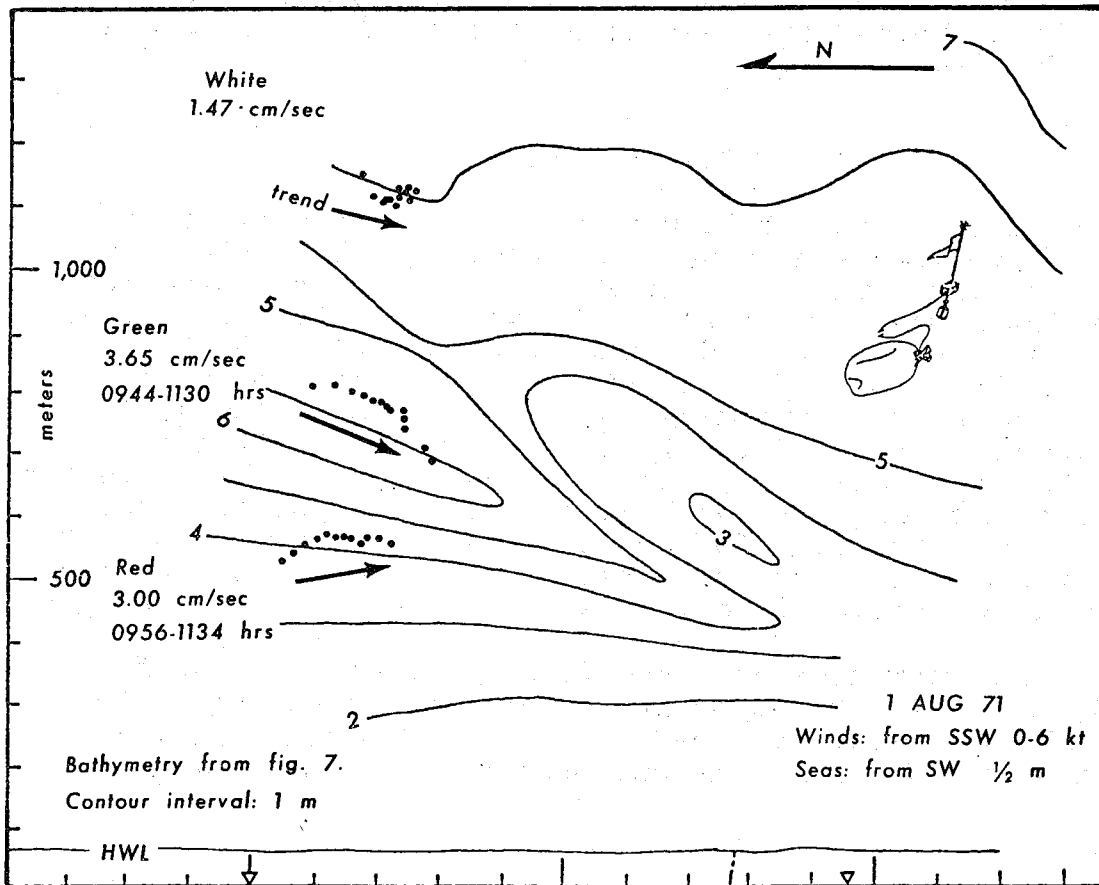
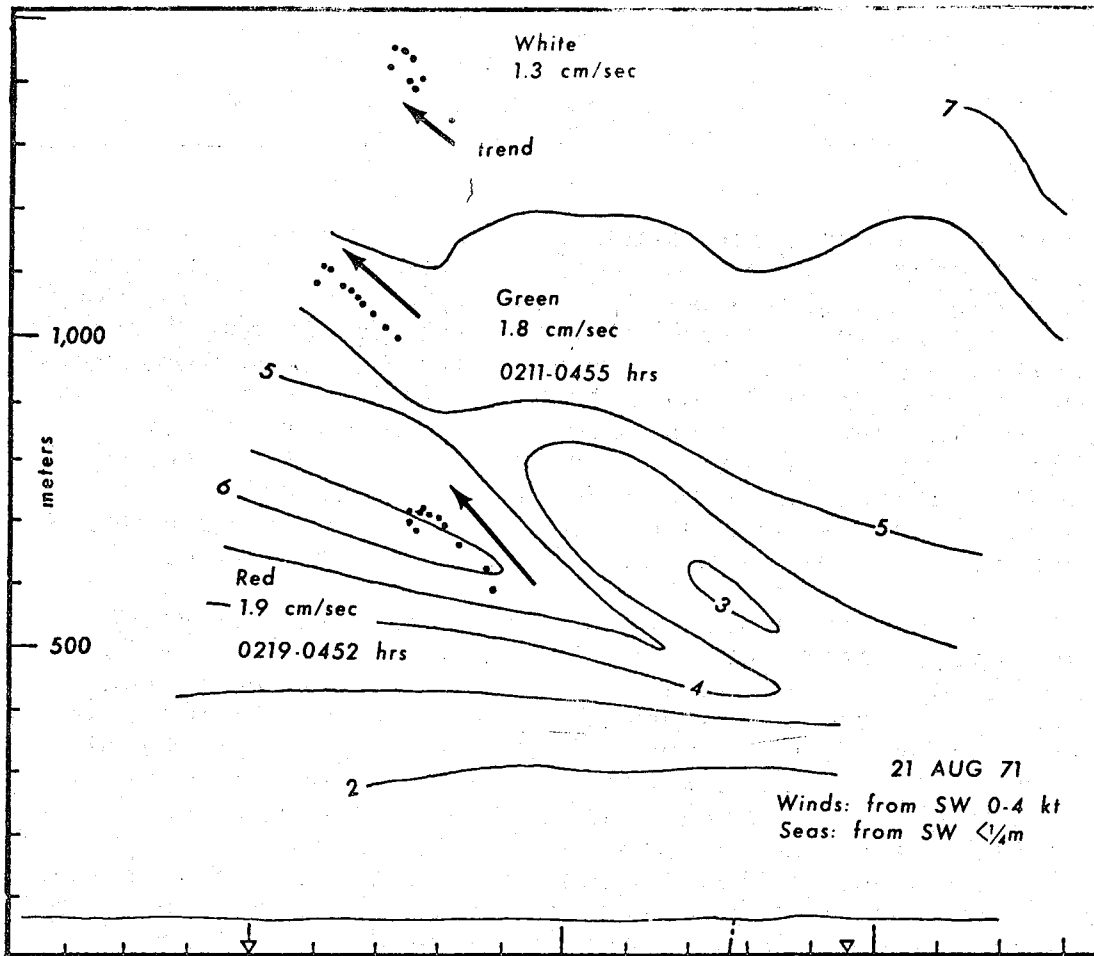


Figure 11 FAIR WEATHER DROGUE RESULTS

19-17

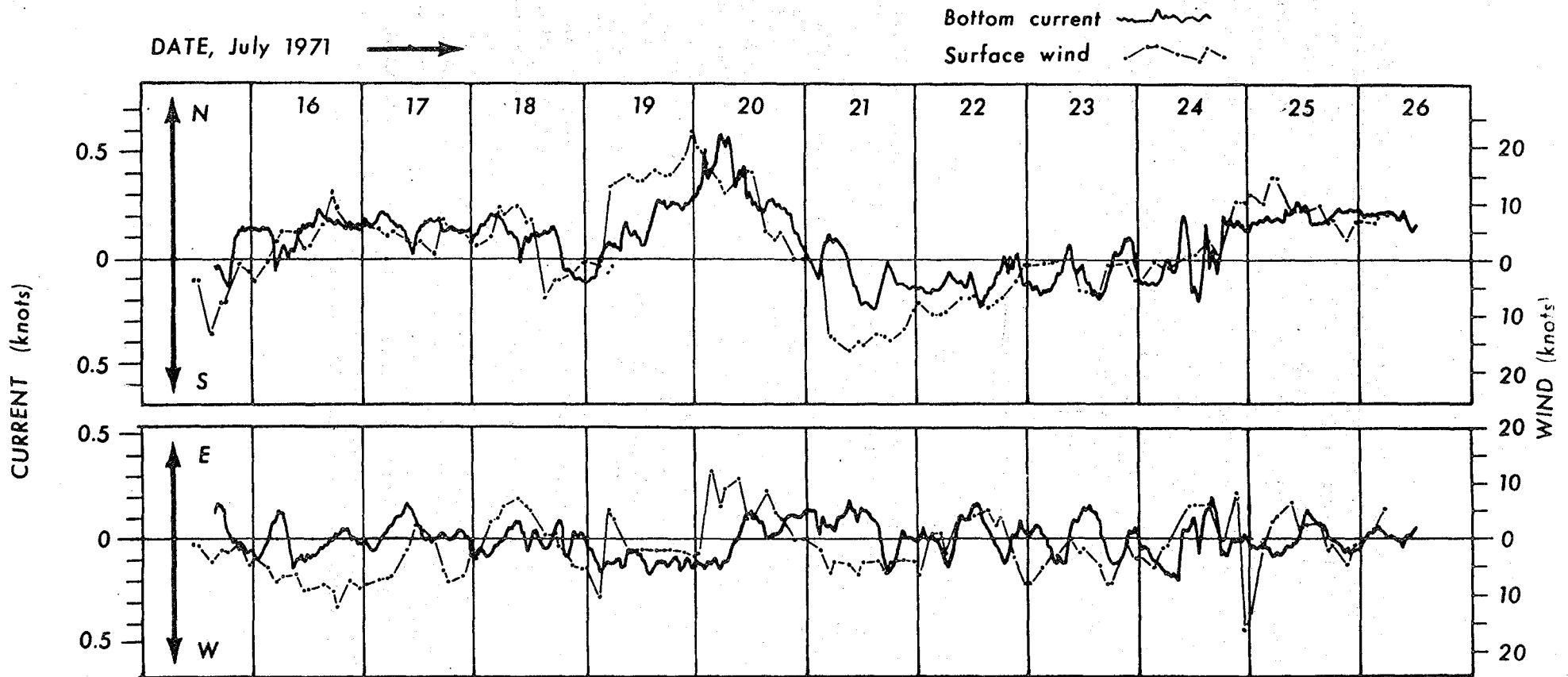


Figure 12 Simultaneously recorded surface wind and bottom current components.
Bottom currents recorded at Z-ridge, winds at Chesapeake Light Tower.

a process-response model for maintaining the False Cape sand ridges. Prevailing storm winds from the northeast produce a water setup against the coast resulting in a strong southerly current. As the current is channeled into the trough, waves surging over the associated ridge produce an overturn of water and an increase in total mass transport. This results in a coast-parallel helical flow of water the trough, with ascending components located along the landward flank of the ridge. Outside the ridge, wave action maintains a net landward bottom transport (see Fig. 13). As the confined water mass approaches the attached end of the trough and ridge system it finally bursts over the ridge and spills out to sea as a large rip current.

CONCLUSIONS

Generation of a Shoreface-Connected Sand Ridge

Nearshore open coast waters can be put into motion by several forces, namely, ocean currents, estuarine mixing, tides, winds and waves. Of these forces, only winds and waves of storm origin have been associated with bottom currents strong enough to move sand at False Cape. The inner ridge is oriented on a line between the coast and the prevailing direction of attack from storm winds and their associated waves. The result is a funneling of water and entrained sediments in a southward and landward direction. The traction load of wave-drift currents associated with obliquely approaching waves supplies the crest with sand from seaward, upwind sources. The ridge now experiences a feedback situation landward of the ridge where a surface current of water is pumped obliquely over the crest by breakers. This wave set-up landward of the ridge induces a secondary flow component on the coast-parallel wind-set current. A southwesterly trending surface current is compensated by a southeasterly moving underflow. The underflow transports nearshore sand back to the ridge crest where it creates the shoal conditions necessary for breaking waves. The net effect of these southward converging bottom currents would be to nourish the ridge and to produce a landward movement of sediments along the crest.

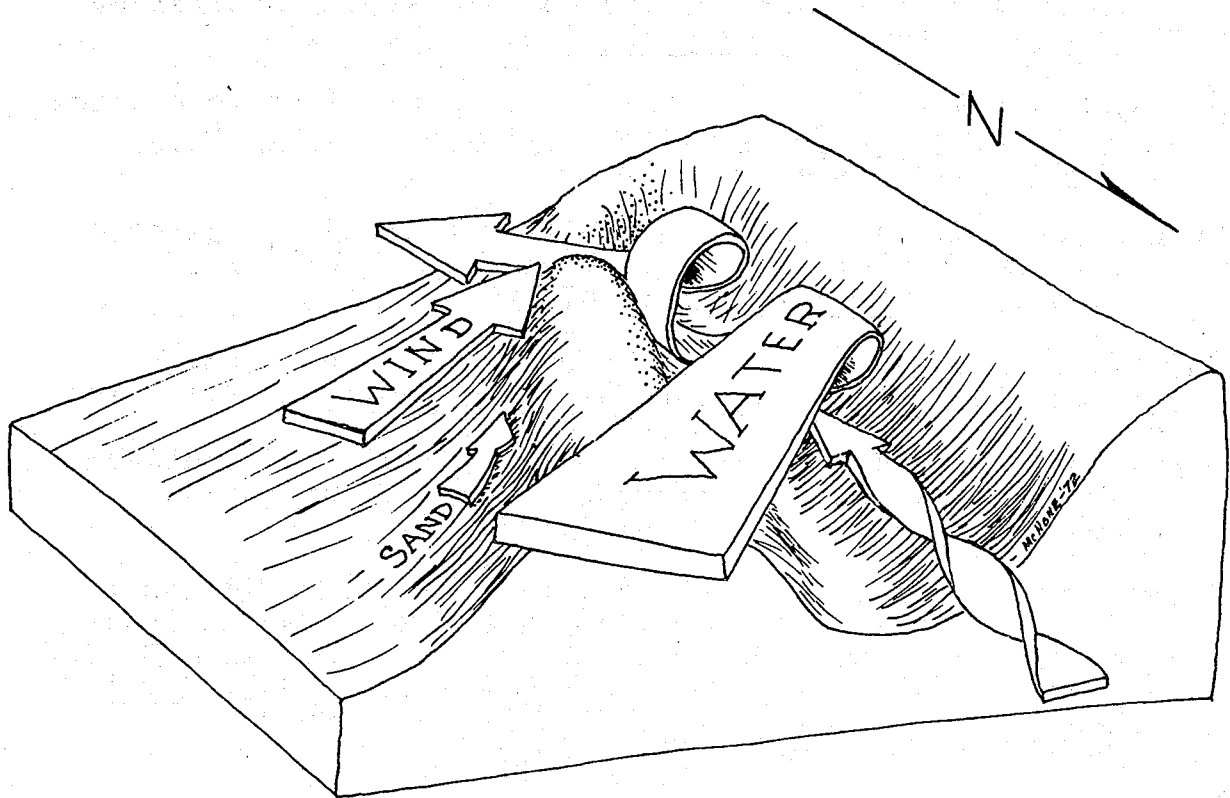


Figure 13. HELICAL FLOW PROPOSED FOR THE FALSE CAPE INNER TROUGH.

REFERENCES CITED

- Bond, G. C. and Meade, R. H., 1966. Size distribution of mineral grains suspended in Chesapeake Bay and nearby coastal waters. Chesapeake Sci., 7:208-212.
- Bruun, P., 1962. Sea level rise as a cause of shore erosion. J. Waterways and Harbors Div., Am. Soc. Civ. Eng. Proc., 88:117-130.
- Congress, 83rd. Sess. 1, 1953. Virginia Beach, Virginia, erosion control study. (letter from Chief, Army Engineers, House Doc. 186, 45 pp.
- Davies, J. L., 1964. A morphogenetic approach to world shorelines. Zeitschrift für Geomorphologie, 8:127-142.
- Dietz, R. S., 1963. Wave-base, marine profile of equilibrium, and wave built terraces: a critical appraisal. Geol. Soc. Am., Bull., 74:971-990.
- Duane, D. B., Feld, M. E., Swift, D. J. P., and Williams, J. S., in press. Linear shoals on the Atlantic inner continental shelf, Florida to Long Island. In: D. B. Duane, O. H. Pilkey, D. J. P. Swift (Editors), Shelf Sediment Transport: Process and Pattern, Dowden, Hutchinson, and Ross, Strousburg, Pa.
- Dunn, G. E. and Miller, B. I., 1960. Atlantic Hurricanes. Louisiana State Univ. Press, Baton Rouge, La., 377 pp.
- Emery, K. O., 1966. Atlantic continental shelf and slope of the United States, geologic background. U. S. Geol. Survey Prof. Pap., 529-A:1-2-3.
- Field, M.E., Duane, D.B., 1976. Post-Pleistocene history of the United States inner continental shelf: Significance to origin of barrier islands; Geol. Soc. Am., Bull., 87:691-702.
- Fisher, J. J., 1967. Development Pattern of Relict Beach Ridges, Outer Banks Barrier Chain, North Carolina. Thesis, Univ. North Carolina (unpublished), 250 pp.
- Fisher, J. J., 1968. Preliminary quantitative analysis of surface morphology of inner continental shelf, Cape Henry, Virginia, to Cape Fear, North Carolina. In: A. E. Margolis and R. C. Steer (Editors), Transactions National Symposium on Ocean Sciences and Engineering of the Atlantic Shelf, Marine Technology Society, Washington, D. C. pp. 143-149.
- Folk, R. L. and Ward, W. C., 1957. Brazos River Bar: A study in the significance of grain size parameters. J. Sediment. Petrol., 27:3-27.

- Goldsmith, V., Morris, W.D., Byrne, R.J., and Whitlock, C.H., 1974. Wave Climate Model of the Mid-Atlantic Shelf and Shoreline (Virginian Sea): Model Development, Shelf Geomorphology, and Preliminary Results: VIMS SRAMSOE No. 38, 146 p.
- Harrison, W., Norcross, J. J., Pore, N. A. and Stanley E. M., 1967. Circulation of shelf waters off the Chesapeake Bight. Environ. Sci. Services Amimn., Prof. Pap., 3:1-82.
- Hayes, M. O. and Boothroyd, J. C., 1969. Storms as modifying agents in the coastal environment. In: M. O. Hayes (Editor), Coastal Environments, Northeast Massachusetts and New Hampshire. Coastal Res. Group Contrib. No. 1, Geol. Dept., Univ. Massachusetts, Amherst, Mass., pp. 245-265.
- Holliday, B. W., 1971. Observations on the Hydraulic Regime of the Ridge Swale Topography of the Inner Virginia Shelf. Thesis, Old Dominion Univ. (unpublished), 88 pp.
- Holliday, B. W., Hopkins, S., Lavelle, W., McHone, J. F., Nelson, T., Shideler, G. L. and Swift, D. J. P., 1973. Hydraulic process and substrate response on a transgressed estuary, inner Virginia shelf. J. Geophys. Res. (in press).
- Holmes, A., 1965. Principles of Physical Geology. Ronald Press, New York, N. Y., 1288 pp.
- Ingle, J. C., 1966. The Movement of Beach Sand. Amsterdam Elsevier, 221 pp.
- Johnson, D. W., 1919. Shore Processes and Shoreline Development. Wiley, New York, N. Y., 548 pp.
- Johnson, J. W. and Eagleson, P. S., 1966. Coastal Processes In: A. T. Ippen (Editor), Estuary and Coastline Hydrodynamics. McGraw-Hill, New York, N. Y., 744 pp.
- Keulegan, G. H., 1948. An experimental study of sand bars. Beach Erosion Board, U. S. Army Corps of Engineers, Tech. Rept. 3:1-42.
- King, C. A. M., 1972. Beaches and Coasts. Saint Martin's Press, New York, N. Y., 570 pp.
- King, C. A. M. and Williams, W. W., 1949. The formation and movement of sand bars by wave action. Geograph. J. 113:70-85.

- Kraft, J. C., 1971. Sedimentary facies patterns and geologic history of a Holocene marine transgression. Bull. Geol. Soc. Amer., 82:2131-2158.
- Longuet-Higgins, M. S., 1953. Mass transport in water waves. Philos. Trans. Roy. Soc. London, 245:535-581.
- McHone, J.F., Jr., 1972. Morphological time series from a submarine sand ridge on the south Virginia coast: Masters Thesis, Old Dominion University, Norfolk, Virginia, 59 p.
- Milliman, J. D. and Emery, K. O., 1968. Sea levels during the past 35,000 years. Science, 162:1121-1123.
- Moody, D. W., 1964. Coastal Morphology and Processes in Relation to the Development of Submarine Sand Ridges off Bethany Beach, Delaware. Thesis, Johns Hopkins Univ. (unpublished), 167 pp.
- Nero, L. L., 1972. Grain Size Distribution on an Obliquely Trending Shoreface Connected Ridge of False Cape, Virginia. Old Dominion Univ. (unpublished report).
- Norcross, J. J. and Stanley, E. M., 1967. Inferred surface and bottom drift. In: W. Harrison, J. J. Norcross, N. A. Pore, and E. M. Stanley. Circulation of shelf waters off the Chesapeake Bight. Environ. Sci. Serv. Admin., Prof. Pap., 3:11-40.
- Oaks, R. Q. and Coch, N. K., 1963. Pleistocene sea levels, Southeastern Virginia. Science, 140:979-183.
- Payne, L. L., 1970. Sediments and Morphology of the Continental Shelf off Southeastern Virginia. Thesis, Columbia Univ. (unpublished), 70 pp.
- Sanders, J. E., 1962. North-south trending submarine ridge composed of coarse sand off False Cape, Virginia, (Abstr.). Bull. Amer. Petroleum Geologists, 46:278.
- Saville, T., 1954. North Atlantic coast wave statistics hindcast by Bretschneider - Revised Sverdrup-Munk method. Beach Erosion Board, U. S. Army Corps of Engineers, Tech. Mem. 55:1-18.
- Schwartz, M. L., 1965. Laboratory study of sea level rise as a cause of shore erosion. J. Geol., 73:528-534.
- Shepard, F. P., 1950. Longshore-bars and longshore-troughs. Beach Erosion Board, U. S. Army Corps of Engineers Tech. Mem. 15:1-32.

- Shepard, F. P., 1963. Submarine Geology, 2 ed. Harper and Row, New York, N. Y., 557 pp.
- Shideler, G. L. and Swift, D. J. P., 1972. Seismic reconnaissance of post-Miocene deposits, middle Atlantic continental shelf - Cape Henry, Virginia to Cape Hatteras, North Carolina, Mar. Geol., 12:165-185.
- Swift, D. J. P., Sanford, R. B., Dill, C. E., Jr., and Avignone, N. F., 1971. Textural differentiation on the shore face during erosional retreat of an unconsolidated coast, Cape Henry to Cape Hatteras, western North Atlantic shelf. Sedimentology, 16:221-250.
- Swift, D. J. P., 1972. Inner Shelf Sands of the Virginia-northern North Carolina Shelf: Texture as a Guide to Beach Borrow, (unpublished talk).
- Swift, D. J. P., Holliday, B., Avignone, N., and Schideler, G., 1972. Anatomy of a shoreface ridge system, False Cape, Virginia. Marine Geol., 12:59-84.
- Swift, D. J. P., Kofoed, J. W., Saulsbury, F. P., and Sears, P., in press. Holocene evolution of the shelf surface, central and southern Atlantic shelf of North America. In: D. B. Duane, O. H. Pilkey, D. J. P. Swift (Editors), Shelf Sediment Transport: Process and Pattern, Dowden, Hutchinson, and Ross, Strousburg, Pennsylvania.
- Thompson, E. D., and Harris, D. L., 1972. A wave climatology for U. S. coastal waters. Fourth Annual Off-shore Technology Conf. Pap., OTC 1693:14 pp.
- U. S. Army Corps of Engineers, 1960. Shore protection planning and design. Coastal Engineering Research Center Tech. Rept., 4:401 pp.
- U. S. Army Corps of Engineers, Norfolk District, 1970. Virginia Feasibility Report for Beach Erosion Control and Hurricane Protection.
- Veatch, A. C. and Smith, P. A., 1939. Atlantic submarine valleys of the United States and the Congo submarine valley. Geol. Soc. Am., Spec. Pap., 7:101 pp.
- Weinman, Z. H., 1971. Analysis of Littoral Transport by Wave Energy: Cape Henry, Virginia to the Virginia-North Carolina Border. Thesis, Old Dominion Univ. (unpublished) 64 pp.
- Whipp, D. M., 1953. "808" fathometer errors. The Journal, Coast and Geod. Surv., 5:27-32.
- Zenkovich, V. P., 1967. Processes of coastal development, Wiley, New York, N. Y., 738 pp.

MEASUREMENTS OF HISTORICAL SHORELINE CHANGES

ALONG THE COAST OF THE VIRGINIAN SEA

Carolyn H. Sutton, Anita W. Haywood and
Adam A. Frisch

INTRODUCTION

The study of the historical shoreline changes from Montauk Point, Long Island, New York to Cape Hatteras, North Carolina was undertaken to further the understanding of shoreline processes and development. At the same time, it was hoped to delineate the precision of these measurements, possibly compute an accuracy envelope to these measurements, and a confidence interval to the final results.

SOURCES OF SHORELINE DATA

Portions of the area encompassed by this study (Long Island, New York to Cape Hatteras, North Carolina) have been dealt with previously by the Army Corps of Engineers in several of their Beach Erosion Control Board Studies (discussed below). The historical shoreline changes for Long Island were discussed briefly in Taney (1961), and full scale reproductions of the original shoreline change diagrams were requested from the appropriate District Offices of the U.S. Army Corps of Engineers. The economic value of the New Jersey Ocean front prompted two studies (U.S. Army, 1958 and 1959) which covered the entire coastline and included detailed maps of historical shoreline changes. Studies were also made for Maryland (U.S. Army, 1965) which included both shoreline changes and offshore bathymetric changes. These Corps' studies contain shorelines compiled from original hydrographic sounding sheets and topographic maps. However, all are corrected by the Corps to a common "high water shoreline". These Corps' studies, along with unpublished historical shoreline maps of Virginia, were most of the maps used in the shoreline measurements.

At the present time, the shorelines for Delaware and North Carolina which lack the above charts are being taken from original hydrographic sounding sheets. Several problems have occurred, the least of which is lack of comparable data. In some cases there are old shorelines but no recent shorelines. Topographic maps are available, but they state that. "Shoreline shown represents the approximate line of mean high water," whereas hydrographic sounding sheets are corrected to mean low water, and any comparisons would not be a true representation of shoreline changes. Therefore, since the Corps has already made many of these corrections, put the shorelines on a common base, and since less total transfer error is involved, the Corps' charts are preferable, where available.

METHODS

In most cases, at least two shorelines are represented for each section of the coastline where the Army Corps of Engineers have not made beach erosion studies. In order to compare these shorelines, one hydrographic sounding sheet is used as a base map. If they are both the same scale, one chart can be transferred directly to the base map on stable base material. The majority of the shorelines were not the same scale, and had to be transferred point by point using latitude and longitude as the grid. This method was found to be the most accurate since "the distorting influence of the projection becomes non-significant since the comparison is based on latitude and longitude," (Sallenger, et al., 1975).

The next step involves transferring a superimposed map projection in the form of a square co-ordinate system from the original grids used in the Virginian Sea Wave Climate Model Studies (Goldsmith, et al., 1974) onto the base maps. This provides the minimum error due to the transfer by latitude-longitude, and also allows the comparison of shorelines by inputting them with reference to an x-y co-ordinate system. It was found previously that "grids imposed on the original drawn skewed lines of latitude and longitude (corrected for datum) will somewhat diminish the effects of distortion for the entire comparison," (Sallenger, et al., 1975).

ACCURACY

In order to correctly evaluate the data from these shoreline comparisons, it was necessary to look into the possible error connected with each shoreline. A draft publication has been prepared by Tanner and others entitled, "Standards for Measuring Shoreline Changes" and is being used as a basis for these accuracy determinations. This publication outlines errors to be considered when dealing with different scales and different types of maps.

For example, on two maps of 1:40,000 scale, using Tanner's (1977) strict limit of 0.2 mm for scale correction the smallest measurable field limit is 8 meters. If the maps are approximately 80 years apart it would give us a limit of .1 m/yr. Any changes, whether accretional or erosional, which is smaller than this value, cannot be measured. This is just based on considerations of scale. In addition, there are the accuracy considerations, which for U.S.G.S. topographic maps is about .5 mm (Tanner, 1977, p. 5-6). These two must be added ($8 \text{ m} + 20 \text{ m} = 28 \text{ m}$), which is the \pm envelope of the change.

In some situations one can only consider the "generous case" which would be 0.5 mm. This would give a field limit of 20 m which would be added to 20 m (map accuracy) and divided by the total number of years, increasing our limit to 0.5 m/yr (approximately 1.5 ft). Since there are two maps involved, each with these same associated errors, these limits then need to be added. Assuming both charts have the same standards, as discussed above, the shoreline changes would have to be greater than 0.5 m/yr plus 0.5 m/yr, or 1 m/yr to be considered real changes.

In both cases, the limits are reasonable, but this situation is about the simplest case that could possibly occur in this research. The maps for a given section of shoreline are rarely ever the same scale, and sometimes are not made with the same map standards. All these factors must be considered and an amount or per cent error attached to each shoreline. In this way, "real" changes in shorelines can be measured and correct evaluations can be made from the data.

The changes which can be seen in Figures 1 and 2 are in the initial stage of comparison. The axis is set up to

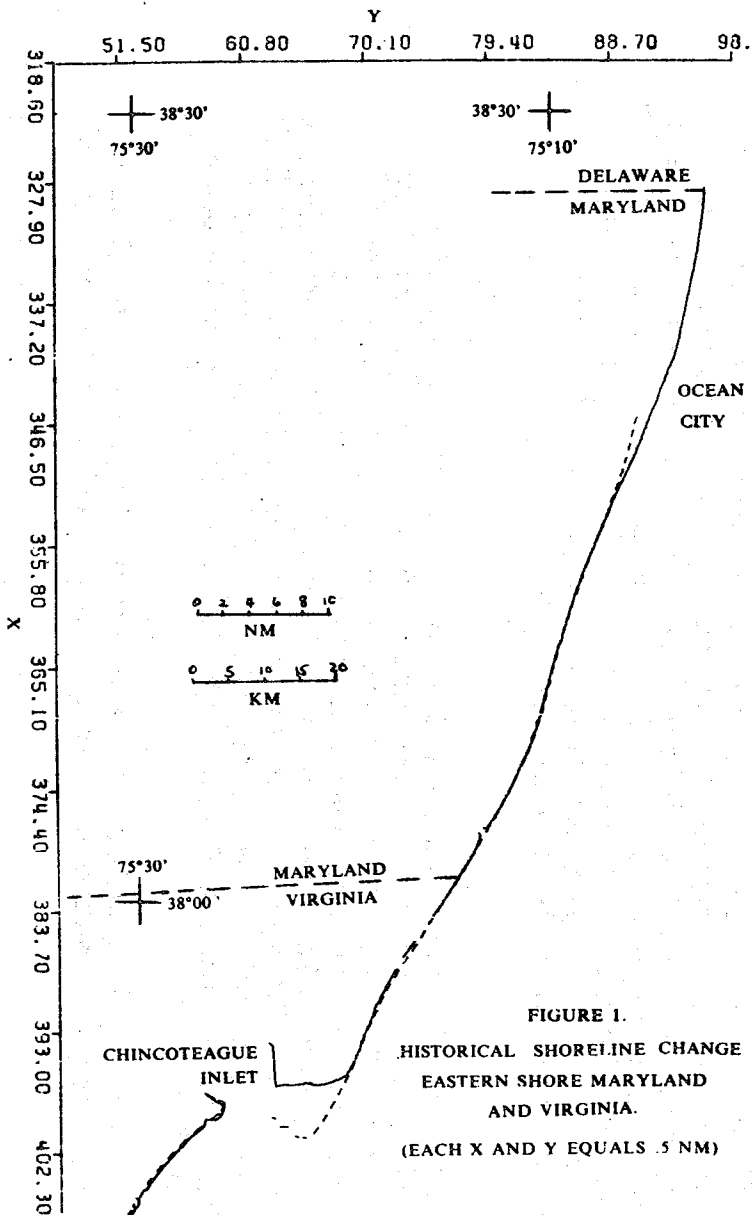
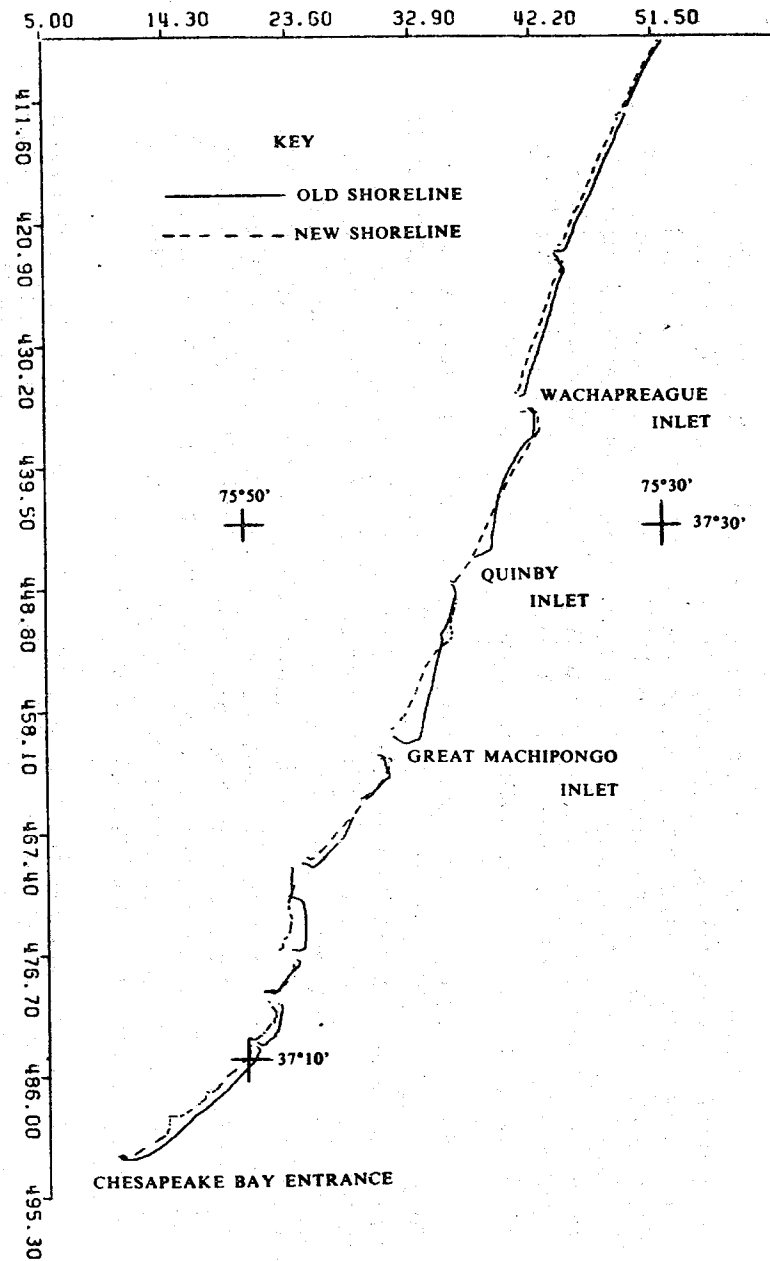
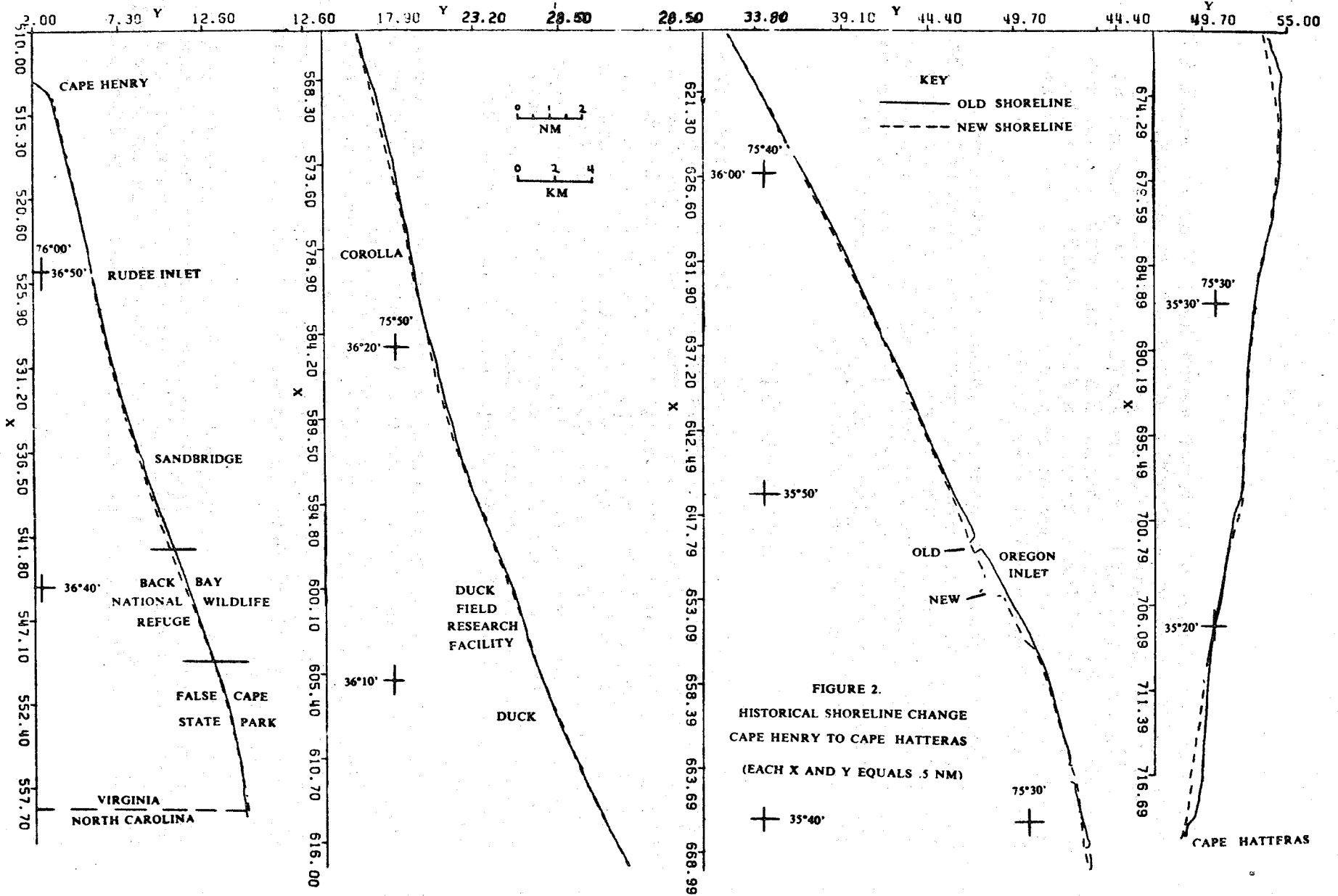


FIGURE 1.
HISTORICAL SHORELINE CHANGE
EASTERN SHORE MARYLAND
AND VIRGINIA.
(EACH X AND Y EQUALS .5 NM)





plot the shorelines with input every half X value which is approximately .46 km (.25 nm). Although the accuracy envelope has not been included as yet, it is clear that some of the net changes are so small that they cannot be considered real changes within this framework. Thus, the true magnitude of these trends will be modified, by the accuracy limits, and some uncertainty added as to whether the smaller changes are really there.

Figure 1 shows the eastern shore of Virginia and Maryland. Notice the clockwise rotational movement of the lower barrier islands. The movement of these inlets and relation to changing wave patterns, has been discussed in detail (Goldsmith, et al., 1973) and have been compared to the movement of the barrier island chain along the New Jersey Coastline (Sutton, et al., 1976).

CURRITUCK SPIT

A region of particular interest is the area from Cape Henry to Cape Hatteras, encompassing Currituck Spit, Virginia-North Carolina. The amount of beach profile data for this shoreline allows the comparison of the beach changes with the historical changes. However, a note of caution is in order. Some of the charts show not only an overall change, but also periods of shoreline erosion followed by periods of accretion, and then the beach again erodes. A look at just the oldest and most recent shorelines may indicate an overall period of erosion when in reality, the beach is undergoing more changes than are shown.

Figure 2 shows the historical shoreline changes between Capes Henry and Hatteras over the largest amount of time for which data is available. The "old" shoreline is actually a mixture of shorelines from 1859 to 1870 depending on the oldest available data. Similarly, the most recent shorelines range from 1939 to 1968, with the exception of a small area three miles north of Cape Hatteras, which was most recently surveyed in 1917.

The area from Cape Henry to False Cape, Virginia, which has been referred to as the Southeast Virginia Coastal Compartment (Goldsmith, et al., 1977) displays historical changes which are similar to beach profile changes measured in recent studies (see Goldsmith, et al., this volume). The diverging

longshore transport nodal point at Sandbridge, Virginia, hypothesized from beach profile data, also is indicated by historical erosion at Sandbridge with accretion taking place north and south of this area, in Cape Henry and False Cape, respectively.

South of False Cape, there are alternating areas of erosion and accretion. These areas look small at this scale, but in reality, they indicate maximum erosion of approximately 300 m, or about 4 m/yr. The beach at Duck, North Carolina and below shows little change until about $36^{\circ}20'$ where there is slight amount of erosion increasing uniformly to the south, to the area immediately north of Oregon Inlet. Figure 1 clearly shows the 2 km southwest migration of Oregon Inlet.

SUMMARY

The shoreline changes along Currituck Spit, are quite variable, with most of the shoreline having alternate zones of erosion (maximum of about 4 m/yr) and accretion. For example, the Southeast Virginia Coastal Compartment, Cape Henry to False Cape, Virginia, displays historical shoreline changes of maximum erosion in the Sandbridge vicinity, flanked by accretion on both sides, suggesting a diverging longshore transport nodal point. These historical changes are similar in pattern to recent (1969-1976) shoreline changes as measured by beach profiles.

REFERENCES

- Goldsmith, V., Byrne, R., Sallenger, A., and Drucker, D., 1973. The Influence of Waves on the Origin and Development of the Offset Coastal Inlets of the Southern Delmarva Peninsula, Virginia: VIMS Contribution No. 579.
- Goldsmith, V., Morris, W.D., Byrne, R.J., and Whitlock, C.H., 1974. Wave Climate Model of the Mid-Atlantic Shelf and Shoreline (Virginian Sea): Model Development Shelf Geomorphology and Preliminary Results: VIMS SRAMSOE No. 38.
- Goldsmith, V., Sturm, S., and Thomas, G., 1977. Variations in Beach Erosion and Accretion Trends at Virginia Beach, Virginia, and Vicinity: Final Report CERC Contract DACW-72-C-0008 and CERC Tech. Memo No. (in press), C.E.R.C., U.S. Army Corps of Engs., Ft. Belvoir, Virginia: VIMS SRAMSOE No. 122.
- Sallenger, A.H., Jr., Goldsmith, V., and Sutton, C.H., 1975. Bathymetric Comparisons: A Manual of Methodology, Error Criteria and Techniques: VIMS SRAMSOE No. 66.
- Sutton, C.H., and Goldsmith, V., 1976. Regional Trends in Historical Shoreline Changes: New Jersey to Cape Hatteras, North Carolina. Presented at G.S.A. NE-SE Conference, March 1976, Washington, D.C.
- Tanner, W.F., 1977. Standards for Measuring Shoreline Changes. Coastal Plains Center for Marine Development Services (in prep).
- Taney, Norman B., 1961. Geomorphology of the South Shore of Long Island, New York. Beach Erosion Board, Office of the Chief of Engineer, U.S. Army Corps of Engineers. TM No. 128.
- U.S. Army. BEB Study, 1959. Shore of New Jersey-Barnegat Inlet to Cape May Canal, Beach Erosion Control Study, House Document No. 196, 87th Congress, 1st Session.
- U.S. Army. Beach Erosion Control Board, 1958. Shore of New Jersey from Sandy Hook to Barnegat Inlet. Beach Erosion Control Study. House Document No. 332, 85th Congress, 2nd Session.

U.S. Army Corps of Engineers, 1965. Atlantic Coast from
the Delaware-Maryland Line to Gargathy, Inlet, Virginia.
House Document No. 144, 89th Congress, 1st Session.

BEACH TRENDS IN THE SOUTHEASTERN VIRGINIA
COASTAL COMPARTMENT¹

Victor Goldsmith, Susan C. Sturm and George R. Thomas

ABSTRACT

Analyses of 629 VIMS-CERC beach profile measurements at 18 locations in southeast Virginia (September 1974 to December 1976) and 114 older profile lines (November 1956 to January 1974) at 14 of these same locations, show that this 42-kilometer shoreline varies widely in beach response to both moderate storms and "daily" wave, tide, and wind processes. During the 27 month VIMS-CERC study, a time of relatively low storm-induced beach erosion, total net cumulative volume changes were quite low, with maximum accretion at the north and south ends of the study area (e.g., 26 cubic meters per linear meter of beach at Profile line 1 at Fort Story) an maximum erosion in the middle profile locations (e.g., 23 cubic meters per meter at Profile line 9 in Sandbridge). Most profile locations underwent monthly or storm changes larger than their total net cumulative 27 month volume changes.

Because of the large monthly profile volume changes relative to total net changes, a statistical method is employed to delineate erosion-accretion trends at various levels of significance for each profile location. Profile lines 1, 14, 16, and 18 and Profile lines 3, 6, 9, and 11 have statistically significant (at the 99.0 percent level) accretion and erosion trends, respectively. These area changes generally correlate with observed beach morphology; i.e., wide, low-gradient beaches on the north and south ends, and narrow, steep beaches in the middle of the area.

¹This section is taken from a report (in press) of the Coastal Engineering Research Center of the U.S. Army Corps of Engineers, which supported this study during 1974 to 1976 (Goldsmith, et al., 1977).

Classic "ridge and runnel" morphology is completely absent from this area.

Under present conditions, rates of erosion and accretion are independent of the four types of shore usage defined for this study area (commercial, natural, military, and residential). The narrow, erosional beaches are located in the center of the study area in Back Bay National Wildlife Refuge (natural area), Dam Neck (military), and Sandbridge (residential), while the wide, accretional beaches are located at the north and south ends of the study area in Fort Story (military) and False Cape State Park (natural).

Instead of beach usage, it is suggested that the observed differences in beach morphology and response are related to the location of a diverging nodal zone of longshore transport in the middle of the study area (approximately Dam Neck to Back Bay). North of this zone net transport is to the north, and south of this zone, it is hypothesized that net transport is to the south. The net, but irregular, movement of sediment out of the middle area explains the narrow, relatively inactive, erosional beaches observed in the middle and the wide, active, accretional beaches observed on the ends, as well as the large variations in beach response between locations.

PREVIOUS STUDIES

Of the eighteen beach profile locations measured monthly and after eight storms during 1974-1976, 14 of these same locations had been previously measured by earlier investigators. These previous beach studies are summarized in Table 1 and the profile locations shown in Figure 1.

Watts (1959) studied effects of beach fill on Virginia Beach and calculated net volume changes in the nearshore and intertidal parts of the profile line between 1946, 1952, 1955, and 1958. He concluded that 84 percent of the nourishment material placed on the beach between Rudee Inlet and 46th Street between September 1964 and June 1952 had been lost. However, the beach width remained the same during this period due to the nourishment. The first detailed studies of beach changes in Virginia were undertaken by Harrison and Wagner (1964). In this study, monthly, weekly, and daily changes were monitored at four locations in Virginia Beach and one at Camp Pendleton. These profile lines were measured intermittently between November

Table 1. Beach profile history.

Profile line ¹	Distance to next profile line ²		Previous investigators	Dates sampled	Survey technique
	(mi)	(km)			
1	2.0	3.2	Fausak (1970)	Daily, 10 Aug. to 9 Sept. 1969	Tape and level
2	3.1	5.0	Harrison and Wagner (1964)	4 Nov. 1956 to Sept. 1958, 7 and 8 Mar. 1962	Tape and level
3	0.9	1.4	Harrison and Wagner (1964)	25 Mar. and 10 Apr. 1963, 11 June to 5 July 1963	Tape and level
4	0.9	1.4	Harrison and Wagner (1964)	25 Mar. and 10 Apr. 1963, 11 June to 5 July 1963	Tape and level
5	1.4	2.2	Harrison and Wagner (1964)	Mar. and Apr. 1963, 10 June to 5 July 1963	Tape and level
6	1.7	2.7	New profile line		
7	1.0	1.6	Goldsmith, Smith, and Sutton (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
8	3.1	5.0	Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz on man beach profile technique
			Goldsmith, Smith, and Sutton (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
9	1.7	2.7	New profile line		
10	1.3	2.1	Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz one man beach profile technique
			Goldsmith, Smith, and Sutton (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
11	0.5	0.8	Goldsmith, Smith, and Sutton (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
12	0.8	1.3	Goldsmith, Smith, and Sutton (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery

Table 1. Beach profile history.--Continued

Profile line ¹	Distance to next profile line ²		Previous investigators	Dates sampled	Survey technique
	(mi)	(km)			
13	0.5	0.8	Goldsmith, Smith, and Sutton (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
14	1.6	2.6	Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz one man beach profile technique
			Goldsmith, Smith, and Sutton (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
15	2.9	4.7	Goldsmith, Smith, and Sutton (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
16	1.5	2.1	Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz one man beach profile technique
			Goldsmith (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
17	1.5	2.4	Schideler, Swift, and McHone (1971) unpublished data	Oct. 1970 to Oct. 1971	Tape and level
			Goldsmith (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
18			Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz one man beach profile technique
			Goldsmith (1974) unpublished data	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery

¹Total of 42.2 kilometers between profile lines 1 and 18.

²Average of 2.5 kilometers between each profile line.

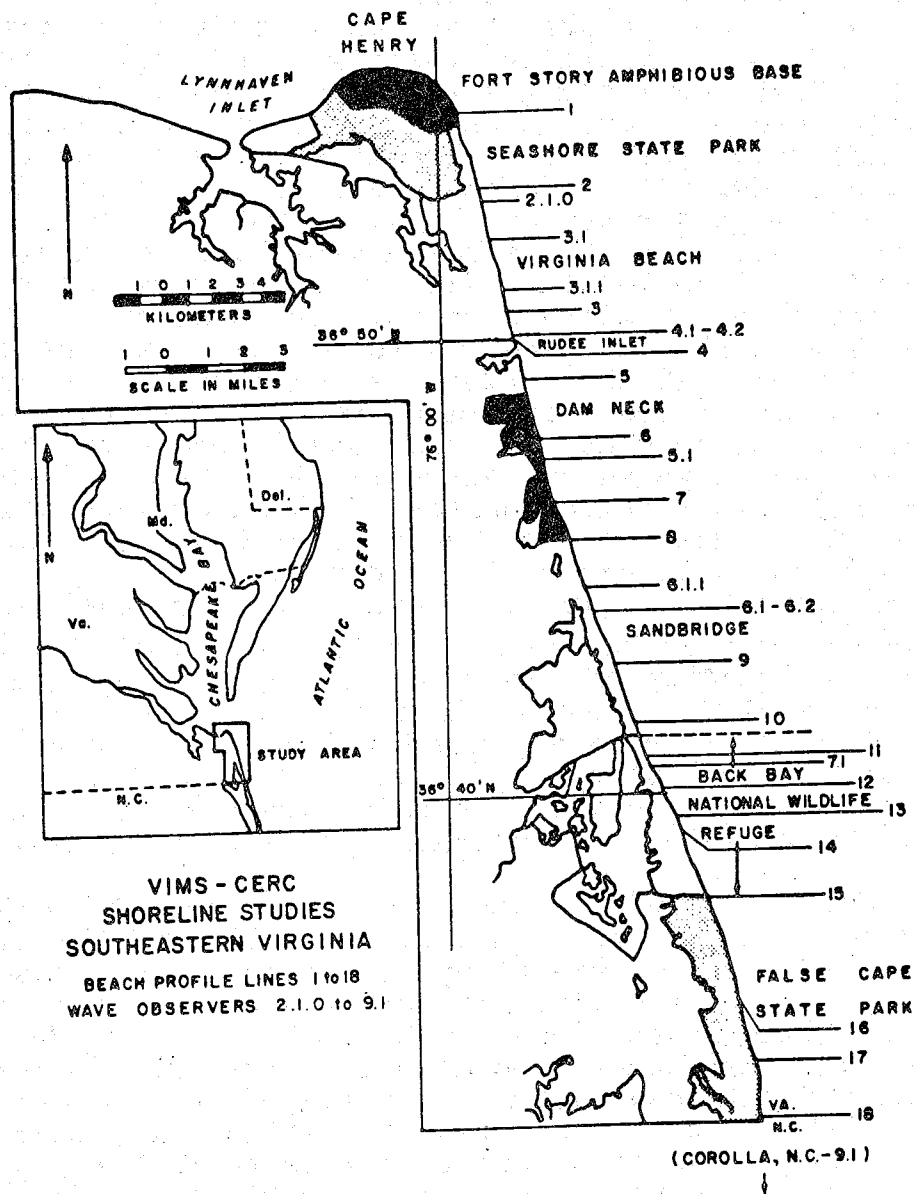


Figure 1. Location map of profile lines and wave observation sites.

1956 and May 1963. The maximum vertical change at the 61st Street profile line, observed during this 27 month period, was 2.0 meters and occurred midway between mean sea level and mean high water. Approximately one half of the dune was lost during the storm of 7 to 8 March 1962. With respect to the profile lines at 15th and 3d Streets, the data "...do not show convincing differences between winter and summer profiles" (Harrison and Wagner, 1964, p. 27). Post-storm changes measured on both the beach and nearshore area out to depths of 5 meters indicated "...that under great storm conditions the foreshore slope and beach ridge will undergo greater change than the nearshore bottom" (Harrison and Wagner, 1964, p. 9). The precise locations of these beach profile lines have been reoccupied. Additional studies were conducted at Fort Story, north of Virginia Beach by Harrison, et al. (1968), in which more than a dozen environmental variables were measured over a 28-day period. No discussions or conclusions were mentioned. The importance of the beach water table response to tidal fluctuations in the Fort Story area was investigated by Fausak (1970). He found that the water table fluctuations decreased about 60 meters from the beach. Studies of the beach water table at Camp Pendleton in 1966, and at Fort Story in 1969, are reported in Harrison, et al. (1971). Multiregression analysis of the data show that the most important variables influencing changes in quantity of foreshore sand (in decreasing order of importance) were changes in ocean still water level, an index of groundwater head, and the number of swash events per unit of time (Harrison, et al., 1971, p. 43). Fausak's Fort Story beach profile line which was monitored in August and September 1969, was reoccupied in September 1972.

A detailed study of beach changes along the outer coast of Virginia was reported in Bullock (1971) and Harrison and Bullock (1972). In this study, 16 beach locations were surveyed between the Virginia-Maryland and the Virginia-North Carolina State lines for 20 months. These data were then used to calibrate a model which attempted to forecast changes in beach sand volume resulting from storm conditions. "The results indicated that it may be possible to develop prediction equations to forecast beach changes for sections of ocean beach that do not exhibit complex offshore bathymetry" and that initial beach volume was a strong determinant of beach volume change (Bullock, 1971, p. 61). Six out of seven of these beach profile lines in the Virginia Beach coastal compartment were precisely located and remeasured at bimonthly intervals between September 1972 and January 1974, by Goldsmith, Smith, and Sutton (1974, unpublished). Numerous studies of the False Cape area, including

beach survey measurements, have been conducted by G. Shideler and others (1971, unpublished). Three out of four of these beach profile lines, going back to 1969, were reoccupied in September 1972 by Virginia Institute of Marine Science (VIMS) and Old Dominion University (ODU) personnel, and by V. Goldsmith, F. Smith, and C. Sutton (1974, unpublished) at bimonthly intervals, through January 1974. Copies of all the above previous beach profile data are stored at VIMS.

Beach changes were monitored once a month at Virginia Beach at 1,000-foot (305 meters) intervals between 49th Street and Rudee Inlet by an engineering firm under contract to the City of Virginia Beach and the U.S. Army Engineer District, Norfolk. Once a year these profile lines are extended out to depths of 25 feet (8 meters) (H.J. Fine, Chief, Water Resources Planning Beach, U.S. Army Engineer District, Norfolk, personal communication, 1972). This 4-kilometer stretch of shoreline includes the major zone of public concern about beach erosion, but less than 10 percent of the total ocean shoreline of southeastern Virginia.

A beach survey network consisting of 13 beach survey locations over a 24-kilometer stretch of coast between Rudee Inlet and the Virginia-North Carolina border was set up in the summer of 1972. These profile lines were surveyed at bimonthly intervals with the cooperation and assistance of the personnel of the Back Bay National Wildlife Refuge, U.S. Fish and Wildlife Service, and graduate student volunteers at VIMS. This survey network consisted of three older profile lines of Schideler and others (1971), the five profile lines of the Back Bay National Wildlife Refuge personnel, and five profile lines of Bullock (1971).

PURPOSES OF THIS STUDY

The previous studies indicate large variations in beach response at these different survey localities from both storms and daily low wave energy-type processes. Thus, the primary objective of this study was to investigate beach behavior by measuring beach survey changes for 27 months over a 45-kilometer stretch of coastline containing a variety of beach types and an irregular offshore bathymetry.

Special attention was paid to the variations in cultural usage and to the location of the focus of longshore transport reversal as possible causes of the differing beach

response. Although this 1974-1976 interval was a time of relatively low storm-induced beach erosion, there were storm events of sufficient intensity as to clearly delineate differing erosional responses between survey locations. The interpretation of these variations is assisted by concomitant shoreline wave observations, and ground and aerial photos. Probably the most important purpose is to relate the VIMS-CERC profile lines (1974-76) to the older survey data in order to delineate the long-term trends (by surveying standards) of between 4 and 18 years at 14 of these locations since such lengthy survey histories are relatively rare in the United States. Further, the application of standard statistics to test and delineate these beach trends is illustrated.

METHODS

The 18 beach survey locations were measured once each month for 27 months and after eight storms (i.e., defined as periods of high waves). Vertical distances were measured with a Dietzgen automatic level and a telescoping fiberglass leveling rod graduated to 0.01 foot (0.003 meter). Horizontal distances were measured with a fiberglass-polyester woven tape graduated to 0.05 foot (0.015 meter).

Each profile line was measured from the top of the most seaward of three pipes (pipe 1) taking vertical and horizontal readings at all significant breaks in slope, to as far seaward of mean sea level as possible under the existing wave climate. Scarps, berms, last high tide lines, and the waterline (or swash zones) were points also measured and specifically noted on the specially designed VIMS Beach Survey form along with other pertinent data gathered at the survey locations. The advantage of this form is that it can be handed directly to the keypuncher at the VIMS Computer Center for data processing.

These data were used to compute net beach volume changes between times of profiles in cubic meters of sand per linear meter of beach from the most seaward pipe (usually on the front dune line) to the surveyed MSL datum.

Because of large fluctuations in volume changes between surveys at each of the survey locations, it is often difficult to discern net erosion or accretion trends at a profile line. Also, even when trends are apparent, some appear to be "stronger" at some locations than at others.

In order to quantify this heretofore subjective evaluation of the main factor describing the beach activity, erosion versus accretion, a statistical scheme was developed and first used in Goldsmith, et al., 1974a. This scheme was adopted in this study, and is described below.

To test for statistically significant erosion or accretion trends at each beach profile line, a linear regression line was calculated for cumulative beach volume change against time (in weeks) using a standard canned program on the VIMS IBM 370 computer. The null hypothesis assumed that the calculated regression line represented the distribution of beach volume change with time (i.e., significantly different from chance within the 27 months of survey measurements). This was tested at various levels of statistical significance (e.g., 1, 5, 10, and 50 percent) and the null hypothesis was accordingly rejected at the appropriate significant level, and the erosion-accretion trend was considered to be statistically significant at that level. It is interesting to note that all eight profile lines exhibiting trends considered statistically significant (at 1 percent level) showed a large statistical difference from the other profile lines (i.e., there was a major break in the groupings of the significance levels).

PROCESSES

Tides, wave and wind climate, storms and storm surges, and eolian processes are all exhaustively discussed elsewhere in this volume.

BEACH NOURISHMENT

Since 1952, a beach nourishment program for Virginia Beach has been conducted along an 8-kilometer shoreline from Cape Henry to Rudee Inlet. Concentration of this effort has centered in the 5.5 kilometers just north of Rudee Inlet, of which 3 kilometers have been bulkheaded with a concrete "boardwalk" in the area of the ocean-front hotels.

By the end of fiscal year 1976 it was reported by the Norfolk District that a total of 5.9 million cubic yards (4.5 million cubic meters) of sand had been placed on the beach (Table 2) to check the loss of material due to a northerly transport and other erosional factors.

Table 2. Gross quantities of material placed on Virginia Beach, fiscal years 1952 to 1976.

Fiscal year	Initial restoration (yd ³)	Truck haul (yd ³)	Early inlet dredging (yd ³)	Inlet bypassing (yd ³)	Owl's Creek (yd ³)	P.L. 875 dredging (yd ³)	Inlet "from source" (yd ³)	Total (yd ³)
1952	20,000							20,000
1953	1,363,000							1,363,000
1954	60,000	34,000	44,000					138,000
1955		30,000		17,500				47,500
1956				35,000				35,000
1957				44,000	80,000			124,000
1958				50,000	70,000			120,000
1959				46,000	93,000			139,000
1960				48,000	84,000			132,000
1961				62,000	91,000			153,000
1962		113,000 ¹		53,000	101,000	205,000		472,000
1963					121,000			121,000
1964					215,000			215,000
1965					218,000			218,000
1966					174,000			174,000
1967					177,500			177,500
1968				139,000	8,400			147,400
1969				100,500	0			100,500
1970				104,000	143,800			247,800
1971				127,000	103,600			230,600
1972		43,100		114,900	230,500		101,300	489,800
1973		12,000		86,300	260,300			358,600
1974		12,500		103,300	49,700			167,500
1975		112,470		160,960				273,430
1976		98,980		142,630				241,610
								8,900,000 Total

¹Truck haul placed under P.L. 875.

(From U.S. Army Engineers District, Norfolk, 1971)

Various means of supplying the sand were: (a) Hauling by truck from a distant sand stockpile at Cape Henry where the dredged material from Thimble Shoal Channel in Chesapeake Bay entrance, has been pumped ashore and stored; (b) dredging of Rudee Inlet; (c) sand sources dredged by enlarging "Rudee Harbor"; and (d) bypassing of ocean-front sand from the south side of the inlet jetty to the north side of the inlet.

Approximately 9 percent of the total volume that has been used to nourish the beaches, or 515,040 cubic yards (391,000 cubic meters), has been placed on the beach since the beginning of fiscal year 1975. Most of this has been either inlet-bypassed, or truck-hauled from the Thimble Shoal stockpile at Cape Henry.

It has been observed that much of the nourished sand is usually removed by the first small or moderate storm. Therefore, nourishment is required, more or less, continuously. The net northerly transport moves some of this sand to the north to Cape Henry and Thimble Shoal Channel, where with the aid of man, the sand is recycled back into the transport system.

BEACH CHANGES

In analyzing 27 months of data from the study area, it became evident that certain areas had usually accreted, some had usually eroded, and some were either stable or fluctuated too much for any discernible trend to be recognized. Figure 2 represents graphically the 27-month total cumulative volume at each profile line. All these volume data represent net changes along the profile line between the number 1 pipe and the MSL intercept determined by surveyers. A qualitative description of the 27-month volume trends and major events is presented in Table 3. Statistical analyses of beach trends for the 27-month study and the historical changes are given in Tables 4 and 5, respectively.

Fort Story (Profile line 1) appears to have accreted throughout the study. Even the severest storms did little damage at this survey location. Whereas, the 1 July 1975 storm was followed by significant accretion, and the 25 November 1975 storm was followed by minor erosion. However, one factor, whose influence remains unknown, is the occasional leveling of the wide beach area with a road grader by the U.S. Army (Fig. 3).

The Virginia Beach area (Profile lines 2, 3, and 4) displayed an erosional tendency, which was offset with

Table 3. Qualitative description of 27-month beach trends.

Profile line	Net trend	Effect of 25 November 1975 storm	Rate of beach change (x)			Significant activities of man
			Very active	Active	Less active	
1	Accretion				x	Grading
2	-	Erosion ¹	x			
3	Erosion	Erosion			x	Nourishment
4	Erosion	Accretion ²		x		Nourishment
5	Accretion	Erosion			x	Inlet jetty
6	Erosion	Erosion	x			
7	-				x	
8	-		x			Fence
9	Erosion	Erosion		x		
10	Accretion	Erosion			x	
11	Erosion	Erosion			x	
12	-				x	
13	Erosion, then accretion after 10 March 1975				x	
14	Erosion, then accretion after 10 March 1975	Erosion			x	
15	Erosion, then accretion after 10 March 1975			x		
16	Accretion			x		
17	-				x	
18	Accretion		x			

¹Storm was the major erosional event of study.

²Storm was the major accretional event of study.

Table 4. Linear regression lines fitted to the beach volume trends and statistical significance of the 27 month trends.
September 1974 to November 1976

<u>Profile line</u>	<u>Estimated coefficient</u>	<u>Y Intercept</u>	<u>T Statistic</u>	<u>R²</u>	<u>Significance¹</u>	<u>Trend²</u>
1	6.40	-2053.81	7.47	0.67	0.001	+
2	0.14	- 88.76	0.26	0.001	0.80	+
3	-3.02	914.63	-3.80	0.33	0.001	-
4	-0.50	233.36	-0.78	0.02	0.50	-
5	0.14	- 74.65	0.34	0.001	0.75	+
6	-2.94	790.22	-5.39	0.50	0.001	-
7	0.73	- 195.27	1.56	0.08	0.20	+
8	0.17	- 51.78	0.24	0.001	0.95	+
9	-2.16	524.26	-4.48	0.41	0.001	-
10	0.92	- 305.47	2.23	0.16	0.05	+
11	-2.15	586.32	-3.85	0.36	0.001	-
12	2.47	- 241.60	0.37	3.01	0.70	+
13	0.84	- 404.56	1.68	0.09	0.25	+
14	1.61	- 573.04	3.01	0.24	0.01	+
15	0.72	- 308.91	1.59	0.08	0.20	+
16	2.15	- 619.17	3.50	0.29	0.01	+
17	0.40	- 130.00	1.01	0.03	0.40	+
18	1.65	- 544.24	3.35	0.26	0.01	+

¹The lower the number, the higher the significance; e.g., 0.001 indicates that the erosion or accretion trend is not due to chance at the 99.9 percent level.

²+, accretion; -, erosion.

Table 5. Linear regression lines fitted to the beach volume trends and statistical significance of the long-term trends.
(See Section III, 6 for explanation and App. C)

<u>Profile line</u>	<u>Estimated coefficient</u>	<u>Y Intercept</u>	<u>R²</u>	<u>Significance¹</u>	<u>Trend²</u>
1 ³					
2 ³					
3 ³					
4 ³					
5 ³					
8	-0.52	- 151.59	0.14	0.001	-
10	0.16	- 27.49	0.03	0.20	+
12	6.74	-2203.28	0.68	0.001	+
13	1.09	- 489.12	0.06	0.10	+
14	4.08	-1399.52	0.38	0.001	+
15	-0.05	- 85.93	0.001	0.90	-
16	0.04	46.60	0.001	0.001	+
17	1.26	- 232.90	0.31	0.001	+
18	5.47	-1743.74	0.92	0.001	+

¹The lower the number, the higher the significance; e.g., 0.001 indicates that the erosion or accretion trend is not due to chance at the 99.9 percent level.

²+, accretion; -, erosion.

³Data does not meet basic assumptions.

21-15

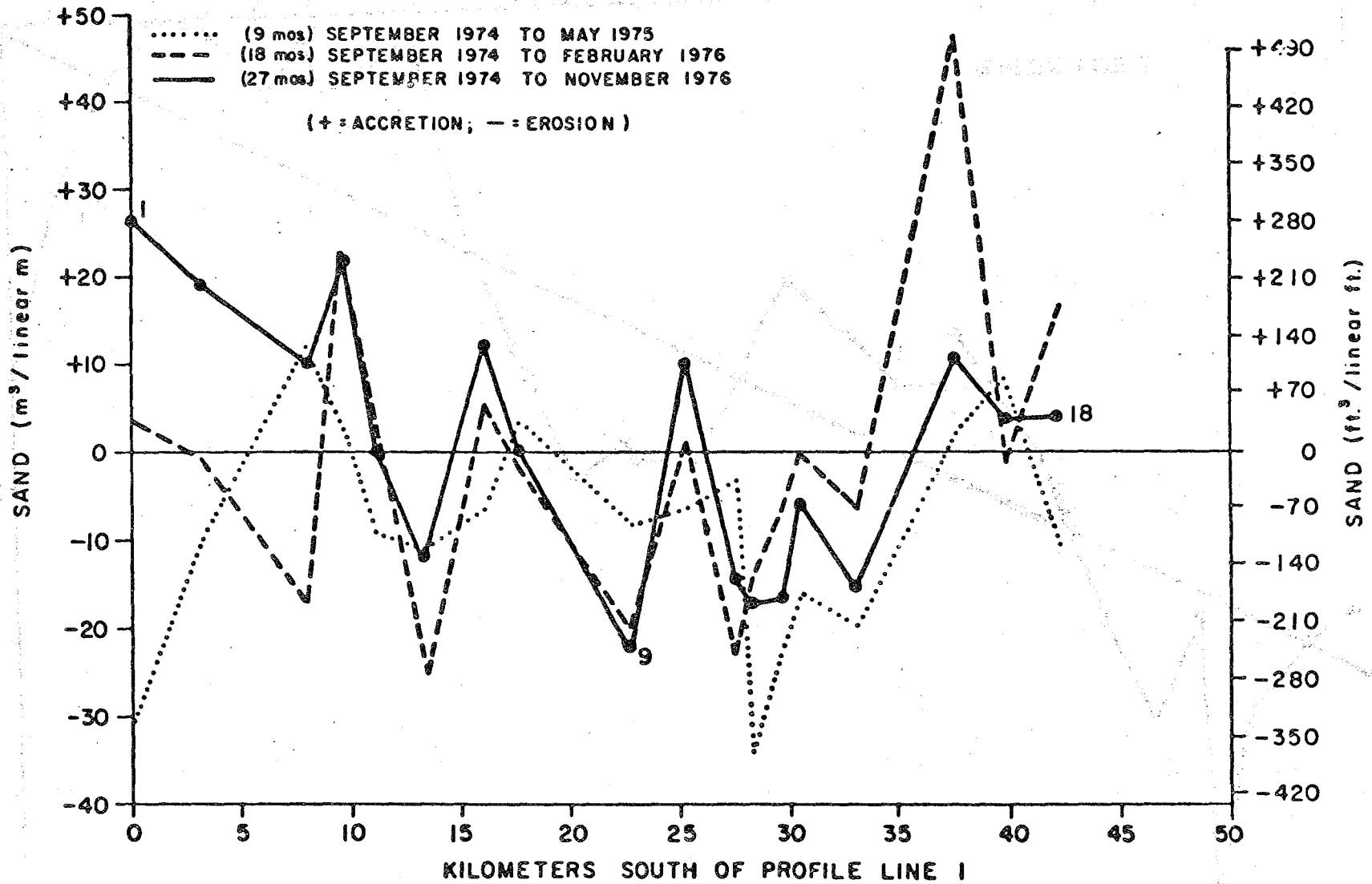
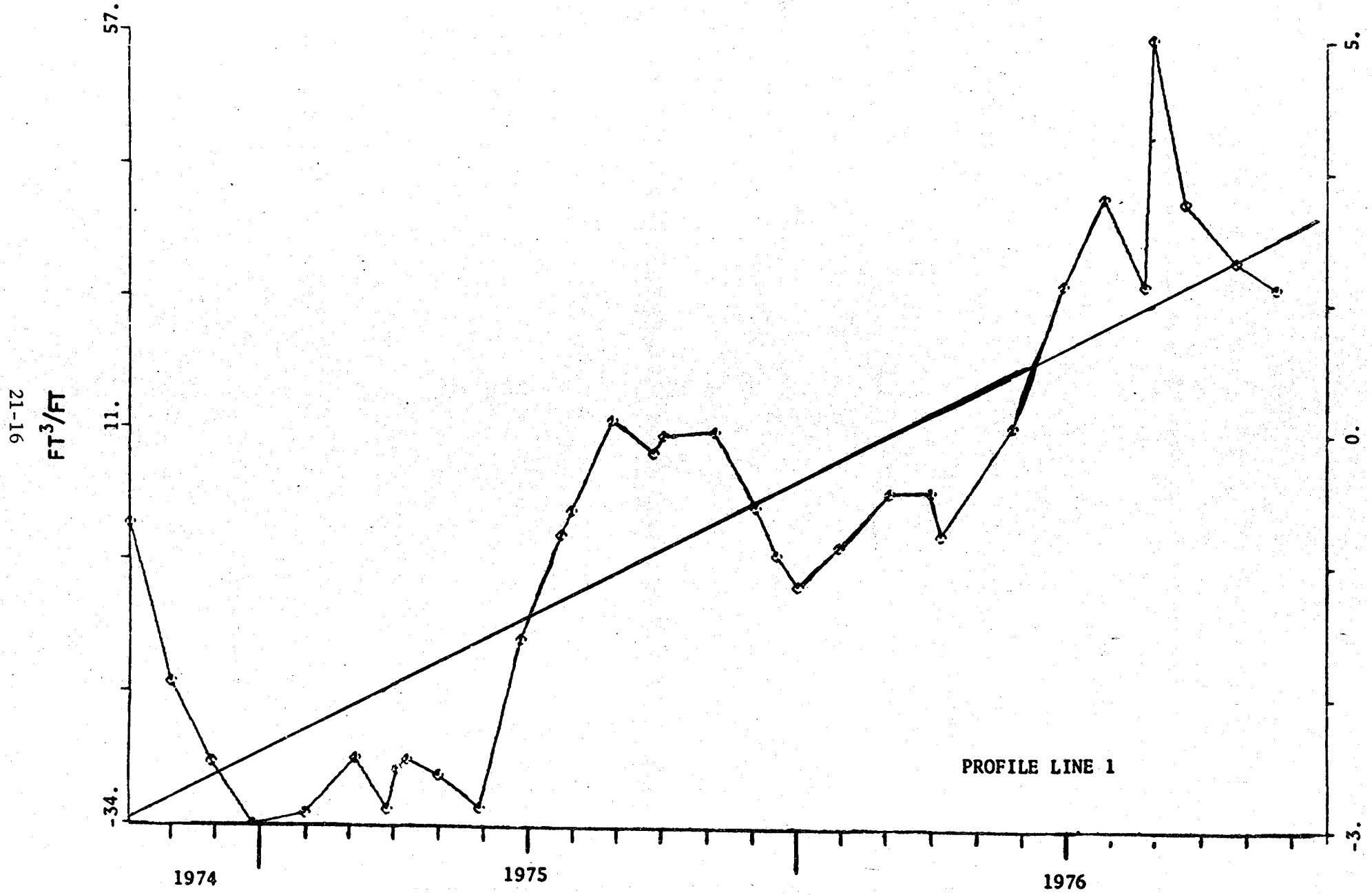


Figure 2. Cumulative beach area change at 9-month intervals, September 1974 to November 1976. Numbers 1, 9, and 18 indicate profile lines.

Figure 3.



beach nourishment. The total volume of the profile lines fluctuated considerably and is probably due, to some extent, to sand nourishment. However, it would seem accurate to assume that the area would be erosional, without beach nourishment. Profile line 5, updrift of Rudee Inlet, displayed a slight, but statistically nonsignificant accretional trend.

In the Dam Neck area, Profile line 6 appears to be erosional, while Profile lines 7 and 8 seem to be slightly accretional to no trend because of "very active" volume changes. Profile line 8 follows a fence which separates Dam Neck from Sandbridge and observations clearly indicate that the sand level has been rising next to the fence above the high tide line, while the beach face has remained the same or slightly eroded during the study.

In Sandbridge, Profile line 9 appears to have an erosional trend. This profile line has proved to be vulnerable to storms, and storm recovery has usually been slow. Profile line 10 has a slight accretional trend, with the exception of the major influence of the 25 November 1975 storm.

The Back Bay area (Profile lines 11 to 15) appears to be in an accretional state, except for Profile line 11 (Fig. 4) which appears to be erosional due mainly to the effects of the 25 November 1975 storm. Beginning with Profile line 12, and moving south, the beaches become wider and flatter, and from the survey data, tend to display "net" accretional trends (Figs. 5 and 6).

The entire False Cape area (Profile lines 16, 17 and 18) appears to be accretional (with Profile line 17 less accretional) (Fig. 7). An intertidal and subtidal area of stumps believed to be the remnants of a cypress forest, is located in the northern section of this area between Profile lines 15 and 16. Most of the time these stumps are nearly covered with sand, and are most often exposed only after storms. In general, the stumps were most exposed (since 1972) in November 1975, and gradually became covered during the following year. Although storm effects may be fairly severe, recovery is usually very fast, and the long-term trend is accretional.

In general, the trends readily apparent are:

- (a) Accretion at the north and south ends of the study area (Profile lines 1 and 2 and 12 to 18). Profile lines 1, 14, 16 and 18 have statistically very significant (99.0 percent) accretional trends.

Figure 4.

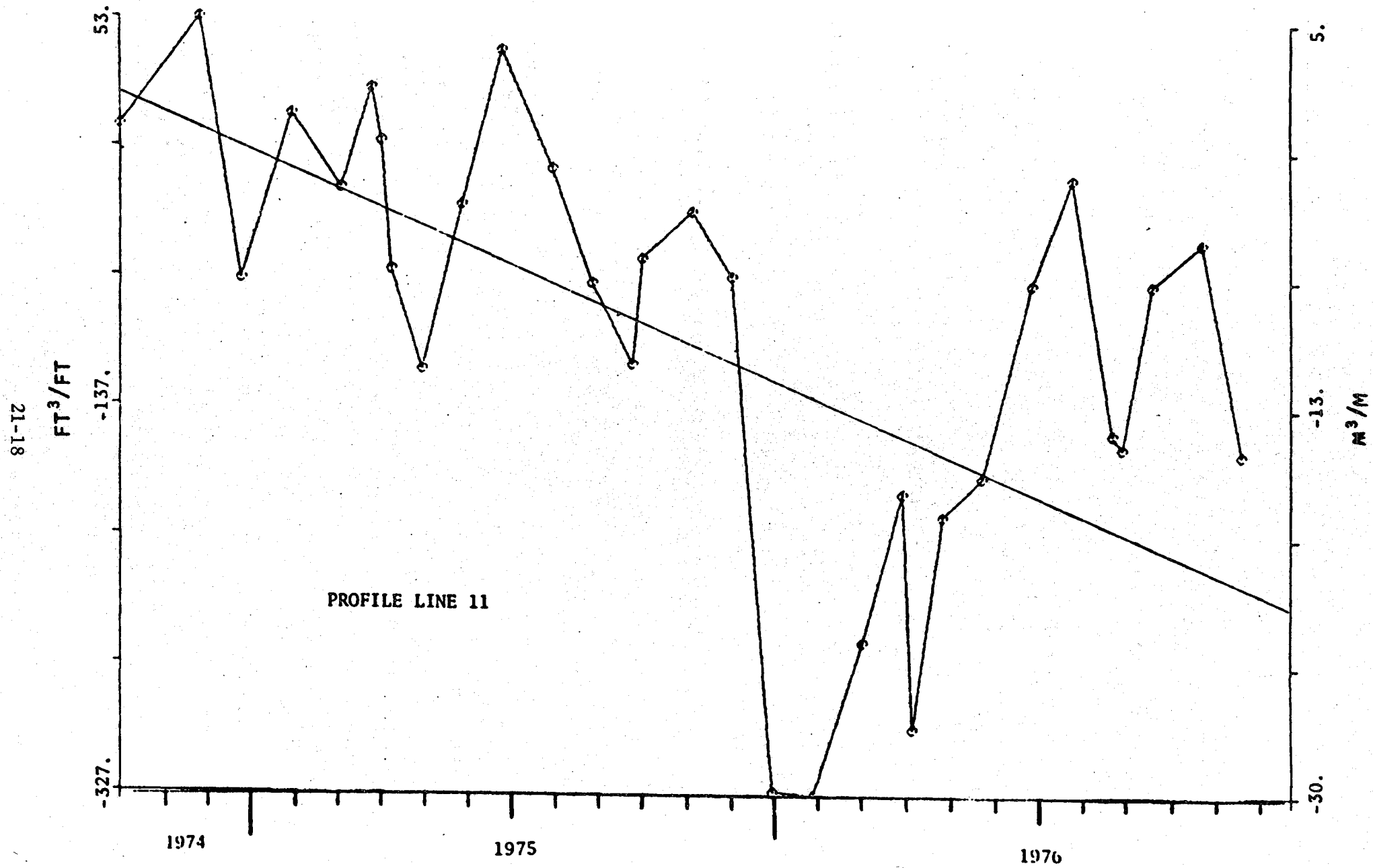


Figure 5.

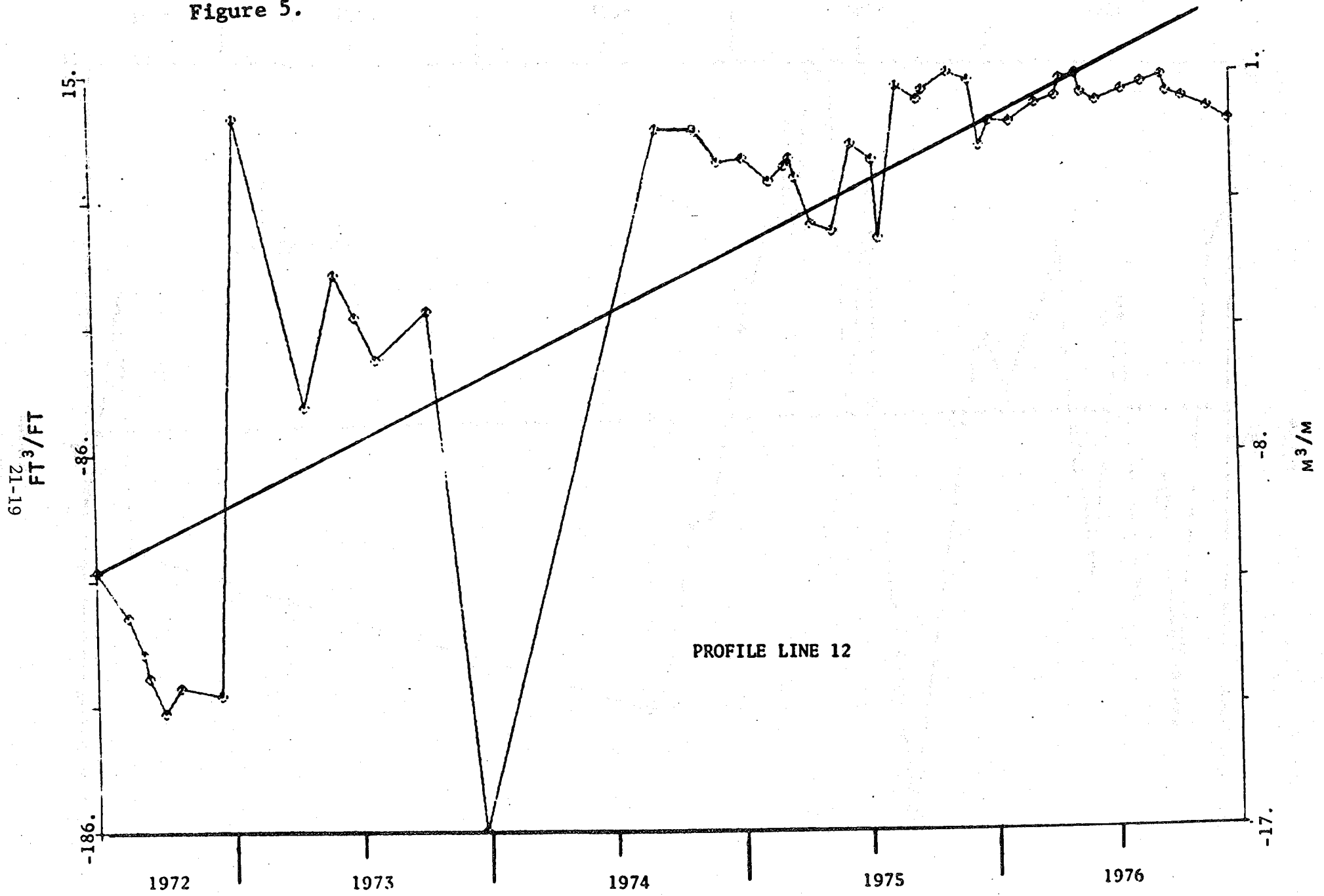


Figure 6.

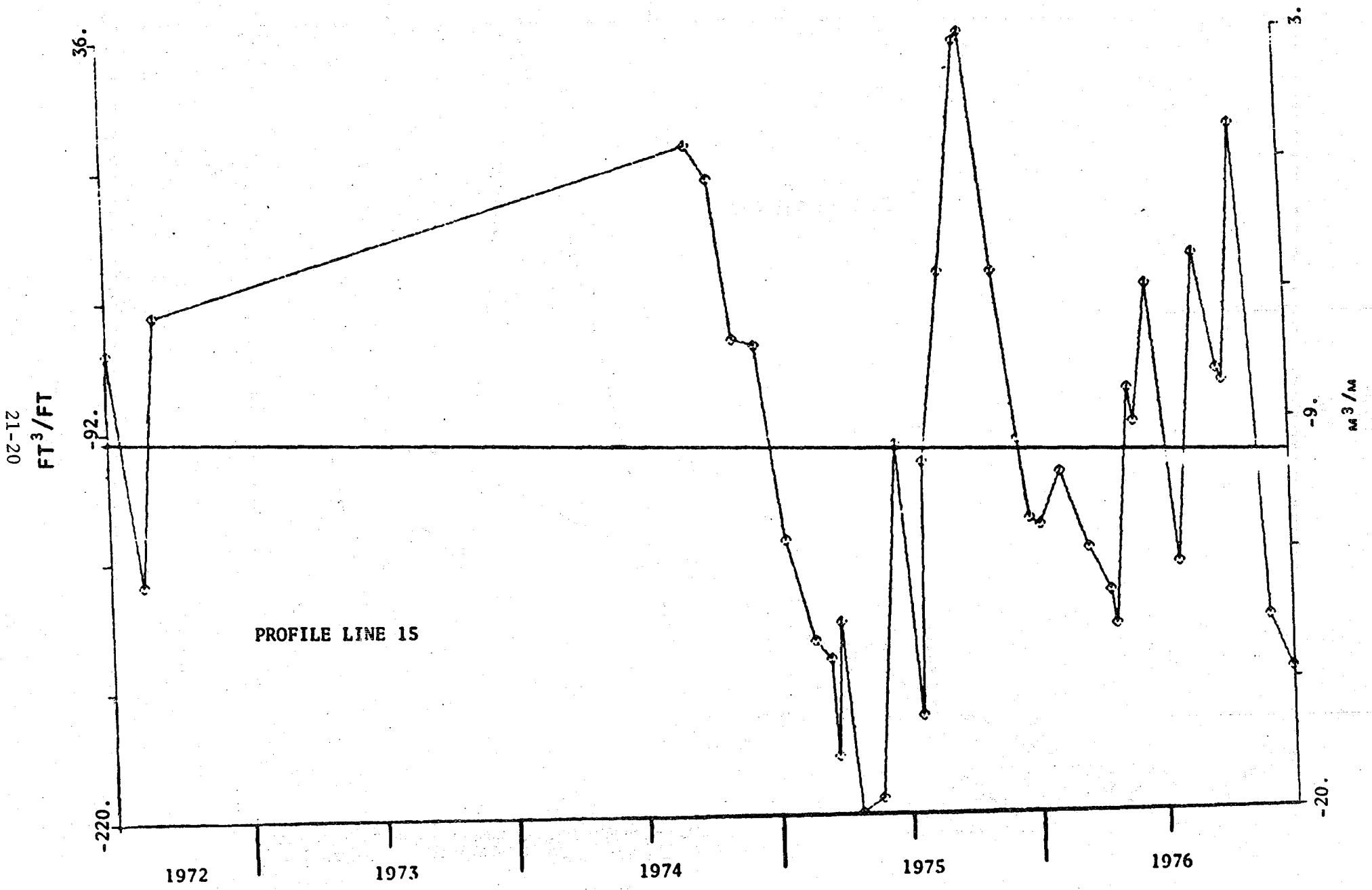
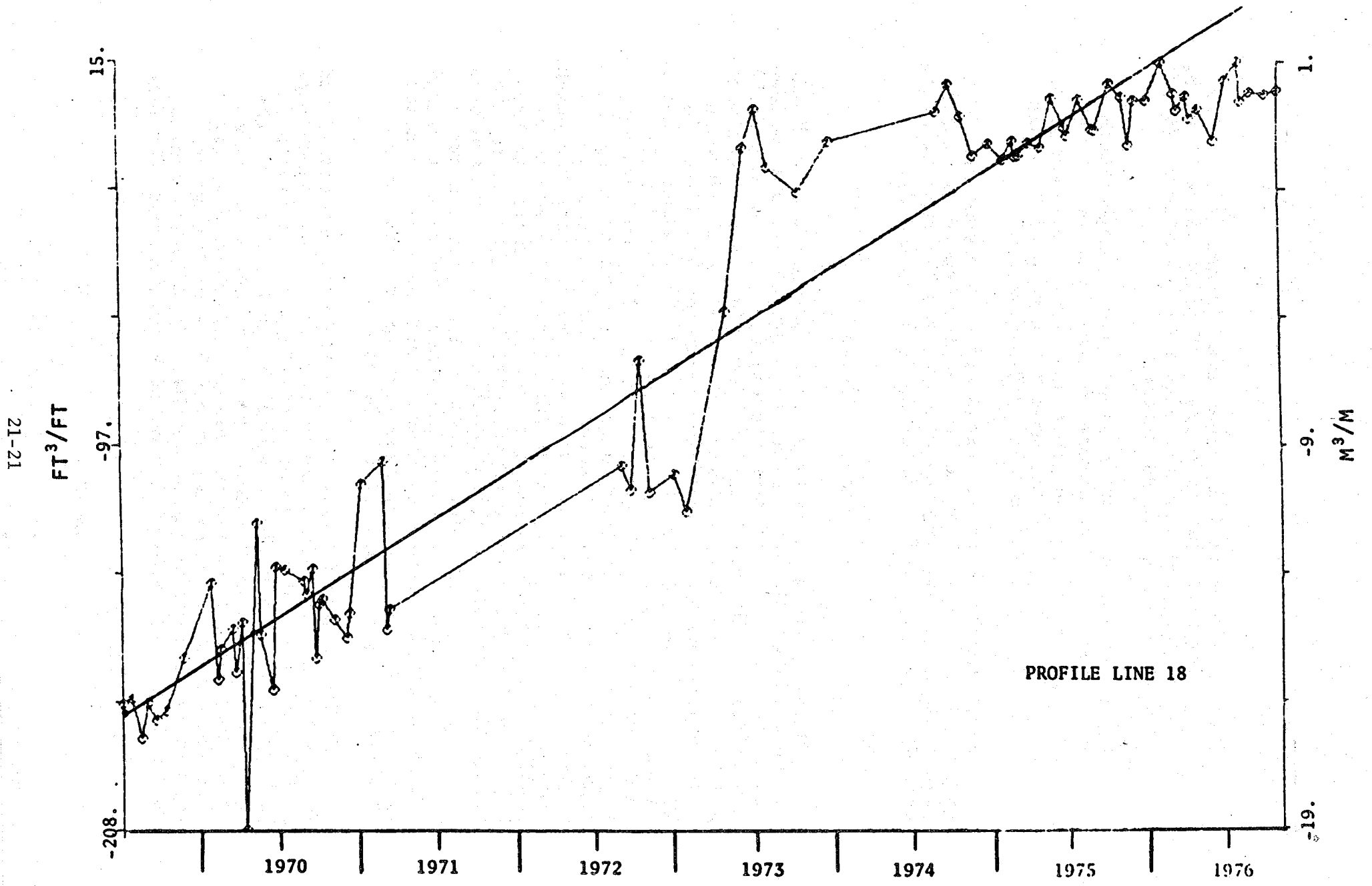


Figure 7.



- (b) Erosional profile lines are, in general, in the center of the study area. Profile lines 3, 6, 9, and 11 have statistically very significant (99.9 percent) erosional trends.
- (c) Most active profile lines (i.e., large fluctuations in beach volume changes) also tend to be at the north and south ends (Profile lines 2, 5, 7, and 17) and the most inactive profile lines (9 to 13) are in the center (Table 6).

Superimposed on these trends are many exceptions (e.g., accretion at Profile line 10 between two erosional profile lines) and extensive masking of the natural trends by man's activities (e.g., Profile lines 1, 3, 4, 5, and 8).

BEACH USAGE AND IMPACT

The study area encompasses four categories as defined by beach usage: Natural, military, commercial, and residential. Profile lines 1 (Fort Story), 6, 7, and 8 (Dam Neck) are military. The beach at Fort Story is probably the most disturbed (of the four profile lines) as far as vehicular traffic is concerned. Amphibious vehicles are driven in the waters just off the beach, followed by landing maneuvers on the beach itself. Military night maneuvers are also conducted at times with a number of men (the numbers vary) fully outfitted in military garb and gear, disturbing the fragile dunes by digging trenches, foxholes, etc. In addition, a road grader was used at times to keep the beach, from the base of the dune seaward, as flat and smooth as possible. All these events have occurred directly at Profile line 1. There is less vehicular beach traffic on the beaches at Dam Neck, although amphibious vehicles have been observed on occasion. The Marines conduct drill exercises on the lower beach, but avoid the dunes. There is a recognition of the importance of dunes at Dam Neck as indicated by an extensive and active sand fencing program and an effort to keep everyone out of the dunes.

Virginia Beach Profile lines 3 and 4 may be classified as commercial, Virginia Beach Profile line 2 and Sandbridge Profile lines 9 and 10 may be classified as residential. Both beach areas are closed to vehicular traffic, and the residential areas experience a moderate amount of usage from sunbathers, surfers, and fishermen, and the storage of light catamaran sailboats at the base of the dunes, especially during the summer months. Immediately behind the beach in the commercial area of Virginia Beach (Profile

Table 6. Average cumulative volume changes for four beach usage types.

<u>Beach type</u>	<u>Profile lines</u>	<u>Avg. cum. vol. change¹</u> <u>(m³/m)</u>	<u>Annual avg. cum. vol.</u> <u>change (m³/m)</u>
Military	1, 6, 7, 8	+ 6.5	+2.89
Residential	2, 9, 10	+ 2.1	+0.93
Commercial	3, 4, 5	+10.6	+4.71
Natural	11-18	- 6.6	-2.93

¹Over the 27-month survey period.

Table 7. Average cumulative volume changes by reach.

<u>Beach type</u>	<u>Profile lines</u>	<u>Reach</u>	<u>Avg. cum. vol. change¹</u> <u>(m³/m)</u>	<u>Annual avg. cum. vol.</u> <u>change (m³/m)</u>
Residential	1, 2	Virginia Beach	+23.7	+10.5
Commercial	3, 4	Virginia Beach	+15.8	+ 7.0
Military	5, 6, 7, 8	Dam Neck	0.0	0.0
Residential	9, 10	Sandbridge	- 6.5	- 2.9
Natural	11, 12, 13, 14, 15	Back Bay	-13.6	- 6.0
Natural	16, 17, 18	False Cape	+ 9.6	+ 4.3

¹Over the 27-month survey period.

lines 3 and 4) is a concrete boardwalk which contains a vertical bulkhead, protecting the city's multistory hotels, condominiums, and restaurants from the ocean waves. Although the beach is only used by sun-worshippers during the summer months, the effects of the bulkheaded boardwalk are felt all year long. Because of the observed reflection of waves off the concrete wall during storm conditions, which are due to the absence of adequate amounts of sand, the natural beach processes (i.e., poststorm recovery) are unable to proceed. Thus, the beaches, if left alone, would erode down to the Sandbridge Formation. It is for this reason that a beach nourishment program of dumping sand from Thimble Shoals (in Chesapeake Bay entrance) and pumping sand to the beaches to the north directly from the south side of Rudee Inlet, which traps the dominant northerly transport (see Fig. 1), had to be devised.

Back Bay Profile lines 11 to 15 and False Cape lines 16, 17, and 18 are designated as Natural areas. Thus, the study area is divided into four categories by beach usage: Natural, residential, commercial (resort), and military. It would seem that this large variability in beach usage would be reflected to some extent in beach behavior. However, as shown in Table 6, the average cumulative volume changes for the four beach types show almost no differences. Table 7 represents average cumulative volume changes by reach.

It does seem apparent from the accretional value for the commercial area of Virginia Beach that the sand nourishment program is both necessary and successful. As for the erosional value for the natural area, it must be remembered that many profile sites in this location are erosional, due in part to the high wave energy concentration in this area (Goldsmith, et al., 1974b). The fact that these differences in beach response for the four usage types are not significant, given the large dichotomy, is in itself significant. It appears that the natural processes dominate over-usage effects, as shown by the volume change averages, which in turn correlate closely with the variations in beach morphology, both of which transcend the usage types. It appears that the Virginia Beach commercial area would be far more erosional without the extensive sand nourishment and that this beach fill is necessary for the long-term stability of the Virginia Beach commercial beaches.

PROFILE SHAPES

Beaches have been found to be ever-changing in response to the dynamic processes. As would be expected, the beaches in the study have changed during the interim from September 1974 to November 1976. However, despite these repeated changes, certain shapes are prevalent.

Generally, beaches at Profile lines 1 and 14 to 18 are wide and flat; Profile lines 2 to 13 are narrow and steep with a well-defined convex-upward profile shape. Whereas, Profile lines 2 to 8 and 14 to 17 tend to be active, Profile lines 9 to 13 tend to be inactive. These characteristics were maintained throughout the course of the study; however, individual profile lines have changed somewhat in shape. These two general types of shapes are exemplified in comparisons of Profile lines 1 and 9 (Figs. 8 and 9).

SUMMARY

The extensive data from this study may be succinctly summarized as follows:

a. The shore in this area is characterized by two reaches of net accretion, separated by one reach of net erosion. Cape Henry (Profile line 1) at the north end and False Cape State Park (Profile lines 15 and 18) at the south end are accreting at an average rate of 4.9 cubic meters per meter per year while the reach from Dam Neck to Back Bay (Profile lines 8 to 15) is eroding at an average rate of -4.7 cubic meters per meter per year (Fig. 2).

b. Most profile lines underwent large monthly volume changes relative to total net volume changes. Statistically significant (at 99 percent level) 27-month accretional trends are delineated at Profile lines 1, 14, 16 and 18, and statistically significant erosional trends are delineated at Profile lines 3, 6, 9, and 11.

c. When combined with older survey data at 14 of the same 18 locations, the same erosion and accretion trends are apparent at most locations for the past 8 years, which encompasses a time of greater storm-induced erosion (1972-1974) than the 1974-1976 VIMS-CERC study.

d. The erosion and accretion measured at these locations correlate well with the observed beach morphology, with wide, low-gradient, active beaches at the ends of the study area, and narrow, steep, relatively inactive beaches in the middle.

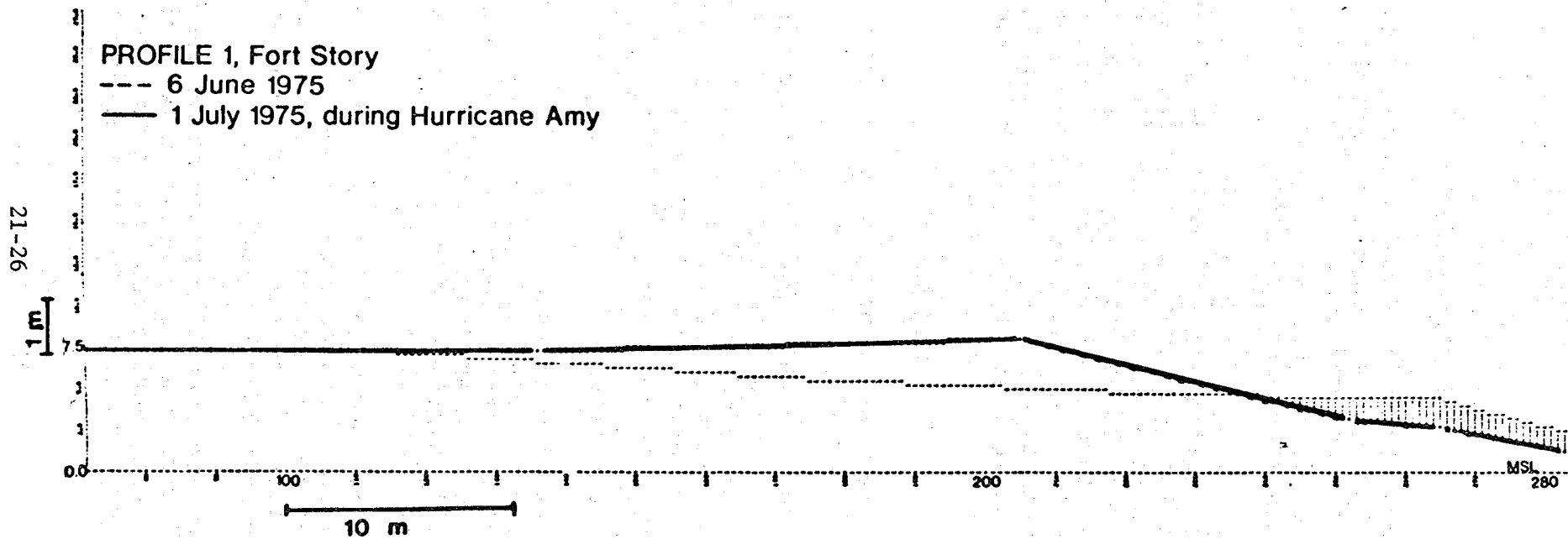


Figure 8. Plot of typical profile at wide, accretional beach illustrating both accretional (6 June 1975) and erosional (1 July 1975) shapes. In comparing with Figure 22, note that the most landward 70 horizontal feet (21.3 meters) of beach are not included here, and the scales are different.

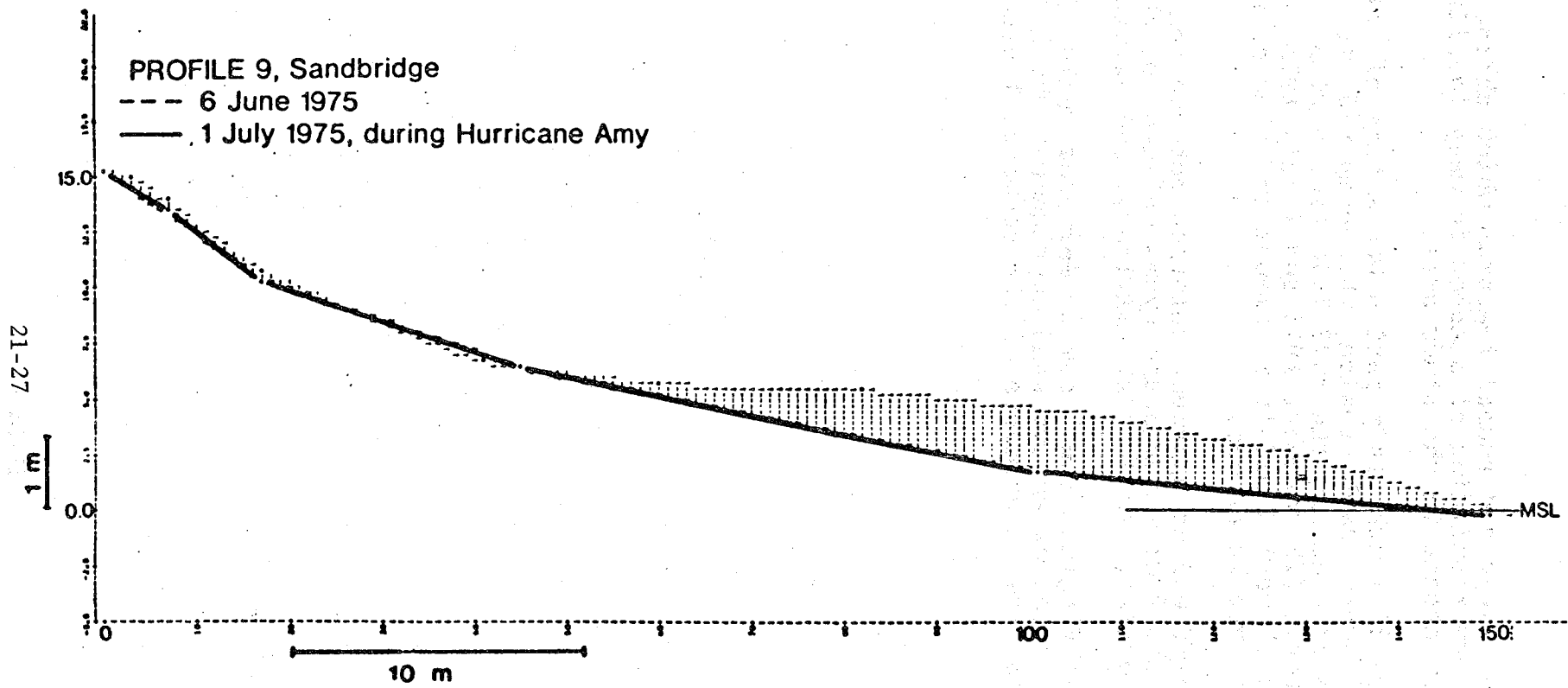


Figure 9. Plot of typical profile line at narrow beach illustrating both accretional (6 June 1975) and erosional (1 July 1975) shapes. Compare with changes at Profile line 1 during the same time interval.

e. The ridge and runnel features which characterize the post-storm rebuilding of beaches in many localities were totally absent in the study area.

f. The 27-month study period was a time of relatively low storm-induced beach erosion, when compared with beach surveys measured during the 1972-1974 time period. Two moderate storms (25 November 1975 and 1 July 1975) caused erosion, which varied widely in amount and time of recovery among the survey locations.

g. There was no apparent relation between beach response and the four major usage types defined for this area: Commercial, residential, military, and natural.

h. The Virginia Beach commercial area would be erosional without the extensive sand nourishment which is necessary for the maintenance of the commercial beaches.

REFERENCES

- Bullock, P.A., 1971. The Feasibility of Developing Forecast Systems to Predict Changes in Beach Sand Volume on Ocean Beaches During Storms, Masters Thesis, Virginia Institute of Marine Science, Gloucester Point, Va.
- Fausak, L.E., 1970. The Beach Water Table as a Response Variable on the Beach-Ocean-Atmosphere System, Masters Thesis, Virginia Institute of Marine Science, Gloucester Point, Va.
- Fine, H.J., 1972. Personal communication, Chief Water Resources Planning Branch, U.S. Army Engineer District, Norfolk, Va.
- Goldsmith, V., Farrell, S., and Goldsmith, Y.E., 1974a. Shoreface Morphology Study of the South End of Long Beach Island, Little Beach Island, and the North End of Brigantine Island, New Jersey, Annual Report (28 May 1974 to 29 May 1974), Coastal Dynamics, Inc., Gloucester Point, Va.
- Goldsmith, V., Morris, W.D., Byrne, R.J., and Whitlock, C.H., 1974b. Wave Climate Model of the Mid-Atlantic Continental Shelf and Shoreline: I-Model Description, Shelf Geomorphology, and Preliminary Data Analysis, SRAMSOE No. 38, Virginia Institute of Marine Science, Gloucester Point, Va.
- Goldsmith, V., Smith, F., and Sutton, C.H., 1974. Unpublished Data Stored at Virginia Institute of Marine Science, Gloucester Point, Va.
- Goldsmith, V., Sturm, S., Thomas, G., 1977. Variations in Beach Erosion and Accretion Trends at Virginia Beach, Virginia, and Vicinity: Final Report CERC Contract DACW-72-C-0008 and CERC Tech. Memo No. ___ (in press), C.E.R.C., U.S. Army Corps of Engs., Ft. Belvoir, Virginia; VIMS SRAMSOE No. 122.
- Harrison, W., Rayfield, E., Boon, J., Reynolds, G., Grant, J., and Tyler, D., 1968. A Time Series From the Beach Environment, Technical Memorandum AOL-1, Environmental Science Services Administration Research Laboratories, Miami, Fla.

Harrison, W., Boon, J., Fang, C.S., Fausak, L., and Wang, S., 1971. Investigation of the Water Table in a Tidal Beach, ONR Final Report, Special Scientific Report No. 60, Virginia Institute of Marine Science, Gloucester Point, Va.

Harrison, W., and Bullock, P.A., 1972. Changes in Sand Volume of Virginia's Ocean Beaches, Abstract, American Society of Civil Engineers, N.Y. and Proceedings of the 13th International Conference on Coastal Engineering, Vancouver, B.C., pp. 261-264.

Harrison, W., and Wagner, K.A., 1964. Beach Changes at Virginia Beach, Virginia, Miscellaneous Paper 6-64, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Washington, D.C., Nov.

Shideler, G.L., Swift, D., and McHone, J., 1971. Unpublished Data Stored at Virginia Institute of Marine Science, Gloucester Point, Va.

Watts, G.M., 1959. Behavior of Beach Fill at Virginia Beach, Virginia, TM-113, U.S. Army, Corps of Engineers, Beach Erosion Board, Washington, D.C., June.

U.S. Army, Coastal Engineer Research Center, 1973. Shore Portection Manuel, Vol. I, U.S. Government Printing Office.

TEMPORAL OCCURRENCE OF BEACH EROSION AND
ACCRETION IN SOUTHEAST VIRGINIA BEACHES

Adam A. Frisch

INTRODUCTION

Beaches are the most dynamic system in the nearshore environment with rapid fluctuations in shape, size, and resulting total sediment volumes. These fluctuations follow a particular temporal periodicity in most places. This periodicity is usually called seasonality (Shepard, 1950). Shepard calls an erosional beach, a winter beach, and an accretional beach, a summer beach because, in California, the damaging waves are in the winter and the "accretional" waves in the summer (Fig. 1). Both the yearly beach cycles and long-term cycles (i.e., multi-year) coincide with local climatic conditions.

However, Shepard's winter-summer concept of erosion and accretion may not be directly applicable to Southeast Virginia. Galvin and Hayes (1969) state:

Development of winter profiles on beaches of the U.S. Atlantic coast north of Delaware Bay, and on beaches of the California coast, differs in a way that appears to depend on mean wave climates, and seasonal changes in wave climates, of the two regions. Eroded winter profiles, typical of California, are less well developed and sometimes absent on northern Atlantic beaches.

Also, Sonu (1966) found "profiles resembling the accepted summer and winter type barely several hundred feet apart on the same section of beach", at Cape Hatteras, North Carolina. As can be seen in Figure 1 from the Shore Protection Manual (CERC, 1973), the seasonal (winter-summer) differential in

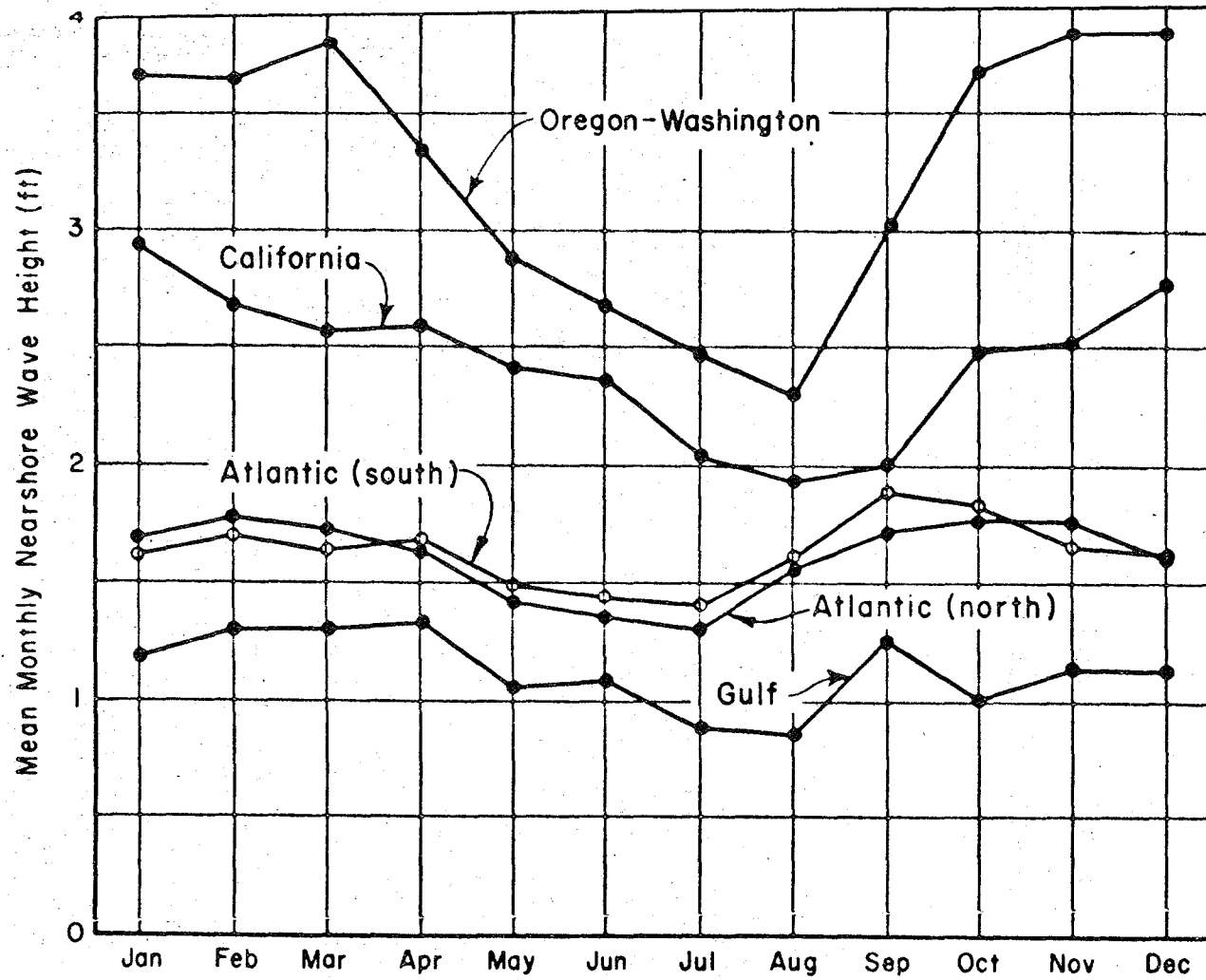


Figure 1 Mean Monthly Nearshore Wave Heights for Five Coastal Segments
(from C.E.R.C., 1973)

mean monthly wave heights are much greater for the west coast of the United States than for the east coast.

BEACH PROFILE DATA AND METHODOLOGY

The short-term data used in this study was collected in the September 1974 through December 1976 period by Goldsmith, et al. (1977) at VIMS under contract with the Coastal Engineering Research Center. Goldsmith also compiled older beach profile data from 14 of the same 18 beach profile locations, back to the fall of 1969. The methods of data collection are described fully in Goldsmith, et al. (1977). The data of beach changes was computed in the form of cumulative changes in beach profile sediment volumes, with zero set as the volume of the initial profile survey.¹

Figure 2 is the cross section of a typical measured beach profile. The changing profile volumes were calculated from the surveys and then plotted as a function of time. Figures 3-6 are representative curves at four profile locations, with Figures 3 and 4 being short-term (i.e., 1974-1976), and 5 and 6 being long-term (i.e., 1969-1976). As can be seen on these plots, there are no times with zero volume change, though some are close. The profiles are either increasing in volume or decreasing in volume. A time of erosion is defined as the time interval when the profile volume curve has a negative slope, and accretion as the time when the curve has a positive slope. This time is dependent on the frequency of profile surveys, which was monthly, and after storms.

Figures 7 and 8, compiled from Figures 3-6 and similar data for all 18 profiles, show the times of erosion and accretion throughout the profile history at each of these 18 profile locations. These bar graphs were then divided into calendar seasons, and the percent of the total time per season that a profile was erosional was calculated. The complement of this number is the percent of the total time per season each profile was accretional. These calculations are tabulated in Tables 1 and 2.

¹Beach profile volume is the amount of sand within the space one meter wide under the profile line from the landward survey pipe in the foredune or equivalent, to mean sea level (MSL). The lower volume boundary is at MSL, and extends landward to the point directly below the pipe.

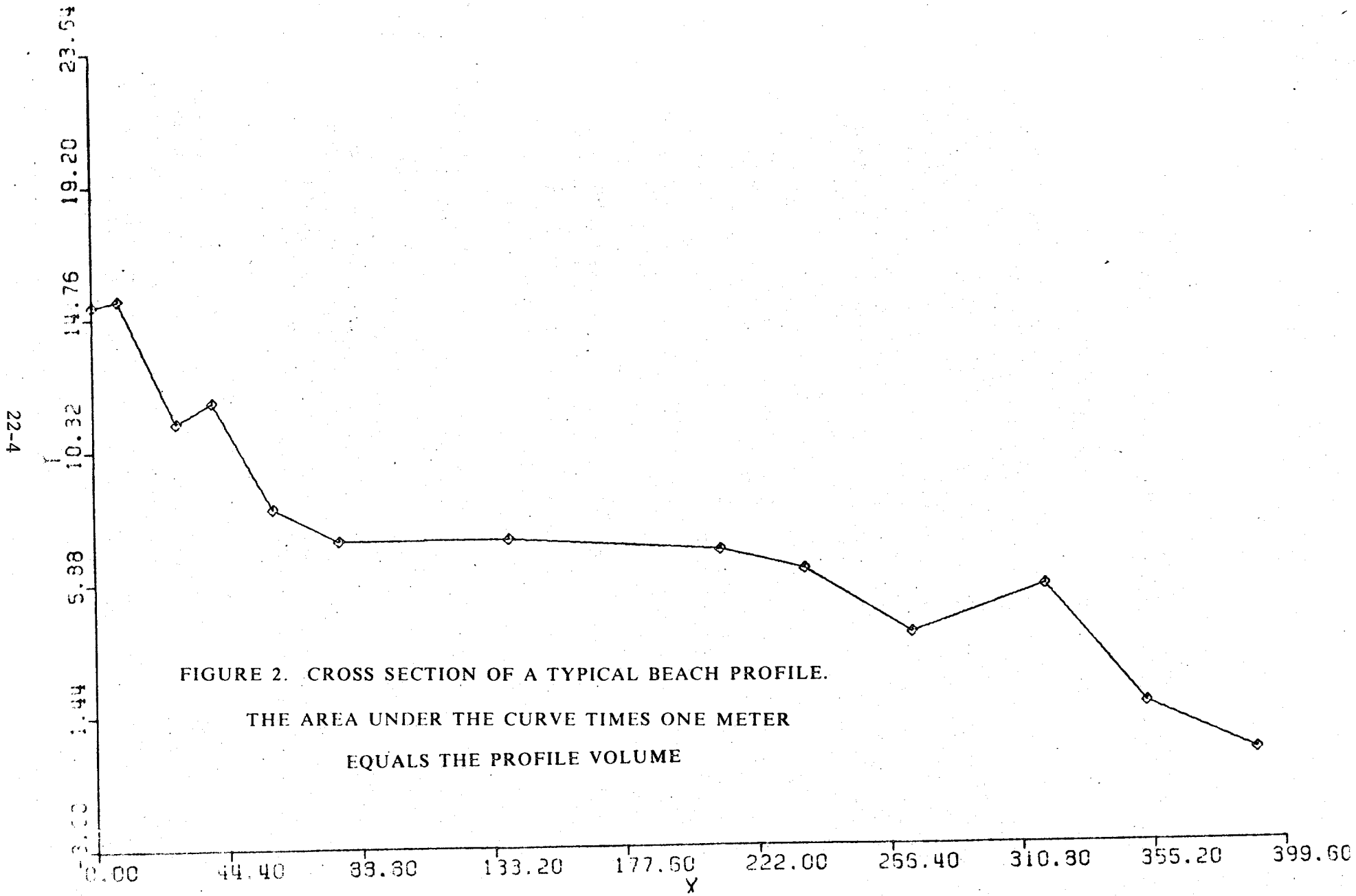


FIGURE 2. CROSS SECTION OF A TYPICAL BEACH PROFILE.

THE AREA UNDER THE CURVE TIMES ONE METER
EQUALS THE PROFILE VOLUME

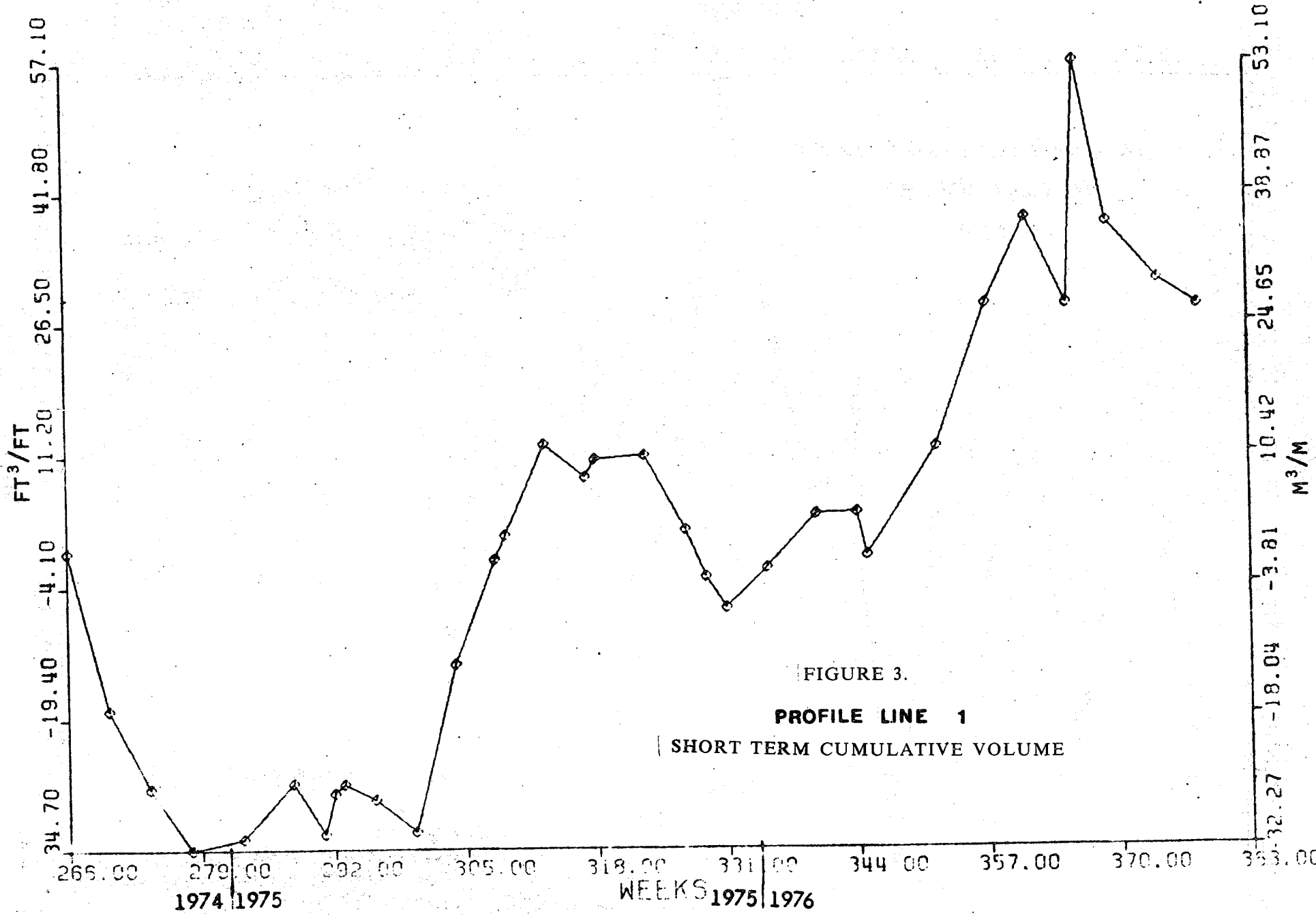


FIGURE 3.

PROFILE LINE 1

SHORT TERM CUMULATIVE VOLUME

22-6

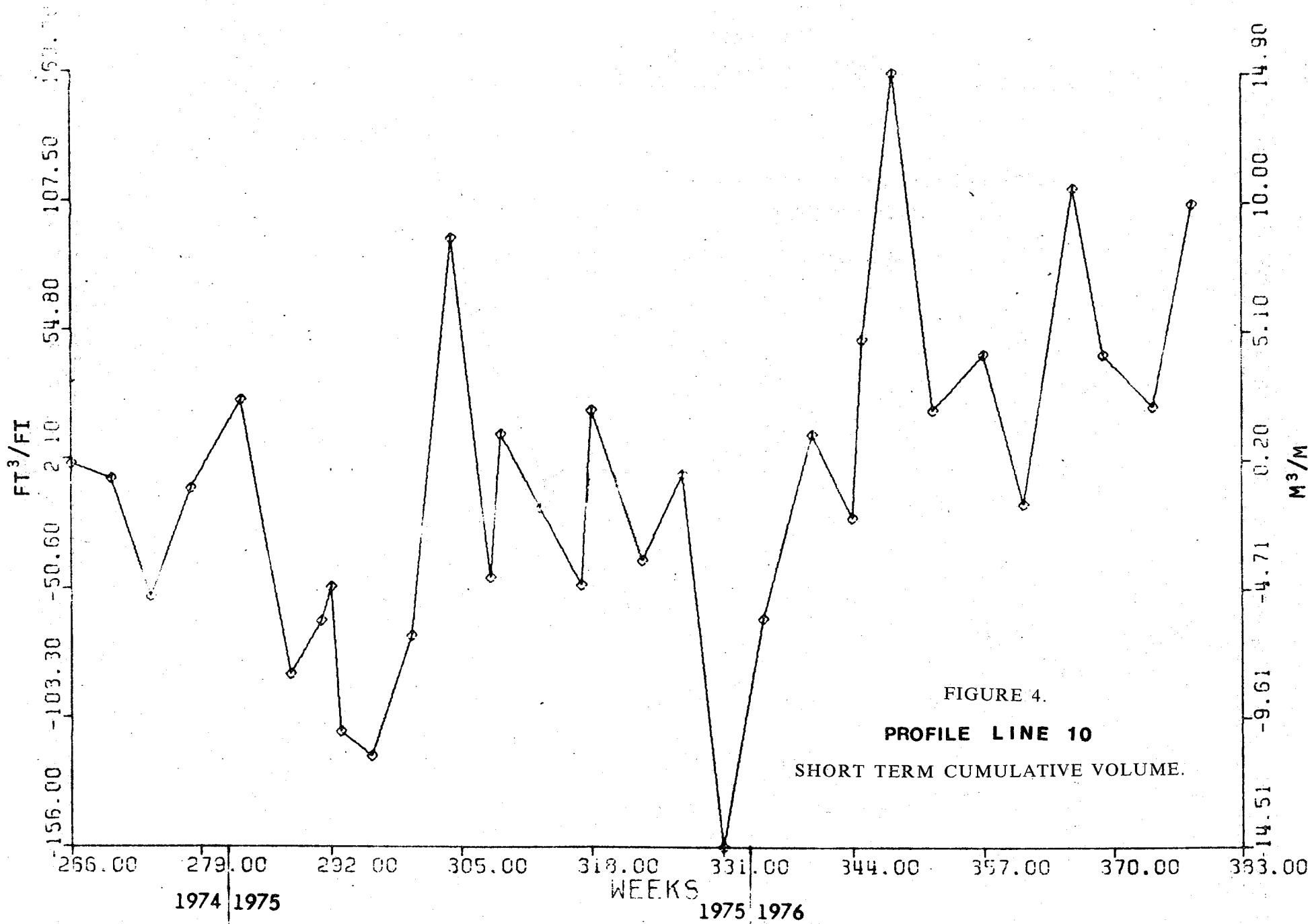


FIGURE 4.
PROFILE LINE 10
SHORT TERM CUMULATIVE VOLUME.

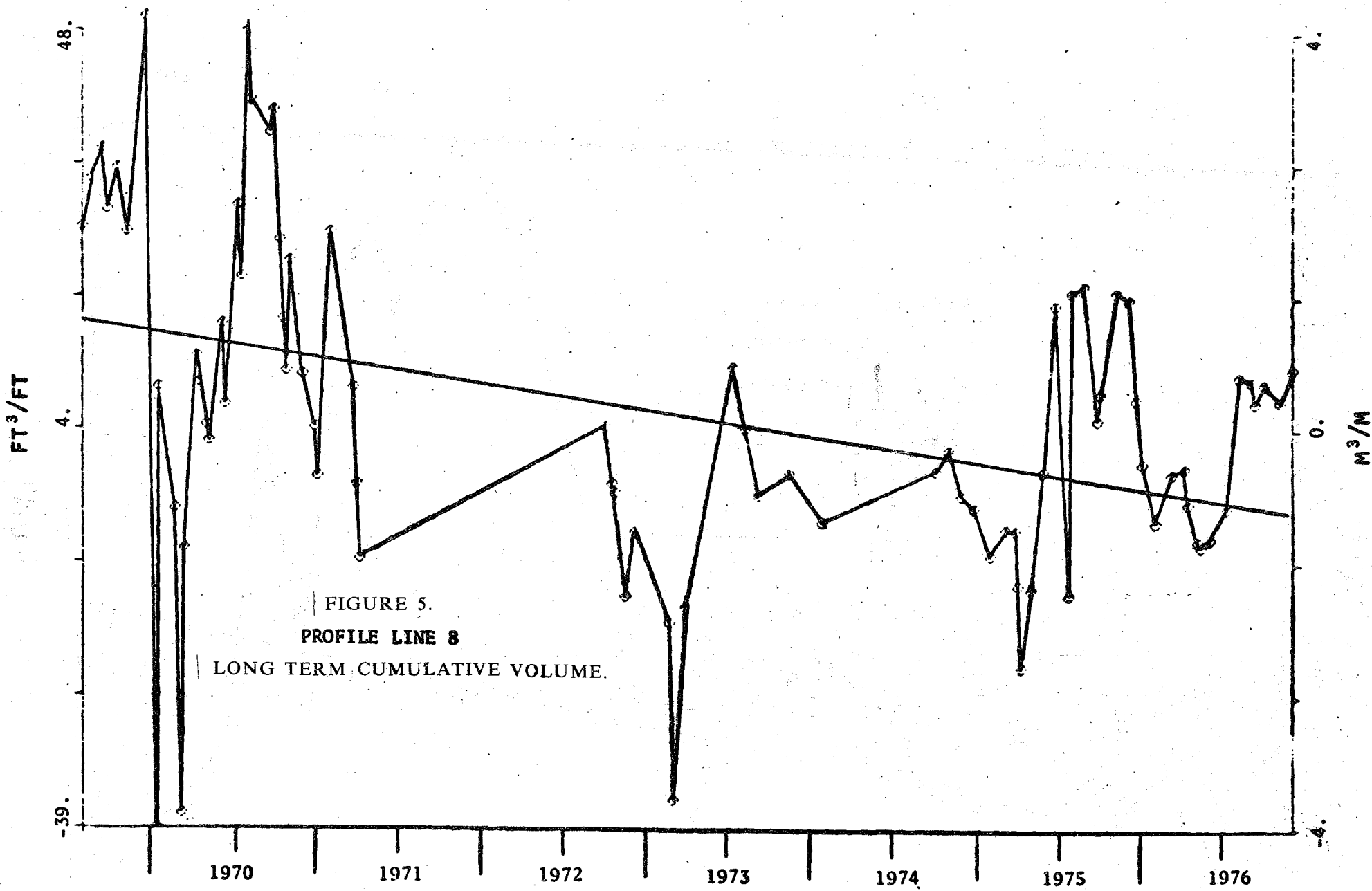


FIGURE 5.
PROFILE LINE 8
LONG TERM CUMULATIVE VOLUME.

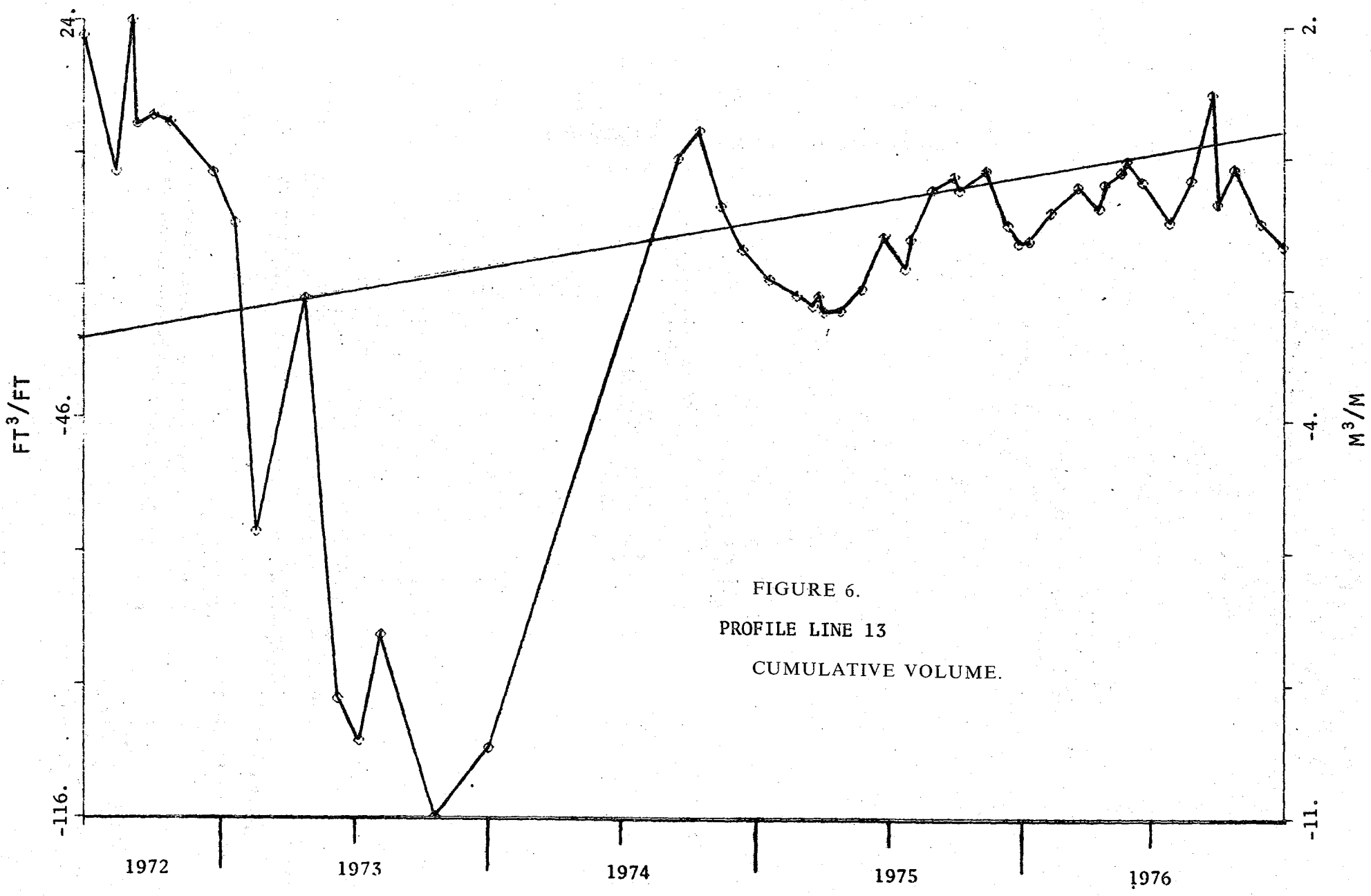


FIGURE 6.
PROFILE LINE 13
CUMULATIVE VOLUME.

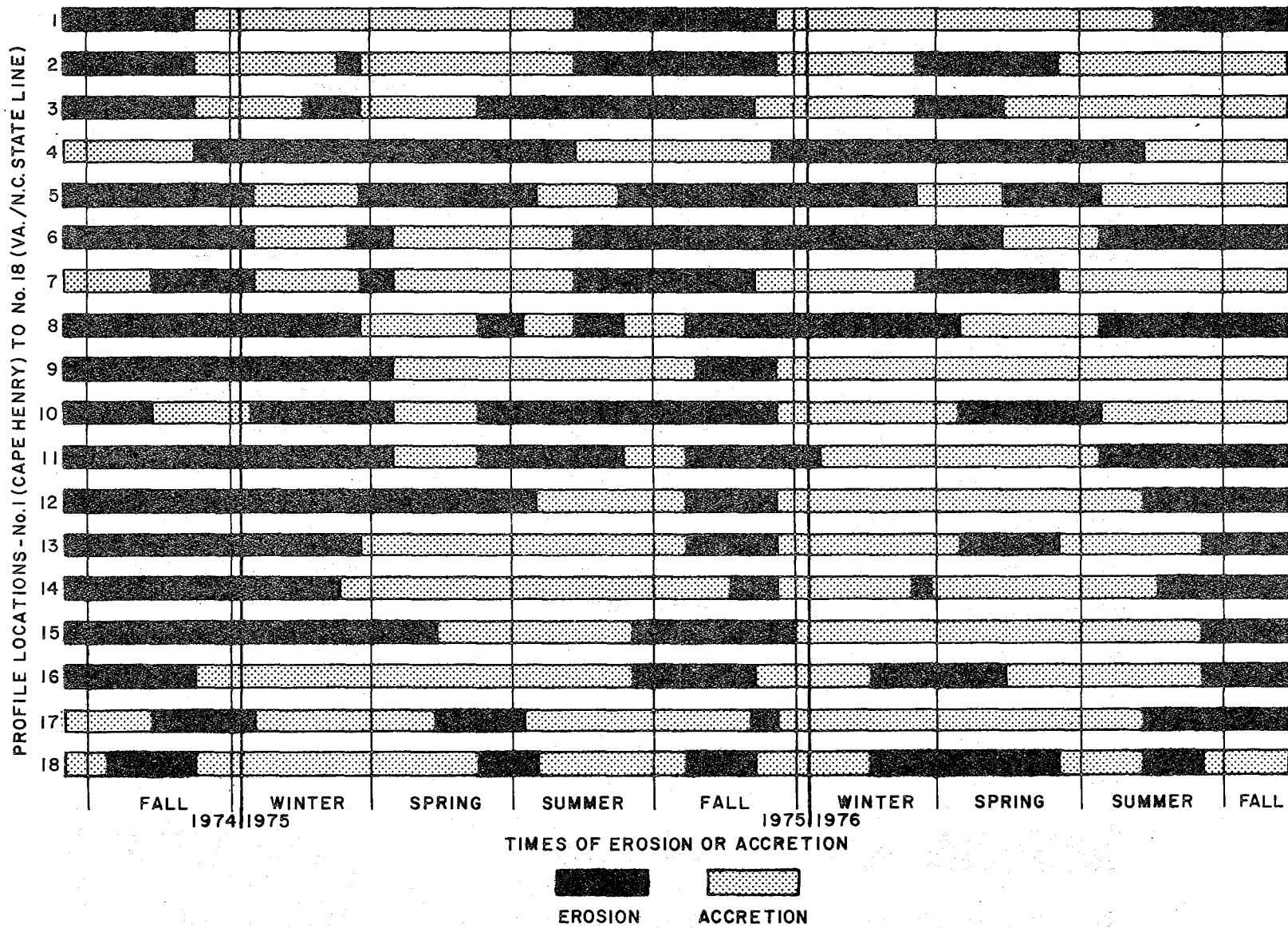


FIGURE 7

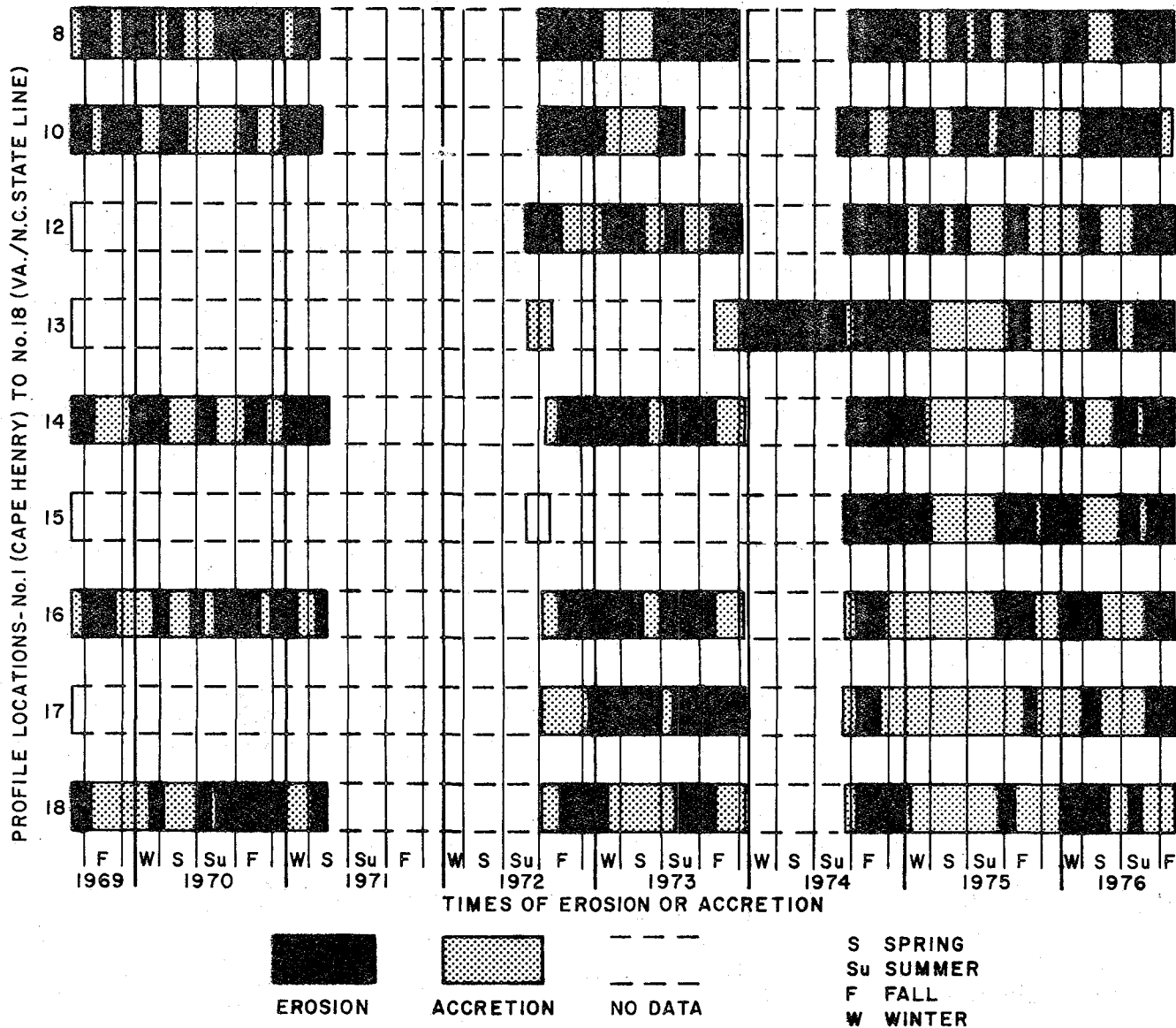


FIGURE 8

Table 1. Percent time of erosion by season and profile, Southeast Virginia.
1969 - 1976

Profile location no.	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall*	Total 1974-1976
1	77	0	0	52	82	0	0	50	100	40
2	77	15	0	52	82	15	82	0	0	36
3	77	42	21	100	68	15	45	0	0	41
4	23	100	100	45	17	100	100	50	0	59
5	100	15	100	37	100	85	53	17	0	56
6	100	20	15	50	100	100	45	85	100	68
7	50	15	15	50	67	15	83	0	0	33
8	100	95	22	35	73	100	15	85	100	69
9	100	100	15	0	50	0	85	0	0	39
10	48	95	37	92	84	0	0	18	0	42
11	100	100	37	83	78	8	0	83	100	65
12	100	100	100	20	54	0	0	51	100	58
13	100	95	0	0	54	0	56	13	100	48
14	100	73	0	0	28	13	0	50	100	40
15	100	100	45	15	100	6	0	13	100	53
16	77	0	0	15	69	45	47	13	100	41
17	54	7	52	7	17	0	0	54	100	32
18	60	0	22	18	43	46	87	42	0	35
Average Erosion (%)	80	54	32	37	65	30	39	35	56	47
Standard Deviation (%)	24	43	35	31	26	39	38	30	51	

* Fall- September to November

Table 2. Percent time of erosion by season and profile, Southeast Virginia.

1969 - 1976

Profile location no.	1970				1971				1972				1973				1974				1975				1976				Total % 1969-1976	
	F	W	S	Su	F	W	S	Su	F	W	S	Su	F	W	S	Su	F	W	S	Su	F	W	S	Su	F	W	S	Su		
8	74	95	33	39	100	33	35	*	*	*	*	*	100	42	10	100	100	*	*	*	100	95	22	35	73	100	15	85	100	66
10	76	52	68	0	25	80	39	*	*	*	*	*	100	66	0	62	*	*	*	*	48	95	37	92	84	0	0	18	0	47
12	*	*	*	*	*	*	*	*	*	*	*	30	51	39	55	40	68	*	*	*	100	100	100	20	54	0	0	51	100	54
13	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	0		91	100	85	100	95	0	0	54	0	66	13	100	50
14	27	75	20	51	52	70	48	*	*	*	*	*	62	100	61	88	41	*	*	*	100	73	0	0	28	13	0	30	100	50
15	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*	*	100	100	45	15	100	6	0	13	100	48
16	87	13	26	61	91	74	26	*	*	*	*	*	65	100	51	100	40	*	*	*	77	0	0	15	69	45	47	13	100	52
17	*	*	*	*	*	*	*	*	*	*	*	*	0	88	99	72	100	*	*	*	54	7	52	7	17	0	0	54	100	46
18	13	20	10	89	100	30	34	*	*	*	*	*	45	73	0	66	32	*	*	*	60	0	22	18	43	46	87	42	0	40
Average Erosion (%)	55	51	31	48	74	57	36	*	*	*	*	10	60	73	39	75	54	Δ	Δ	Δ	82	63	31	22	58	23	24	38	78	50
Standard Deviation (%)	33	35	22	33	34	24	8	*	*	*	*	17	34	25	37	22	37	Δ	Δ	Δ	23	46	33	28	27	34	34	26	44	

* No data
 Δ Basic assumptions have not been met
 S Spring
 Su Summer
 F Fall
 W Winter

22-12

SHORT TERM DATA (1974-1976)

When studying the graphs in Figures 7 and 8 the fall appears to be dominantly erosional over the entire 18 profiles for the first two falls surveyed (1974, 1975). The data for the fall of 1976 is incomplete, but the fall is still the most erosional season of 1976. The average time of erosion in each season for the combined 18 profile locations (in percent) and the associated standard deviations are also presented in Table 1. The variability of the fall erosion amongst the 18 profiles, is very low, as shown in the fall standard deviations. The high standard deviation for the fall of 1976 is due to incomplete data for that season. The recovery from fall erosion (i.e., accretion) takes the rest of the year in some profiles, but in others the trend is more towards a quick recovery at first and then a continued slow build up until the next erosional period. The variability of the winter, spring, and summer data, as shown by their high standard deviations, indicate an insignificant difference, in their percent time of erosion. However, the average times of erosion of the 1974 and 1975 fall seasons are significantly different to a confidence limit of 80%.

LONG TERM DATA (1969-1976)

The long term data generally substantiates the trend of fall erosion followed by recovery through the rest of the year. The standard errors of the data are higher as a result of the incomplete long term data, but in five of the seven years (1970, 1972, 1974, 1975, and 1976) the largest percent time of erosion is in the fall. In 1971 and 1973, the largest percent time of erosion is in the winter. This may be caused by a delay of the storm season.

The long term erosion-accretion, as tabulated here, could be a sensitive test for an extremely subtle climatic cycle relating to storm frequency and intensity, but undisclosed in normal climatological data.

CONCLUSIONS

There is a seasonal cycle of beach changes in Southeast Virginia which is dominated by erosion in the fall (September through December). This is followed by general accretion, of widely varying amount and spatial distribution, throughout

the rest of the year. The percent time of erosion for the falls of 1969, 1970, and 1972 through 1976 are 55%, 74%, 60%, 54%, 82%, 58%, and 78%, respectively. The spring is the most accretional period, with an average of 76% of the springtime being accretional. The fall erosional trend is very consistent from Cape Henry to the Virginia-North Carolina State line, but the time of accretion varies between profile locations.

REFERENCES

Coastal Engineering Research Center, 1973, Shore Protection Manual, U.S. Government Printing Office, Vol. 1, p. 4-31.

Galvin, S.J., and Hayes, M O., 1969, Winter Beach Profiles and Wave Climate: G.S.A. Abstracts with Programs for 1969, Part 7, p. 74.

Goldsmith, V., Sturm S., and Thomas, G., 1977, Variations in Beach Erosion and Accretion Trends at Virginia Beach, Virginia, and Vicinity: Final Report CERC Contract DACW-72-C-0008 and CERC Tech. Memo No. 122 (in press), C.E.R.C., U.S. Army Corps of Engs., Ft. Belvoir, Virginia: VIMS SRAMSOE No. 122.

Shepard, F.P., 1950, Beach Cycles in Southern California: Beach Erosion Board, U.S. Army Corps of Engineers, Tech. Memo No. 20, 26 p.

Sonu, C.J., 1966, Topographic Changes in the Surf Zone Profile: Coastal Engineering Conference, A.S.C.E., Technical Report No. 50, o. 502-524, Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana.

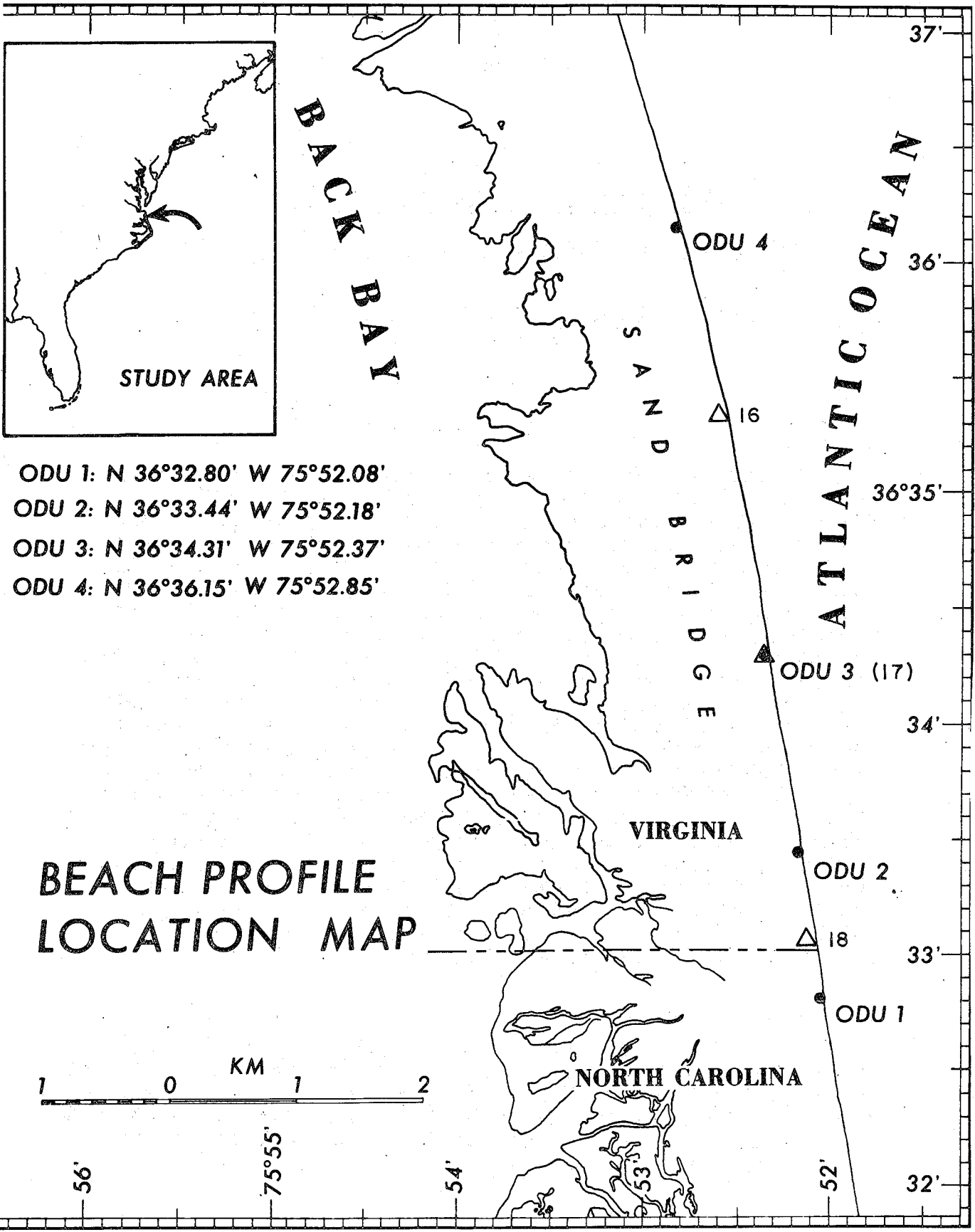
BEACH RESPONSE IN THE VICINITY OF A
SHOREFACE RIDGE SYSTEM: FALSE CAPE, VIRGINIA

Victor Goldsmith, Gerald L. Shideler¹,
John F. McHone¹ and D.J.P. Swift¹

INTRODUCTION

Submarine ridge and swale systems constitute a conspicuous topographic element of the Middle Atlantic shelf. These ridge systems are morphologically diversified, and have been extensively described by several investigators (e.g., Shepard, 1963; Uchupi, 1968; Duane, et al., 1972; Swift, et al., 1972b). One of the most interesting and perplexing varieties of submarine ridges are the oblique-trending, shoreface-connected ridges, such as ideally exemplified at False Cape, Virginia (Fig. 1). The genetic significance of the False Cape Ridge System has been an issue of controversy. Sanders (1962) has suggested that the ridges are relict Pleistocene beach ridges. However, more recent studies of the system suggest that they represent large-scale modern hydraulic bedforms that are maintained by southward flowing coast-parallel storm currents (Swift, et al., 1972a, 1973; McHone, 1972). Even more recently, Swift (1976a and b) suggested that the ridges form in response to southward moving coastal jet currents formed on the shelf in response to winter northeaster storms. Additional studies by Hunt, et al. (1977) and Swift, et al. (1977) indicate that large bedforms are associated with the linear ridges.

¹A draft of this paper was jointly prepared in 1972 using beach profile data collected by the last three authors while at Old Dominion University, Norfolk. It was revised for this volume by the first author, who added the VIMS-CERC profile data and who accepts full responsibility for all conclusions and shortcomings.



- ODU 1: N 36°32.80' W 75°52.08'
- ODU 2: N 36°33.44' W 75°52.18'
- ODU 3: N 36°34.31' W 75°52.37'
- ODU 4: N 36°36.15' W 75°52.85'

In an attempt to explain the sediment source for ridge construction, a conceptual model has been hypothesized (Swift, et al., 1970); the model employs the Bruun coastal retreat concept (Bruun, 1962; Schwartz, 1965), whereby shoreface erosion along a retrograding coast during rising sea level results in equal-volume aggradation along the adjacent sea floor. The aggraded sediment may then be subsequently molded into a shoreface-connected ridge by the modern hydraulic regime. After development, the ridge would function as a feedback element by influencing coastal currents and impinging wave characteristics. In turn, this feedback influence could exert control over erosional and accretionary processes along the adjacent beach sector, as manifested in beach morphology. The False Cape Ridge illustrated in Figure 1 shoals and closes toward the south; consequently, differential influences might be anticipated along the beach sector adjacent to the ridge. Such differential effects have been noted along the adjacent subaqueous shoreface during the 1922-1969 interval, where erosion occurred along the central and northern portions of the sector, while the southern portion was characterized by accretion (Swift, et al., 1972). Similar differential effects were also noted along the adjacent beach of this sector for the same time interval (Felton, unpublished manuscript, Norfolk District Corps of Engineers), with retrogression toward the north, and progradation toward the south.²

The purpose of the present paper was to gain greater insight into the influences exerted by the False Cape submarine ridge on beach processes along the adjacent coastal sector. This was accomplished by conducting a time series study of beach morphology during the 1969-1972 interval. Beach topographic profiles were obtained periodically at four selected stations along the coastal sector adjacent to the False Cape Ridge (Fig. 1), employing the leveling technique described by Emery (1961). The comparative profile data were processed with an IBM 360 computer, employing a curve plotting program which permitted direct volumetric comparisons of morphological variations occurring during sequential time intervals (Colonell and Goldsmith, 1972). It was believed that a study of this nature might be helpful in predicting the response characteristics of similar beach sectors throughout the world which are flanked by shoreface-connected ridge systems.

²See Sutton, this volume.

1969-1971 BEACH PROFILE DATA (O.D.U.)

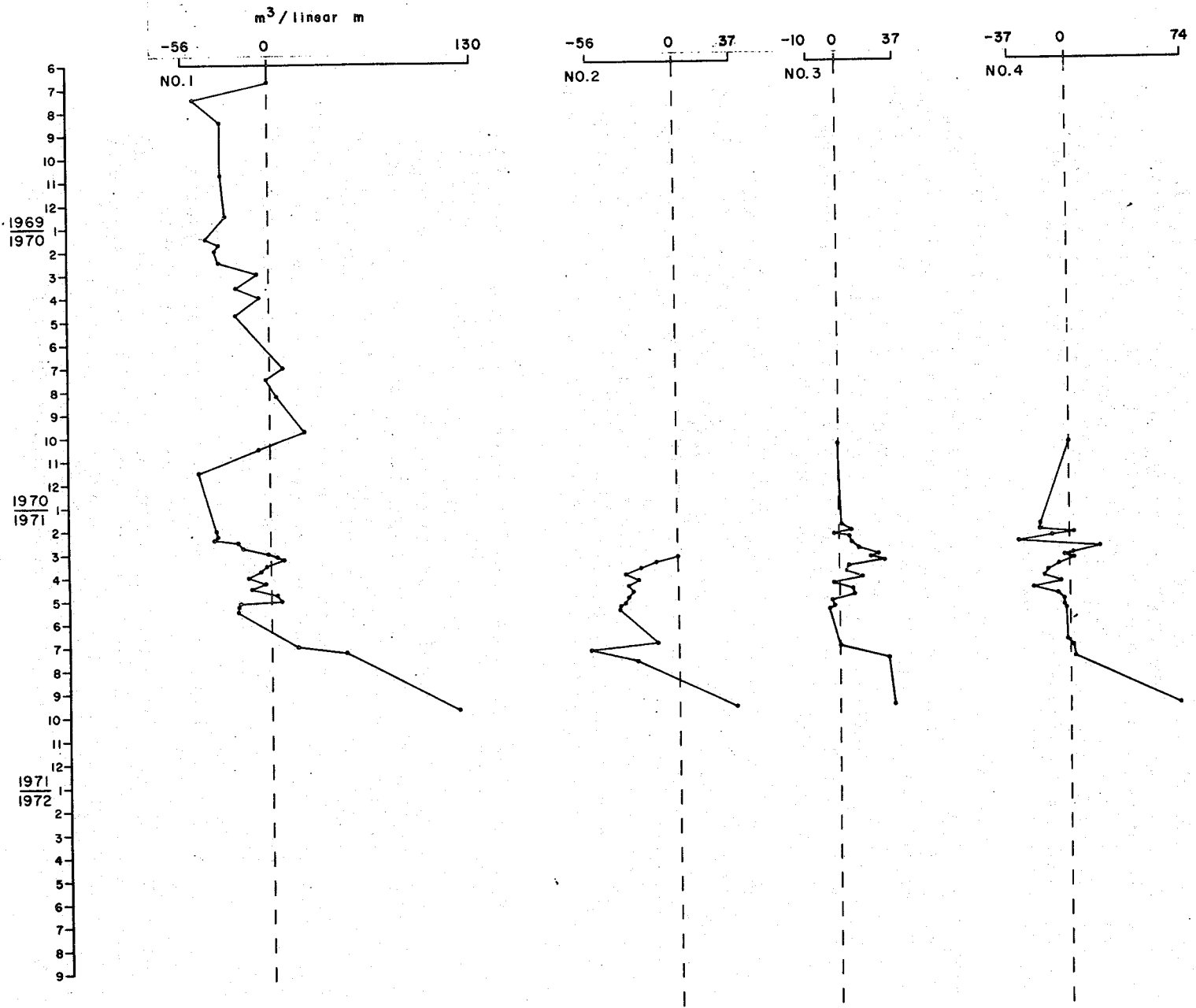
ODU-1 at the south end of the studied sector illustrates the most extensive coverage, ranging from June, 1969 to September, 1971 (Fig. 2). This 27-month curve nicely illustrates two distinct sources of variability: (1) Long-period trend - this trend consists of a cyclic component that appears to generally reflect seasonal variations in the hydraulic regime, though not in every season. The fall and winter months can be generally characterized as an erosional or destructive phase. In contrast, the spring and summer months are generally characterized as accretionary phases.

On an annual basis, this particular beach section appears to approach a condition of dynamic equilibrium over the monitored 27-month interval. If mid-June is used as a reference point, the cumulative curve illustrates a nearly constant annual transfer of sand, with very little net loss or gain from this specific locality. However, on a longer term secular basis (e.g., 1922-1969), this may be a prograding locality. Progradation is suggested by what appears to be an accretionary linear component of the long-term trend. This would be compatible with other data (e.g., Swift, et al. 1972) suggesting progradation in the southern end of the False Cape sector. This station exhibits a total net change consisting of 120 m² of accretion over the monitored time interval.³ (2) Short-period variations - relatively short period variations superimposed on the long-period trend reflect highly transient events, such as storm erosion and subsequent beach rebuilding episodes. The most prominent events, which involved volumetric changes exceeding 28 m²/linear meter occurred during the following comparison intervals: 6/30/69-7/18/69 (49 m² erosion), 4/26/70-7/8/70 (30 m² accretion), 9/25/70-10/20/70 (29 m² erosion), 10/20/70-11/17/70 (31 m² erosion), 5/22/71-7/4/71 (38 m² accretion), 7/4/71-7/14/71 (31 m² accretion), and 7/14/71-9/26/71 (73 m² accretion).

The cumulative curve from ODU-2 provides only a 7-month coverage from March, 1971 to September, 1971. The curve

³Profile changes are presented here in area change between two successive beach profiles (ODU data) or in volume change/linear meter of beach (VIMS-CERC data). Since the volume is for one linear meter of beach, the numbers are actually the same for volume and area.

23-5



is of insufficient length to delineate a long-term trend, but it does illustrate a total net change consisting of 37 m² of accretion. The curve illustrates short period transient events. The most prominent events (> 28 m²) occur in succession during the latter three comparison intervals: 7/4/71-7/14/71 (43 m² erosion), 7/14/71-7/28/71 (31 m² accretion), and 7/28/71-9/26/71 (63 m² accretion). This sequence appears to reflect a major storm, followed by an extensive rebuilding phase.

The cumulative curve from ODU-3 provides an eleven-month coverage from October, 1970 to September, 1971. The curve is of insufficient length to delineate a well-developed long-period trend, but it does illustrate a total net change consisting of 34 m² of accretion. Short-period transient variations are readily apparent; the most prominent transient event occurred during the 7/14/71-7/28/71 comparison interval, resulting in 31 m² of accretion.

The cumulative curve from ODU-4 also provides an eleven-month coverage from October, 1970 to September, 1971. The curve's short length does not adequately delineate a long-term trend, but it does illustrate a total net change consisting of 71 m² of accretion. The curve also illustrates some short-period transient events, with the most prominent ones occurring during the 2/27/71-3/5/71 interval (52 m² accretion), and the 7/28/71-9/26/71 (68 m² accretion) interval.

In comparing the time series response characteristics of the four beach stations, the only available comparison interval is from March, 1971 to September, 1971. During this interval, the cumulative curves of the four stations do illustrate differences in magnitude, but not in occurrence of net erosion and accretion. This indicates differential beach response characteristics in a north-south direction, possibly induced by the southward shoaling False Cape Ridge, since the most accretional profile is ODU-1. There are two features which correlate well among the four curves. One feature is the brief two-cycle sequence of minor erosion and accretion which occurred during April, 1971. The second feature is a major accretionary phase which commenced during July, 1971, and continued into September, 1971. In general, erosion and accretion occur simultaneously at all four locations, but differ in magnitude. This suggests that the False Cape Ridge is only partially effective in inducing differential beach response characteristics along the studied sector over the short term.

1969-1976 BEACH PROFILE DATA (VIMS-CERC)

These data include the reoccupied profile locations of ODU-3 (VIMS No. 17) and Harrison and Bullock, 1972 (VIMS Nos. 15, 16 and 18) (Figs. 1 and 3). The tape and level surveying methods employed in the 1974-1976 VIMS-CERC study, and other pertinent aspects are discussed in Goldsmith, et al., 1977, and in this volume. Net longshore transport is concluded to be to the south in the False Cape area (Goldsmith, et al., 1977).

Figure 3 illustrates the relation between the beach profile locations and the adjacent offshore bathymetry (from Sutton, et al., 1976). Note that profile locations 17 (ODU-3), ODU-2, 18 and ODU-1 are opposite the portion of the relatively shallow False Cape Ridge System which abuts against the shore; and that profile locations 15, 16 and ODU-4 are opposite a steeper portion of the nearshore where the 30' depth contour (9.1 m) is much closer to shore.

Figures 4 through 7 show the volume changes at profile locations 15, 16, 17 (ODU-3) and 18, respectively, between 1969 and 1976. Profile locations 17 and 18 show very dramatic accretional trends. Whereas profile locations 15 and 16 show large volume fluctuations, the net accretional trend at 16 is quite subdued relative to locations 17 and 18, and 15 shows no trend. Table 1 gives the linear regression lines fitted to the volume trends, and the statistical tests for the goodness of fit (i.e., significance) of the linear regression lines.

It is interesting to note that a similar trend exists to the north, in that profile locations 12, 13, and 14, which are opposite a relatively wider shoreface, as delineated by the 30 ft (9.1 m) contour, are also characterized by larger net accretion.

This may be explained, simply, as due to the wider shoreface acting as a wave buffer, causing the frictional loss in wave energy as the waves pass over the shallower area. More complexly, the shoreface ridge systems may provide a conduit for longshore sediment transport, resulting in larger accumulations at the shorelines where the obliquely oriented ridge systems are attached to shore.

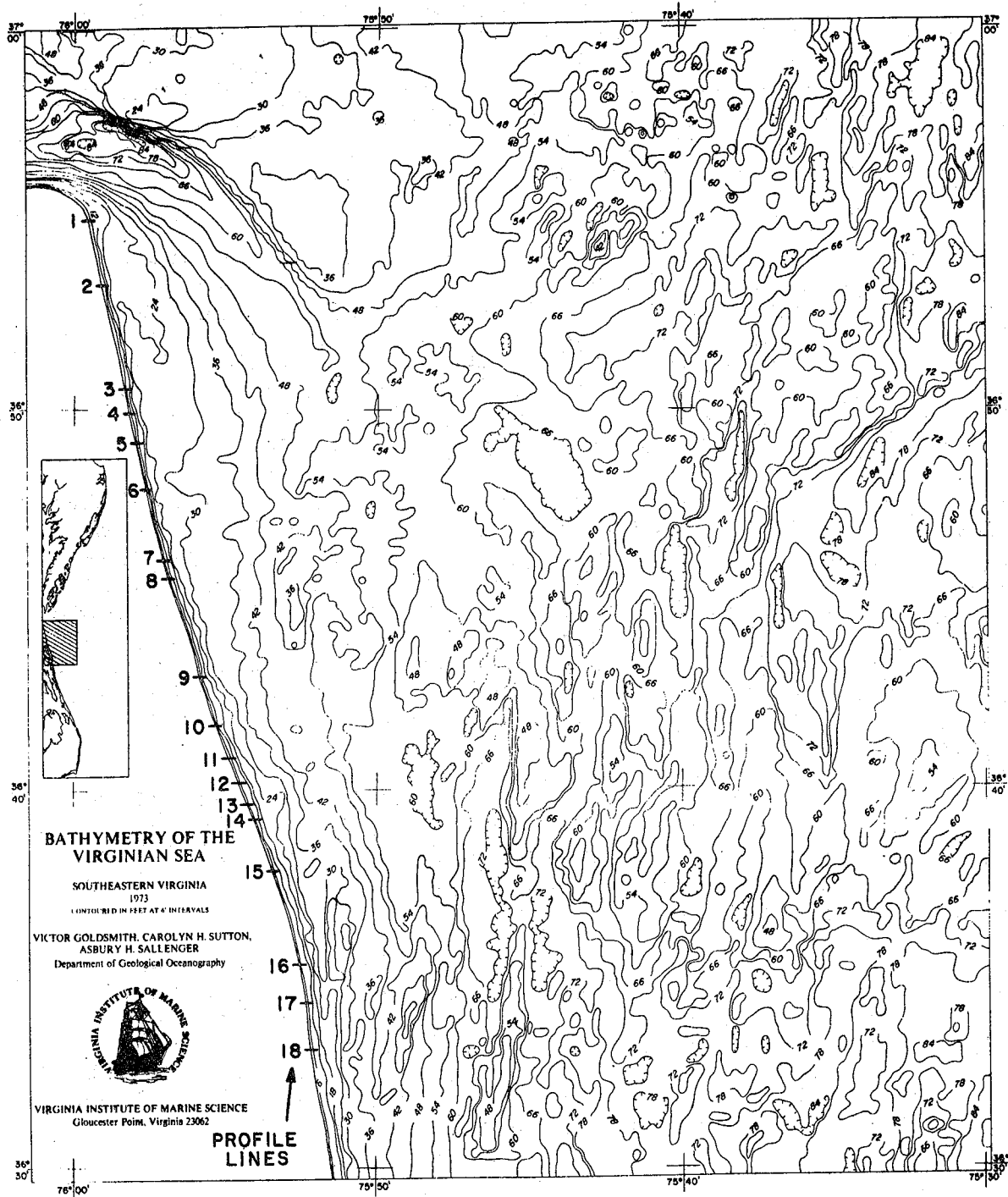


Figure 3. Bathymetry of southeast Virginia shelf; contours in feet (1 foot = 0.305 meter).

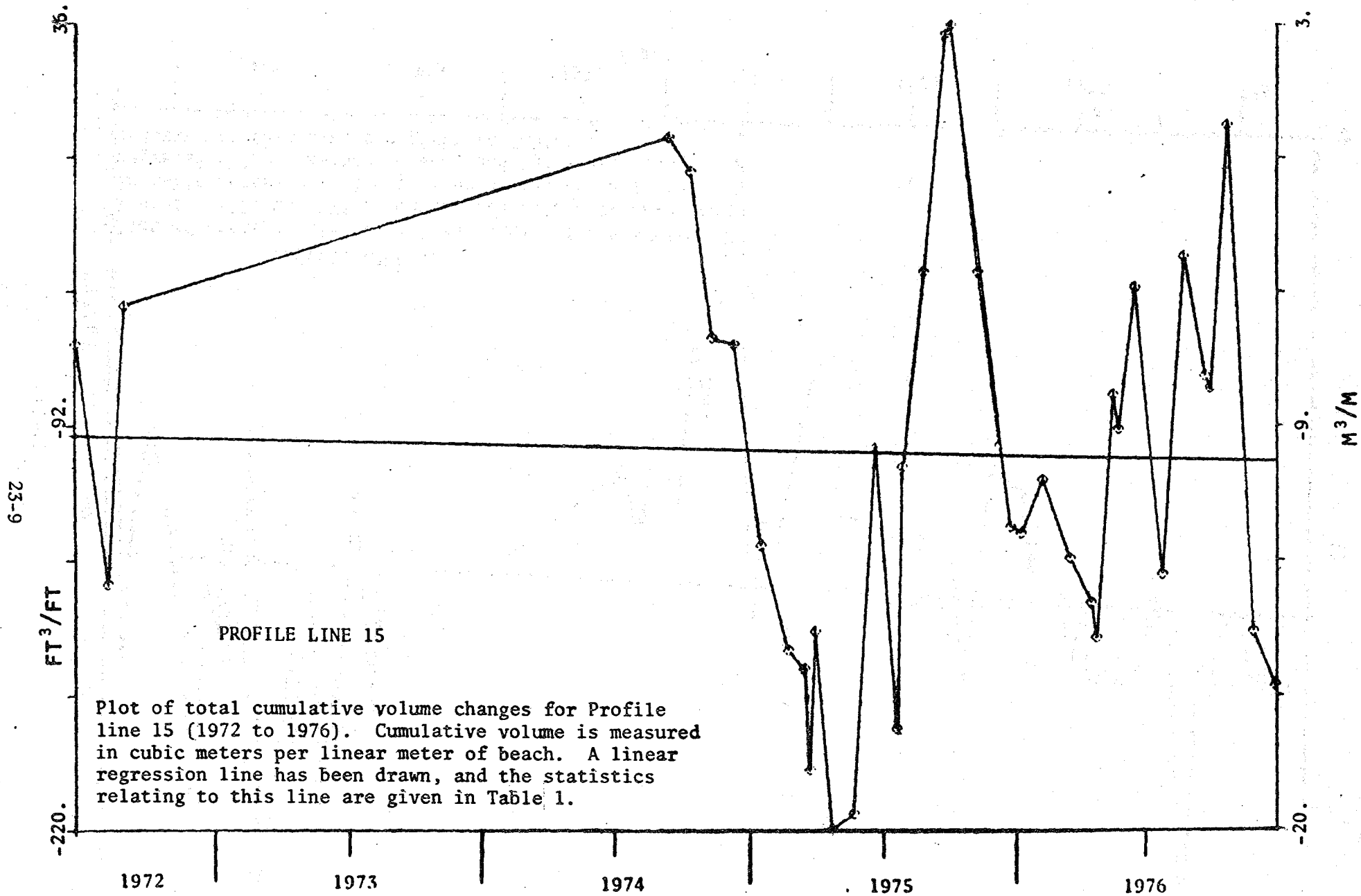


Figure 4.

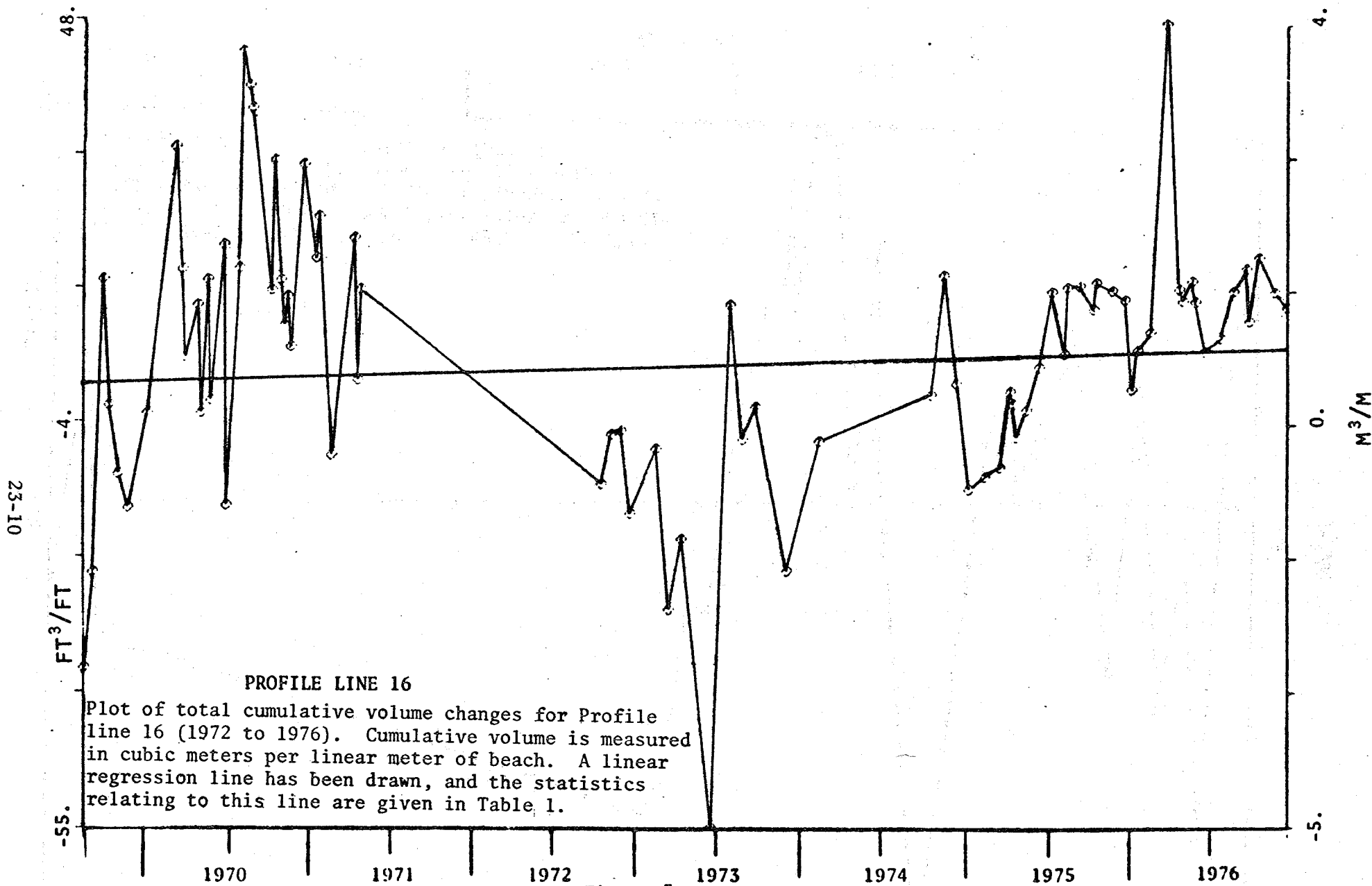


Figure 5.

23-11

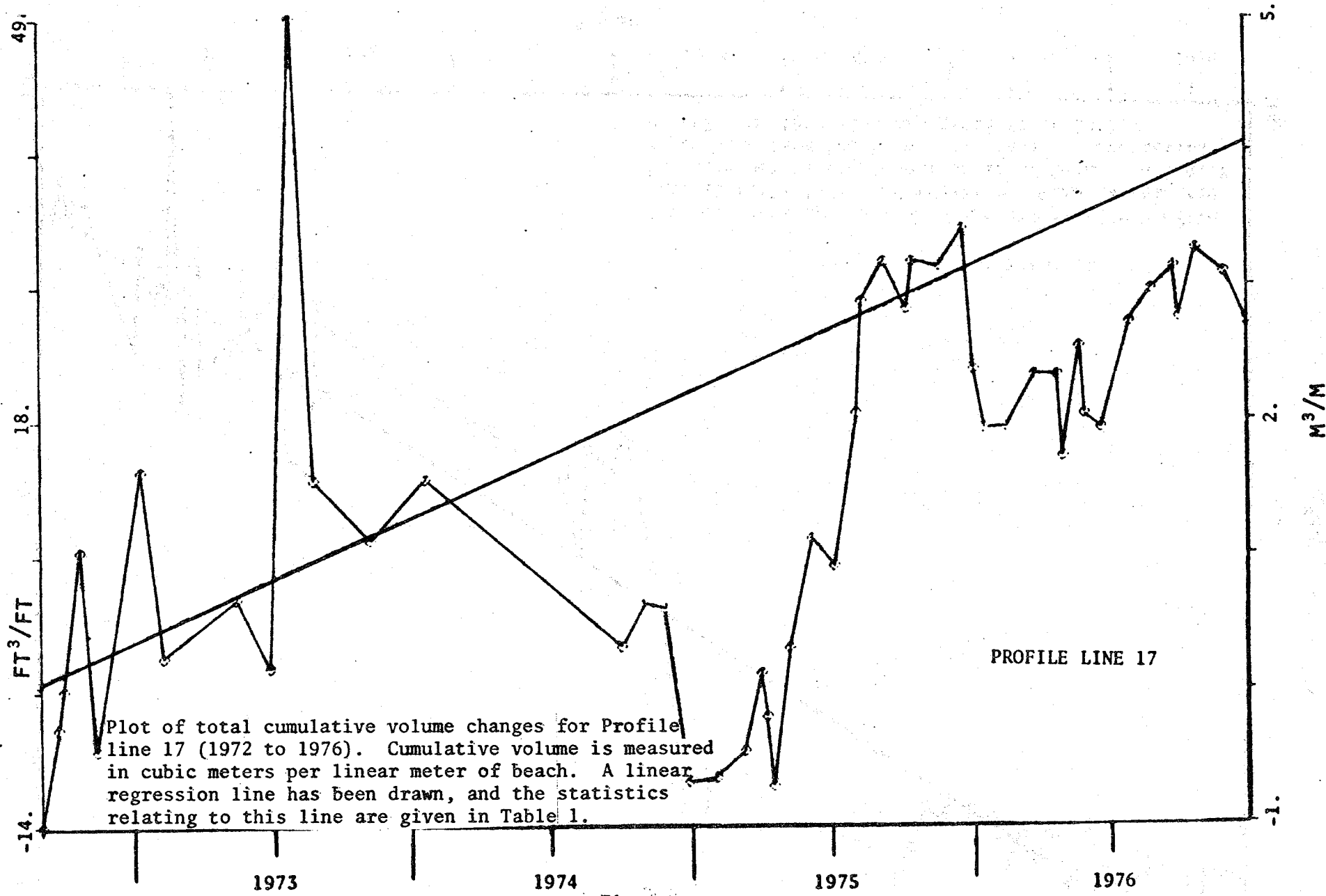


Figure 6.

23-12

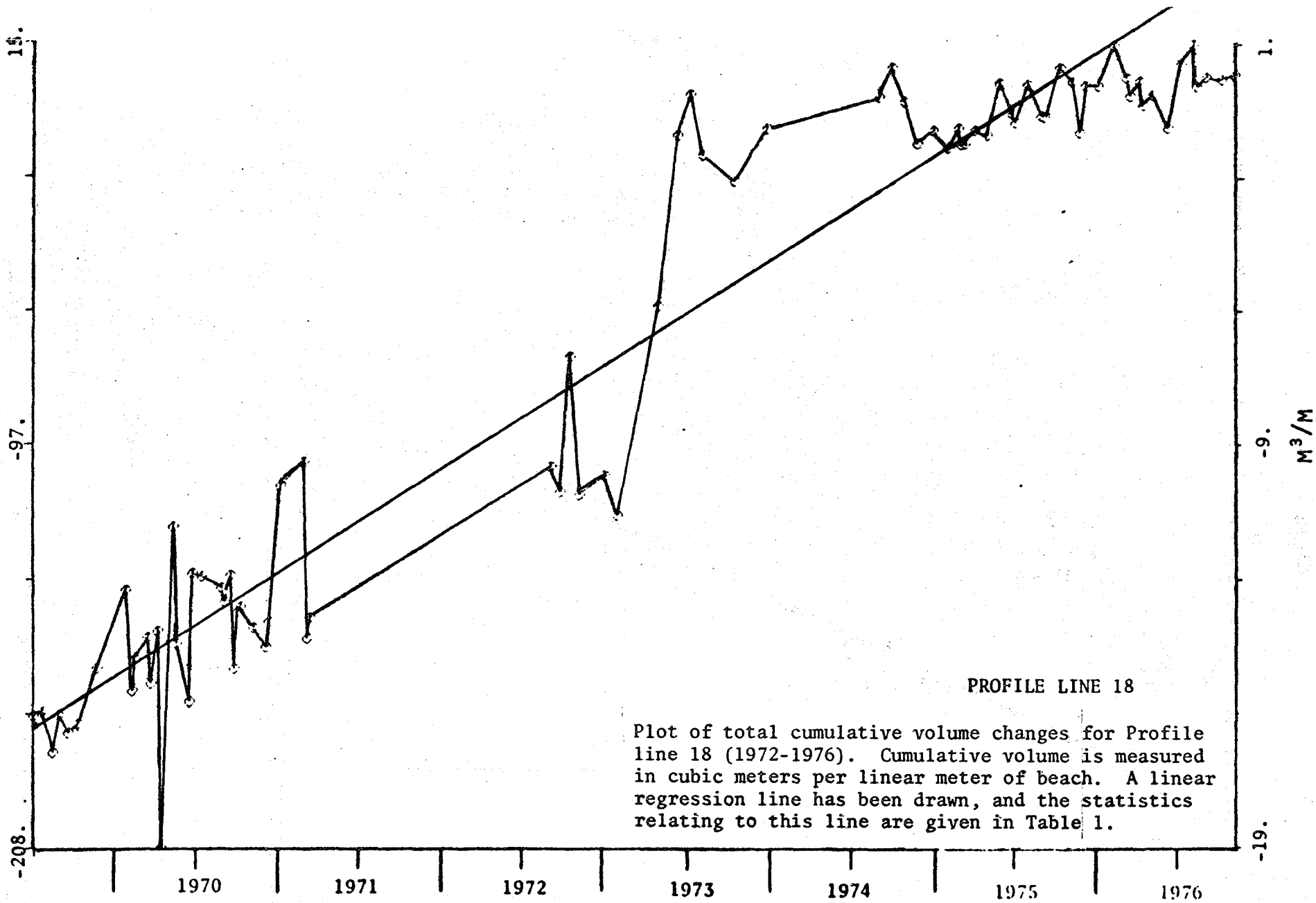
FT³/FT

Figure 7.

Table 1 Linear regression lines fitted to the beach volume trends and statistical significance of the long-term trends.

<u>Profile line</u>	<u>Estimated coefficient</u>	<u>Y Intercept</u>	<u>R²</u>	<u>Significance¹</u>	<u>Trend²</u>
12	6.74	-2203.28	0.68	0.001	+
13	1.09	- 489.12	0.06	0.10	+
14	4.08	-1399.52	0.88	0.001	+
15	-0.05	- 85.93	0.001	0.90	-
16	0.04	46.60	0.001	0.001	+
17	1.26	- 232.90	0.31	0.001	+
18	3.47	-1743.74	0.92	0.001	+

¹The lower the number, the higher the significance; e.g., 0.001 indicates that the erosion or accretion trend is not due to chance at the 99.9 percent level.

²+, accretion; -, erosion.

³Data does not meet basic assumptions.

SUMMARY

Long-term beach trends (1969-1976) in the vicinity of the False Cape Ridge System show variations in the magnitude but not in the general concurrent occurrence of erosion and accretion. The most accretional beach profile locations (17 and 18) are opposite the area of attachment of the ridge system, and the least accretional profile locations are opposite the narrowest portion of the shoreface, as delineated by the 30 ft (9.1 m) contour.

These trends are not apparent in the short-term (1970-1971) beach profile data.

It is hypothesized that the larger accretional trends may be due to the obliquely-oriented ridges acting as conduit for longshore transport resulting in additional accretion at the profile locations opposite the area of ridge attachment to the shoreline. Since profile locations 15 and 16 are also the most active with respect to daily and weekly wave events, the ridge at shoreline attachment may also "dampen" these daily and weekly wave events.

REFERENCES

- Bruun, P., 1962. Sea Level Rise as a Cause of Shore Erosion: Jour. Waterways Harbors Div., Amer. Soc. Civil Eng., V. 88, p. 117-130.
- Bullock, P.A., 1972. The Feasibility of Developing Forecast Systems to Predict Changes in Beach Sand Volume on Ocean Beaches During Storms: Masters Thesis, Virginia Institute of Marine Science, Gloucester Point, Va.
- Duane, D.B., Field, M.E., Meisburger, E.P., Swift, D.J.P., and Williams, S.J., 1972. Linear Shoals on the Atlantic Inner Continental Shelf, Florida to Long Island: in Processes and Patterns of Continental Shelf Sediment Transport: Swift, Duane, and Pilkey (editors), Dowden, Hutchinson and Ross Co., Stroudsburg, Pa.
- Emery, K.O., 1961. A Simple Method of Measuring Beach Profiles: Limn. and Ocean., V. 6, p. 90-92.
- Goldsmith, V., Sturm, S., Thomas, G., 1977. Variations in Beach Erosion and Accretion Trends at Virginia Beach, Virginia, and Vicinity: Final Report CERC Contract DACW-72-74-C-0008 and CERC Tech. Memo (in press), C.E.R.C., U.S. Army Corps of Engs., Ft. Belvoir, Virginia, VIMS SRAMSOE No. 122.
- Goldsmith, V., Sutton, C.H., and Davis, J.S. 1973. Bathymetry of the Virginian Sea-Continental Shelf and Upper Slope, Cape Henlopen to Cape Hatteras: Bathymetric Map, Virginia Institute of Marine Science, SRAMSOE No. 39.
- Hunt, R.E., Swift, D.J.P., Palmer, H., 1977. Construction Shelf Topography, Diamond Shoals, North Carolina: Geol. Soc. of Amer. Bull., Vol. 88, p. 299-311, 16 figs.
- McHone, J.F., Jr., 1972. Morphological Time Series From a Submarine Sand Ridge on the South Virginia coast: Unpublished M.S. Thesis, Old Dominion Univ., 59 p.

- Sanders, J.E., 1962. North-South Trending Submarine Ridge Composed of Coarse Sand Off False Cape, Virginia (abst): Amer. Assoc. Pet. Geol., Bull., Vol. 46, p. 278.
- Schwartz, M.L., 1965. Laboratory Study of Sea Level Rise as a Cause of Shore Erosion: Jour. Geology, Vol. 75, p. 76-92.
- Shepard, F.P., 1963. Submarine Geology: Harper and Row, N.Y., 567 p.
- Swift, D.J.P., 1976a. Coastal Sedimentation: Chapter 14, p. 255-310, In Marine Sediment Transport and Environmental Management, Stanley and Swift (eds.), Wiley, N.Y., 602 p.
- Swift, D.J.P., 1976b. Continental Shelf Sedimentation: Chapter 15, p. 311-350, In Marine Sediment Transport and Environmental Management, Stanley and Swift (eds.), Wiley, N.Y., 602 p.
- Swift, D.J.P., Holliday, B., Avignone, N., and Shideler, G., 1972a. Anatomy of a Shoreface Ridge System, False Cape, Virginia: Marine Geology, Vol. 12, p. 59-84.
- Swift, D.J.P., Kofoed, J.W., Saulsbury, F.P., and Sears, P., 1972b. Holocene Evolution of the Shelf Surface, Central and Southern Atlantic Shelf of North America: in Processes and Patterns of Continental Shelf Sediment Transport: Swift, Duane, Pilkey (editors), Douden, Hutchinson, and Ross Co., Stroudsburg, Pa.
- Swift, D.J.P., Lavelle, J.W., Ludwick, J.C., McHone, J.F., Shideler, G.L., McFall, J.C., Holliday, B.W., 1973. Ridge Fields of the Inner Virginia Shelf: Substrate Response to Wind and Wave Currents During Storms (abst.): Amer. Geophy. Union, Transactions, Vol. 54, p. 334.
- Swift, D.J.P., Sears, P.C., Bohlke, B., and Hunt, R., 1977. Evolution of a Shoal Retreat Massif, North Carolina: Inferences from Areal Geology: Marine Geology (in press).

Swift, D.J.P., Shideler, G.L., Avignone, N.F., and Holliday, B.W., 1970. Holocene Transgressive Sand Sheet of the Middle Atlantic Bight - A Model for Generation by Shoreface Erosion (discussion paper): Geol. Soc. America, Abstracts with Programs, Vol. 2, p. 757-759.

Uchupi, Elazar, 1968. The Atlantic Continental Shelf and Slope of the United States: Physiography: U.S. Geol. Survey Prof. Paper, 529-C, 30 p.

BEACH CUSPS

Asbury H. Sallenger, Jr.¹

PREFACE

Beach cusp spacings were measured in the False Cape, Virginia area on numerous occasions during 1973-74 as part of a study on the formation of beach cusps. The mean spacings of series of cusps varied between 19 and 33 m and were generally larger than cusps observed on two more protected estuarine beaches (Fig. 4). An interesting long-shore trend in spacing was observed near False Cape and in Kitty Hawk, North Carolina, where cusp spacing tended to be largest over the salients of giant cusps, the shoreline manifestations of rhythmic topography, and decreased into the embayments (Fig. 5). What follows is a synopsis of the author's dissertation on the formation of beach cusps.

Abstract

Observations of beach cusps forming in the field showed that: 1. The morphology of the observed cusps was a product of swash erosion of shore parallel ridges; and 2. measured spacings of cusps agree well with computed cusp spacings due to the presence of edge waves.

INTRODUCTION

Numerous hypotheses on beach cusp formation have been published, but there is no apparent concensus as to which if any are valid. Development of the cusped form has been attributed to accretional processes (Branner, 1900; Kuenen, 1948; Komar, 1971; Sanders, et al., 1976), erosional processes (Johnson, 1910; Rivas, 1957; Smith and

¹U.S. Geological Survey, Menlo Park, California.

Dolan, 1960) or both (Otvos, 1964, Gorycki, 1973; Guza and Inman, 1975). Proposed mechanisms controlling the uniform spacing of cusps include adjustment of initial foreshore irregularities (Johnson, 1919), edge waves (Galvin, 1964; Bowen and Inman, 1969; Komar, 1973; Guza and Inman, 1975), instabilities in breaking waves (Cloud, 1966) or swash (Gorycki, 1973), and a variety of mechanisms requiring a non-normal incident wave approach to the shoreline (Branner, 1900; Rivas, 1957; Schwartz, 1972; Dalrymple and Lanan, 1976).

The hypotheses are based primarily on theoretical grounds, laboratory experiments, conjecture and/or field observations of cusps whose form and spacing were established before the observations. Few detailed observations of beach cusps forming in the field have been reported. The approach taken here was to occupy a beach after a storm of sufficient energy to leave a plane foreshore, and then to monitor sediment level changes and pertinent wave parameters through cusp formation.

DEVELOPMENT OF THE CUSPATE FORM

A grid composed of narrow rods driven into the sediment surface 2 m apart was laid out across the foreshore extending 10 m parallel to the shoreline on Parramore Island, Virginia. After the elevation of the top of each rod was measured with respect to a datum, periodic measurements of the length of exposed rod revealed the changing form of the foreshore.

Immediately prior to cusp formation the incident wave field changed from an oblique to a normal approach to the shoreline. On the flood tide following this change in wave direction, a shore parallel ridge of sediment cut by a series of channels equally spaced along its length was accreted onto the foreshore (Fig. 1, A). The swash, flowed up the seaward face of the ridge, was partially ponded behind the ridge crest and the ponded swash was released seaward through the channels. In response to this circulation and the flooding tide the ridge migrated shoreward, while the longshore positions of the channels remained fixed. On ebb tide the seaward regression of the swash zone stranded the ridge on the upper foreshore and a stage was reached where the swash could no longer effectively overtop the ridge. The swash then flowed shoreward through the channels and eroded the channel mouths progressively

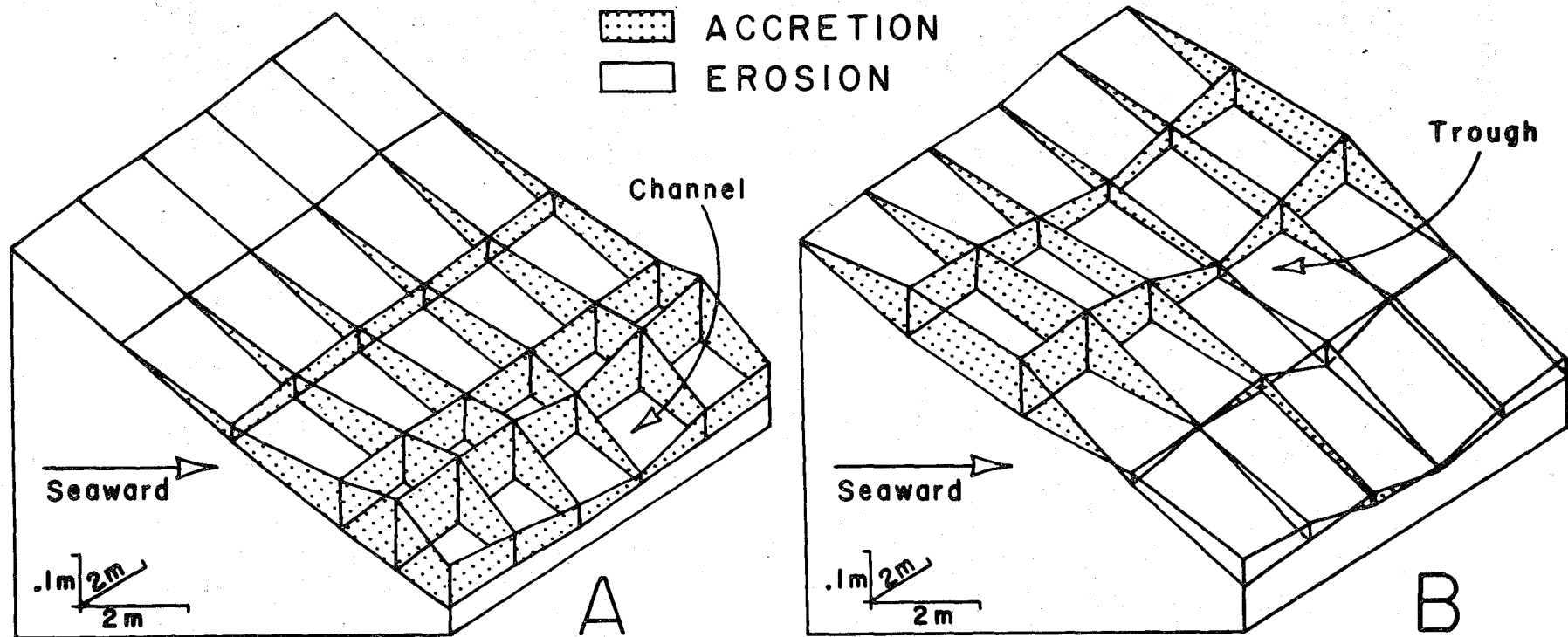


Fig. 1. Block diagrams showing the development of the cusate form. A. During flood tide a ridge was deposited onto the foreshore with equally spaced channels distributed along its length. The crest of the ridge lay between lines of rods and its position and approximate form has been added to the diagram. B. The ridge migrated shoreward with the flooding tide. On ebb tide the mouths of channels were progressively widened by erosion until adjacent mouths met, effecting a cusate shape.

wider until adjacent mouths met, effecting a cusped shape (Fig. 1, B).

This sequence of events leading to the development of the cusped form was observed on several different occasions and beaches. In support of the general applicability of these observations, Mii (1968) and Smith and Dolan (1960) reported the internal structure of cusps indicates an erosional origin consistent with the observed transformation from a ridge to cusps. Laminations within a horn along a cross section parallel to the shoreline are plane and level and are truncated at the sloping horn surfaces (Fig. 2). The plane and parallel laminations are what would be expected within the body of a ridge, and the truncations would be the expected result of swash erosion of channels in creating troughs. These results support previous investigators' (Evans, 1945; Williams, 1973) contentions on the applicability of ridges to cusp formation and are contrary to assertions by Kuenen (1948) that ridges are of significance only in tideless seas and Russel and McIntyre (1965) that ridges have no role in cusp development. These results do not, however, preclude additional modes of formation. For example, Komar (1971, 1973) has observed in the field cusps forming in response to deposition in the lee of rip currents and relatively small cusps developing as ridges normal to the shoreline.

PROCESS CONTROLLING THE SPACING OF CUSPS

For the observed cases, the mechanism controlling the spacing of cusps must be operable under a normal wave approach and capable of eroding equally spaced channels along a ridge. Of the few hypotheses which conceivably satisfy these criteria, the edge wave hypothesis is the only one with a strong theoretical basis (Eckart, 1951; Ursel, 1952). Furthermore, edge waves are applicable to cusp formation in wave tank experiments (Galvin, 1964; Guza and Inman, 1975), and their potential significance in the prototype is shown by evidence of edge waves in the field (Huntley and Bowen, 1973).

Edge waves are free modes of nearshore water motion trapped against the shoreline by refraction. Edge wave amplitudes decay exponentially offshore and vary sinusoidally alongshore. Application of edge waves to channel development involves the influence on swash of regular longshore variations in wave height resulting from edge

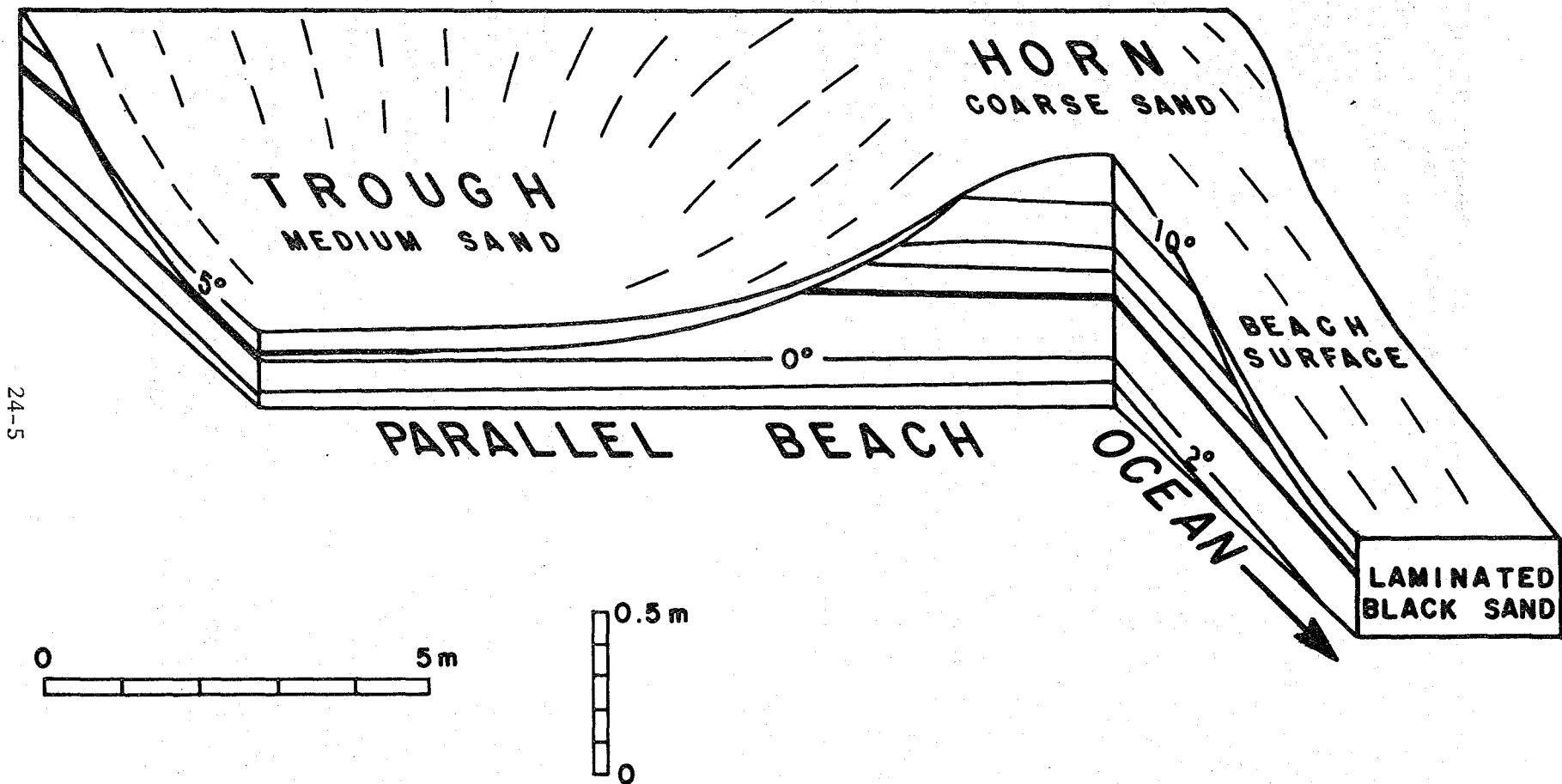


Fig. 2. Cross-sections through a cusp showing erosional internal structures (from Mii, 1968).

wave-incident wave superposition. On the passage of every incident wave crest, synchronous edge waves, where the edge wave period is equal to the incident wave period, will cause a longshore spacing of wave-height maximums equal to one synchronous edge wave wavelength. Resulting longshore variations in swash overtopping a ridge will cause ponded swash to converge at points of low swash and flow seaward as relatively narrow currents eroding channels spaced at one synchronous edge wavelength. For subharmonic edge waves, where the edge wave period is twice the incident wave period, wave-height maximums will alternate with wave-height minimums on the passage of every incident wave crest since the edge wave completes only one-half cycle between successive incident waves. Consequently, position of swash convergence over a ridge will alternate with divergence areas with every swash cycle. Conceivably, seaward flowing currents at convergent positions would be capable of initiating channel erosion and once initiated the flows would become topographically controlled and develop channels. The resulting channel spacing would then be one-half the subharmonic edge wave wavelength. For either case, the longshore positions of convergence zones must be fixed. This is satisfied when the incident wave approach is normal to the shoreline (Guza and Bowen, 1975).

The wave length of an edge wave is given by (Ursel, 1952):

$$L = \frac{g}{2\pi} T_e^2 \sin(2n + 1) \beta$$

where T_e is the edge wave period, g is the gravitational acceleration, n is the modal number, a positive integer, and β is the beach slope. Cusp spacing due to synchronous edge waves is L and due to subharmonic edge waves is $L/2$ or $2L$ when $T_e = 2T_i$ where T_i is the incident wave period. For synchronous edge waves, laboratory experiments indicate n increases with surf zone width (Bowen and Inman, 1969). For subharmonic edge waves, Guza and Davis (1974) found the zero mode to be the likeliest to occur.

During observations of beach cusp formation on different beaches the incident wave period, beach slope and resulting mean cusp spacing were measured. The period measurements were based on visual observations of the number of waves passing a fixed point during three, two

minute time intervals. The slope was taken over a distance of $.1 (g/2\pi) T^2$ seaward of the break point, where the distance is a scaling factor to the edge waves.

Measured cusp spacings are plotted versus computed spacings due to edge waves in Fig. 3. The computed spacings for data sets I and II are based on subharmonic edge waves of $n = 0$. A reasonably good agreement is apparent. The relatively small cusps of data set III show a closer correspondence to computed spacings based on zero mode synchronous edge waves. Low incident wave heights of only a few centimeters during the formation of these cusps suggest a low mode number due to the very narrow swash zone (Bowen and Inman, 1969).

The breaking wave form for data sets II and III was surging. This agrees with Guza and Inman's (1975) assertion that either subharmonic or low mode synchronous edge waves are responsible for cusp formation where incident waves are mostly reflected which would be the case for surging breakers. Wave heights for data set III were close to the theoretical minimum for subharmonic excitation. Synchronous edge waves can develop when incident wave heights are below the minimum for subharmonic edge waves (Guza and Inman, 1975) which may explain the better agreement with synchronous edge waves for this data set. The breaking wave form for data set I was plunging, but the incident wave heights were close to the theoretical maximum for subharmonic excitation and may still fall within the limits of Guza and Inman's (1975) analyses.

Reanalyses of Komar's (1973) field data (Sallenger, 1974; Guza and Inman, 1975) support these results in that the majority of observed cusp spacings can be accounted for by zero mode subharmonic edge waves. Furthermore, Huntley and Bowen (1975) noted an apparent correspondence between the spacing of relatively small cusps found in the field and due to zero mode synchronous edge waves.

In support of the general applicability of these findings, edge waves may be able to explain the dependence of cusp spacing on the degree of beach exposure (Russel and McIntyre, 1965; Williams, 1973). For example, in Figure 4 it is shown cusp spacing tended to be largest on an ocean beach, intermediate in size on a beach exposed to a relatively wide estuary and smallest on a well protected estuarine beach. Since wave period is in part a function of fetch length, one would generally expect

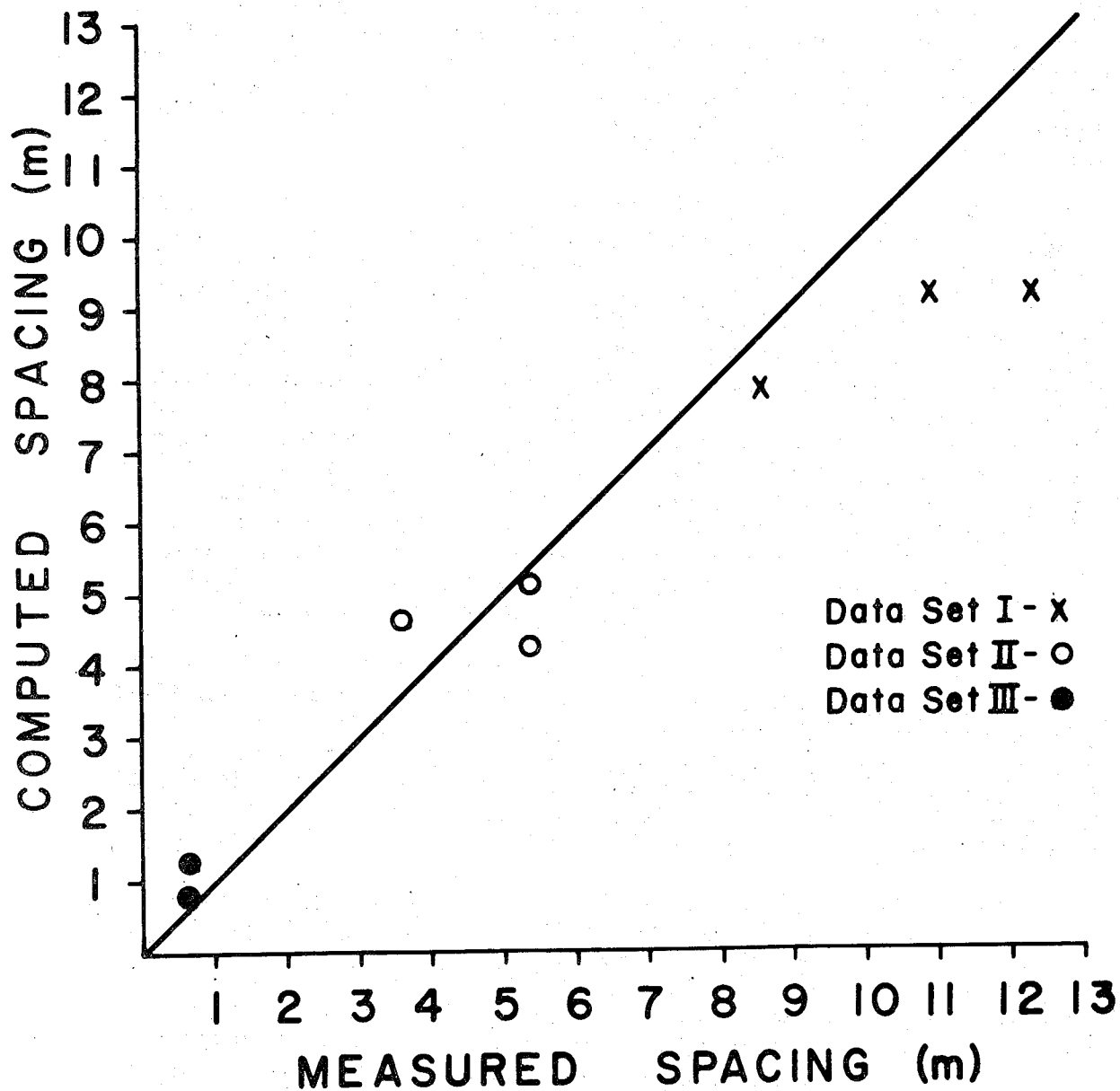


Fig. 3 Measured cusp spacing versus computed cusp spacing due to the presence of edge waves. Computed cusp spacings for data sets I and II are based on zero mode subharmonic edge waves and for data set III on zero mode synchronous edge waves. Each data set represents an experiment involving several monitored sites. Data set I is from Parramore Island, Virginia and II and III are from a beach on the York River estuary in Gloucester Point, Virginia.

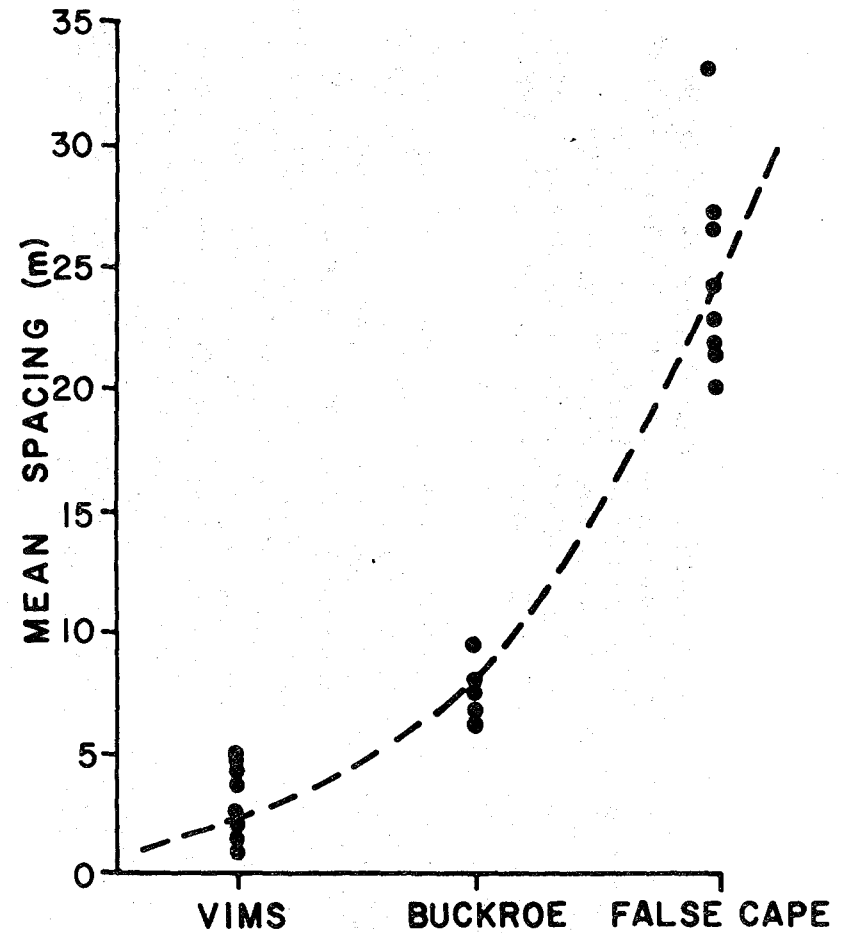
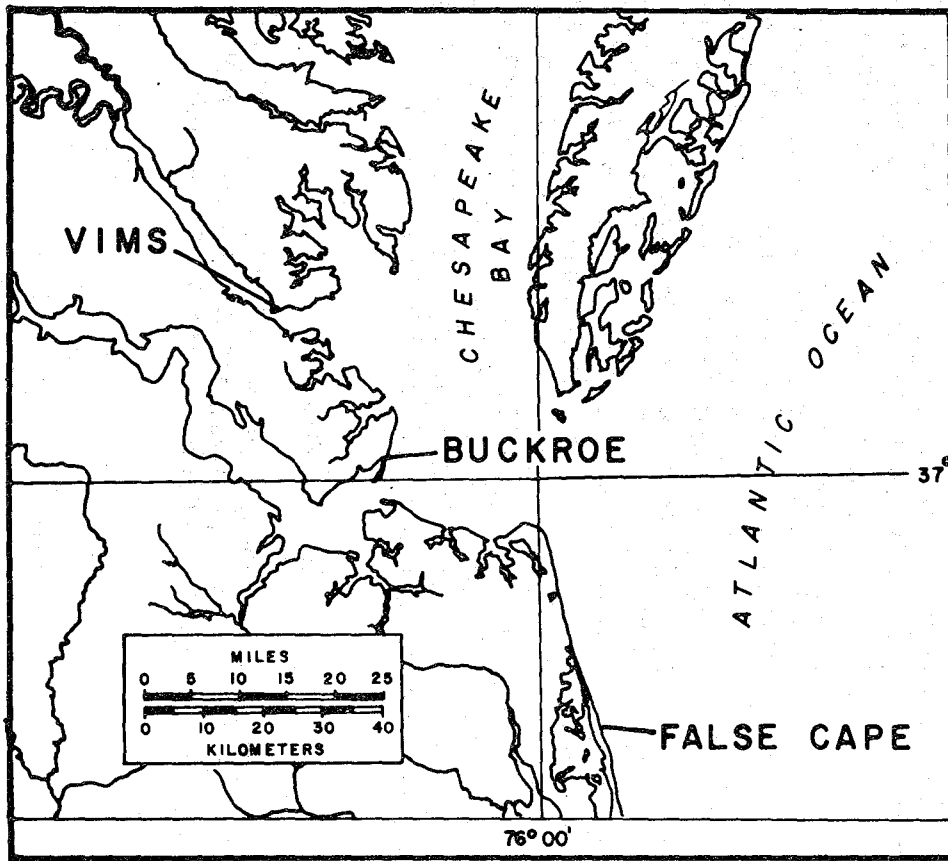


Fig. 4. Mean spacings of beach cusps found on a relatively exposed shoreline (False Cape), a beach exposed to a relatively wide estuary (Buckroe) and a well protected estuarine beach (VIMS). Each circle represents the mean of a series of cusps.

periods effecting these beaches would increase with increased exposure. Edge waves could control these differences in spacing if T^2 is more variable than $\sin \beta$. Furthermore, the modal number may show a concomittant increase with exposure for synchronous edge waves since wave energy and consequently surf zone width would tend to increase with exposure.

Cusp spacing also tends to vary concomittantly with beach slope along certain shoreline shapes. In Figure 5 cusp spacings are shown to be largest over salients of giant cusps and decrease into the embayments of either side. Sonu (1973) has shown slope tends to be the largest over salients and decrease into the embayments. Along a bay of log spiral shape, Krumbein (1947) showed cusp spacing and beach slope increased outward from the concavity of the bay. Since the wave period is generally constant alongshore at any given time, these trends in spacing could be explained by edge wave theory, assuming the theory can be qualitatively applied to these curved shorelines.

These results support the validity of the edge wave hypothesis, but whether cusp spacing is controlled by edge waves under all conditions is a point of contention. For example, some of the data from Longuet-Higgins and Parkin (1962) are not consistent with the edge wave hypothesis. Guza and Inman (1975) conclude edge waves control the spacing of cusps under conditions where incident waves are surging and mostly reflected, but where wave breaking and nearshore circulation cells are significant mechanisms other than edge waves may be important. Other processes are theoretically possible was recently illustrated by Dalrymple and Lanan (1976) for the case where incident waves of the same frequency approach the shoreline at opposing nonnormal angles. Other hypotheses, involving the instabilities of the cylindrical wave form (Cloud, 1966) and the swash (Gorcyki, 1973) can account qualitatively to some extent for alongshore and between shore variations in cusp spacing (Sallenger, 1974), but have not been sufficiently quantified to be testable.

CONCLUSIONS

The breaching of a ridge at a spacing consistent with the edge wave hypothesis has been shown to ultimately produce beach cusps. Under different conditions other

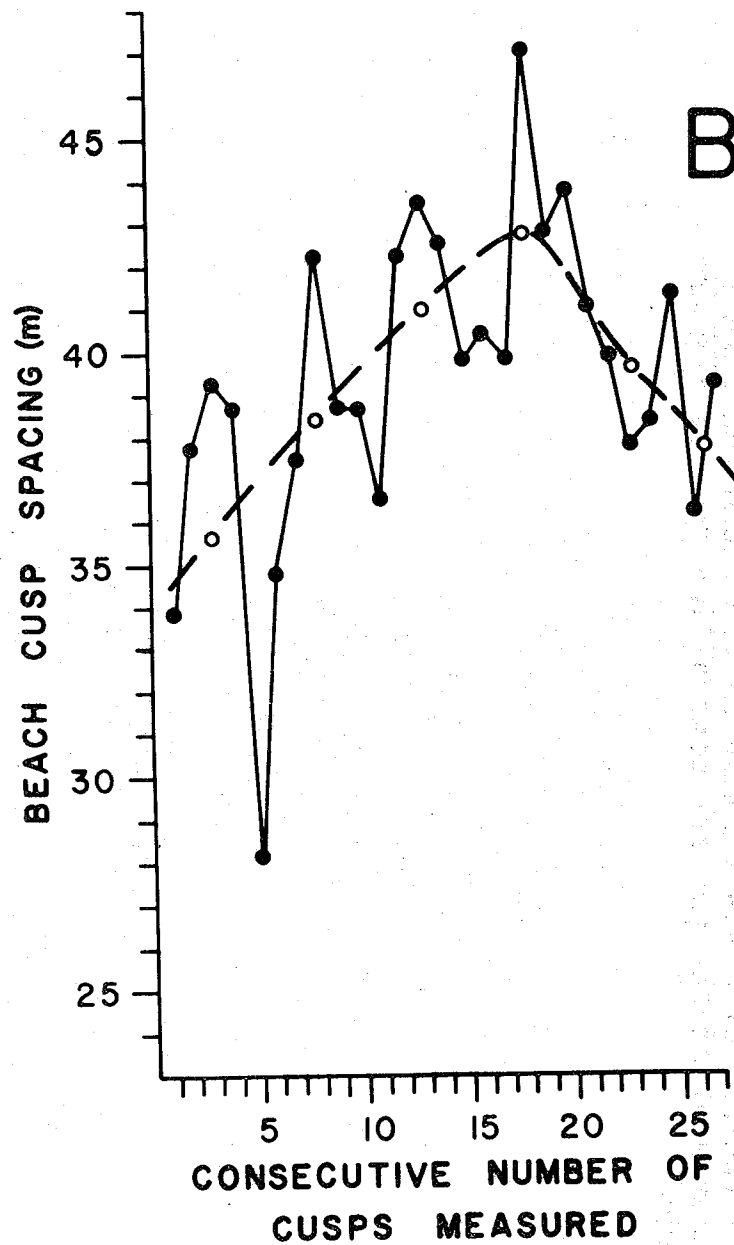
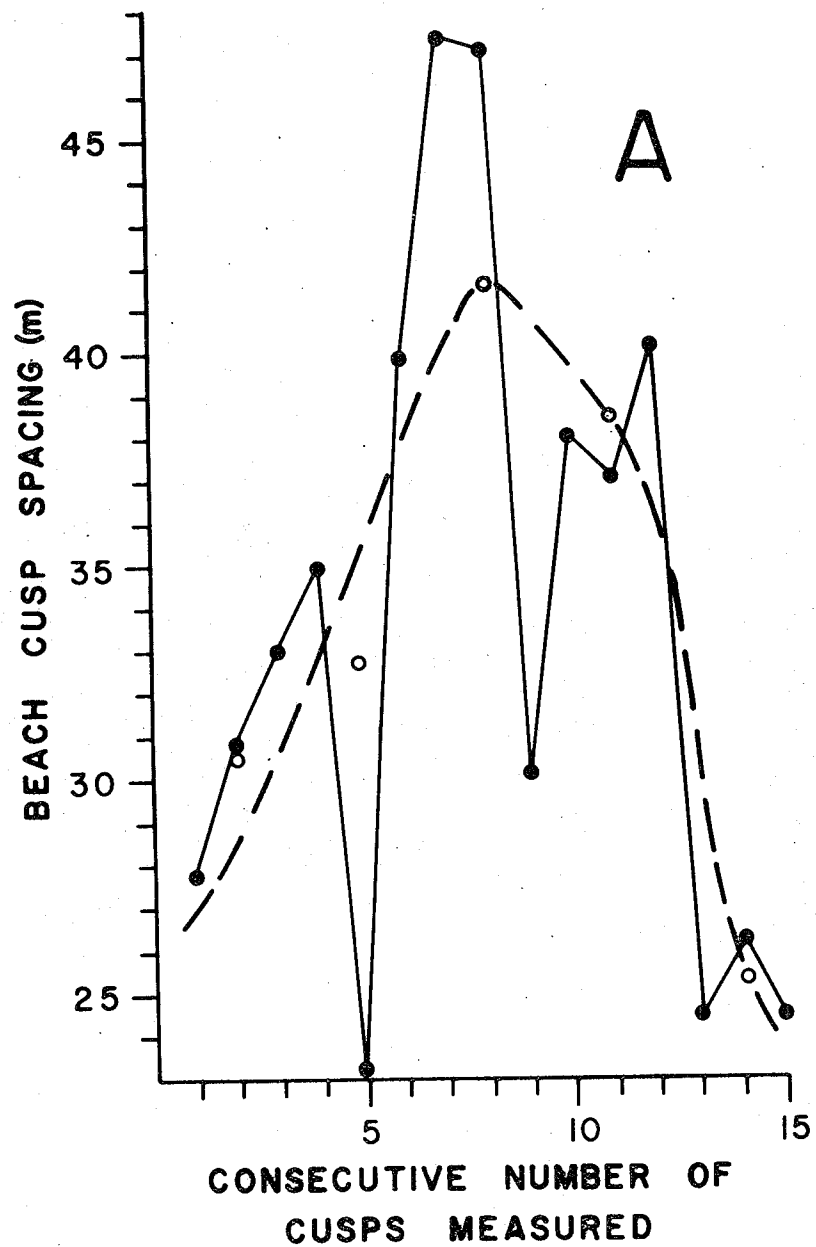


Fig. 5. Measurements of cusp spacing around giant cusps. The darkened circles with connecting solid lines represent individual measurements and the open circles with connecting dashed lines represent a running average. A. Data from the False Cape Virginia area. Cusp 1 was in the center of an embayment, 8 on a salient and 15 in the adjacent embayment. B. Data from Kitty Hawk, North Carolina. Cusp 1 was in the center of an embayment, 18 on a salient and 27 in the adjacent embayment.

processes may, however prevail. Certainly additional observations of cusps forming in the field and direct measurement of the process controlling the spacing are needed.

REFERENCES

- Bowen, A.J. and Inman, D.L., 1969. Rip currents: 2. laboratory and field observations. J. Geophys. Res., 74: 5479-5490.
- Branner, J.C., 1900. The origin of beach cusps. J. Geol., 8: 481-483.
- Cloud, P.E., 1966. Beach cusps: response to Plateau's rule?. Science, 154: 890-891.
- Dalrymple, R.A. and Lanan, G.A., 1976. Beach cusps formed by intersecting waves. Geol. Soc. Am. Bull., 87: 57-60.
- Eckart, C., 1951. Surface waves on water of variable depth. Wave Rep. Univ. of Calif., Scripps Inst. of Oceanogr., La Jolla, 100, Ref. 51-12, 99 pp.
- Evans, O.F., 1945. Further observations on the origin of beach cusps. J. Geol., 53: 403-404.
- Galvin, C.J., 1964. Cusps formed by standing edge waves on a laboratory beach. Geol. Soc. Am. Spec. Pap., 82: 69.
- Gorycki, M.A., 1973. Sheetflood structure: mechanism for beach cusp formation and related phenomena. J. Geol., 81: 109-117.
- Guza, R.T. and Davis, R., 1974. Excitation of edge waves by waves incident on a beach. J. Geophys. Res., 79: 1285-1291.
- Guza, R.T. and Inman, D.L., 1975. Edge waves and beach cusps. J. Geophys. Res., 80: 2997-3012.
- Guza, R.T. and Bowen, A.J., 1975. The resonant instabilities of long waves obliquely incident on a beach. J. Geophys. Res., 80: 4529-4534.
- Huntley, D.A. and Bowen, A.J., 1973. Field observations of edge waves. Nature, 243: 160-162.
- Huntley, D.A. and Bowen, A.J., 1975. Field observations of edge waves and a discussion of their effect on beach material. Geol. Soc. London, 131: 69-81.

- Johnson, D.W., 1910. Beach cusps. Geol. Soc. Am. Bull., 21: 599-624.
- Komar, P.D., 1971. Nearshore cell circulation and the formation of giant cusps. Geol. Soc. Am. Bull., 82: 2643-2650.
- Komar, P.D., 1973. Observations of beach cusps at Mono Lake, California. Geol. Soc. Am. Bull., 84: 3593-3600.
- Krumbein, W.C., 1947. Shore processes and beach characteristics. Tech. Memorandum, Beach Erosion Board, U.S. Army Corps of Engs., 3, 35 pp.
- Kuenen, P., 1948. The formation of beach cusps. J. Geol., 56: 34-40.
- Longuet-Higgins, M.S. and Parkin, D.W., 1962. Sea waves and beach cusps. Geogr. J., 128: 193-201.
- Mii, H., 1968. Beach cusps on the Pacific coast of Japan. Science Reports, Geology, Tohoku Univ., 29: 77-111.
- Otvos, E.G., 1964. Observations of beach cusps and beach ridge formation on Long Island Sound. J. Sed. Petrology, 34: 554-560.
- Rivas, P.G., 1957. Beach cusps and a proposed explanation. In: D.D. Brand (Editor), Coastal Studies of Southwest Mexico. Tech. Rep. Univ. Texas, 1: 25-49.
- Russel, R.J. and McIntyre, W.G., 1965. Beach cusps. Geol. Soc. Am. Bull., 76: 307-320.
- Sanders, J.E., Fornari, D.J. and Wilcox, W., 1976. Symmetrical beach cusps on two modern beaches: depositional origin proved by stratigraphic evidence. Geol. Soc. Am. Abstracts with Programs, 7: 1085.
- Sallenger, A.H., 1974. Mechanics of Beach Cusp Formation, Unpub. Ph.D. thesis, Univ. Va. Charlottesville, 214 pp.
- Schwartz, M.L., 1972. Theoretical approach to the origin of beach cusps. Geol. Soc. Am. Bull., 83: 1115-1116.
- Smith, D. and Dolan, R.G., 1960. Erosional development of beach cusps along the Outer Banks of North Carolina. Geol. Soc. Am., 71: 1979.

Sonu, C.J., 1973. Three-dimensional beach changes. J. Geol., 81: 42-64.

Ursel, F., 1952. Edge waves on a sloping beach. Proc. R. Soc., A214: 79-97.

Williams, A.T., 1973. The problem of beach cusp development. J. Sed. Petrology, 43: 857-866.

FORECASTING STORM-RELATED BEACH EROSION INTENSITY
ALONG THE OCEANIC COASTLINE OF VIRGINIA

William S. Richardson¹

ABSTRACT

An equation to forecast qualitative estimates of storm-related beach erosion along the oceanic coastline of Virginia has been developed. This was done by a statistical evaluation of beach erosion reports and selected parameters from previous storms. The forecast equation was derived from a multiple regression screening program. The regression program correlated qualitative estimates of erosion (predictand), with meteorological and oceanographic parameters (predictors) during 36 extratropical storms from winter seasons (November 1 through April 30) for the period 1962-1973.

Qualitative estimates for erosion (none, minor, moderate, major, and severe) were extracted from the Environmental Data Service publication, Storm Data, and then converted to assigned numerical values. The trial predictors were storm duration, tide height at National Ocean Survey tide stations, mean amplitude of the spring tide, length of time between erosion events, type of beach material, month of the year, wave height and period at offshore light stations, and wave height and period computed by the Sverdrup-Munk-Bretschneider (SMB) hindcast equations for deep and shallow water.

A generalized beach erosion equation was derived which computes beach erosion intensity as a function of storm duration, maximum tide height, maximum storm surge height, and month of the year, since these are the dominant trial predictors. The multiple correlation coefficient associated with this equation is 0.69. The derived beach erosion

¹Techniques Development Laboratory, National Weather Service, Silver Spring, Maryland.

equation was tested on independent data. The results of these tests indicate that the beach erosion equation provides meaningful forecast guidance.

INTRODUCTION

The coastal storm of early March 1962 affected the entire Atlantic Coast of the U.S. causing severe erosion at Virginia Beach (see Fig. 1). It is fortunate that storms causing this much damage are rare. However, storms with large erosion potential affecting small coastal lengths can occur each winter. Virginia's oceanic coasts experience storm-related beach erosion about once every two years. Of these erosion events, one-third (one event every 6 years) is severe erosion (Richardson, 1977).

Factors important in determining storm-related erosion (Hayes and Boothroyd, 1969; U.S. Army Corps of Engineers, 1971; King, 1972; and U S. Army Coastal Engineering Research Center, 1973) are:

- (1) winds (speed and direction)
- (2) waves, swell, and effect of offshore bathymetry
- (3) breakers
- (4) astronomical tide
- (5) storm surge
- (6) initial condition of the beach.

A discussion of these factors is given by Richardson (1977).

Beach erosion has been studied by many people in private and government agencies. These studies are of two types:

(1) Wave tank and laboratory studies which are conducted in a controlled environment (Johnson, 1952). These studies are described by Wiegel (1964, p. 373-376).

(2) Field studies which are conducted in the uncontrolled environment. Field studies can be subdivided into dynamical studies and empirical (statistical) studies. Dynamical studies relate erosion to physical laws and principles (Bagnold, 1966). Empirical studies relate erosion to a set of independent variables based on observations (Harrison, et al., 1971; Davis and Fox, 1972; and Wasserman and Gilhousen, 1973).



Figure 1. Property damage at Virginia Beach, Va., following the severe March 1962 storm.
(Photograph by N. Arthur Pore)

Most studies which predict the transport of sand along or away from a beach in dimensions of volume per unit time (cubic yards per hour) would not mean very much to the general public. A much more useful prediction is a qualitative forecast of erosion (minor, moderate, major and severe) as recommended by Harrison, et al. (1971) and Rush (1973).

Richardson (1977) constructed a storm-related erosion intensity matrix for Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida. The matrix was constructed in the following manner: a numerical value was assigned to separate qualitative terms describing the intensity of storm-related beach erosion for a coastal state. The numerical values and their qualitative terms are: 0 (no erosion), 1 (minor erosion), 2 (moderate erosion), 3 (major erosion), and 4 (severe erosion). Beginning with March 1962 and continuing through April 1973, all winter Storm Data volumes (November 1 through April 30) were scanned for beach erosion in all Atlantic Coast states. Any time there was mention of erosion or wave damage along an Atlantic Coast state, an intensity of 1, 2, 3, or 4 was assigned to the affected state. The assignment was made in accordance with the descriptive terms shown in Figure 2. An abbreviated storm-related erosion intensity matrix for Virginia is shown in Table 1. Although summer storms can cause beach erosion, only winter (defined here as November 1 through April 30) storm data were scanned because erosion events which occur in summer and early fall are often associated with tropical storms. (These storms were not considered in this study.)

Derived Beach Erosion Intensity Equation

The beach erosion intensity matrix (predictand) was correlated with meteorological and oceanographical parameters (predictors) using a statistical screening procedure. For a discussion of these predictors refer to Richardson (1977). Data from Maine, Massachusetts, Rhode Island, New York, New Jersey, Delaware and Virginia were pooled (230 sets of data) to derive the following generalized equation:

$$BE = -0.77 + 0.64(SD2.5) + 0.20(MT) + 0.18(MS) - 0.32(BC(FEB))$$

BE is beach erosion intensity (linear scale 0 through 4). SD2.5 is storm duration, the number of consecutive high tides (approximately 12.4 hours apart) that the tide is greater than or equal to a "critical value". The critical value for the Virginia Coast is 4.0 feet above mean sea level (MSL). MT is maximum tide height in feet above MSL. MS is maximum storm surge height (feet). BC(FEB) is the monthly beach cycle predictor which assigns the following weights to the six winter months: January (0.86), February (1.0), March (0.86), April (0.50), November (0.0) and December (0.50).

This equation shows as the storm duration (SD2.5), maximum tide height (MT) and maximum storm surge (MS) increase, the erosion intensity increases. The first two predictors (storm duration and maximum tide height) were the same predictors that Darling (1964) used in constructing his "vulnerability curve" for Atlantic City, New Jersey.

The fourth predictor, the monthly beach cycle predictor, [BC(FEB)] is selected with a negative sign. The greatest number of erosion events occurred in November, December and February (Richardson, 1977). January and February are the months in which maximum wave heights occur along the east coast (Galvin and Hayes, 1969). Therefore, by February, in general, the berm has already been cut back, and there is less sand to be eroded. This is in agreement with the erosion equation which shows that if two erosional storms struck the same coastal state (one in November, and one in February) and if the three predictors (storm duration, maximum tide height, and maximum storm surge height) were the same for both storms, the November storm would have a higher (0.32 higher) erosion potential. This has also been noted by Harrison, et al., 1971.

The predictor which has the highest simple correlation with the predictand (beach erosion intensity) is storm duration (SD2.5). The simple correlation between these two variables is 0.60. The relatively high correlation between these two variables shows that erosion intensity is greatly dependent on the period of time that the super elevated water surface acts on the beach face. For example, if the Virginia coast during the month of March experienced a storm which lasted through one high tide with a maximum tide at Sewalls Point of 7.1 feet above MSL and a maximum storm surge of 5.6 feet, the beach erosion intensity computed by the equation would be 2.0. However, if this same storm remained in the same area for 5 high tides, as did the March 1962 storm, the erosion intensity would increase from 2.0 for one high tide to 4.6.

NUMERIC VALUE QUALITATIVE TERM DESCRIPTIVE TERMS

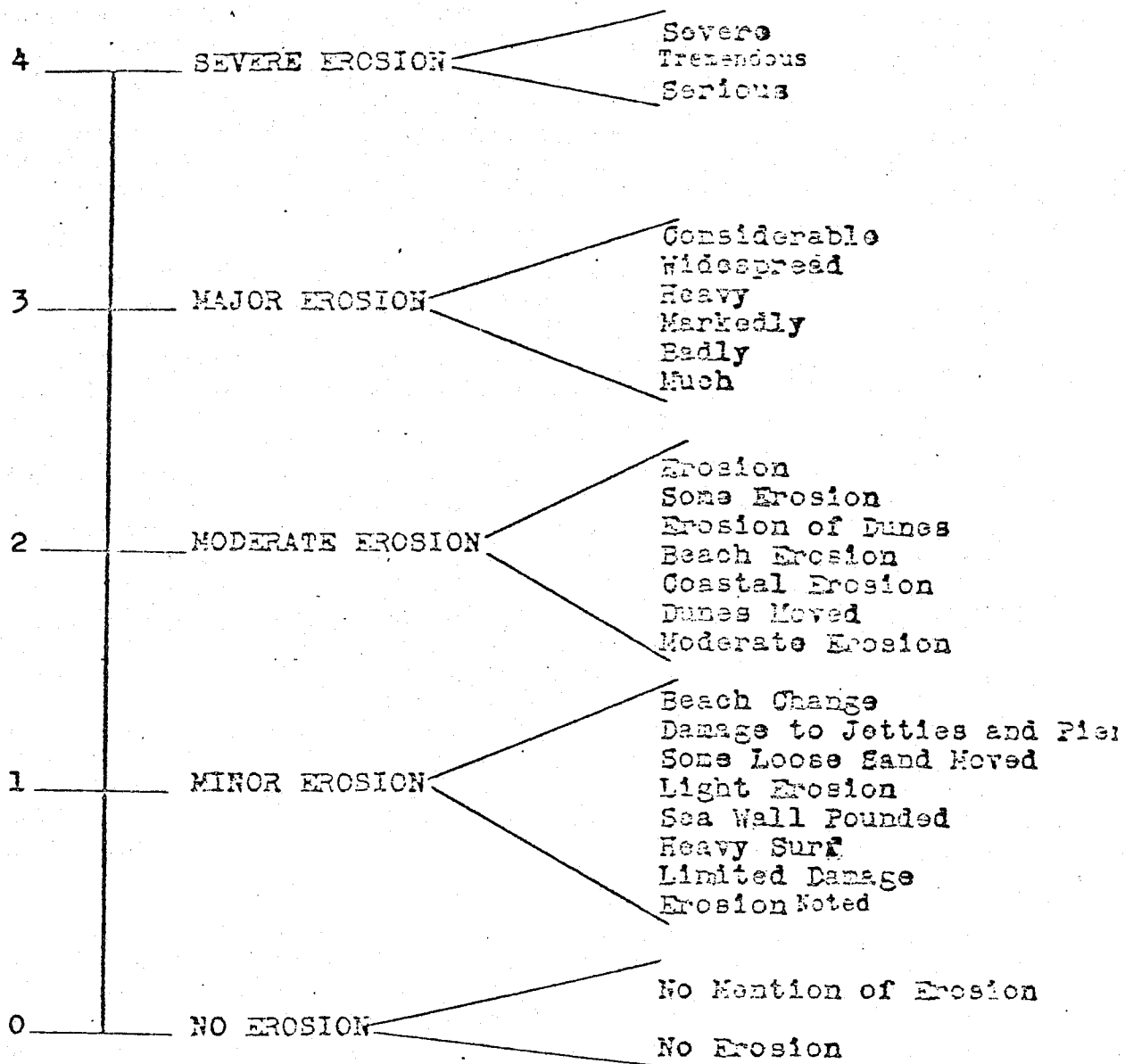


Figure 2. Storm-related erosion intensity scale and associated qualitative and reported descriptive terms.

Table 1. Abbreviated storm-related erosion intensity matrix for Virginia.

Storm dates	Numerical value	Qualitative term
March 6-9, 1962	4	SEVERE
November 26-30, 1962	3	MAJOR
*November 29-30, 1963	0	NONE
November 11-13, 1968	1	MINOR
April 6-7, 1971	2	MODERATE
** February 19-20, 1972	0	NONE

*Major and moderate erosion along the Maine and Massachusetts coast

** Severe erosion along the Maine and Massachusetts coast

Table 2. Observed and computed qualitative erosion intensities for the abbreviated storm-related erosion intensity matrix for Virginia (Table 1).

Storm dates	Observed Qualitative term	Computed Qualitative term
March 6-9, 1962	SEVERE	SEVERE
November 26-30, 1962	MAJOR	MODERATE
November 29-30, 1963	NONE	NONE
November 11-13, 1968	MINOR	MODERATE
April 6-7, 1971	MODERATE	MINOR
February 19-20, 1972	NONE	NONE

VERIFICATION

The derived beach erosion equation was used to compute erosion intensity values for the five storm events listed in Table 1. The observed and computed qualitative erosion intensities for these five events are shown in Table 2. The "severe" and "no" erosion events are properly specified, while the "major", "moderate" and "minor" events are each "off" by one category.

Since the development of the erosion forecast equation in 1975 there have been no cases of reported erosion along the Virginia Coast. During two years of testing, the erosion equation has forecast no cases of erosion along the Virginia coast. The equation did forecast a major erosion event along the Maine and Massachusetts coast on March 16-17, 1976 which verified very well with observed erosion reports.

SUMMARY

The National Weather Service is using the statistical beach erosion equation on a trial basis to cast beach erosion in qualitative terms. In the future these generalized qualitative forecasts may be localized by including wave refraction information (e.g., such as from Goldsmith, et al., 1974). For example, if a refraction diagram based on wave forecasts for a particular storm shows a convergence of wave orthogonals at Virginia Beach, Virginia, and if moderate beach erosion is forecast for the Virginia Coast, then a generalized forecast of erosion such as, "Moderate erosion along the Virginia coast", could be localized and changed to "Moderate erosion along the Virginia Coast, except in the Virginia Beach area, where erosion is expected to be severe".

REFERENCES

- Bagnold, R.A., 1966. An Approach to the Sediment Transport Problem from General Physics, Geological Survey Professional Paper 422-I, U.S. Government Printing Office, Washington, D.C., 37 pp.
- Darling, J.M., 1964. Seasonal Changes in Beaches of the North Atlantic Coast of the United States, Proceedings of the 9th Conference on Coastal Engineering, ASCE, pp. 236-248.
- Davis, R.A., Jr., and W.T. Fox, 1972. Coastal Dynamics Along Mustang Island, Texas, Office of Naval Research Geology Branch, Technical Report No. 9, October, 68 pp.
- Galvin, C.J., Jr., and M.O. Hayes, 1969. Winter Beach Profiles and Wave Climate (Abs.) in Program, Annual Meeting, Geological Society of America, Atlantic City, N.J., November 10-12.
- Goldsmith, V., Morris, W.D., Byrne, R.J., and Whitlock, C.H., 1974. Wave Climate Model of the Mid-Atlantic Shelf and Shoreline (Virginian Sea): Model Development, Shelf Geomorphology, and Preliminary Results: VIMS SRAMSOE No. 38, 146 p.
- Harrison, W., P.A. Bullock, and N.A. Pore, 1971. Forecasting Storm-induced Beach Changes Along Virginia's Ocean Coast, U.S. Army Coastal Engineering Research Center, Washington, D.C., December, 47 pp.
- Hayes, M.O., and J.C. Boothroyd, 1969. Storms as Modifying Agents in the Coastal Environment, Coastal Environments, Geology Department, University of Massachusetts, Amherst, Mass., pp. 245-265.
- Johnson, J.W., 1952. Sand Transport by Littoral Currents, State University of Iowa Studies in Engineering Bulletin 34, Proceedings of the 5th Hydraulic Conference, June, pp. 89-109.
- King, C.A.M., 1972. Beaches and Coasts, Second Edition, St. Martin's Press, Inc., N.Y., 570 pp.
- Pore, N.A., W.S. Richardson, and H.P. Perrotti, 1974. Forecasting Extratropical Storm Surge for the Northeast Coast of the United States, NOAA Technical Memorandum NWS TDL-50, January, 70 pp.

Richardson, W.S., 1977. Forecasting Beach Erosion Along the Oceanic Coastlines Northeast and Mid-Atlantic States, Masters Thesis, School of Marine Science, The College of William and Mary, Williamsburg, Va., 121 pp.

THE "VAMP" COASTAL DUNE CLASSIFICATION

Victor Goldsmith, Harold F. Hennigar
and Andrew L. Gutman

INTRODUCTION

With respect to long-term viability and preservation of Currituck Spit, the most important processes appear to be eolian. Recent studies by Hennigar (1977) and Gutman (1977), and discussed in this volume, indicate that the various types of dunes exhibited on Currituck Spit can change, and have completely changed, within the time frame of 10 to 20 years. Despite the large spatial and temporal variability in dune form and processes, there occur four basic types of dunes. These same dune types occur in coastal areas throughout the world,¹ though most areas (especially on the U.S. east coast) are not as blessed with the variety of eolian forms and processes as those here on Currituck Spit.

VAMP

Using the "VAMP" Coastal Dune Classification System proposed by Goldsmith, et al. (1977), there are four basic types of dunes in the study area. These include (1) Vegetated Dunes; (2) Artificially-Inseminated Dunes (AID); (3) Medaños and (4) Parabolic Dunes. The first letters of these four dune types conveniently form the word "VAMP".

There are, of course, other types of coastal dunes such as eolianites (i.e., made of calcium carbonate which later "cements" together) and lunettes (made of silt-clay). These two dune types occur primarily in Australia and are not included here because they are relatively rare compared to the four main dune types.

¹A thorough review of coastal dune types around the world is in Goldsmith (1975) and so will not be duplicated here.

Vegetated Dunes

Vegetated dunes accumulate around vegetation, which act as sandtrapping baffles (vertical growth of 0.3 to 1.0 m/yr), and also as an internal skeleton fixing the dunes in place. This results in a characteristic internal geometry containing low-angle dipping beds ($m = 12^\circ$) and polymodal dip directions (Goldsmith, 1973, 1975). Vegetated dunes form the foredunes or the front dune line which occurs commonly around the world. In this area the vegetated foredunes are highest and most prominent at the north end of Virginia Beach, in Back Bay and in False Cape where they reach elevations of more than 10 m. At Cape Henry and in Currituck County the foredunes are lower in elevation (usually about 3 m) and grade landward into sparsely vegetated eolian flats containing multiple lines of sand fencing. On the east coast of the United States the dominant grass in the front dune line is Marram Grass (*Amophilia arenaria*) and Sea Oats (*Uniola paniculata*) in the areas roughly north and south of North Carolina, respectively (Fig. 1).

The internal geometry of the vegetated coastal dunes on Currituck Spit (discussed by Rosen, et al., in this volume) is similar to other coastal areas around the world (Goldsmith, 1973) in that they are all characterized by low angle dipping beds ($m = 14^\circ$ on Currituck Spit). They appear unique in that the bimodal dip direction is bisected by the axis of shoreline orientation on Currituck, rather than the dominant wind directions as on other coastal areas (Figs 2a, b and c).

It is generally assumed that foredunes form during periods of beach accretion and widening from sand blowing off the intertidal beach. However, recent field studies (discussed in this volume, Leatherman, 1976 and others) indicate that this is an overly simplistic view and that foredunes continue to grow upward and landward, even during periods of beach erosion with the sand supplied from the landward side of the dunes (Fig. 3). The internal geometry studies (Fig. 2) further support the concept of vegetated foredunes composed of sand supplied from many directions. This is due to the dominance of the westerly winds (in both speed and percent frequency) on the east coast of the United States; the southwest, northwest, and northeast winds are of about equal frequency, and the northeast and southwest are about the same average speed (see Gutman, this volume).



Figure 1. The main two types of vegetation instrumental in the growth of vegetated dunes on the U.S. east coast are marram grass (top) north of North Carolina, and sea oats (bottom) from North Carolina to the south.



Figure 2a. Low angle bedding dipping both seaward (toward the viewer), and landward (into the photo) is typical of the foredunes on Currituck Spit. Low angle bedding, but in polymodal directions is typical of the parabolic dunes. (Photos at south end of Back Bay Wildlife Refuge, Virginia October 12, 1972).

Figure 2b.

FOREDUNE CROSSBEDS, CURRITUCK SPIT VA./N.C. AZIMUTHS AND AMOUNT OF DIP

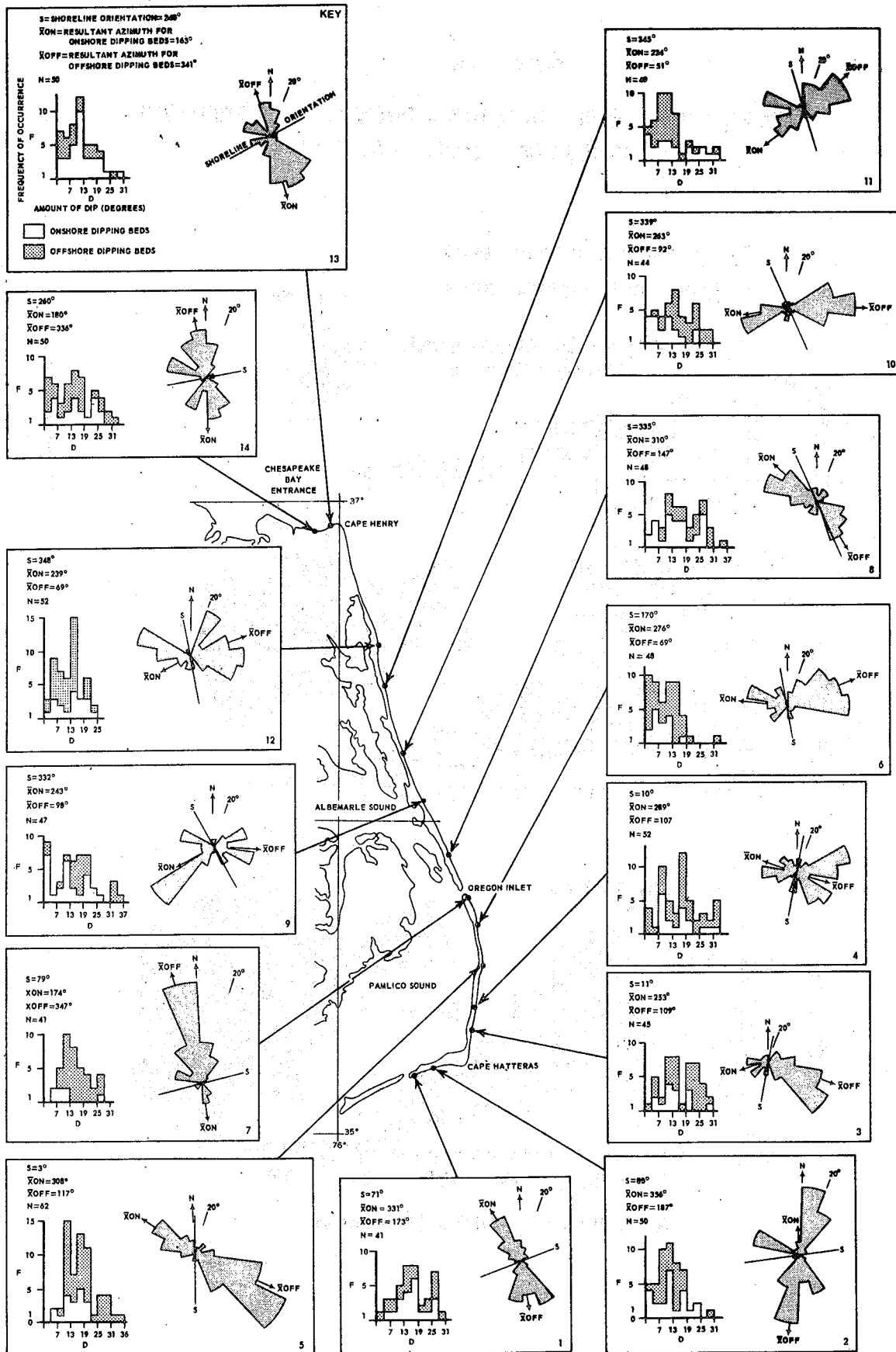
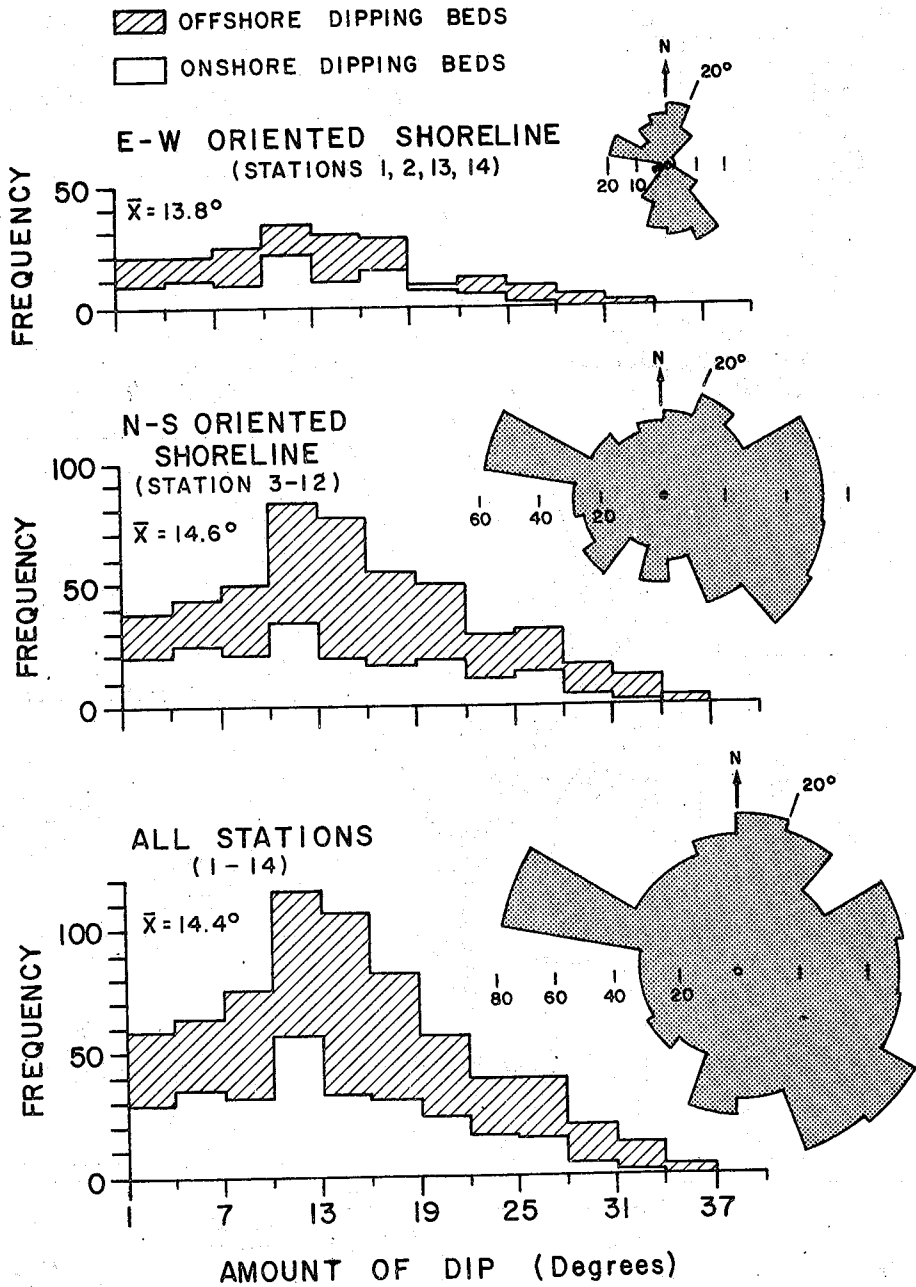


Figure 2c.

FOREDUNE CROSS BED DIP ANGLES & AZIMUTHS
CURRITUCK SPIT, VA. /N.C.



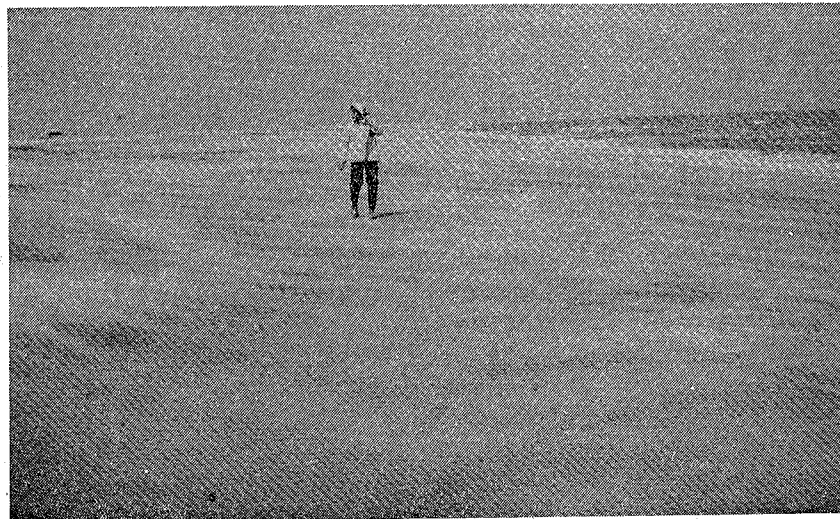


Figure 3. Sand from the interior blows both into the fore-dunes and back onto the beach under the effects of the dominant westerly winds.

Artificially-Inseminated Dunes (AID'S)

AID's have an anthropomorphic origin, but the concomitant and subsequent sand accumulation processes are natural. AID's commonly transition into vegetated dunes, though in many cases, AID's result in different types of dunes. Examples of the 'seed' are dune fencing, vegetation plantings, bulldozing and anthropomorphic sedimentation. Two major types of AID's are (1) Accidental and (2) Planned. Accidentally inseminated dunes are those in which the seed consists of ship wrecks, car wrecks (Fig. 4), house wrecks and abandoned beach slum housing. Planned artificially inseminated dunes, consist of bulldozed beach sand, Christmas trees, WWII Army bunkers, and most commonly and effectively, snow fencing and planting of beach grass.

One thinks of sand dune growth as a dynamic, but natural process whereby sand is accumulated by wind into topographic highs, and in which man's presence is quite subtle, if at all. The reality of the situation is that this is not true for most of the coastal dunes on the U.S. East coast, and especially not true in the last 40 years. Most of these coastal dunes bear the inprint of people in both subtle, and in very dramatic ways.

On Currituck Spit, planting of grass is now relatively rare, and the major AID programs are fencing and bulldozing (Figs. 5a and b, and 6). Back Bay's active sand fencing program in the dunes ended in 1974 by order of the Department of Interior. This was due more to a lack of funds rather than an overt decision by the Department of Interior (D. Hollands, Back Bay Wildlife Refuge, personal communication). The emplacement of sand fencing was observed to be quite effective in accumulating sand and building up the dunes; e.g., at Profile location 14 in Back Bay a 1.8 m high fence was completely encased in sand within a two year period (1972-74). Dune fencing has been actively employed during the last five years by the developers at the south end of Currituck County (south of Corolla). However, it's emplacement appears to be sporadic in the form of dune erosion and the new construction of houses too close to the beach.

Medaños

Medaños are large, isolated hills of sand 10 to 100 m in elevation, asymmetrical in profile, lacking vegetation, migrating downwind up to tens of m/yr, resulting in characteristic slipfaces of unconsolidated sand at the angle of

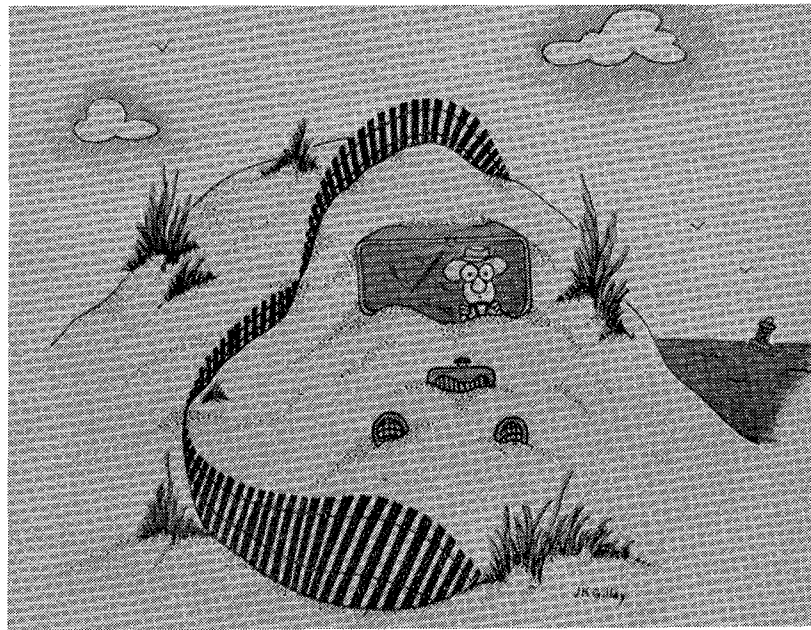


Figure 4. An example of one of the two main types of Artificially Induced Dunes (i.e., AID), Planned and Accidental (schematicized in the top), is shown in the bottom view at Penney Hill, North Carolina.

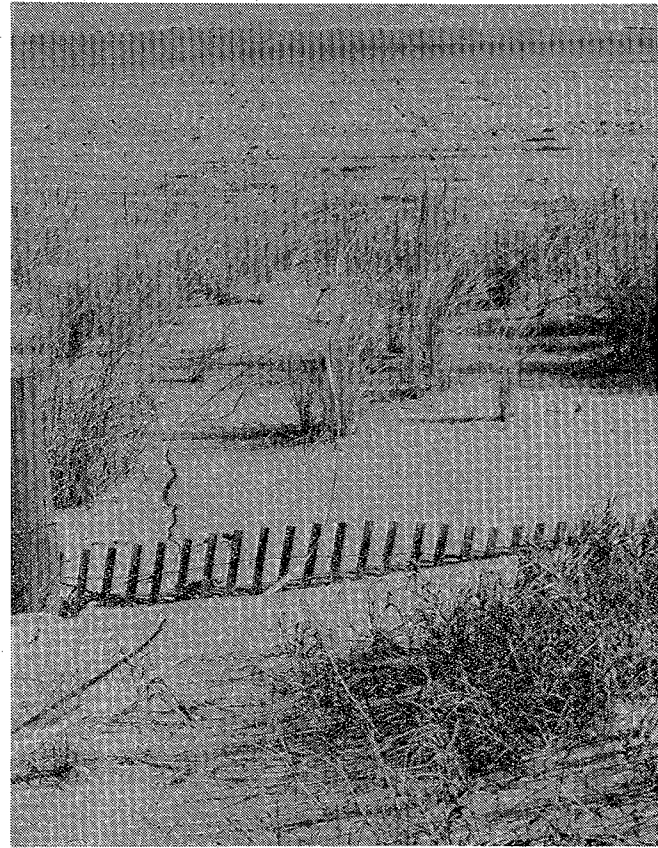


Figure 5a. The effectiveness of sand fencing as an AID for dune growth is illustrated in these two views at U.S. Back Bay Wildlife Refuge profile location number 14 on September 20, 1972 (left) and December 3, 1974 (right), indicating 1.5 m of vertical eolian accumulating.



Figure 5b. The ineffectiveness of bulldozing is illustrated in these two views of the same dune gap on September 1976 (top) and February 10, 1977 (bottom). The wind has removed all the bulldozed sand.



Figure 6. The dramatic natural, vegetation-induced, dune growth is illustrated in these two views at False Cape State Park on September 20, 1972 (bottom) and February 10, 1977 (bottom), indicating vertical eolian accumulation of about 40 cm/year.

repose which are oriented transverse to the wind. About two dozen medaños occur in Currituck County (Fig. 7), with elevations up to 25 m (Lewark Hill) and migration rates up to 13 m/yr (Jones Hill, 1940-1975). In total, the amount of sand in the medaños on Currituck Spit represent a significant amount of sand (i.e., many times the annual long-shore drift rate).

These are presently active and dynamic dunes. Monthly overflights made during the 1974-1976 interval indicated dramatic differences in the dune surfaces on a monthly time scale. Although the slipfaces are dominantly on the southwest sides of the dunes, a second slipface often develops on the east sides in response to either northwest or southwest winds. The dominant geomorphic form of sediment transport appears to be sand waves about 1 m in height and 20-40 m in wavelength. However, these eolian sand waves only appear during high velocity wind conditions and quickly dissipate with decreasing wind velocity. Thus, the upper surface of the dune is quite dynamic, with much back and forth motion of sand.

The actual amount of net movement in one direction (e.g., towards the southwest) has been measured by Gutman (1977, and in this volume). Relative to total transport, however, there is probably very little net transport. Thus, the cause of the large height is hypothesized to be the movement of sand from the three major wind directions, which results in the upward buildup and in this rather distinctive sand hill shape, defined here as a medano (see A.G.I. Glossary of Geology, 1972 edition).

The internal geometry of these medaños is unknown. Since these dunes resemble transverse desert dunes, it is presumed that the internal geometry of the desert dunes (i.e., dominance of high angle cross-beds) as described in Goldsmith (1975) is probably representative of these dunes. However, the high angle beds would be bimodal here, and the dunes would have smaller-scale crossbedding from the sand waves.

Parabolic Dunes

Parabolic dunes (defined by their characteristic planimetric view), are similar to medaños in that they have a slipface formed in direct response to the wind, and a deflation zone within their upwind concave side (Fig. 8), but are different in that they have an internal geometry more

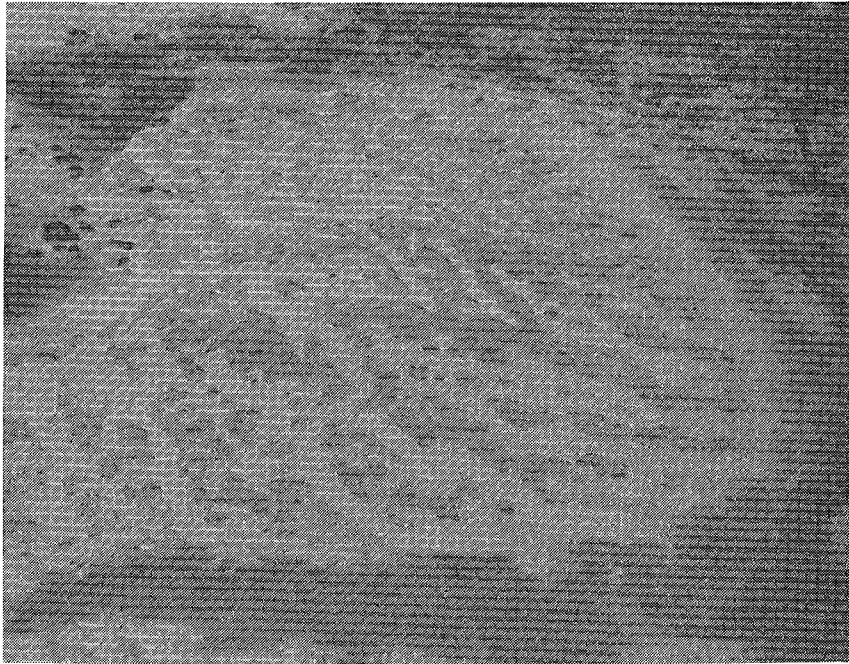


Figure 7. Lewark Hill medaño, approximately 20 m in elevation illustrating sand waves which are formed under high-velocity wind conditions.

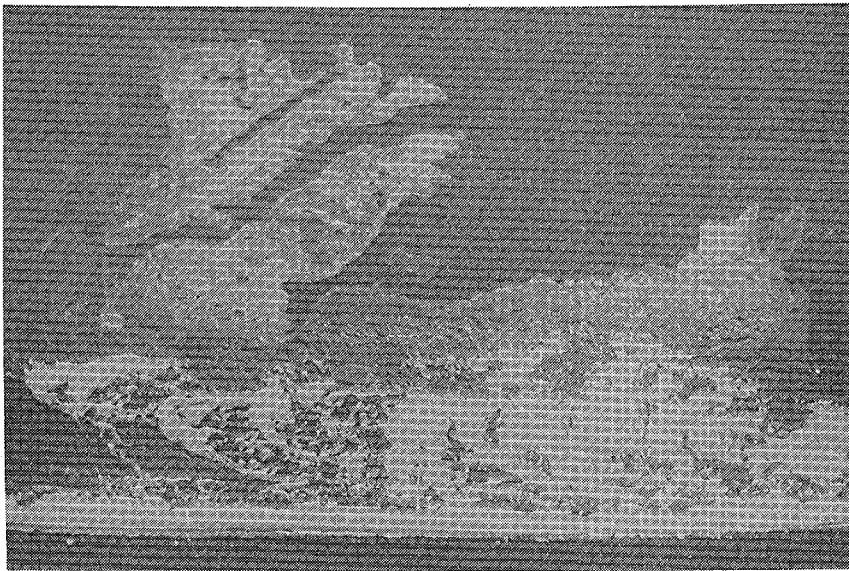


Figure 8. Parabolic dunes north of Virginia/North Carolina State line.

characteristic of vegetated dunes (Figs. 9a, b, and c) and may be fixed in place depending on their recent vegetation history. Parabolics occur prominently in False Cape State Park, and also in southern Currituck County where their aerial distribution generally grades from vegetated parabolics to transverse dunes (i.e., medaños) in an upwind (i.e., north) direction. (See cover photographs.)

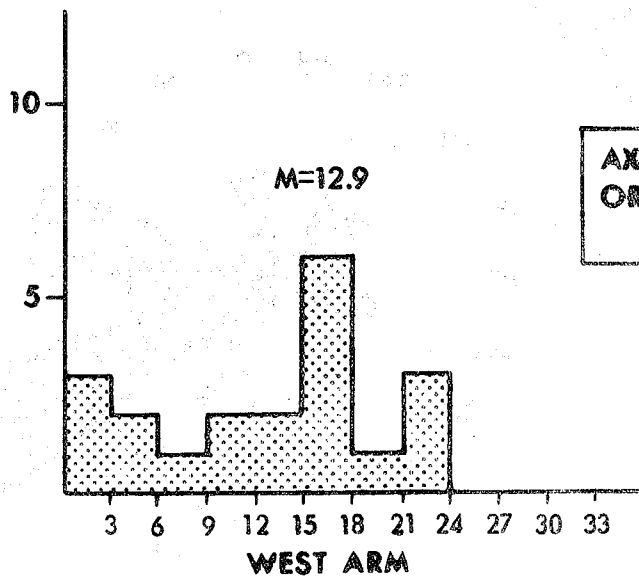
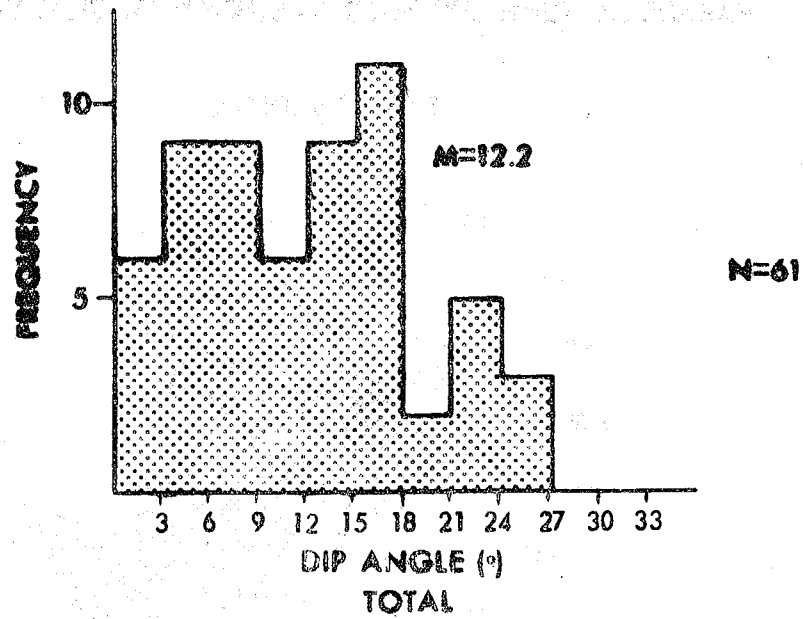
Parabolics have shown in situ temporal changes from other dune types. Studies by Hennigar (1977, and in this volume) show that the dune history at False Cape State Park since the 1930's is: (a) Unvegetated sand sheet; (b) Medaños; (c) Parabolic Dunes. Hennigar relates this dune evolutionary sequence to: (a) the emplacement of fencing (i.e., AID's) close to the beach, forming a high foredune; and (b) the growth of a high maritime forest on the bay side; both of which resulted in a cut-off of sand supply to the interior and a gradual stabilization of the unvegetated sand sheet through the sequence mentioned above. Gutman (1977, and in this volume) has further defined the specific changes of a parabolic dune from its' initial development through its final stage, and alignment of the dune (the most dramatic aspect) to the wind climate.

The internal geometry of parabolic dunes is not well known. The internal geometry (direction and amount of dip of the beds) of one parabolic dune on Currituck Spit, Virginia-North Carolina was measured in 1975 by V. Goldsmith, P.S. Rosen, M. Boule and Y.E. Goldsmith and was plotted by E. Barnett (Figs. 9a, b and c). The most surprising aspect is that most beds have low angle dips with mean dips of 12.2° , 12.9° , 13.5° and 10.4° for all beds, the west arm, the east arm, and the south end, respectively. Also, there is a wide scatter in dip direction (A_z), although most beds dip towards the sector of 60° to 160° . This is approximately 90° counterclockwise from the downward direction apparent from the surface geometry. It is probably due to the importance of the northwest winds which are most apparent in beds in the east arm, which dip primarily towards 60° to 140° . The beds in the west arm, in contrast, are evenly distributed, and dip in all directions. However, the beds in the south end dip primarily towards the 120° to 220° and thus are most representative of the apparent wind direction, as interpreted from the surface geometry (i.e., the axis of dune orientation is 189° azimuth).

In summary, the internal geometry is more representative than the surface geometry of the multidirectional wind regime. It is also suggestive of much back-and-forth

Figure 9b.

PARABOLIC DUNE CROSSBEDS—CURRITUCK SPIT, VA./N.C.
AMOUNT OF DIP



AXIS OF DUNE
ORIENTATION
= N 9° E

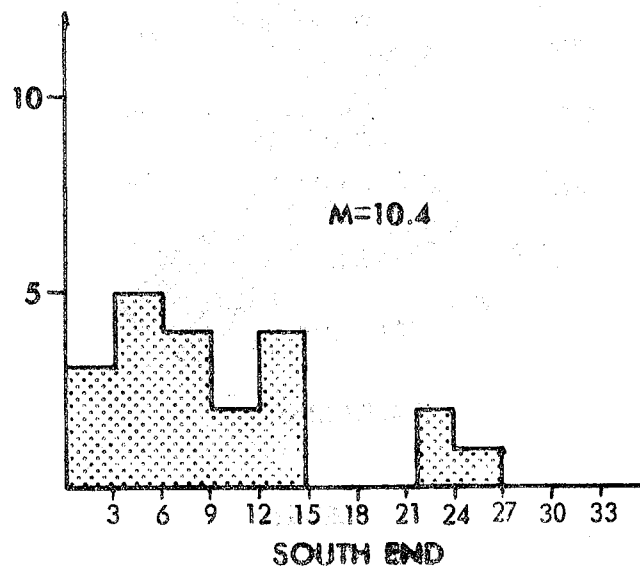
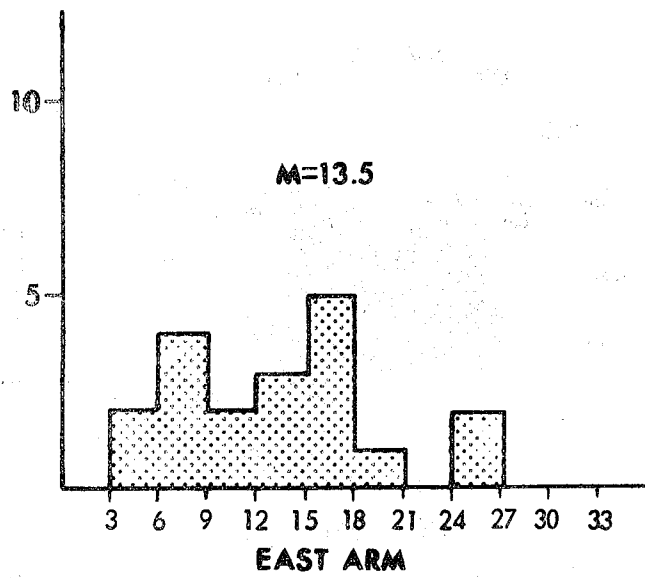
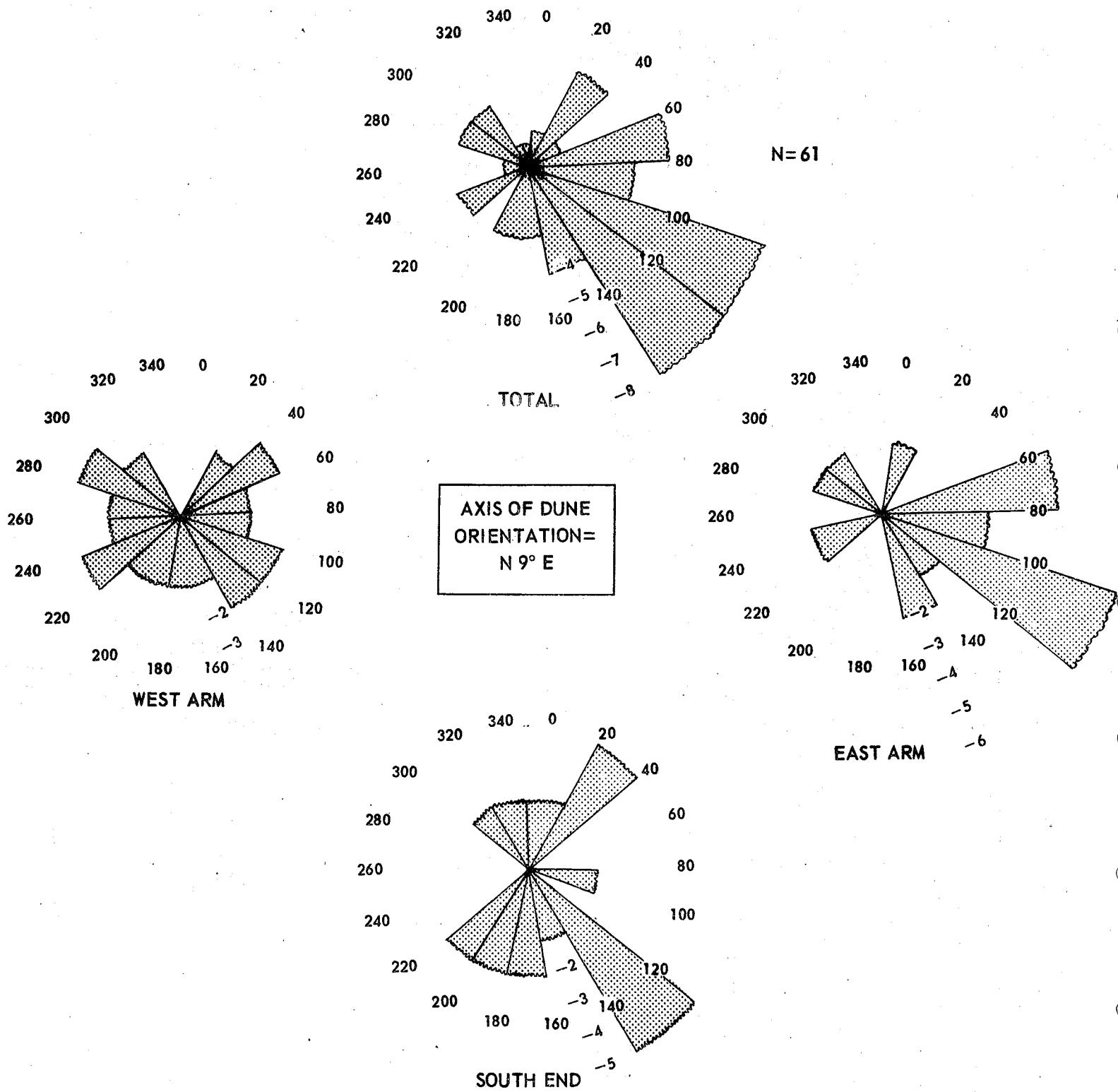


Figure 9c.

PARABOLIC DUNE CROSSBEDS - CURRITUCK SPIT, VA./N.C.

DIP DIRECTIONS



eolian transport within individual compartments, which are isolated by vegetation. This aspect, plus the low dips typical of vegetated dunes, indicate that these parabolic dunes are closer in morphology to vegetated dunes than to transverse, medaño dunes.

SUMMARY

The VAMP Coastal Sand Dune classification scheme is proposed. It is based on the four main types of dunes observed on the coast: (a) Vegetated; (b) Artificially-Inseminated Dunes (AID); (c) Medaños; and (d) Parabolic Dunes.

A typical in situ evolutionary sequence of dune development from unvegetated sand sheets, exemplified at False Cape State Park, Virginia during the last 35 years, is: (a) Medaños; (b) Parabolic Dunes; and (c) Vegetated Dunes.

The internal geometry of parabolic dunes (based on a limited sample) appears similar to vegetated dunes in that both are characterized by low-angle dipping beds ($M = 12^\circ$ and 14°) and polymodal dip directions.

AID's, which commonly transition into vegetated dunes, are relatively abundant in coastal areas. They result from the active fencing and planting programs and the abundance of flotsam and jetsam in beach and dune areas, which all act as baffles, trapping wind-blown sand. The abundance of AID's raises the important question as to what is natural dune development in the coastal zone.

Though four dune types are delineated and defined here, it must be emphasized that both rapid (ten's of years) in situ temporal evolutionary changes between dune types as well as downwind spatial changes in dune types commonly occur. Thus, one needs to be well aware of these dune characteristics and changes in planning the inevitable coastal developments, in order to prevent unforeseen and undesirable changes, such as the renewal of the sand sheets of the 1930's and 1940's throughout the Currituck Spit area.

REFERENCES

- Gary, M., McAfee, R., Jr., and Wolf, C.L., (ed.), 1972. Glossary of Geology, American Geological Institute, Washington, D.C., 805 p.
- Goldsmith, V., 1973. Formation and Internal Geometry of Vegetated Coastal Sand Dunes: J. Sed. Petrol., V. 43, p. 1128-1142, VIMS Contrib. No. 521.
- Goldsmith, V., 1975 (in press). Eolian Sedimentation in Coastal Areas. Chapter 4 in Davis, R.A. (ed.), Coastal Sedimentation, Edwards Bros., Mich., VIMS Contribution No. 533, VIMS Printing.
- Goldsmith, V., Gutman, A., Hennigar, H., Goldsmith, Y.E., Rosen, P.S., Boule, M., and Barnett, E., 1977. Coastal Dune Geomorphology and Classification, Abstract, Proceedings of the American Association of Petroleum Geologists Annual Meeting, Washington, D.C.
- Gutman, A.L., 1977. Aeolian Coastal Processes: Currituck Spit, Virginia-North Carolina, Interaction Between Aeolian Sand Transport, Dune Geomorphology and Vegetation Density. Masters Thesis, Virginia Institute of Marine Science, Gloucester Point, Va., unpublished.
- Hennigar, H.F., 1977. Historical Evolution of Coastal Sand Dunes, Currituck Spit, Virginia-North Carolina. M.S. Thesis, Virginia Institute of Marine Science, Gloucester Point, Va., in prep.
- Hollands, Dennis, 1974. Personal communication, Manager, Back Bay National Wildlife Refuge, Virginia Beach, Va.
- Leatherman, S., 1976. Quantification of Overwash Processes. Ph.D. Dissertation, Department of Environmental Sciences, University of Virginia, Charlottesville, Va.

EVOLUTION OF COASTAL

SAND DUNES: CURRITUCK SPIT, VA/NC

Harold F. Hennigar

Abstract

A sequence of dune succession on Currituck Spit, Virginia/North Carolina is delineated. Active, un-vegetated sand sheets first break up into discrete sand hills (or medanos), which in turn are stabilized by vegetation, and 'metamorphose' into large semi-vegetated parabolic dunes. This sequence appears to be a direct result of sand fencing, which aided the formation of a protective foredune that reduced sand supply to the interior. Four compartments on the Spit were examined, and it is concluded that all are at different stages within the proposed dune succession sequence. The importance for barrier island stabilization of a protective foredune, broken at intervals to allow interaction between beach and interior, is discussed.

INTRODUCTION

Prior to the inception of sand fencing during the late 1930's, Currituck Spit had been transposed from a lush, vegetated "paradise" into a veritable desert.¹ Sand sheets covered the Spit from the Atlantic Ocean to Currituck Sound and most of the population had emmigrated to the mainland. The WPA transported 1500 workers into the area and instituted a massive program to construct a protective foredune and stabilize the interior with vegetation. Within a year, results were apparent and the program appeared to be successful (Stratton, 1943). Unfortunately, World War II interferred and much of the beneficial work that had been completed was rendered useless, either by burial or by storm-induced destruction. Consequently, sand sheets were again released in many areas and grazing resumed (Guild & Fletcher, 1947; Gibbs & Nash, 1961).

¹See A Brief History of Currituck Spit, VA/NC, by H.F. Hennigar, in this volume.

Moving ahead in time to the 1970's, we find many changes have occurred. In some areas large parabolic dunes have formed, in others, an echelon medianos are present, and elsewhere active sand sheets are still in evidence (see STOP description photomosaic). Assuming that natural processes which are acting along this 75 km., inlet-free, barrier spit are nearly identical for the entire length, what then is responsible for these differences in morphology? It is the purpose of this paper to describe and suggest an explanation for these dramatic differences in dune morphology.

In order to determine whether these extreme variations in morphology and vegetation had always been present on Currituck Spit, it was necessary to investigate the history as far back as was possible. From the history² it appears that Currituck Spit was, for the most part, well vegetated until the early nineteenth century. Subsequently, the vegetation decreased due to logging and grazing and resulted in a release of active sand sheets. Imagery dating back to 1937, (northern section) and 1940 (southern section) revealed that a sand sheet covered the Spit. This concurred with the history as reported in the literature. Consequently, it can be assumed that in the late 1930's, conditions along the entire length of the Spit were identical.

With the advent of sand fencing in the late 1930's, differences along the Spit began to develop. In order to delineate these differences, the study area was divided into four compartments; Jones Hill, False Cape, Corolla and Poyner's Hill (See Figure 1).

COMPARTMENT DESCRIPTIONS

A. JONES HILL, N.C.

Starting with the simplest example, Jones Hill is a sand sheet still in the process of dune formation. Fortunately, the formation of the sand sheet has been recorded on film (Figure 2). In Figure 2-A, notice that the sand sheet is in the process of formation. No slipface has developed and this amorphous mass of sand is connected to its source of sediment, namely, the beach. Responding to the north-northeast onshore wind, sand is being blown inland and is forming into

²See Hennigar, this volume.

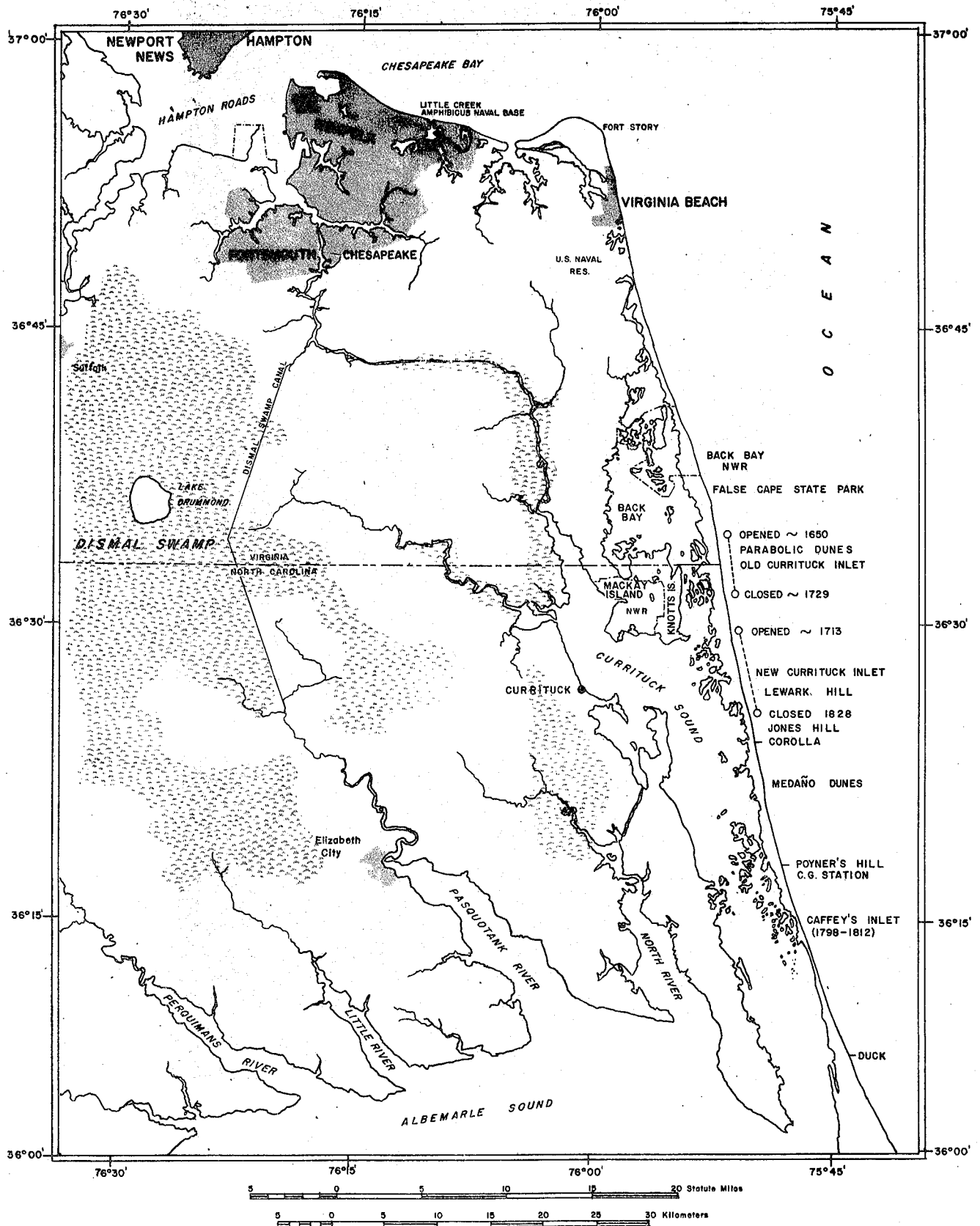


Figure 1. Location map

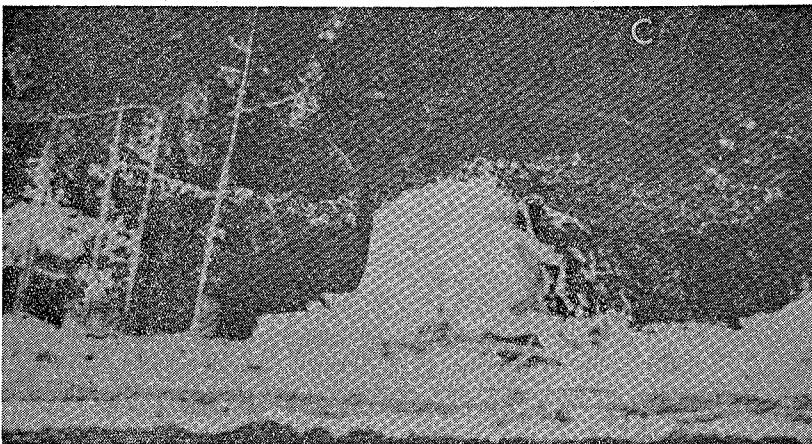
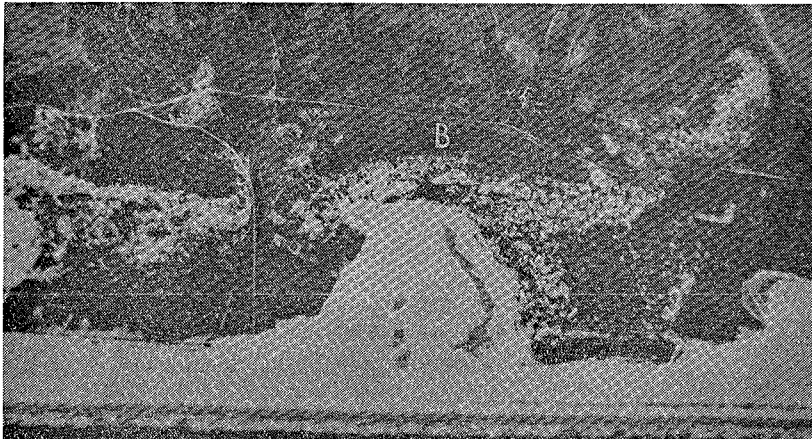
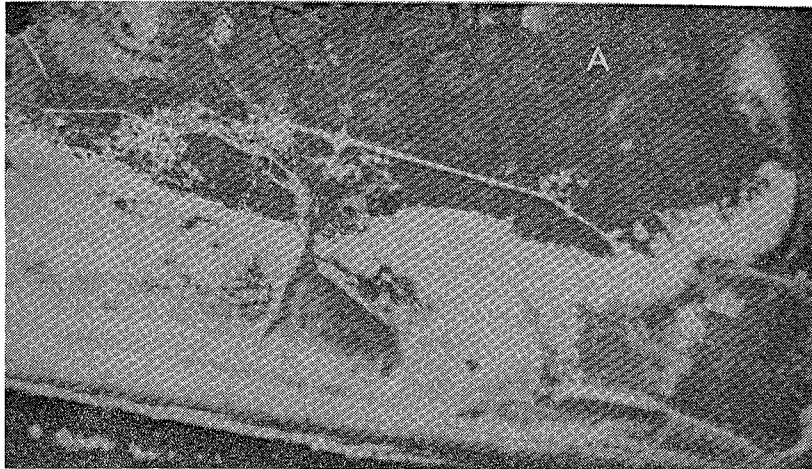


Figure 2. Jones' Hill
A-1940; B-1955; C-1975

Total Distance Migrated

1940-1975 410 m.

Average Migration Rate

1940-1975 12m./year

27-5

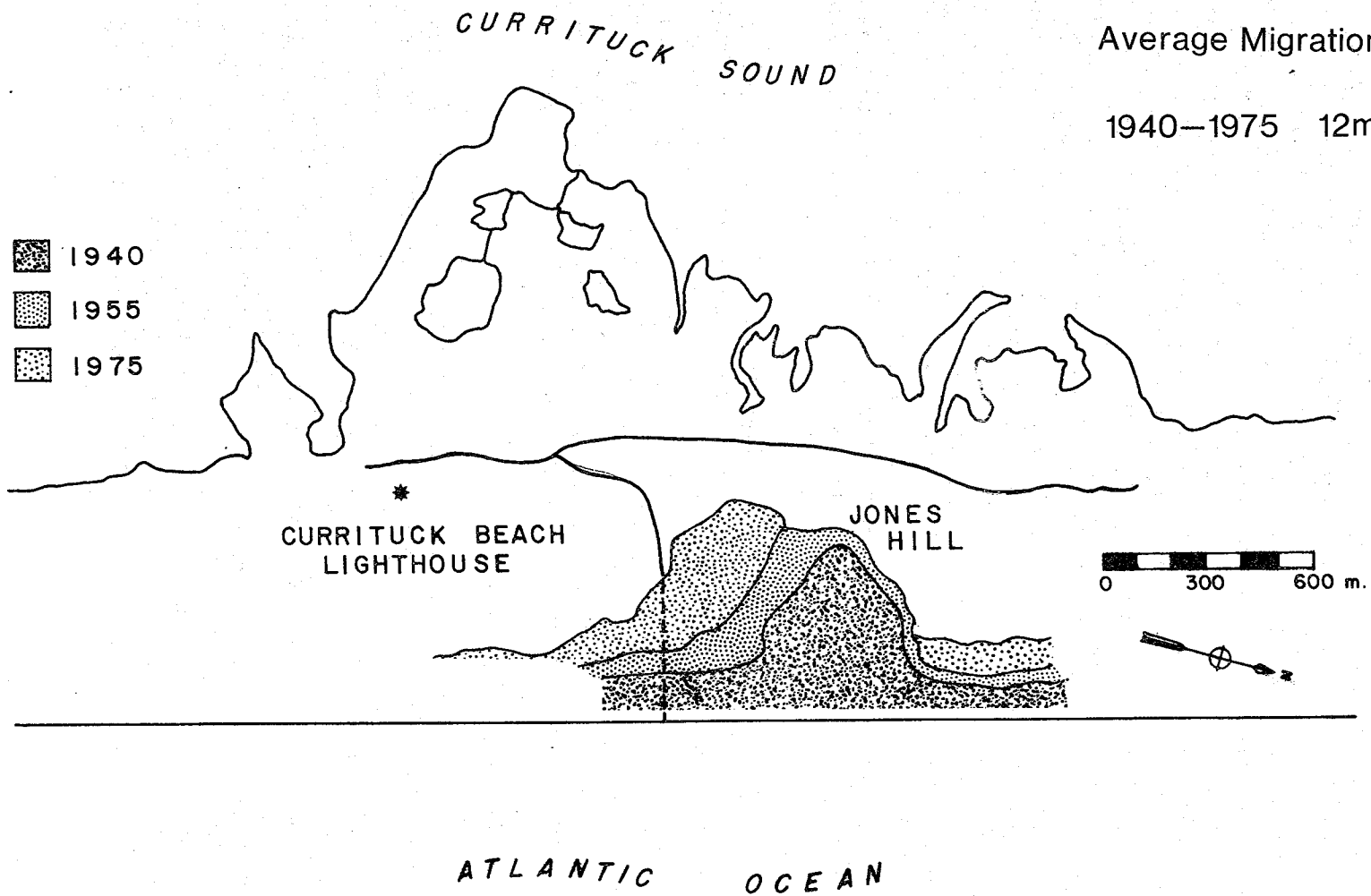


Figure 3. Graphical Summation of Jones' Hill migration.

a sand hill or medaño. The exact sequence of events responsible for dune formation are not known, however, a severe storm probably contributed to the dune formation. During the hurricane of September 1933 much of the area to the north of Jones Hill was overwashed. This extremely low, unvegetated, 4 km long overwash area could have served as the sand source from which Jones Hill emerged. Perhaps a better explanation would be that the overwash event destroyed what little vegetation remained in the area and released the sand. It should be noted that this overwash area was the last site of New Currituck Inlet before it closed in 1828 (Fisher, 1962); consequently, this area was extremely fragile. Concomitant with the closing of the inlet was an increase in logging and grazing in this area. Thus, it is conceivable that this area never fully vegetated itself after the inlet closed, and the hurricane provided the impetus for the formation of Jones Hill. By 1955 (Figure 2-B) the hill enlarged significantly, a slipface formed, and the hill actively migrated toward the southwest toward the main road into Corolla.

By 1975 (Figure 2-C), the road had been inundated, and the town of Corolla, located less than 2 km downwind, appears threatened by the dune. At the present time Corolla itself is not in danger, although development of the area is increasing. As more dwellings and roads are constructed, more of the natural vegetative cover is removed, possibly increasing the rate of migration. Figure 3 summarizes the migration of the hill since 1940.

B. FALSE CAPE, VA.

False Cape represents a different series of events with resulting differences in morphology and vegetation. Whereas False Cape was also covered by a sand sheet in 1937 (Figure 4-A) dune succession in the area has proceeded differently. This is directly related to man's influence, namely the employment of sand fencing. False Cape was initially sand fenced in the late 1930's and this was maintained continuously until 1972 (Lewis B. King, Virginia Department of Parks, Personal Communication). During the 1940's and 1950's many homes were built along the oceanside, usually directly behind the foredune. In order to protect these dwellings sand fencing was

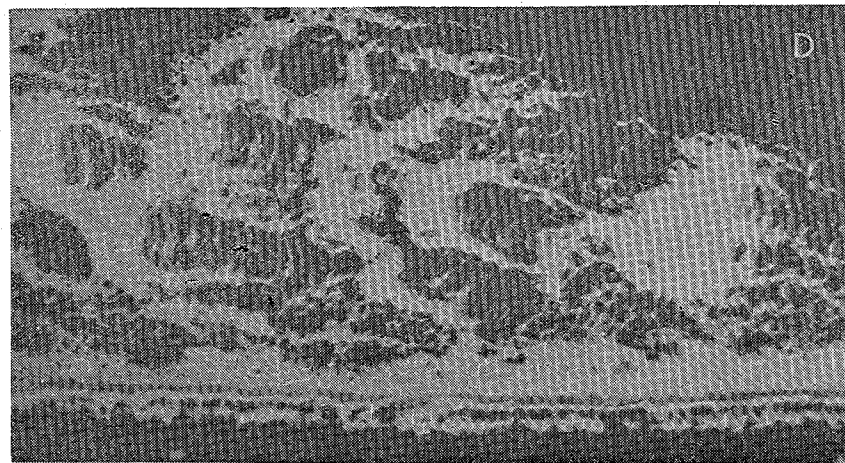
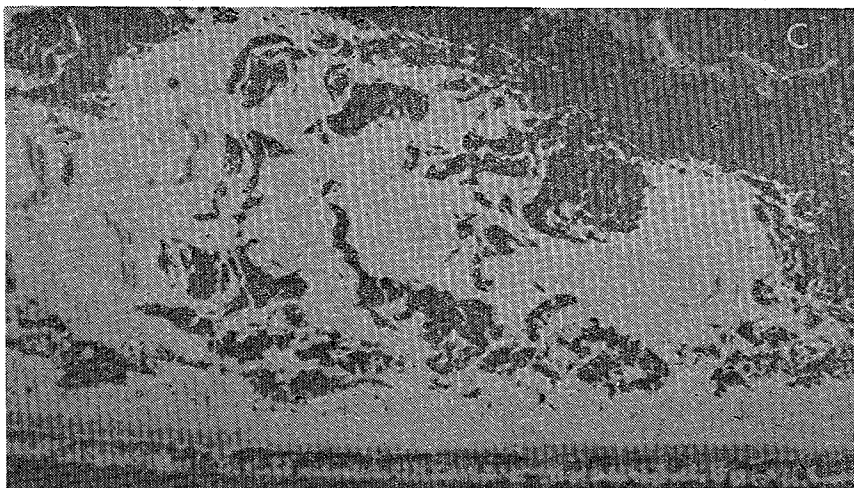
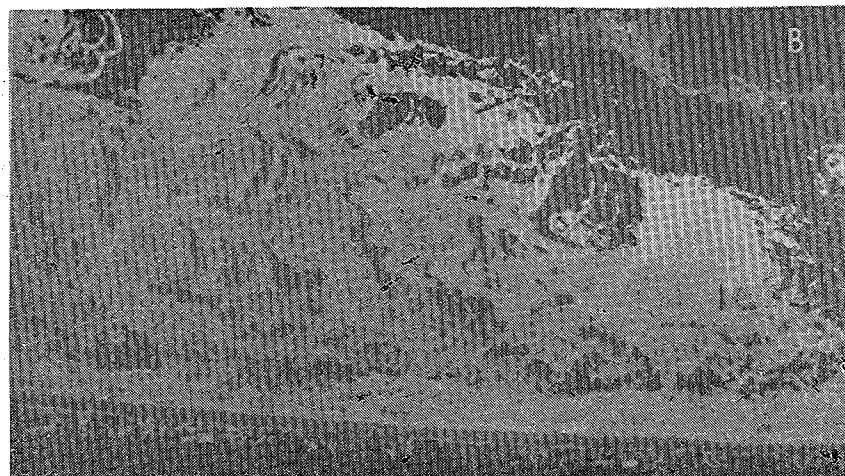
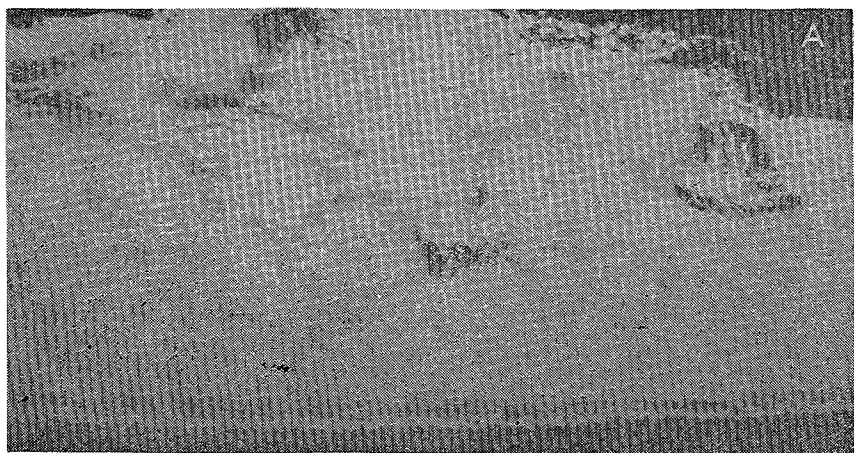


Figure 4. False Cape State Park
A-1947; B-1955; C-1963; D-1975

employed. No federal or state agencies were involved. This was done privately (Personal Conversations with Residents). During the 1960's the Commonwealth of Virginia began purchasing land in order to develop the area into a state park to serve the rapidly expanding Norfolk-Virginia Beach metropolitan area's need for recreation. Subsequently, an intensive program of sand fencing was carried on until 1972, and discontinued with the intention that the area maintain itself naturally. In actuality, economic constraints forced the abandonment of the sand fencing program.

In 1955 (Fig. 4-B) the sand sheet which covered False Cape was in the process of breaking up into small medaños or sand hills. This appears to be a direct result of sand fencing, as sand supply from the beach was disrupted, allowing vegetation to colonize those areas close to the fresh water table. A maritime forest also began to expand seaward, due in part to the protection from wind and salt spray afforded by the foredune. By 1963 (Fig. 4-C) there was a further breakup of the sand sheet, discrete medaños formed, and in the southern portion of the area, incipient parabolic dunes were present. Again, there was an increase in vegetation with grassy vegetation expanding rapidly in the low areas and decreasing the sand supply to the medaños. The maritime forest also increased in width, and woody vegetation began to colonize some of the blowout areas already stabilized by grasses.

The greatest change, however, occurred during the following 11 years. By 1975 the medaños had completely broken up and formed into large parabolic dunes. The reason for this dramatic change would seem to be due to the extensive sand fencing program undertaken by the Commonwealth, as well as to the increase in height of the maritime forest which changed the local wind regime, thus allowing the northeast wind to become dominant. At the present time, these parabolics are relatively inactive, having been recently stabilized by vegetation. Figure 5 is a low altitude oblique 1976 photograph of one of these parabolics. Note that the dune is almost completely vegetated, and is thus stabilized. For a more detailed treatment of this compartment, see Orientation of Coastal Parabolic Dunes and Relation to Wind Vector Analysis by Gutman, in this volume.



Figure 5. Parabolic Dunes
A. View toward south, note heavily vegetated blowout
B. View toward west of same dune

C. COROLLA, N.C.

The Corolla compartment, located about three kilometers south of the town of Corolla, consists of approximately two dozen medaños or sand hills. Some of these hills are over 20 meters in height and all are migrating to the southwest or obliquely toward the Sound side. Again, a sand sheet was present in early imagery (Fig. 6-A), the 1940 set having been taken soon after sand fencing began to be emplaced in the area. Unfortunately, sand fencing was not maintained here and by 1955 (Fig. 6-B), no major changes had occurred. During the early 1960's, sand fencing was emplaced because this area was used by the Atlantic Research Station as a missile development and testing site. Chosen because of its isolation, this area served as a major missile testing base until the mid-1960's. Subsequently, the site was abandoned (Personal conversations with residents). The replacement of sand fencing was done to protect the laboratories in the area, as well as to maintain the road to the south, the only access into the area. By 1975 (Fig. 6-C) after continuous sand fencing by developers in the area, the medaños in the area are being stabilized by vegetation. While still migrating at the rate of about 5 meters/year (See Gutman, this guidebook), it would appear that natural stabilization will become a reality within 10 to 15 years. Unfortunately, since the area is undergoing development, stabilization may be delayed due to the disruption of vegetation by construction and resident activities.

Figure 7 summarizes the changes in vegetation that have occurred since 1940. Note that during the period from 1955 to 1961, vegetated areas did not increase in size, and in fact, there may have been a decline due to burial by sand. Between 1961 and 1975, major changes are apparent due to the increased sand fencing in the foredune area. Figure 8 shows the total area vegetated in an 800 meter long stretch of Spit. The area defined as marsh is not included because it is difficult to measure boundaries, and total marsh area did not appreciably change. It is important to note the change in slope in two portions of the figure. Between points A and B, there is an increase in total vegetation.

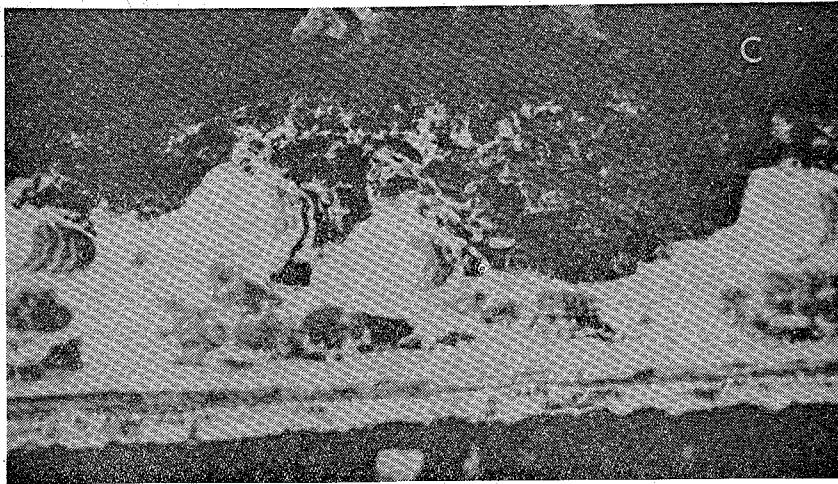
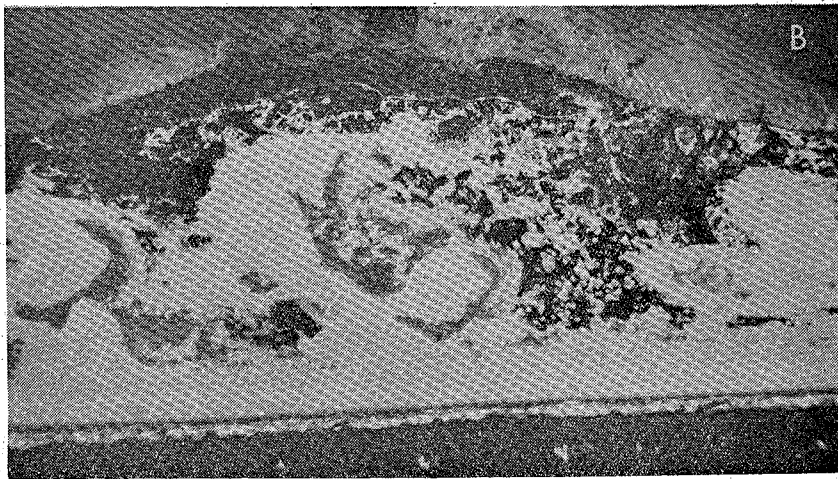
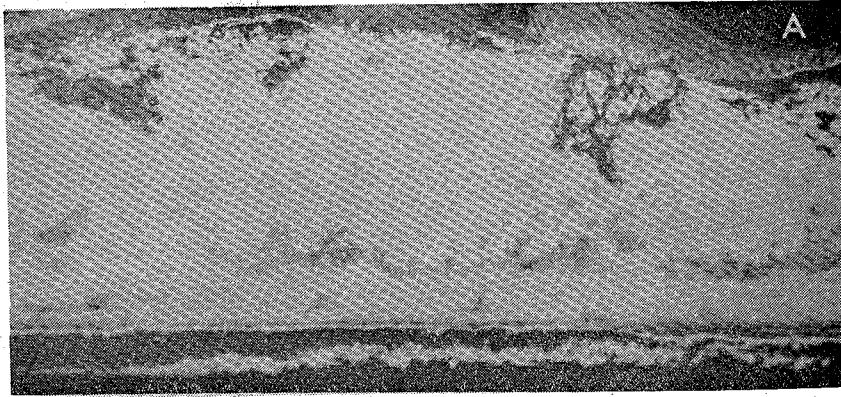


Figure 6. Corolla
A-1940; B-1955; C-1975

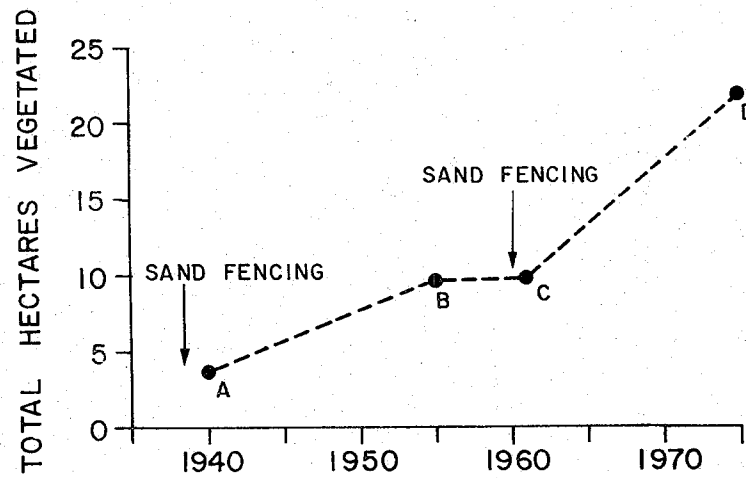


Figure 8. Changes in total vegetation (marsh excluded) from 1940-1975 in the same area mapped in Figure 7.

This is due to sand fencing developed during the late 1930's. Between B and C, there is virtually no change in vegetated area, due to the reactivation of the sand sheet. Although the total vegetated area did not increase, the forest community expanded at the expense of the grassy community. Sand fencing was again installed in the early 1960's and a doubling of vegetated area occurred between 1961 and 1975 (Points C and D). Note the importance of sand fencing in the reestablishment and expansion of vegetation. Similar results have been obtained by Schroeder, et al. (1976) on Ocracoke Island, N.C.

At the present time, development is in its early stages. The effects this will have on further stabilization is not known at this time.

D. POYNER'S HILL, N.C.

During the late 1930's, Poyner's Hill was also covered by a sand sheet (Fig. 9-A). Sand fencing was installed during the late 1930's but, again due to a lack of maintenance, it was rendered useless. In 1955 (Fig. 9-B) there are no drastic changes evident in the imagery. Some grassy vegetation has returned, but this is probably due to a decrease in grazing rather than to any effects of sand fencing since no new fencing was installed. By 1975 (Fig. 9-C) there is a marked change; vegetation is recolonizing the low areas and discrete medanos have formed from the sand sheet. This is due to an active sand fencing and bulldozing program instituted along the foredunes by a developer in the area. At the present time, development is increasing at a rapid rate.

DISCUSSION AND CONCLUSIONS

As has been shown in these four areas on Currituck Spit, coastal dune types are based on vegetation density which resulted in large part from human interference. The entire Currituck Spit is presently in a transition state proceeding from unvegetated sand sheet to a vegetated spit complex, but at different rates in different areas. Based on the data presented, several facts are apparent.

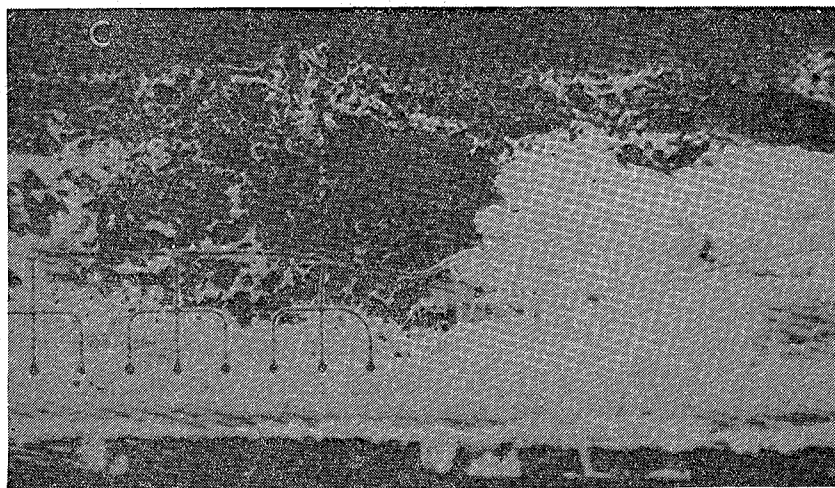
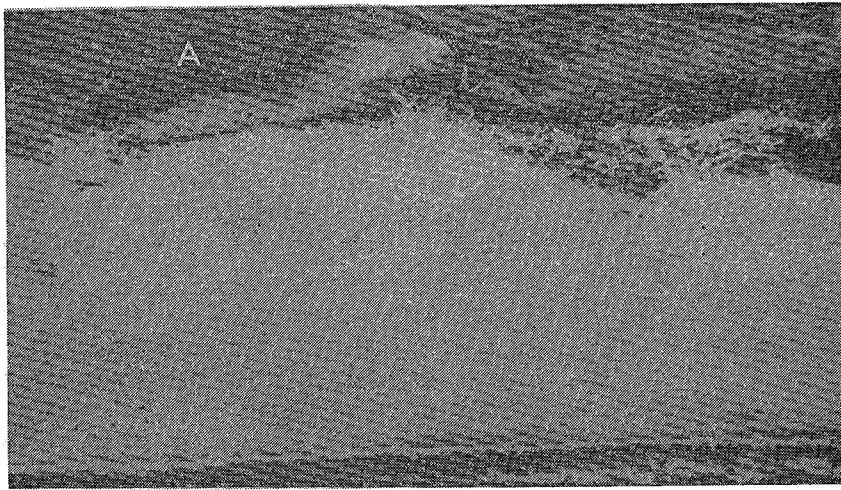


Figure 9. Poyner's Hill Coast Guard Station
A-1940; B-1955; C-1975

With respect to the importance of sand fencing in stabilizing the interior of the Spit, the evidence presented here would seem to indicate that sand fencing is not always detrimental to the integrity of a barrier island. It has allowed vegetation to recolonize parts of the Spit, thus encouraging recovery to the earlier stable condition which was described in A Brief History of Currituck Spit (1600-1945) (this volume). While the effects of sand fencing in the coastal zone have been debated, there is no evidence to support the hypothesis that it is detrimental in the dune areas. Also, the beach may not necessarily narrow and steepen appreciably in those areas where sand fencing has been employed. In fact, during eight years of beach profiles at False Cape (sand fenced continuously since the late 1930's), the beach has actually accreted. (Goldsmith, et al; 1977). Dolan (1972) has documented the effects of an unbroken foredune in the Cape Hatteras National Seashore, and it would appear that these effects (i.e., steepening and narrowing of the beach) do not apply in False Cape. Also, a continuous foredune is not desirable, as it does not allow for interaction between the beach and the interior via overwash and eolian sand transport back onto the beach.

A sequence of events has been delineated which appears to be consistent over the entire length of Currituck Spit. Initially, the Spit was covered by a sand sheet during the 1930's. This sand sheet broke up into discrete medanos which eventually formed into parabolic dunes (in False Cape). Recognition of this sequence has important ramifications for planners as well as developers in the area. For example, the Corolla compartment, described in this article, is presently at the late medaño stage in the sequence. If one compares that 1975 imagery with False Cape in 1955, one sees several similarities, as in both areas, the medanos are being stabilized by vegetation. In False Cape these medanos formed into parabolic dunes with time, and a minimum of human interference. It seems a reasonable assumption that medanos in the Corolla compartment could also metamorphose into parabolic dunes within 20 years. Rather than embark on a program to either cart away the medanos by truck or attempt to build on them, a developer would be wise to allow natural processes to stabilize the area for him. This seems to be the logical, and more importantly, the cheaper alternative for maintaining the area as suitable for dwellings.



Figure 10. Comparison of 1955 False Cape photograph (A) with 1975 Corolla photograph (B) showing similarities in vegetation and geomorphology.

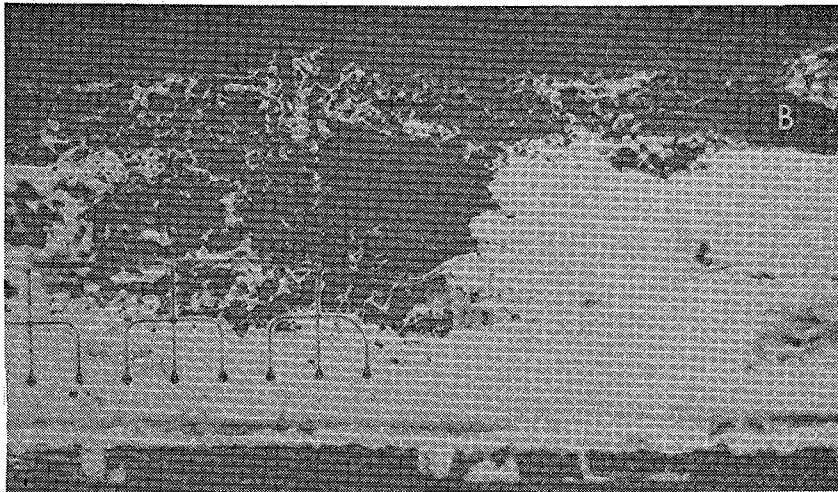


Figure 11. Comparison of 1937 False Cape photograph (A) with 1975 Poyner's Hill photograph (B).

The Poyner's Hill compartment (Fig. 11-A,B), due to the lack of sand fencing until the late 1960's, is still a sand sheet, which at the present time is forming into medanos. This area is extremely fragile, and any major disruption of vegetation could result in the reactivation of the sand sheet. Notice the similarity of Poyner's Hill in 1975 to the 1937 photograph of False Cape. Unfortunately, development has begun first in this area (notice the three "tridents" in the lower left corner of the 1975 photo), the consequences of which are as yet undetermined.

If the past is indeed the key to the future, then a knowledge of the processes responsible for present conditions can aid in formulating a rational plan for land utilization which would allow for long term maintenance of the Spit, as well as use over the shorter term as both a residential and recreational area.

REFERENCES

- Dolan, R., 1972, Barrier Dune System Along the Outer Banks of North Carolina; A Reappraisal, Science 176:286.
- Fisher, J.J., 1962, Geomorphic Expression of Former Inlets Along the Outer Banks of North Carolina., M.S. Thesis, University of North Carolina, Chapel Hill.
- Gibbs, R.F., and Nash, E., 1961, Beach and Sand Dune Erosion Control, Am. Soc. of Ag. Eng. Trans., V 4, No. 2, pp 122-125, 127.
- Goldsmith, V.; Sturn, S.; Thomas, G., 1977, Variations in Beach Erosion and Accretion Trends at Virginia Beach, VA., and Vicinity: Final Report CERC Contract DACW-72-74-C0008 and CERC Tech. Memo No. _____ (in press) C.E.R.C., U.S. Army Corps of Engineers; Ft. Belvoir, VA.; VIMS SRAMSOE No. 122.
- Guild, E.R. and Fletcher, J.E., 1947, Exploring America's Great Sand Barrier Reef, National Geographic, Vol 92, No. 3.
- Hennigar, H.F., 1977, Historical Evolution of Coastal Sand Dunes, Currituck Spit, VA/NC, M.S. Thesis, VIMS, Gloucester Pt., VA (in prep.)
- King, L.B., Head, Dept. of Parks and Planning, Commonwealth of Virginia, Personal Communication, 1976.
- Schroeder, M.P.; Dolan, R.; Hayden, B.P.; 1976, Vegetation Changes Associated with Barrier Dune Construction on the Outer Banks of North Carolina, Environmental Management, Vol. 1, No. 2.

ORIENTATION OF COASTAL PARABOLIC DUNES AND
RELATION TO WIND VECTOR ANALYSIS¹

Andrew L. Gutman

INTRODUCTION

One of the more striking features along Currituck Spit, Virginia-North Carolina (Fig. 1), is a field of parabolic dunes ranging from 3 to 10 meters in height and extending south from False Cape to the state line (Fig. 2). Orientation of these U dunes is a result of the interaction of many environmental variables including wind, vegetation, topography, water-trapped sand, and the sand source. Landsberg (1956) and Jennings (1957) assumed wind was the dominant factor and therefore ignored the remaining environmental variables in their studies of the orientation of parabolic dunes in Denmark and Tasmania, respectively. In this study the effects of vegetation and source of sand are also considered.

Landsberg (1956) first described the evolution of parabolic dunes. Figure 3 shows a four phase sequence which leads to the characteristic U shaped dunes found along many coasts of the world, including Currituck Spit. A large mobile sand mass (Phase 1) becomes increasingly stabilized by vegetation along the flanks which lag behind an advancing slip face and lead to the U shaped dune (Phase 2). Eventually the parabolic dune becomes completely stabilized (Phase 3) and may even completely erode (Phase 4). This complete hypothetical evolutionary sequence of parabolic dunes is presently exhibited in Currituck Spit. Old aerial photos (1937) show a massive sand sheet in this area which eventually developed into the parabolic dune field according to the sequence shown in Figure 2 (Hennigar, 1977).

Barbour's Hill (Fig. 4), located at the northern end of the parabolic dune field, represents the first phase of U-dune development. It is a large (20 meters high)

¹The area of this study is shown on the cover.

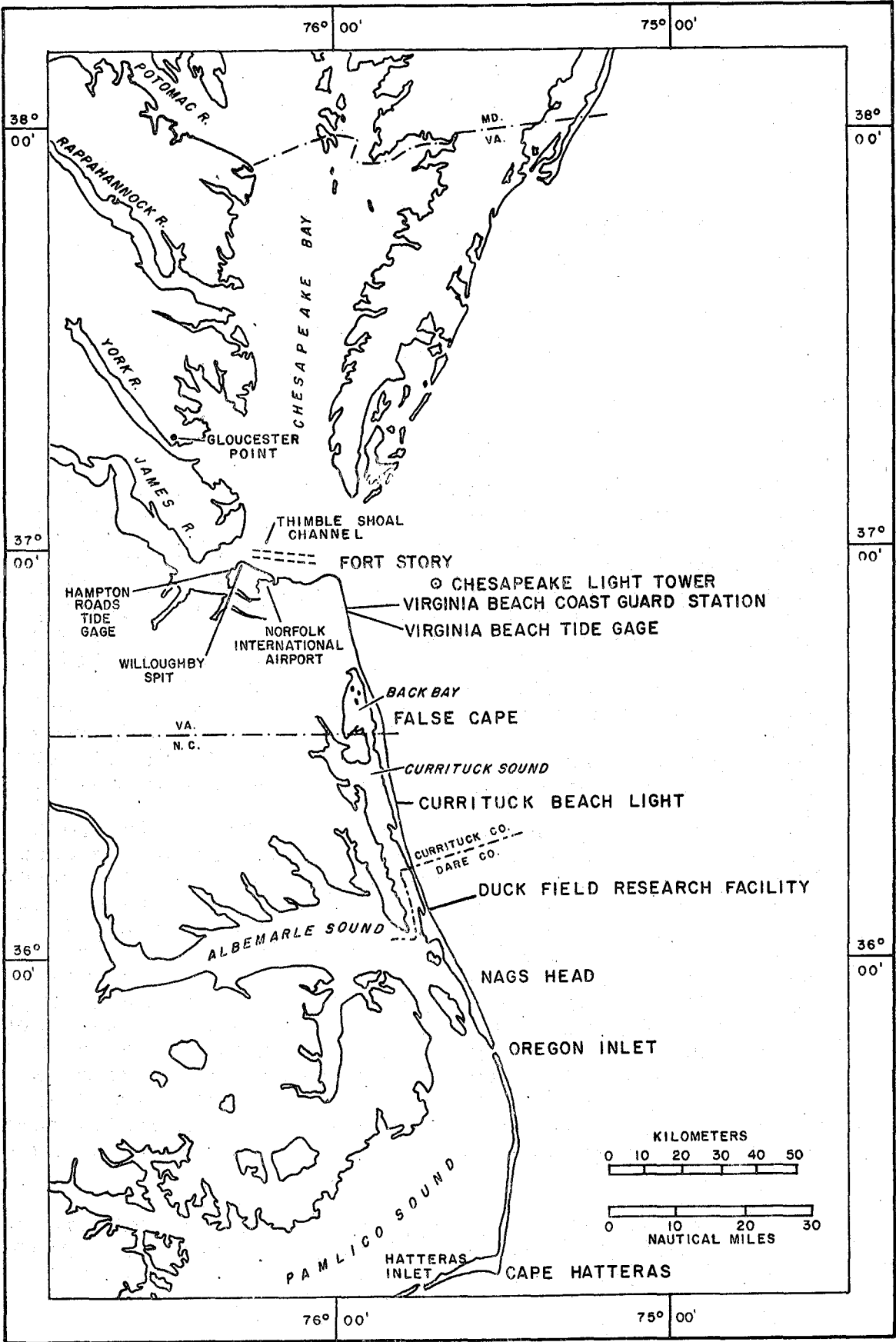


Figure 1. Regional location map of study area and scale A.

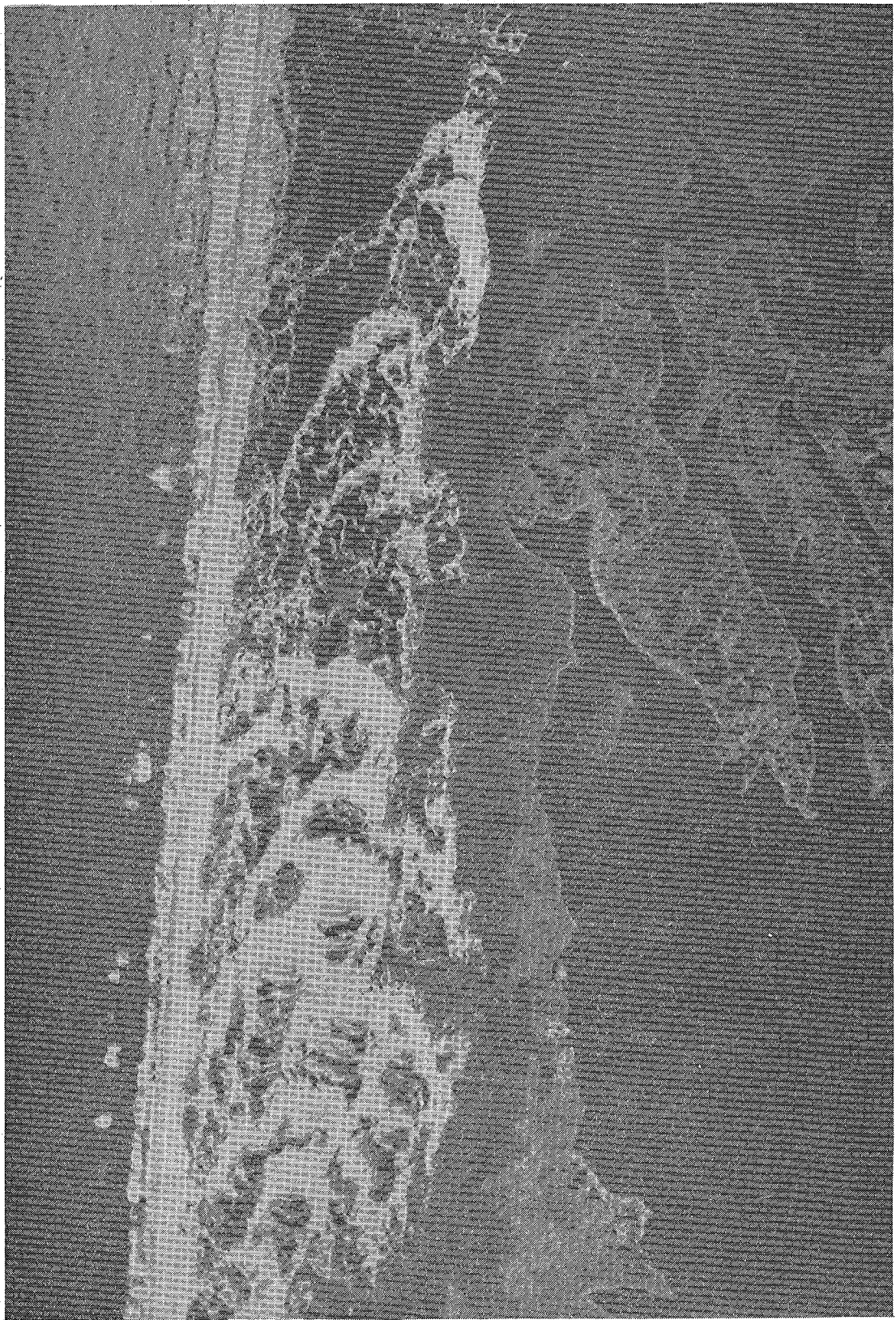


Figure 2. High altitude aerial photograph (April, 1975) of parabolic dune field in False Cape State Park, Virginia, looking south.

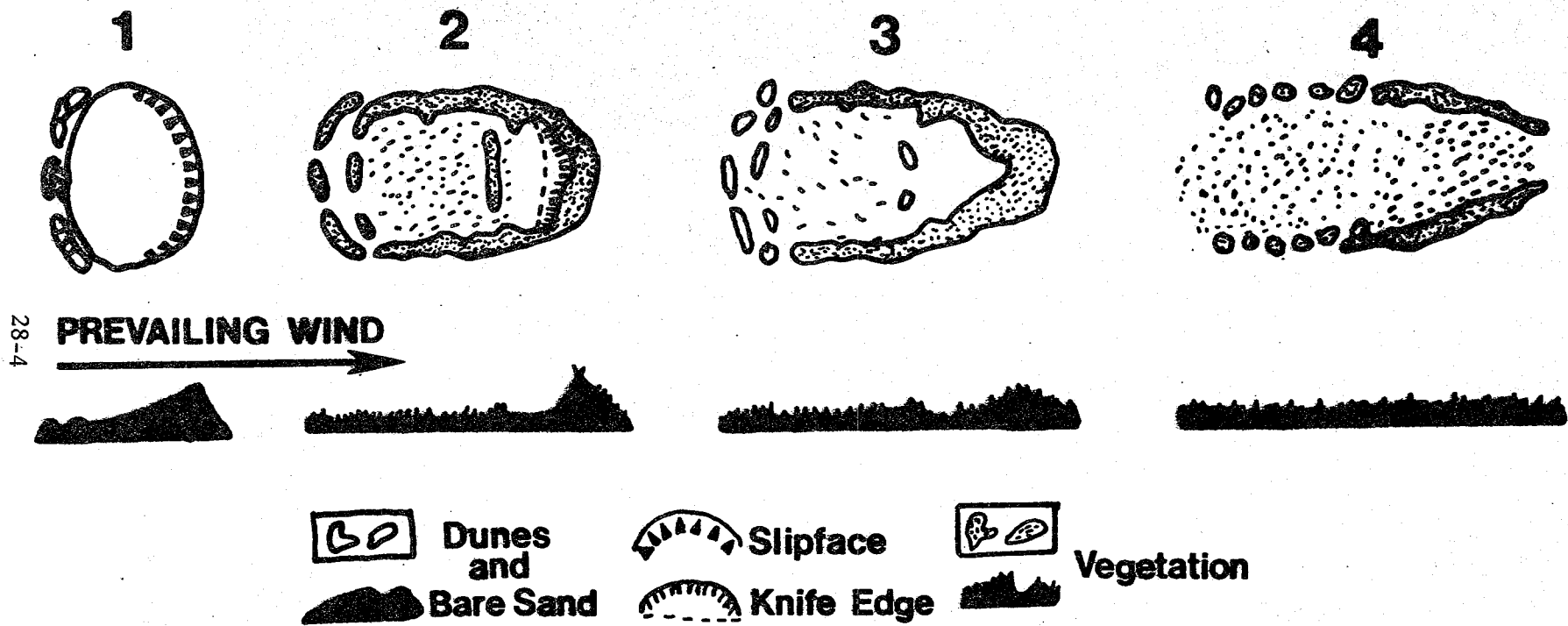


Figure 3. Diagrammatic representation of parabolic dune phases (after Landsberg, 1956). See text for discussion.

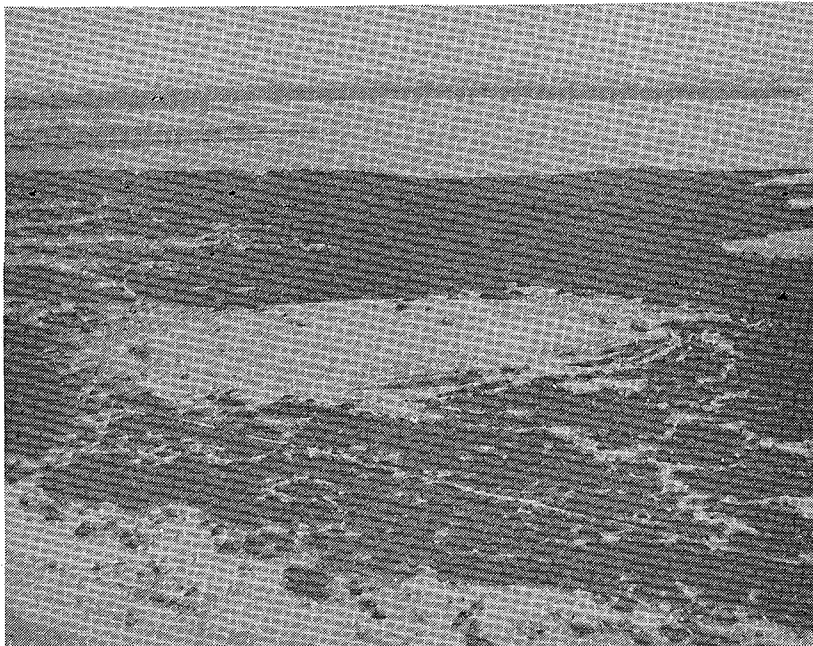
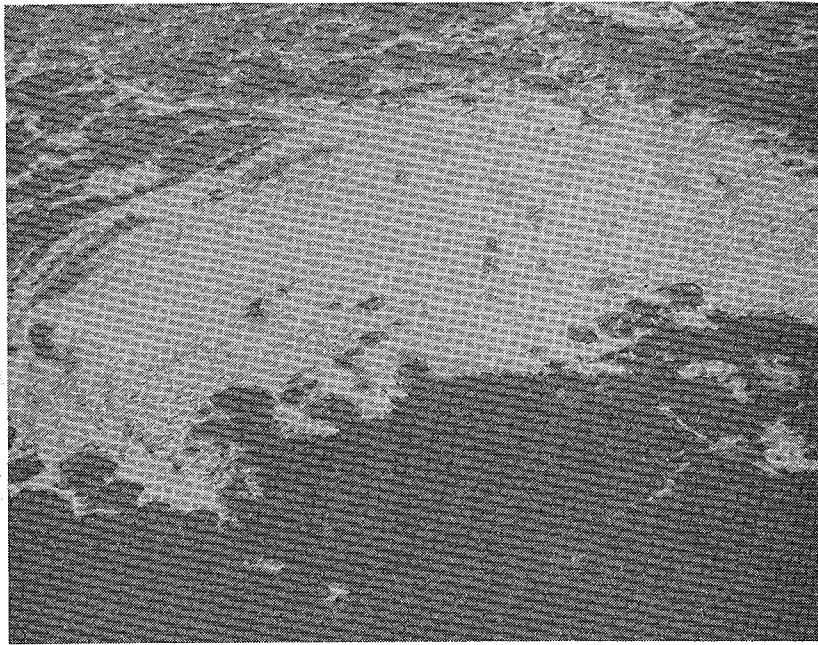


Figure 4. Aerial views of Barbour Hill looking northeast (top, January, 1975) and southwest (bottom, April, 1976). Note extensive vegetation surrounding sand hill.

unvegetated dune with a high (5 meters) active slip face. A small number of phase 2 active parabolic dunes (6 meters in height) are evident to the south of Barbour's Hill. However, most parabolic dunes are lower (3 meters) and completely stabilized phase 3 dunes. Isolated (nonparabolic) dune ridges in the U-dune field indicate in a small number of cases, the development of the last stage of the evolutionary sequence (Phase 4).

It is clear the wind regime and vegetation are both critical in determining the orientation of parabolic dunes. The remaining environmental factor which was considered in this study is the orientation of the beach relative to the dunes. Since the beach is the initial source of sand for dunes, it follows that the orientation of the beach relative to the prevailing and dominant wind regime, and the parabolic dune field will also play a role in determining the orientation of U-dunes.

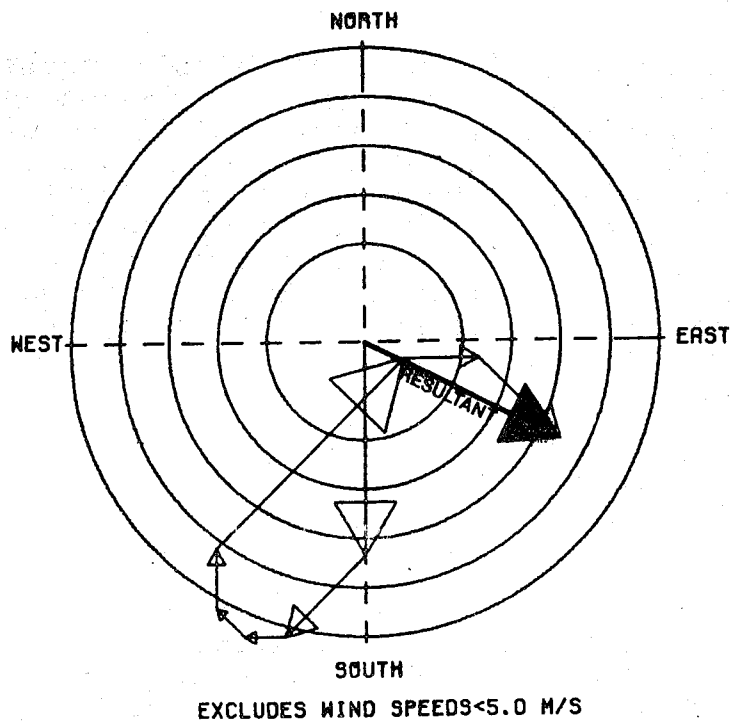
WIND DATA

Because of the importance of local wind in determining orientation, a local recording anemometer was installed on top of the Currituck Beach Light, Corolla, North Carolina (see Fig. 1), at an elevation of 49 meters above sea level, to provide a continuous record of wind velocity and direction over a one year period. Wind data over a longer period (1946-1970) was available from the nearest climatological station at Cape Hatteras, North Carolina, 115 kilometers to the south (Fig. 1). Comparison of wind data from both Corolla and Hatteras station anemometers for the same one year period indicated the Hatteras data was not significantly different in terms of direction from the Corolla data. However, the magnitude of wind speeds were about 50% less for the Hatteras station because this anemometer was located 3 meters above the ground while the Corolla anemometer was 49 meters above the ground. Figure 5 shows a comparison of wind diagrams for both stations. It was concluded from these comparisons that long term wind data from Hatteras station should be applicable to the parabolic dune field at False Cape because of similarities in the directions of the wind regime between the Corolla and Hatteras stations.

WIND VECTOR ANALYSES

If a clear relation exists between the sand transporting capabilities of wind and parabolic dune orientation,

2/76-2/77
COROLLA STATION
WIND RESULTANT



2/76-2/77
HATTERAS STATION
WIND RESULTANT

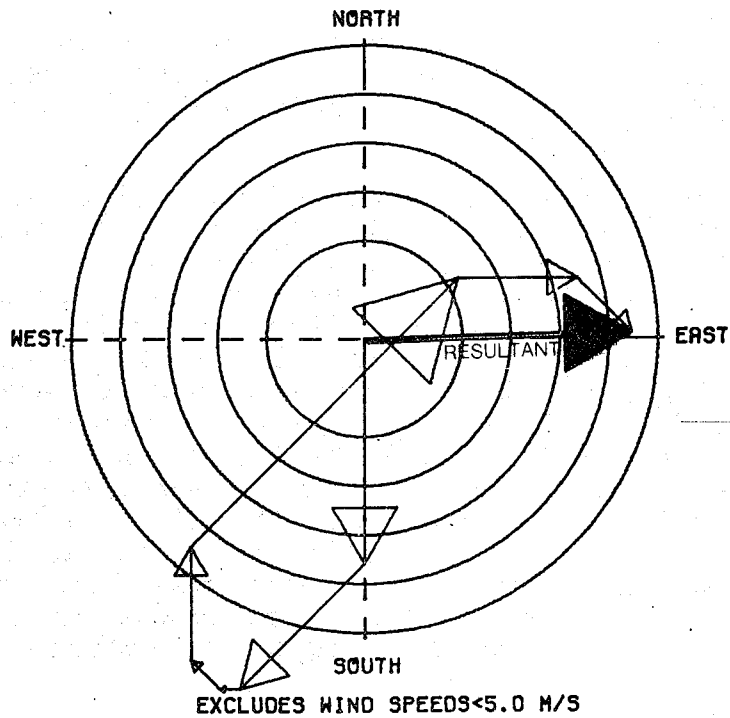


Figure 5. Comparison of Corolla and Hatteras Wind Resultants
2/1976 - 2/1977.

then a vector mean of wind data should correlate with the orientation. As will be shown, this is not necessarily true for coastal dunes. Bagnold (1941) showed, experimentally, aeolian sand transport is proportional to the cube of the wind velocity above a threshold level. Therefore, to accurately evaluate the wind field in relation to eolian transport a method originally proposed by Landsberg (1956) was used to determine the magnitude of individual vectors for each direction on an eight point compass according to the relation:

$$b = s \sum_{1}^n (v - v_t)^3$$

where:

- b = magnitude of individual vector
- s = scaling factor for plotting
- n = number of observations in class interval
- v = wind speed in meters per second
- v_t = threshold velocity in meters per second

After computing each value of b, the 8 vectors were graphically added to determine a wind resultant. Figure 6 shows the Corolla vector wind resultant for the total year, according to the above method.

The Corolla Station annual wind resultant (Fig. 6) is oriented from the northwest to southwest. However, this resultant has no obvious relation with the average parabolic dune orientation.

Figure 7 shows the field of parabolic dunes with arrows indicating their orientation. The orientation was determined by bisecting the angle formed by lines tangent to the two arms of the U-dunes, and then measuring it relative to north. Table 1 lists the orientation of all the dunes measured from vertical aerial photography along with calculations of the mean standard deviation and standard error of the mean. Several sets of imagery (ERTS frames) were utilized to determine orientation due to the difficulty of defining the actual location of flanks and slip faces for certain dunes. The first column on the left in Table 1 lists the orientation of the 11 parabolic dunes shown in Figure 7 and additional dune measurements. The mean orientation of the 30 parabolic dunes is N 8° E. Notice the wind resultant (Figure 6) deviates by about 70°

2/76-2/77
COROLLA STATION
WIND RESULTANT

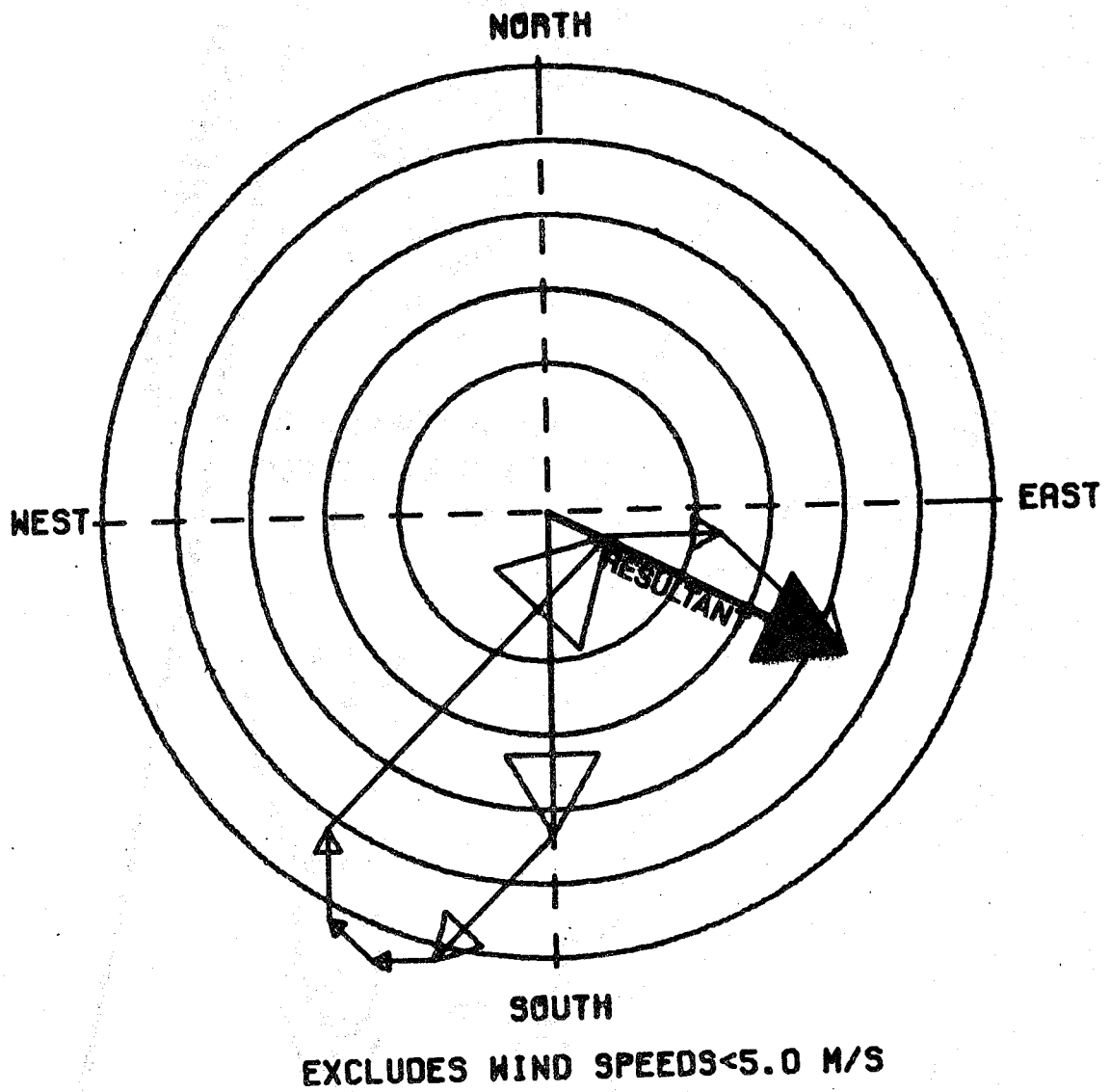


Figure 6. Corolla Station annual vector mean wind resultant (January, 1976 to January, 1977).

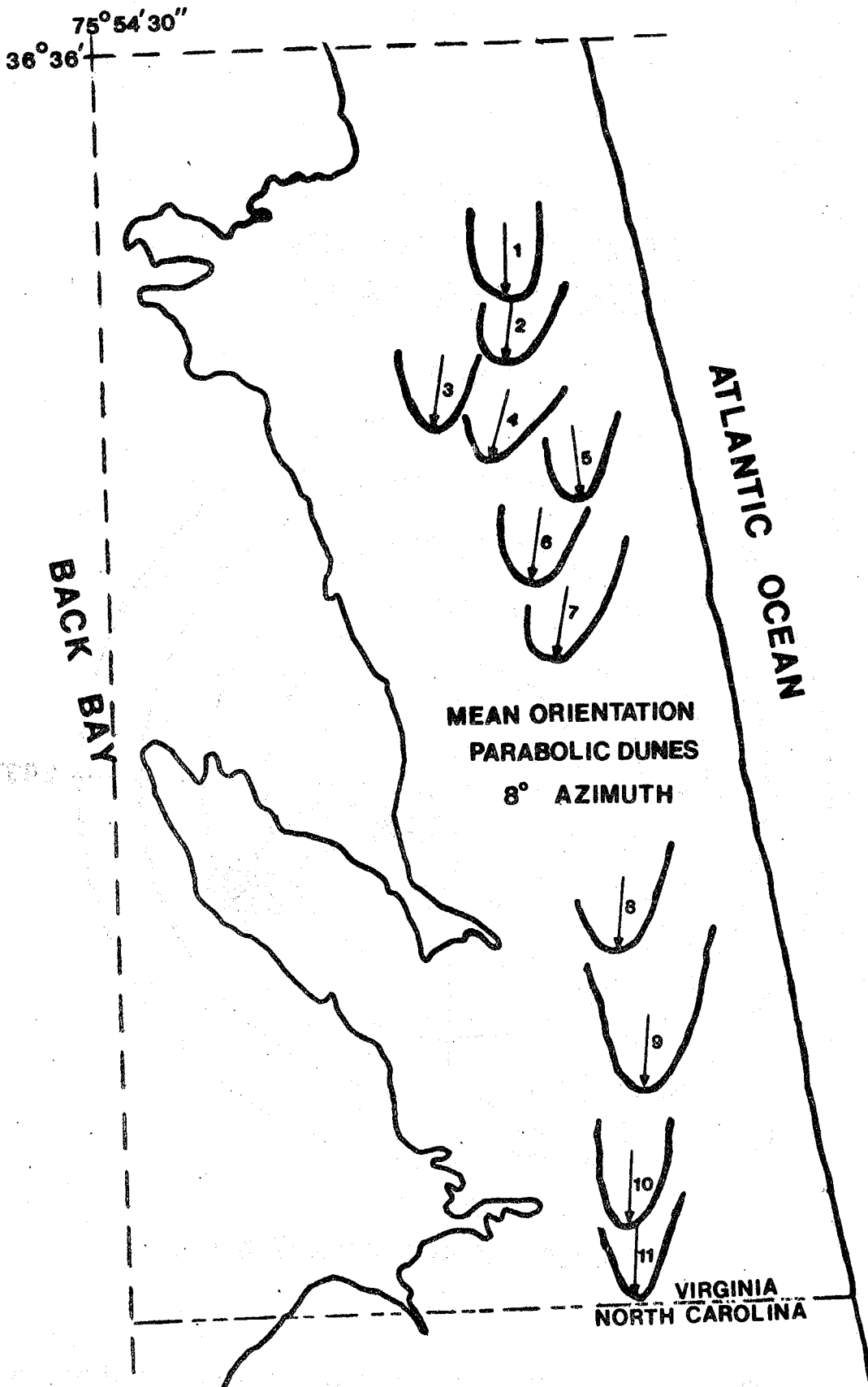


Figure 7. Parabolic Dune Field of False Cape, Virginia, illustrating location, plane view, and orientation of the dunes. The dunes are numbered and keyed to Table 1.

from the mean orientation. Therefore in using the simple vector mean of all cubed wind speeds there is no apparent correlation between wind regime and dune orientation. Jennings (1957) also found little correlation using this method in studies of King Island parabolic dunes.

When two or more modes occur in a circular frequency distribution the vector mean is often not a useful measure (Potter and Pettijohn, 1963). Examination of the Corolla station wind rose for winds greater than or equal to 5.0 meters per second (Fig. 8) show five general modes; northeast, north, northwest, west, and southwest. Figure 5, though it shows a northwest resultant, actually indicates the largest magnitude vectors are from the north and southwest. If, instead of examining just the vector resultant, we concentrate on the effects of vegetation on the individual vectors and the orientation of the shoreline, a much better relation emerges between the orientation of parabolic dunes and the important environmental variables.

Aerial photographs (Fig. 4) show the parabolic dunes developed with a thick and tall (15 meters in height) forest to the west of the dunes. The wind velocity at the surface, and therefore the transporting capability of the wind, is dependent on the roughness characteristics of the surface. Vegetation, a surface roughness element, diminishes the wind velocity at the surface and downwind of the vegetation as a function of the density and height of vegetation (Olson, 1958). Thus, the very thick and high forest of scrub pine and live oak, to the west of the parabolic dune field, greatly reduces the effectiveness of the westerly winds.

To the east of the parabolic dunes, at the time of their formation, was a sand flat with sparse dune grass vegetation. Easterly winds (i.e., northeast winds in this area) were thus unimpeded by vegetation in the transport of sand. The easterly winds must also be considered the important winds for they blow over the primary source of sand for deposition as parabolic dunes. Therefore, given the effects of vegetation in greatly diminishing the sand transporting capability of the westerly winds, and the location of the source of sand relative to the dune field, it is concluded that the onshore winds were dominant in determining the orientation of parabolic dunes. (See photographic sequence on the cover.)

2/76-2/77
**COROLLA STATION
 WIND ROSE**

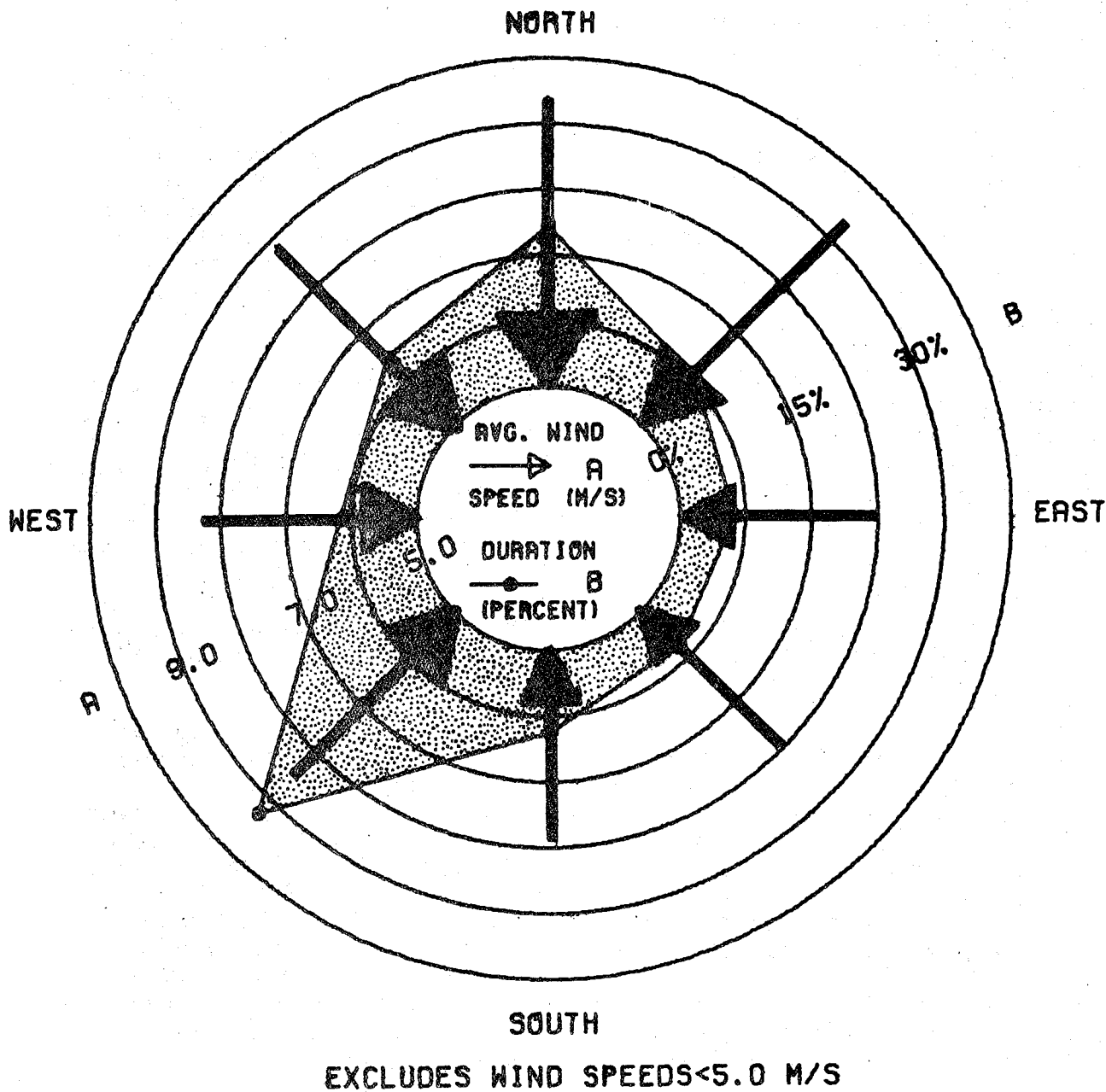


Figure 8. Corolla Station wind rose (January, 1976 to January, 1977) for winds greater than 5.0 m/s indicating average wind speeds (arrows and scale A) and duration (scale B).

Since the initiation of the parabolic dunes, a high foredune with abundant vegetation has formed upwind of the parabolics. Thus, the same situation may not be present now; i.e., the vegetation is now blocking sand transport from onshore winds, as well as the offshore winds.

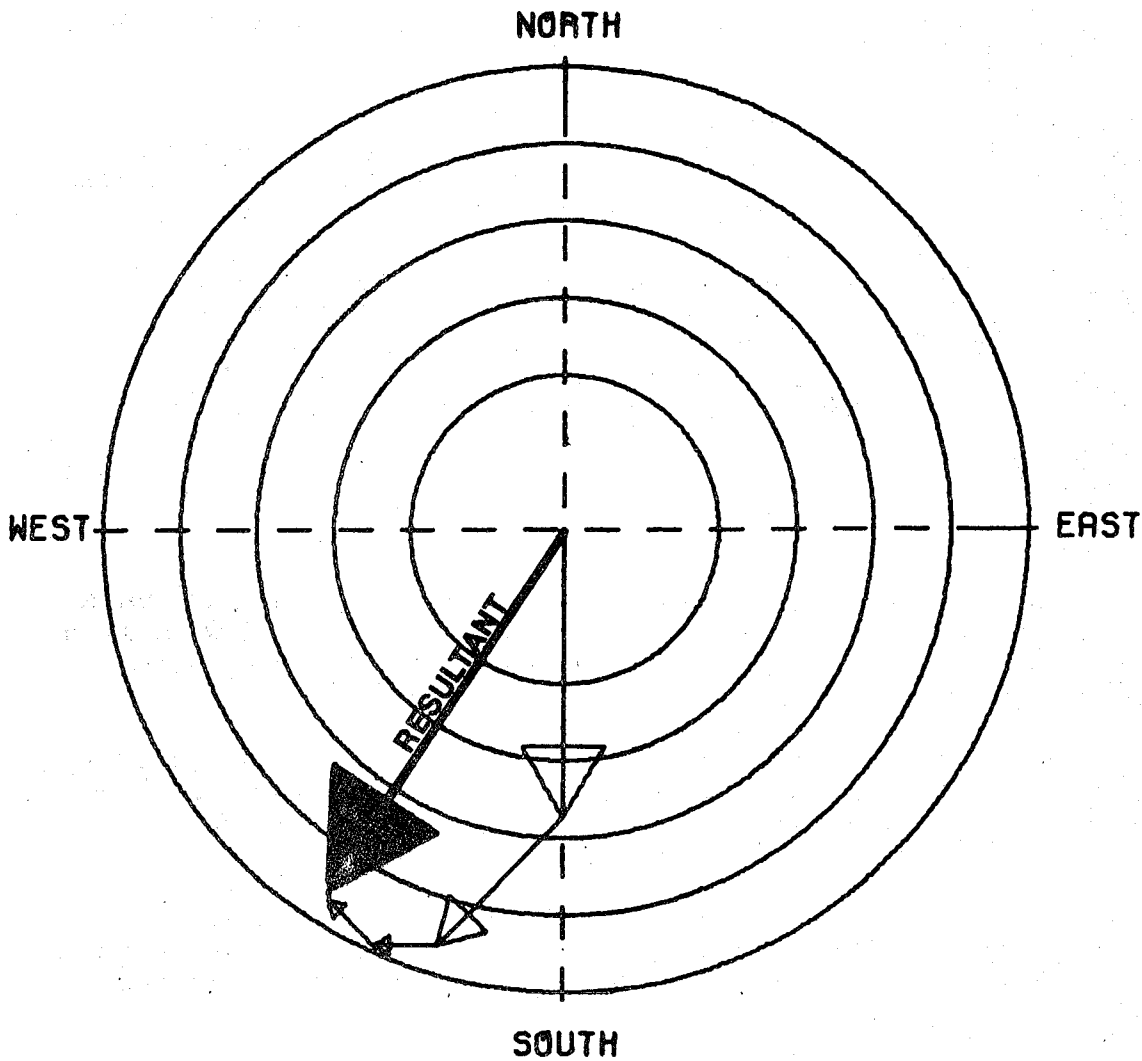
Figure 9 is a wind resultant diagram constructed in the same manner as Figure 6 except all offshore winds are excluded. Notice this resultant is much closer to the mean orientation of the parabolic dunes than the resultant in Figure 6. The resultant is within about fifteen degrees of the mean orientation and much closer for a number of the U-dunes listed in Table 1.

However, does the local one year wind resultant (January, 1976 to January, 1977) represent the typical long term resultant? Figure 10 shows a wind rose diagram for the Hatteras station anemometer 1946-1970, which encompasses the period of parabolic dune formation (Hennigar, 1977). This wind diagram shows modes in the northeast, north, northwest, and southwest as does the Corolla station wind rose (Fig. 8). This comparison indicates the local short term record is, in fact, typical of the long term wind regime which has shaped the parabolic dunes.

CONCLUSIONS

1. A relatively uniformly oriented field of parabolic dunes location in False Cape, Virginia, with a mean orientation of N 8° E, shows an evolutionary sequence similar to that detailed by Landsberg (1956).
2. It was determined that a local one year (January, 1976 to January, 1977) wind record at Corolla is typical of the long term wind regime for the area from Cape Hatteras, 115 km to the south.
3. The vector mean wind resultant determined by cubing all wind speeds greater than 5.0 meters per second showed no correlation with the mean orientation of the parabolic dunes.
4. By assuming winds which blow over the source of sand (onshore winds) play the dominant role in the formation of sand dunes (based on older aerial photographs), a very good correlation was found between the Corolla station wind resultant and the mean orientation of the False Cape parabolic dune field.

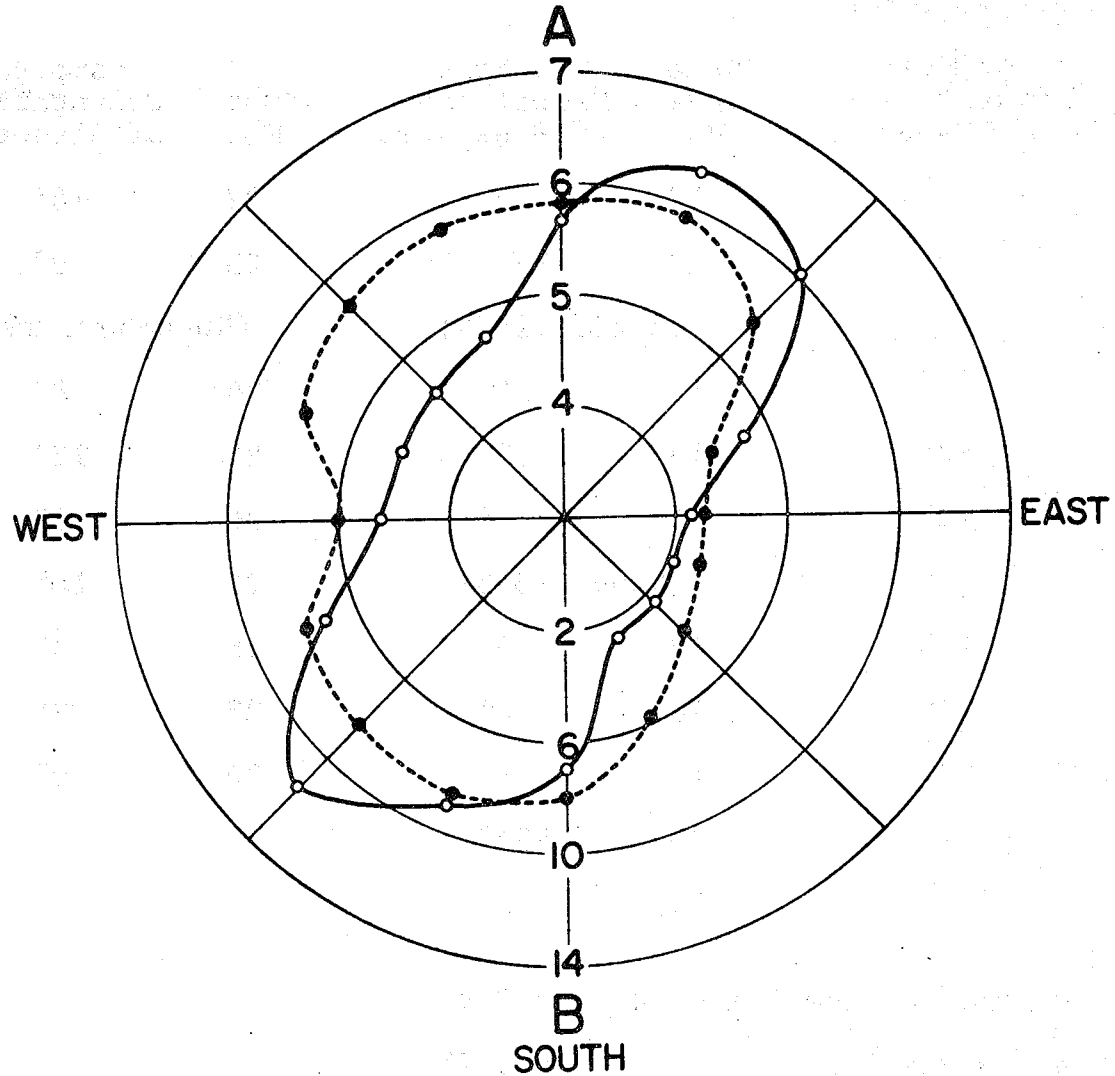
2/76-2/77
COROLLA STATION
WIND RESULTANT



EXCLUDES WIND SPEEDS < 5.0 M/S
AND ALL OFFSHORE WINDS

Figure 9. Corolla Station wind resultant (January, 1976 to January, 1977) excluding all offshore winds.

WIND DIAGRAM
CAPE HATTERAS, N. C.
 (1946-1970)
 NORTH



A ---◆--- AVERAGE VELOCITY (METERS PER SECOND)
B —○— DURATION
 (PERCENTAGE OF TIME BLOWING FROM)

Figure 10. Hatteras Station wind rose (1946-1970).

TABLE 1

PARABOLIC DUNE ORIENTATION FROM AERIAL PHOTOGRAPHS
 Orientation determined from bisector of two arms
 (arranged by dates of aerial photo data sources)

<u>Dec., 1974</u> (see Figure 6)		<u>April, 1965</u>		<u>Dec., 1973</u>	
Dune No.	Compass Orientation of Bisectors	Dune No.	Compass Orientation of Bisectors	Dune No.	Compass Orientation of Bisectors
1	6°	12	2°	22	16°
2	8°	13	359°	23	10°
3	8°	(April, 1975)		(November, 1976)	
4	14°	14	14°	24	8°
5	352°	15	11°	25	12°
6	12°	16	7°	26	0°
7	13°	(June, 1973)		27	14°
8	11°	17	9°	28	3°
9	10°	18	6°	29	9°
10	9°	19	3°	30	9°
11	9°	20	357°		
		21	3°		

Mean Parabolic Dune Orientation = 7.9°

Standard Deviation = 5.5°

Standard Error of Mean = 1.04°

REFERENCES

- Bagnold, R.A., 1941. The Physics of Blown Sand and Desert Dunes: William Morrow and Co., New York, 265 pp.
- Hennigar, H.F., 1977. Historical Evolution of Coastal Sand Dunes, Currituck Spit, Virginia-North Carolina: M.S. Thesis, VIMS, Gloucester Point, Virginia, in prep.
- Jennings, J.N., 1957. On the Orientation of Parabolic or U-dunes: Geog. J., V. 123, pp. 474-480.
- Landsberg, S.Y., 1956. The Orientation of Dune in Britain and Denmark in Relation to Wind: Geog. J., V. 122, pp. 176-189.
- Olson, J.S., 1958. Lake Michigan dune development, 1-2-3: J. Geol., V. 56, p. 254-263, p. 345-351, p. 413-483.
- Potter, P.E., and Pettijohn, F.J., 1963. Paleocurrents and Basin Analysis, p. 264, Academic Press, Inc., New York, 296 pp.

MOVEMENT OF LARGE SAND HILLS:
CURRITUCK SPIT, VIRGINIA-NORTH CAROLINA

Andrew L. Gutman

INTRODUCTION

Large sand dunes (10-25 meters high), representing a significant amount of sand removed from the longshore drift system are located along Currituck Spit between False Cape, Virginia and the Duck Research Facility, North Carolina (Fig. 1). Many of these large dunes are migrating landward towards the southwest, across the barrier island. These dunes are significant in terms of the sediment budget of the spit and their effects on development in the area.

Mobile dunes in the area are notorious for interfering with and often destroying towns, roads and forests. Henry Lathrobe, Esq. (1814), referring to the Cape Henry area, warned that these mobile dunes would eventually "swallow up the whole swamp, and render the coast a desert indeed, for not a blade of grass finds nutriment on this sand". Though the mobile dunes are still a problem 163 years after Lathrobe wrote these words, the coast of Virginia-North Carolina is not a desert. Aerial photographs have, in fact, shown a trend of increasing vegetation since the 1930's, with a concomitant decrease in the amount of shifting sands. The largest increase in vegetation seems to have occurred in False Cape, the northern part of the study area.

False Cape State Park (Fig. 1) is characterized by a large variety of eolian features including relatively high (2-4 meters), continuous, multiple foredune ridges, thick shrub vegetation across the aeolian flat, stabilized parabolic dunes (5-10 meters high) with axis uniformly oriented to the north, several large (15-20 meters) mobile dunes or sand hills (i.e., medanos), and a maritime forest which is presently being invaded by the mobile dunes.

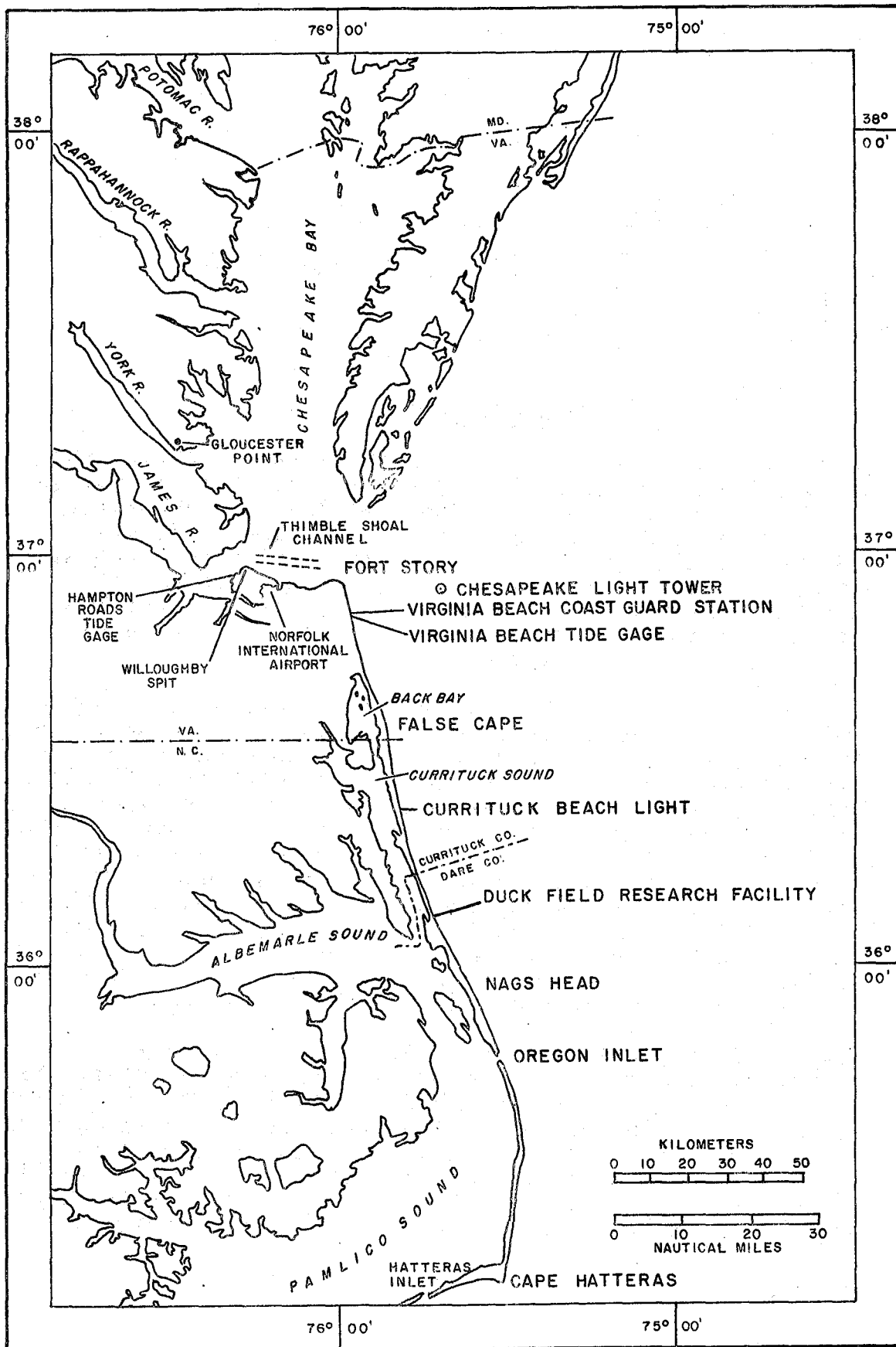


Figure 1. Regional location map of study area.

The area near Corolla, North Carolina is quite different than False Cape, approximately 30-40 km to the north. Here there is a lower (1-3 meters) non-continuous foredune ridge, only sparse dune vegetation across the aeolian flat, and large medanos (10-25 meters) which are highly mobile and temporally varying in orientation. These dunes are also invading a maritime forest on the bay side.

MIGRATION RATES

The migration rate of large dunes on Currituck Spit is useful information for evaluating their role in the sediment dynamics of the spit, the effect of the differences between the northern and southern regions, and for predicting the problems which will occur after development in the terrain surrounding these mobile dunes. Dune migration rates can be determined from the study of aerial photographs, maps and ground measurements. Air photos provide a longer record of migration rates though this rate represents an average for a number of years rather than an actual rate for each of the years. Given the increase in vegetation over the last thirty years a rate determined from old photographs should represent a faster rate than expected today. Figure 2 shows a typical large dune in Currituck Spit and its migration since 1961. Averaging the distance moved over 16 years, it is found that the dune has moved south-southwest toward the bay at about 8 meters per year. There are also problems in accuracy, which is dependent on the photo scale, and in comparing dune movements in this area free of landmarks. Table 1 lists migration rates determined by other investigators for coastal dunes throughout the world. To determine the actual present yearly migration rate, measurements must be conducted in the field.

In March of 1976 reference markers were placed around the perimeters of Whalehead Hill (Fig. 3) located just south of Corolla, and Barbour's Hill (Fig. 4) located at False Cape, Virginia. Both sand hills are approximately 15-20 meters high with active slipfaces (5.5 meters in height) oriented approximately west-northwest east-southeast, and advancing to the south-southwest. Nine other sand hills south of Whalehead Hill show an approximate uniformity in height and spacing, therefore, suggesting that the migration rate measured for Whalehead Hill is typical of the sand hill field to the south.



Figure 2. Distance travelled by Whalehead Hill (1:6000 scale).
1961-1977

TABLE 1

ANNUAL RATE OF COASTAL SAND DUNE MOVEMENT
AT VARIOUS LOCATIONS THROUGHOUT WORLD

from Pickard (1968)

Location	Rate m/year	Source
Coast of France	9.1	Salisbury, 1952
Lancashire, U.K.	5.5-7.3	Salisbury, 1952
Newborough, Warren, U.K.	1.5-3.1	Ranwell, 1958
Lake Michigan, U.S.A.	2.0-4.0	Ranwell, 1958
Cronulla, Australia	8.0-9.0	Pickard, 1968

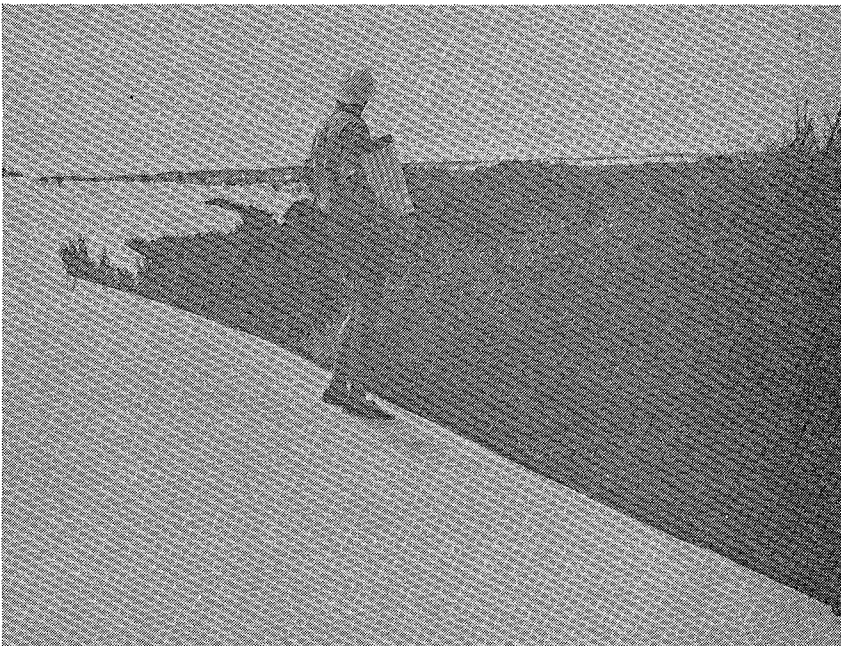


Figure 3. Whalehead Hill Medano looking southwest (top, October, 1976) and southeast (bottom, March 1977). The slipface, 5.5 m high, has migrated 6 m/year to the south-southwest (1976-1977)

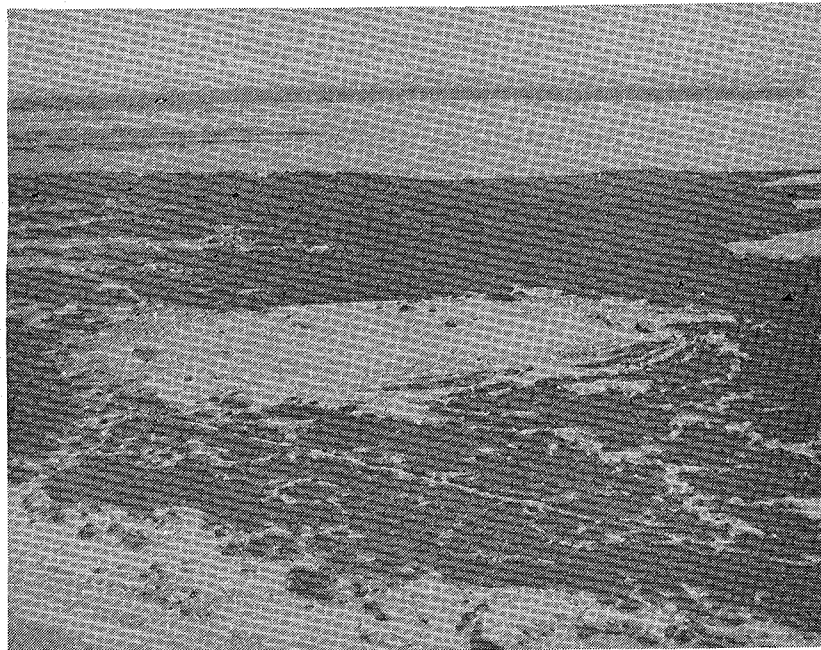
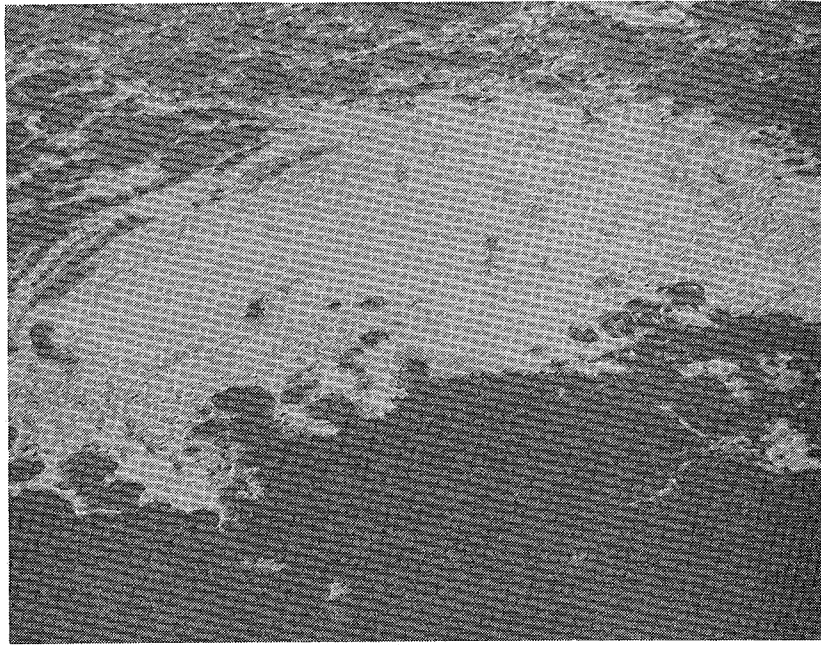


Figure 4. Aerial views of Barbour Hill looking northeast (top, January, 1975) and southwest (bottom, April, 1976). Note extensive vegetation surrounding sand hill.

Figure 5 shows a schematic illustration (not to scale) of the net 12 month movement of the two dunes between March 1976 and March 1977, as measured by the difference to the control points. This distance can be determined definitively only at the slipface for only there does the sand hill show a line of demarkation between the dune and the surrounding terrain. On all other flanks the dunes grade slowly into hummocks and small dunes, making measurement difficult. In addition, only the slipface movement indicates a migration of the entire dune. Extensions along the other flanks reflect sand being blown off the dune and onto the surrounding aeolian flat.

Figure 5 shows that the south-southwest movement of Whalehead Hill, as measured at the slipface, was more than six times greater than the Barbour's Hill rate (6 meters as opposed to .75). At Whalehead a lobe with a low (2 meters) slipface marched about 1.5 meters across an old unpaved road. This movement was particularly evident since travel past the dune along the road, which at the start of this study in 1976 was possible, is now no longer possible (Fig. 6). Notice also that the largest net change occurred on the east flank of Whalehead Hill, which showed a movement of some 9 meters over one year.

Figure 7 shows a wind diagram (see Gutman, 1977 and in this volume) from an anemometer operating at Currituck Light (Fig. 1). Notice that the largest number of wind observations by far were from the southwest. It is not surprising then that the east flank of Whalehead Hill showed a net lateral accretion of 9 meters, derived from sand blowing off the dune onto the adjacent flat. This movement of Whalehead Hill is particularly alarming considering that the new paved road leading to Corolla is located only 100 meters farther to the east of the dune. On many occasions this new (1975) road has been observed to be covered by sand blowing off the large medanos during strong westerly winds.

Northern and Southern Differences in Migration Rate

The present rate of south-southwest migration of Whalehead Hill is approximately 6 meters per year while at Barbour's Hill this rate is less than 1 meter per year. Old aerial photographs (Fig. 2) indicate that the migration rate, which has averaged 8 meters per year over the last 16 years, was considerably greater in the past. These

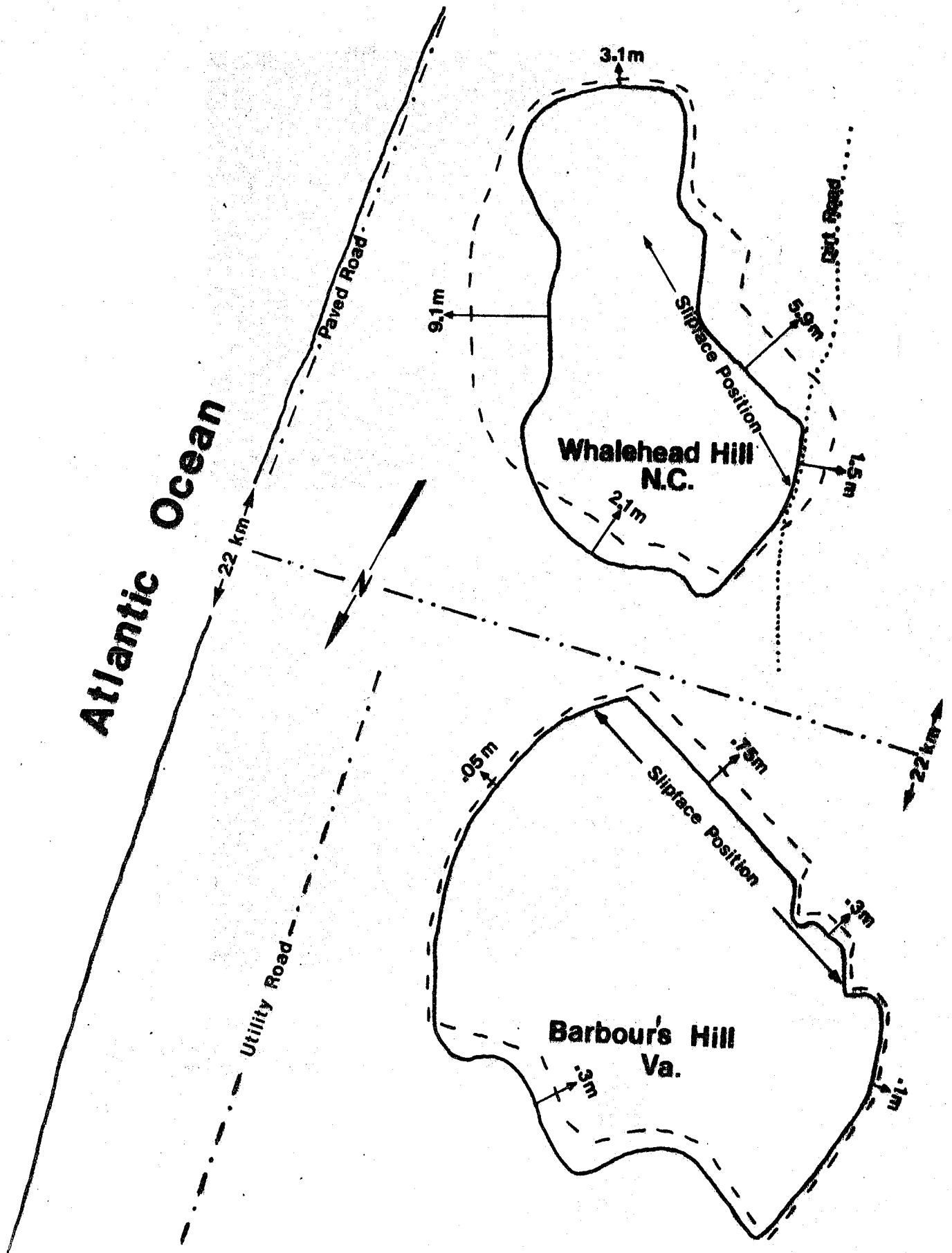
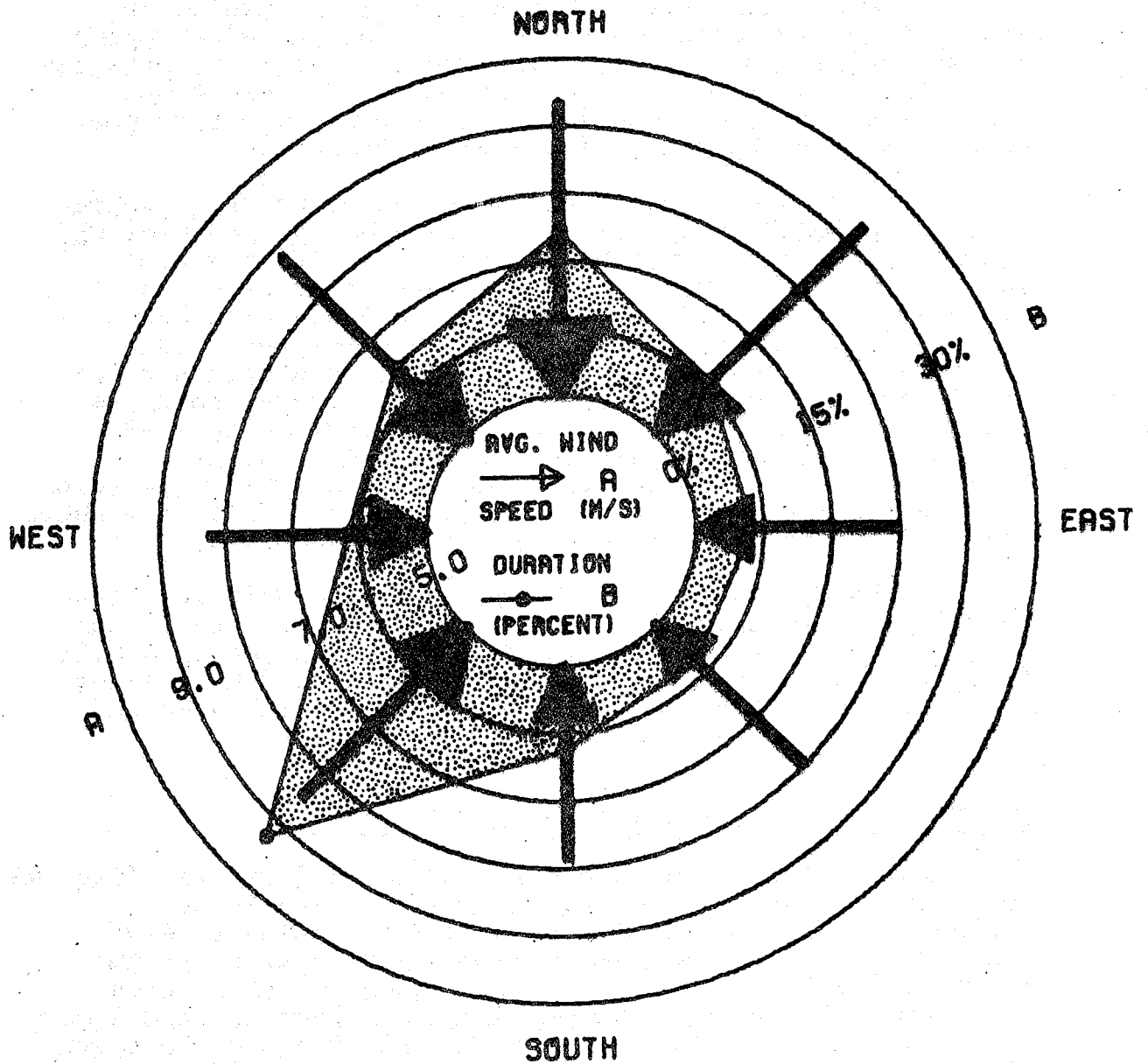


Figure 5. Schematic illustration of the movement of two large sand hills (January, 1976 to January, 1977). Dashed line indicates new dune position.



Figure 6. Aeolian transport of sand off of Whalehead Hill covering paved road to the east (top, March, 1977). Slipface of Whalehead covering dirt road (bottom, March, 1977).

2/76-2/77
**COROLLA STATION
 WIND ROSE**



EXCLUDES WIND SPEEDS < 5.0 M/S

Figure 7. Corolla Station Wind Rose (February 1976 to February 1977) for winds greater than 5.0 m/s indicating average wind speeds (arrows and scale A) and duration (scale B).

past-present and north-south differences are evident even though the dunes are very similar in size (approximately 17 meters high and 200 meters across), the height of the slipface in both cases is about 5.5 meters, and these dimensions have not changed much in the last sixteen years. Therefore other factors must account for the large differences in migration rate.

The migration rate of large dunes is controlled by sand transport, anchoring vegetation, and the wind regime. Sixteen years ago (Fig. 2) there was only scarce vegetation to the east and north of the dune to impede sand transport. Therefore, the dune moved at the maximum rate possible under the existing wind regime of the area.

However, when and if vegetation colonizes the aeolian flat and a foredune system is constructed by sand fencing, the migrating dunes will be cut off from the source of sand. This will cause them to decrease their rates of migration. At False Cape, vegetation colonization has proceeded the farthest (Fig. 4). A stable multiple ridge foredune system has effectively cut off sand transport to the interior allowing thick shrub vegetation to colonize the aeolian flat. Dune grasses have colonized much of Barbour's Hill, further slowing its advance. Since the False Cape region has departed the most from the vegetation-free environment of 15-20 years ago, Barbour's Hill now shows only a slow migration rate to the south-southwest.

In the Whalehead Hill region there are only low, discontinuous foredunes, little aeolian flat vegetation, and a greater flux of sand between the beach and the sand hill (compare Figs. 3 and 4). Therefore, Whalehead Hill shows a much faster migration rate than Barbour's Hill, though still less than the rate of 16 years ago.

Slipface Orientation and Movement Direction

Examination of the Corolla station wind diagram (Fig. 7) leads to the obvious question as to why there is no persistent slipface oriented normal to the southwest winds. Indeed, slipfaces were seen throughout the period on the easterly flanks of Whalehead Hill. However, these were only temporal features lasting until a change of wind direction occurred. On the contrary, the slipface on the south flank of Whalehead Hill is persistent, being evident in all old aerial photographs.

Notice in Figure 7 that the strongest average wind speeds were for the north and northeast directions. The northerly winds (20%) were second in duration only to the southwest winds (32%). However, the effectiveness of the southwest winds are greatly diminished by the presence of a thick forest with trees 15 meters high, to the west of all the sand hills. Due to the blockage of the southwest winds, the northerly winds can be considered dominant. This explains the orientation of the slipface which is approximately normal to, and downwind of, these northerly winds. Once established, this high slipface (6 meters) acts as a sink for any sand blowing over the crest, because the winds blowing over the forest can not develop the sheer velocity necessary to carry sand up the steeply sloping (32°) slipface. Therefore, all of the sand hills show a net movement to the south-southwest in response to the northerly winds, but also movements in other directions in response to the multi-directional wind regime.

VOLUME DISCHARGE OF SAND

The volume discharge of sand across the slipface of both Barbour's and Whalehead Hills can be estimated if the size and rate of advance of the dune is known. Figure 8 shows a schematic of a slipface for a large dune such as Barbour's or Whalehead Hill. The volume discharge is the area of the shaded portion times a unit width which is calculated according to the relation:

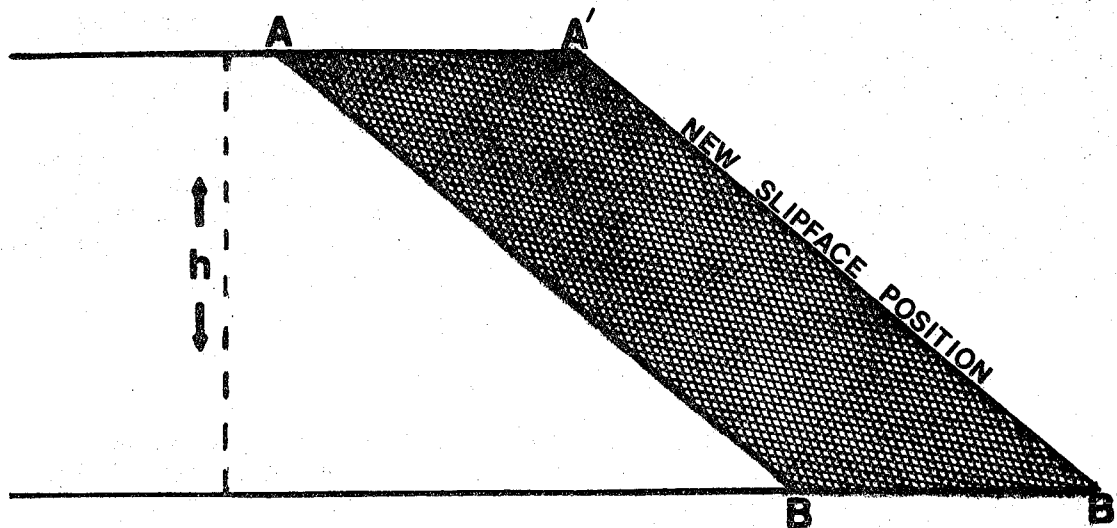
$$V = BB' \times h \times W$$

where:

- V = volume discharge/year/meter of slipface
- BB' = distance dune travelled in one year
- h = height at brink of slipface
- W = length of slipface crest (here set at 1 meter)

Similarly, the equivalent weight of sand discharged:

$$Q = V \times \gamma$$



VOLUME DISCHARGE (SHADED AREA) OF A LARGE SAND DUNE
BASED ON A KNOWN HEIGHT (H) AND MOVEMENT (BB').

WHERE:

$$V = BB' \times H \times W$$

V = VOLUME DISCHARGE/YEAR/METER OF
SLIPFACE

BB' = DISTANCE DUNE TRAVELLED IN ONE
YEAR

H = HEIGHT AT BRINK OF SLIPFACE

W = LENGTH OF SLIPFACE CREST (HERE
SET AT 1 METER)

Figure 8. Volume discharge (shaded area) of a large sand dune based on a known height (h) and movement (BB').

where:

Q = discharge in g/unit width
V = volume discharge
 γ = bulk density of loosely packed sand which is about 1.4 g/cm³
(Inman, 1966)

Therefore the discharge of sand for both Whalehead and Barbour's Hill is:

$$\begin{aligned} V &= 0.75 \times 5.5 \\ &= 4.1 \text{ m}^3/\text{year}/\text{meter width} \\ Q &= 1.3 \times 10^{-3} \text{ cm}^3/\text{cm}/\text{sec} \times 1.4 \\ &= 1.8 \times 10^{-3} \text{ g}/\text{cm}/\text{sec} \\ \text{Barbours Hill Discharge} &= 5.7 \times 10^3 \text{ kg}/\text{m}/\text{year} \end{aligned}$$

$$\begin{aligned} V &= 6.1 \times 5.5 \\ &= 33.5 \text{ m}^3/\text{year}/\text{meter width} \\ Q &= 1.1 \times 10^{-2} \text{ cm}^3/8 \text{ m}/\text{sec} \times 1.4 \text{ g}/\text{cm}^3 \\ &= 1.54 \times 10^{-2} \text{ g}/\text{cm}/\text{sec} \\ \text{Whalehead Hill Discharge} &= 4.9 \times 10^4 \text{ kg}/\text{m}/\text{year} \end{aligned}$$

Over 33 cubic meters of sand at Whalehead Hill, while only 4.1 cubic meters of sand at Barbour's Hill, was transported across one meter of slipface crest between March 1976-March 1977. This corresponds to approximately 49,000 and 5,700 kilograms of sand for each dune, respectively.

Comparison of Observed and Predicted Movement

Inman, et al. (1966) and Tsoar (1974) have compared the measured rate of dune movement with that calculated from empirical equations of aeolian sand transport. Both found that the calculated rate exceeded the measured amount by some constant amount. Inman attributed the discrepancies to calibration of the anemometer or problems associated with the equations. Tsoar attributed the differences to reduction of the transport by soil moisture.

To compare the volume discharge of sand for Whalehead Hill and Barbour's Hill a computer model was developed to calculate the sand transport for each of eight directions from wind and precipitation data for the period March 1976-March 1977. Calculations were performed at 3 hour

intervals for the entire period using equations of Bagnold (1941), Kadib (1964), and Hsu (1974). Precipitation, wind speed and temperature data for each three hour period were utilized to calculate a soil moisture content with an empirical equation derived from field data. This moisture content was input into the equation of Kadib (1964) to calculate a threshold shear velocity. If the shear velocity calculated for the wet three hour interval did not exceed the threshold shear velocity no transport was calculated for the interval. A complete discussion of the model is found in Gutman (1977).

Table 2 lists the output of the model for the one year period of March 1976-March 1977. Notice that the north-east and southwest are by far the dominant directions with respect to aeolian sand transport. Table 2 also indicates the calculated discharge across a typical slipface oriented approximately west-northwest to east southeast. This total was determined by adding together each three hour interval sand transport rate for wind directions between 300° to 90° azimuth. It was assumed that this 150° arc would include all wind directions contributing to sand transport across the slipface.

The total value for calculated sand transport across the slipface agrees extremely well with the measured value for Whalehead Hill (49,000 kg/m/year). Notice that the total predicted by the Bagnold equation and Hsu equation straddle the measured discharge. This comparison of measured and computed discharge correlates better than the studies of Inman (1966) and Tsoar (1974). Tsoar attributed a discrepancy of 10-40% between the measured and computed advance of barchan dunes to precipitation effects. Without considering the effects of precipitation the model would have indicated 20-30% greater sand transport rates than the computed discharge for a large unvegetated sand hill. Notice however that a comparison of the computed transport across the Barbour's Hill slipface shows a very poor correlation. This is attributed to the effects of vegetation on this sand transport model quantitatively shown in this comparison.

CONCLUSIONS

1. Aerial photographs indicate that the migration rate of the large sand hills south of Corolla, North Carolina has averaged about 8 meters/year towards the south-southwest over the last 16 years.

TABLE 2

COMPUTED SAND TRANSPORT FOR ONE YEAR OF
WIND DATA, CURRITUCK LIGHT STATION:

March 1976-March 1977

Direction from	(Bagnold Equation) Total Transport of Sand for Year kg/m/year	(Hsu Equation) Total Transport of Sand for Year kg/m/year
North	13,932	15,209
Northeast	23,537	25,694
East	3,126	3,413
Southeast	3,094	3,378
South	3,874	4,229
Southwest	23,233	25,362
West	4,676	5,105
Northwest	9,464	10,331

TRANSPORT ACROSS SLIPFACE

(150° arc between 300° and 90° azimuth)

47,480

51,832

2. Barbour's Hill in False Cape State Park, Virginia has been nearly stabilized by vegetation and is now migrating at only 1.5 meters/year to the south-southwest. The volume discharged across the slipface was calculated to be about $4. \text{m}^3/\text{m}/\text{year}$.

3. Whalehead Hill has not been stabilized as much by vegetation, and is now migrating to the south-southwest at about 6 meters per year, corresponding to a calculated volume discharge of about $34. \text{m}^3/\text{m}/\text{year}$. The eastern flank of this dune has undergone 9 meters of horizontal accretion in one year towards the new paved road leading to Corolla, to the east.

4. The persistent south-southwest slipface is attributed to the dominance of the north and northwest winds, because of the effect of the maritime forest on the equally frequent and speedy southwest winds.

5. Sand movement predicted by a computer model correlates well with that measured for Whalehead Hill, when the negative effects on transport of precipitation is taken into account. The correlation with that measured for Barbour's Hill is poor as would be expected given the effects of vegetation stabilization.

REFERENCES

- Bagnold, R.A., 1941. The physics of blown sand and desert dunes: William Morrow and Co., New York, 265 p.
- Gutman, A.L., 1977. Aeolian Coastal Processes: Interaction of Aeolian Sand Transport, Vegetation, and Dune Geomorphology: Masters Thesis (in prep), Virginia Institute of Marine Science, Gloucester Point, Virginia.
- Hsu, S., 1973. Computing eolian sand transport from sheer velocity measurements: J. Geology, V. 81, p. 739-743.
- Inman, D.L., Erving, G.C. and Corliss, J.B., 1966. Coastal sand dunes of Guerrero Negro, Baja California, Mexico: G.S.A. Bull., V. 77, p. 787-802.
- Kadib, A.L., 1964. Addendum II: Sand Movement by Wind: U.S. Army Corps of Engineers, C.E.R.C. T.M. #1, 38 pp.
- Lathrobe, H.B., Esq., 1814. On the sand hills of Cape Henry in Virginia: Trans. Amer. Phil. Soc., V. 4, p. 439.
- Pickard, J., 1970. Rate of movement of transgressive sand dunes at Cronulla, New South Wales: J. of Geol. Soc. Australia, V. 19, p. 213-216.
- Tsoar, H., 1974. Desert Dunes Morphology and Dynamics, El Arish (Northern Sinai), Z. Geomorph. N.F. Suppl. 3d. 20, pp. 41-61.

INTERNAL GEOMETRY OF FOREDUNE RIDGES,
CURRITUCK SPIT AREA, VIRGINIA-NORTH CAROLINA

P.S. Rosen, E. Barnett, V. Goldsmith,
G.L. Shideler,¹ M. Boule, Y.E. Goldsmith

ABSTRACT

A total of 673 measurements were made of the internal structure in coastal sand dunes along the Outer Banks barrier island chain, which extends from Cape Henry, Virginia to near Cape Hatteras, North Carolina. The measurements were made to determine the influence of local winds on coastal dune development, to determine the sources of sand comprising the dune ridge, and to compare the internal geometry of this highly stabilized dune system with other dune systems (Goldsmith, 1975).

The results of this study indicate that the coastal dunes exhibit a complex internal structure that has been developed by sand transport from both onshore and offshore winds. The wind-blown sand is derived from both the adjacent beach, and from the backshore areas landward of the dune ridge; consequently, excessive commercial or residential development of the backshore areas could have detrimental effects on dune ridge maintenance by eliminating potential sources of sand nourishment. The high angle bedding is more abundant in the offshore dipping beds, and is the result of talus deposition seaward of wave cut dune scarps. Thus, the internal dune structures also illustrate the effects of storm erosion, and the effectiveness of dune-grass plantings in subsequent dune rebuilding and stabilization. The study further suggests that dune structure is more influenced by coastline orientation than wind direction as in other dune

¹Present address: U.S. Geological Survey, P.O. Box 6732, Corpus Christi, Texas, 78411.

areas. Therefore, the national Outer Banks dune stabilization program, initiated in the 1930's, has resulted in the development of a distinctive variety of internal dune structure.

INTRODUCTION

A total of 673 measurements of the internal geometry (i.e., direction and amount of dip of crossbeds) of fore-dune ridges in the Currituck Spit area were examined to define the bedding characteristics. The objectives were to determine the relationships between dune structure and local wind conditions and to infer source-sediment locations. Fourteen sample locations extend from west of Cape Henry, Virginia on the south shore of the Chesapeake Bay, southward to Hatteras Inlet west of Cape Hatteras, North Carolina (Fig. 1). Most of the study area is an east-facing shoreline, although north and south-facing stations were examined for comparison. Only one tidal inlet (Oregon Inlet) cuts this otherwise continuous 180-km barrier beach complex.

Figures 2a and 2b show the total annual wind roses for Cape Hatteras near the south end of the study area, and for Norfolk at the north end of the study area. The wind patterns in this area are similar to the coastal areas of the northeast United States, with a trimodal wind distribution of northeast, northwest and southwest wind components. All three directions have approximately the same average wind velocities, northwest winds being slightly less frequent than the other two components. In the study area, the major wind directions are obliquely onshore and offshore at most sample locations.

METHODOLOGY

Approximately 50 measurements of dune bedding dip and azimuth direction at each of the 14 sample stations were taken on both the front and back foredune slopes. Bedding structures used for measurements included dark heavy-mineral layers, contacts of different sediment-size modes, and organic layers. Each station comprised about 20 meters of shoreline length. The dip measurements were made by digging a hole about 60 cm deep in the dune face. Only beds observable on at least three sides were measured. An 18-cm disk with a level in the center was inserted and aligned with

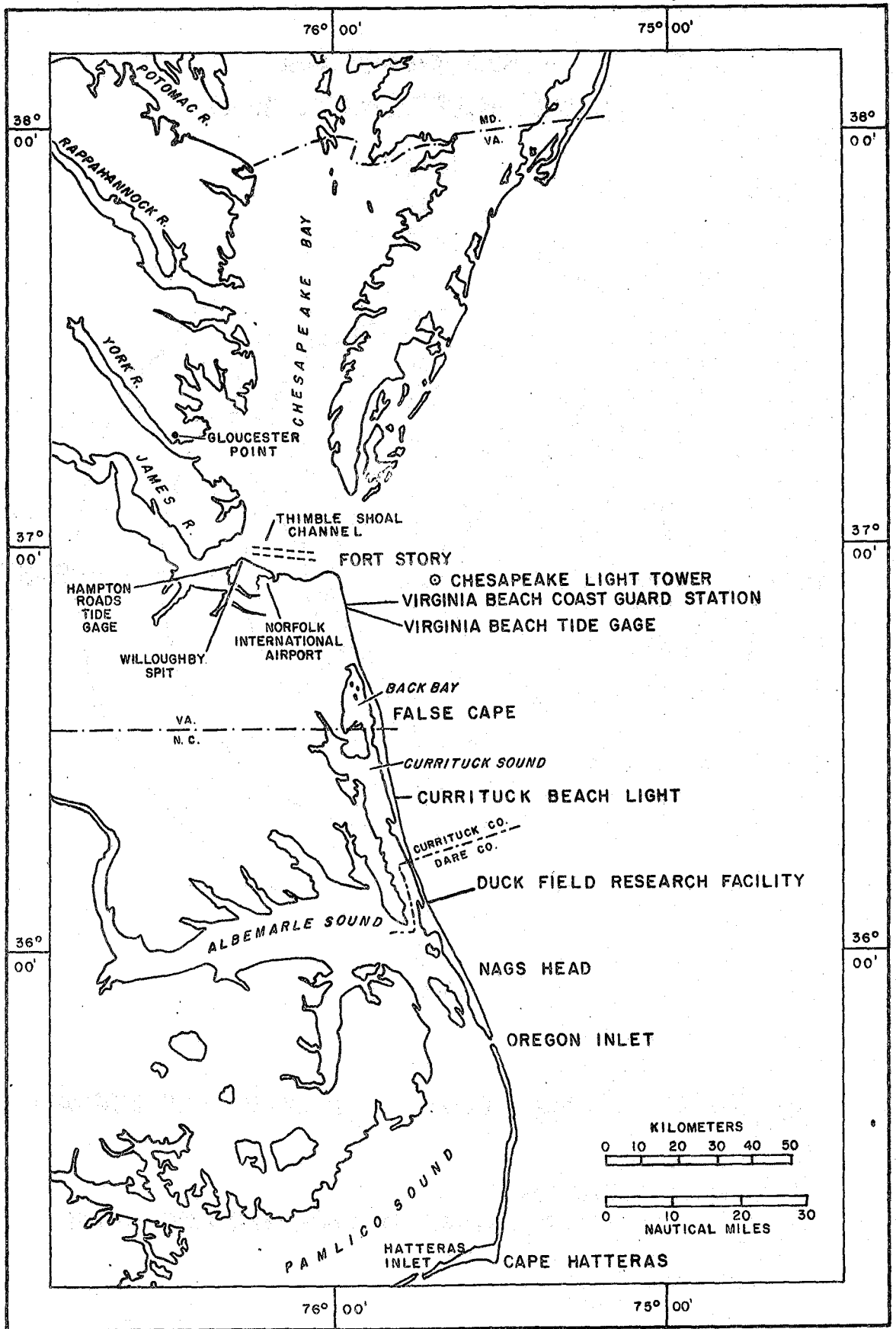
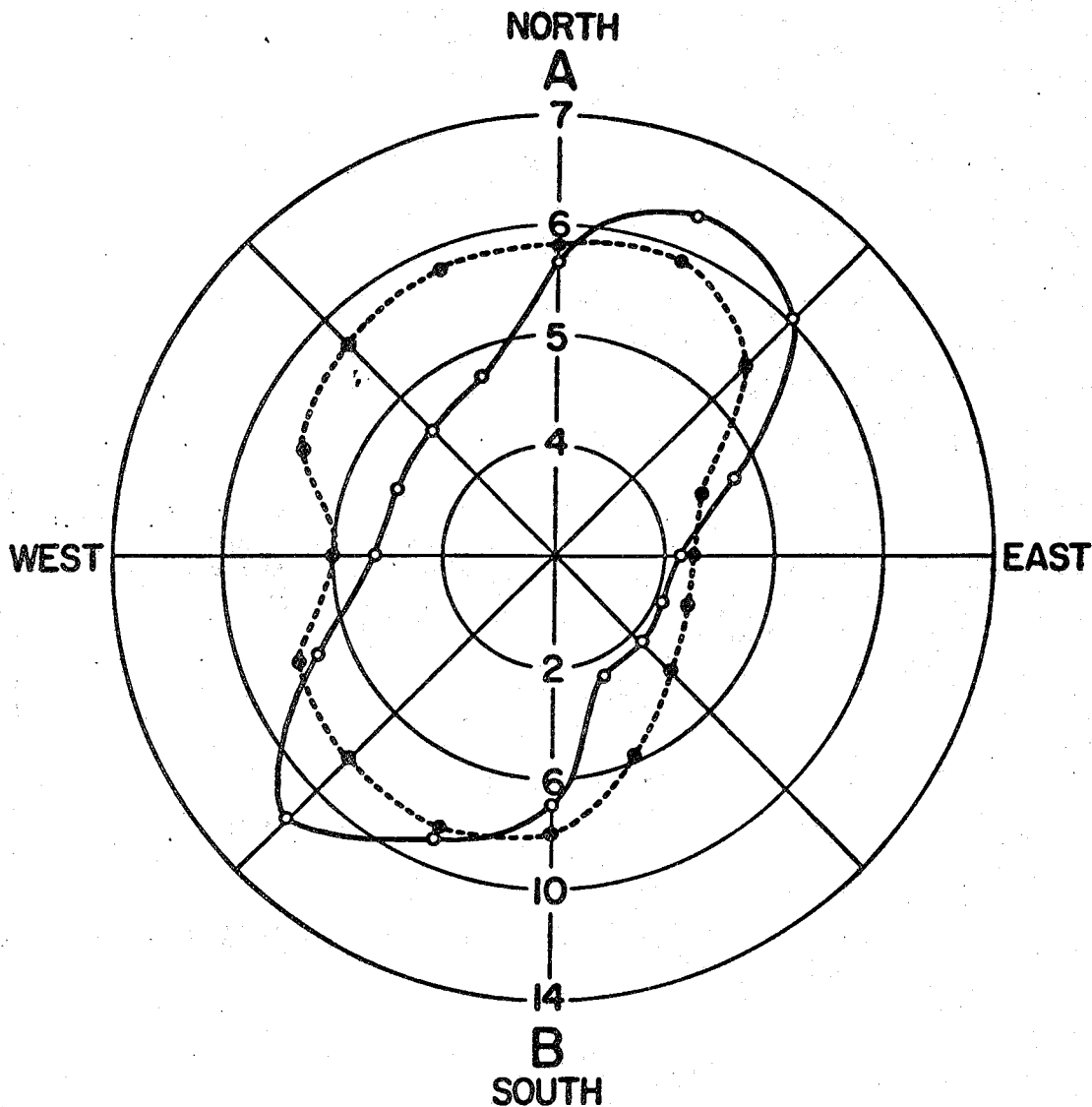


Figure 1. Regional location map of study area.

WIND DIAGRAM CAPE HATTERAS, N.C.



A ---◆--- AVERAGE VELOCITY (METERS PER SECOND)

B —○— DURATION
(PERCENTAGE OF TIME BLOWING FROM)

Figure 2a. Hatteras Station Wind Rose (1946-1970).

NORFOLK WIND DATA
1951 - 1960

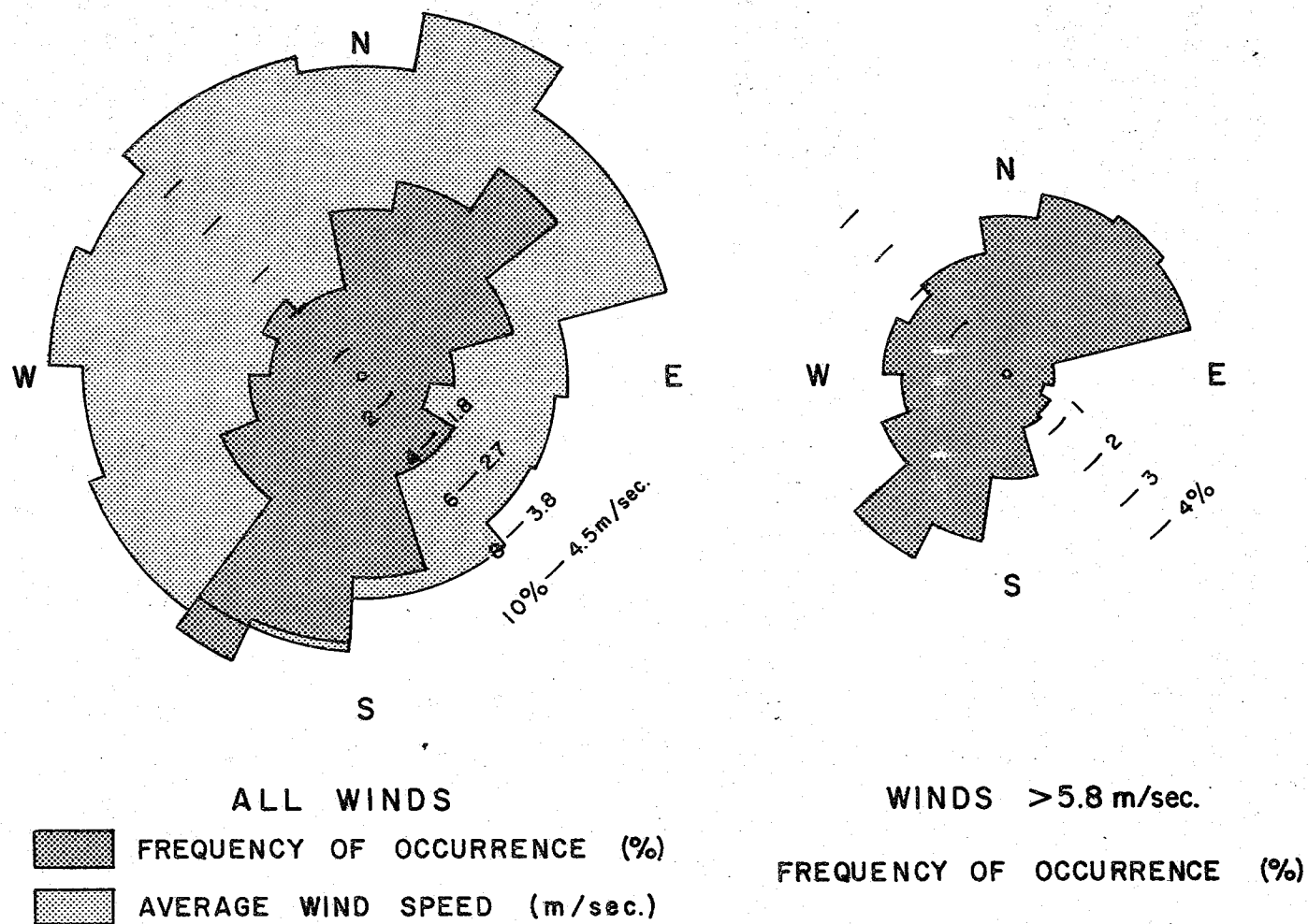


Figure 2b

bedding. The disk was then rotated until the strike was determined. The dip angle and azimuth were then measured with a Brunton Compass (Goldsmith, 1973).

The azimuth distributions involve directional properties which require the use of circular distributions. Statistical parameters for the azimuth distributions were calculated using a vector summation technique (Curry, 1956, p. 118-120), each observation being considered a vector with direction and magnitude. The method calculates the azimuth of the resultant vector which indicates the preferred-orientation direction, and the vector magnitude which is a measure of dispersion (Goldsmith, 1973).

DISCUSSION

Figure 3 shows the sample locations and plots of azimuth and dip distributions at all 14 sample stations. A clear break occurs in the azimuth distributions at all locations. This break is bisected at most locations by the shoreline-orientation axis, thus giving distinct onshore and offshore azimuth components.

The dip distributions also show a bimodality with the two modes being approximately 20° apart. This is most apparent at station locations 1, 3, 8, 11, and 14. At each station, mean dip angles were determined for each mode separately, as well as for the total number of measurements (Table 1). A higher mode (20° - 35°) probably represents slipface or talus-slope deposition, whereas the lower angle mode represents deposition caused by baffling of sediment by dune vegetation (Goldsmith, 1973).

The foredune ridge is a result of vertical growth resulting from sediment baffling by vegetation, and can be also affected by the shore processes of the adjacent beach. The foredune ridge is eroded by waves during storm surge, leaving a steep scarp on the seaward side. In times of fair weather, the dune can be rebuilt by two major processes: 1) further sediment baffling by vegetation, which grows seaward as the beach widens, as well as landward; and 2) the formation of a "talus slope" of sand filling in the area cut at the base of the dune scarp. The latter process results in sand bedding at or near the angle of repose (20° - 35°). This sedimentation is the result of transport by offshore winds. The former process generally forms low-angle bedding and can be affected by any wind. A foredune

FOREDUNE CROSSBEDS, CURRITUCK SPIT VA./N.C. AZIMUTHS AND AMOUNT OF DIP

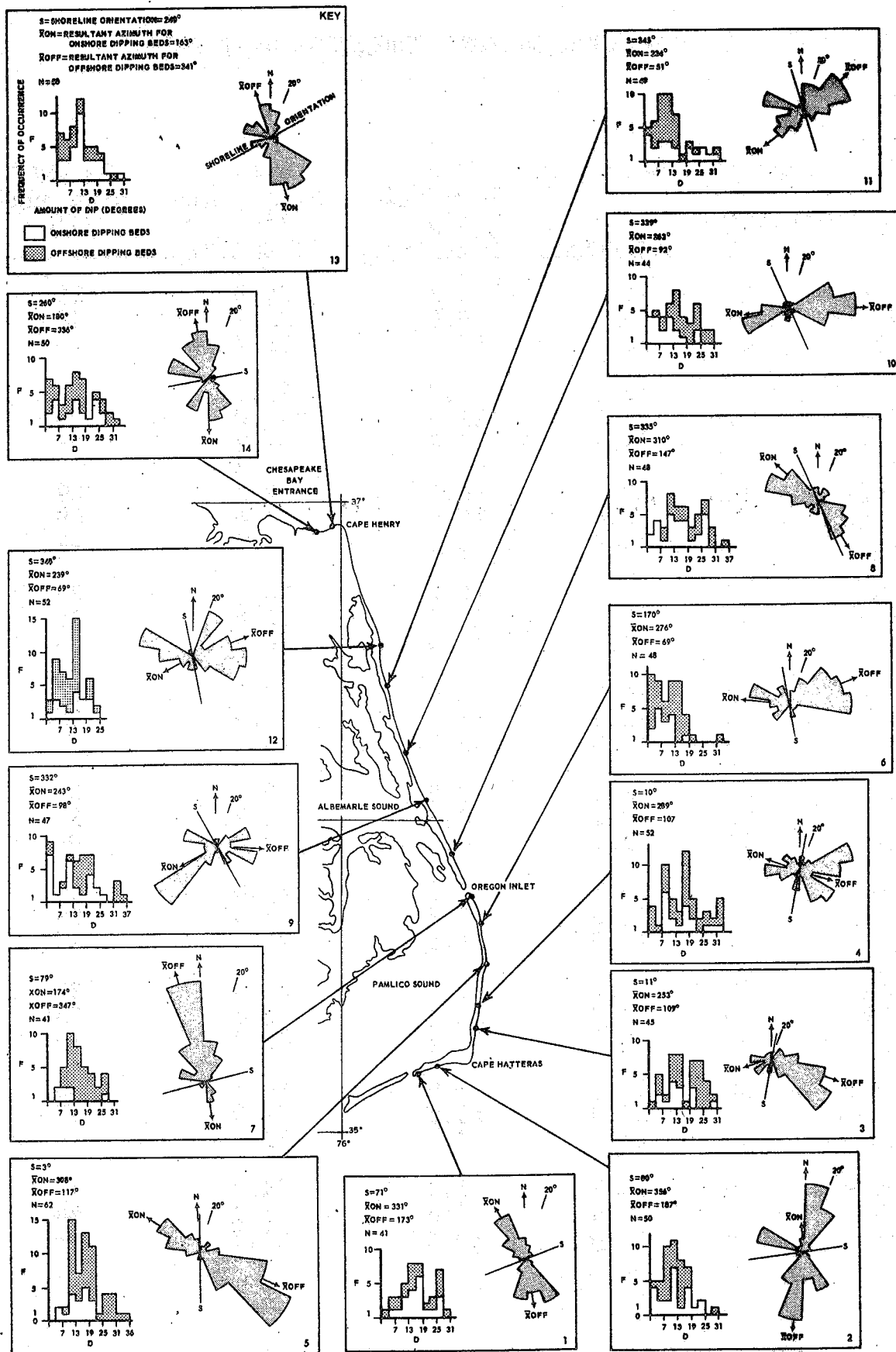


Figure 3.

TABLE 1. DUNE BED DIP DISTRIBUTION, CURRITUCK SPIT AREA

Station	Number of measurements	Mean dip (degrees)	Mean low-angle dip (degrees)	Mean high-angle dip (degrees)	Percent high-angle dip
1 onshore	20	15.9	13.3	24.0	25
1 offshore	21	16.1	10.6	25.1	38
1 total	41	16.0	12.0	21.7	--
2 onshore	23	12.6	9.7	21.0	13
2 offshore	27	12.2	11.5	31.0	4
2 total	50	12.4	10.8	22.4	--
3 onshore	14	13.7	10.4	22.3	29
3 offshore	29	16.8	10.5	23.6	48
3 total	43	15.8	10.4	23.3	--
4 onshore	18	16.3	12.2	24.8	28
4 offshore	34	17.5	11.8	26.8	35
4 total	52	17.1	11.9	26.2	--
5 onshore	18	14.0	12.4	20.3	17
5 offshore	40	18.3	13.3	24.8	45
5 total	58	17.0	12.9	24.1	--
6 onshore	15	8.8	8.8	0	0
6 offshore	34	10.1	8.8	23.7	6
6 total	49	9.7	8.8	17.8	--
7 onshore	7	10.1	7.5	25.0	14
7 offshore	34	16.0	12.9	22.9	29
7 total	41	15.0	11.8	23.1	--
8 onshore	29	15.2	10.0	26.0	28
8 offshore	20	19.7	12.3	25.8	55
8 total	49	17.0	10.7	29.9	--
9 onshore	26	11.5	7.6	18.4	35
9 offshore	21	18.0	13.8	27.5	33
9 total	47	14.4	10.1	23.3	--
10 onshore	19	9.3	7.8	23.0	11
10 offshore	25	17.6	12.8	23.9	44
10 total	44	14.0	10.0	23.8	--

TABLE 1. Cont'd.

Station	Number of measurements	Mean dip (degrees)	Mean low-angle dip (degrees)	Mean high-angle dip (degrees)	Percent high-angle dip
11 onshore	21	13.5	8.3	25.7	33
11 offshore	28	12.5	10.4	24.3	11
11 total	49	12.8	9.6	25.2	--
12 onshore	16	14.1	10.6	22.3	25
12 offshore	34	12.3	11.4	21.3	12
12 total	50	13.1	11.1	21.8	--
13 onshore	32	12.7	10.7	23.6	15.6
13 offshore	18	10.9	9.2	24.0	11.1
13 total	50	12.0	10.1	23.7	--
14 onshore	22	15.1	10.3	24.1	31.8
14 offshore	28	14.3	10.3	28.3	21.4
14 total	50	14.6	10.3	26.1	--

is generally the result of a combination of many generations of scarping and rebuilding by talus deposition and vegetation baffling.

Of the 673 dip measurements, 280 dip onshore, whereas 393 (or 58%) dip offshore. Eleven of the 14 stations show a dominance of offshore dipping beds (all except 8, 9, and 13). The dominant offshore dip suggests that the offshore winds and the back-island areas, as opposed to the beach area, are the dominant source of sediments for the foredune ridge. Observations indicate that offshore-blowing winds also furnish significant amounts of sand to the beach as well.

Eight out of the 14 stations (1, 3, 4, 5, 6, 7, 8, and 10) show a larger percentage of high-angle beds ($> 19^\circ$) dipping offshore than onshore. This is most notable for the southern stations, where the beaches are narrower and more erosional, than for the northern beaches (Goldsmith, et al., 1977). The high-angle bedding is due to the formation of the talus slope on the seaward margin of the dune scarp. Therefore, slumping caused by wave erosion, as indicated by the number of high angle beds, may be a major source of sand in the maintenance of the foredunes. The dominant onshore bedding is low angle, resulting from vegetation baffling, while offshore bedding shows both sediment baffling and talus slope accumulation. Goldsmith (1973, 1975) has discussed the internal geometry of dune bedding in four areas: Monomoy Island, Massachusetts; Praia de Leste, Brazil; Mustang Island, Texas, and the Mediterranean Coast of Israel. The higher angle bedding in these other areas is attributed to pyramidal wind-shadow dune formation. In the Currituck area, the high-angle bedding is also due to slip-face deposition.

Figure 3 and Table 2 show the shore orientations at each station, and the direction and significance of the calculated resultant dip-direction (i.e., azimuth) vectors for the onshore and offshore sub samples. There is no direct relationship between the orientation of the bedding and the wind regime. In nearly all places the dune beds dip perpendicular to the shore orientation even as the shore orientation changes (see stations 1, 2, 7, 13, and 14).

However, in each of the four previously mentioned localities, the azimuth distributions do correlate closely with the local prevailing wind directions; consequently, the Currituck dunes are somewhat anomalous. The foredune ridges of the

TABLE 2. RESULTANT DIP DIRECTIONS, CURRITUCK SPIT AREA

Station	Shoreline orientation	Azimuth resultant vector	Resultant vector magnitude (L)	Magnitude (%)	Level of significance	Azimuth range
1 onshore	--	331.5	17.8	84.8	$< 10^{-5}$	270-50
1 offshore	--	173.2	19.4	92.2	$< 10^{-5}$	127-209
1 total	71°	240.0	7.2	17.1	$> .20$	--
2 onshore	--	356.4	22.7	98.6	$< 10^{-5}$	315-70
2 offshore	--	187.0	24.5	90.6	$< 10^{-5}$	130-242
2 total	80°	249.4	4.7	9.4	$> .60$	--
3 onshore	--	252.8	8.0	57.2	$< .01$	190-343
3 offshore	--	108.8	25.6	88.1	$< 10^{-5}$	50-151
3 total	11°	122.7	19.6	45.7	$< 10^{-3}$	--
4 onshore	--	287.4	11.9	79.1	$< 10^{-4}$	236-1
4 offshore	--	107.4	23.8	64.3	$< 10^{-4}$	38-190
4 total	10°	107.3	11.9	22.9	$> .05$	--
5 onshore	--	308.2	16.6	92.2	$< 10^{-5}$	270-371
5 offshore	--	117.0	32.6	79.6	$< 10^{-10}$	20-179
5 total	3°	105.8	16.7	28.2	$< .01$	--
6 onshore	--	275.9	9.4	66.9	$< .01$	220-332
6 offshore	--	69.2	24.0	66.7	$< 10^{-5}$	1-150
6 total	50°	54.1	16.2	32.4	$> .01$	--
7 onshore	--	173.7	5.7	81.5	$< 10^{-4}$	159-239
7 offshore	--	347.2	33.3	87.7	$< 10^{-10}$	300-40
7 total	328°	345.9	27.7	61.5	$> 10^{-5}$	--
8 onshore	--	309.5	20.5	66.1	$< 10^{-5}$	236-60
8 offshore	--	146.7	15.6	78.0	$< 10^{-5}$	105-202
8 total	335°	270.0	7.2	14.2	$> .3$	--

TABLE 2. Cont'd.

Station	Shoreline orientation	Azimuth resultant vector	Resultant vector magnitude (L)	Magnitude (%)	Level of significance	Azimuth range	
9	onshore	--	243.4	13.5	53.8	$< 10^{-3}$	200-9
	offshore	--	98.3	16.9	80.7	$< 10^{-5}$	48-196
	total	332°	151.1	9.7	20.6	$> .05$	--
10	onshore	--	257.7	12.3	64.6	$< 10^{-3}$	166-2
	offshore	--	91.9	23.8	95.0	$< 10^{-5}$	48-124
	total	339°	106.2	12.2	27.8	$> .04$	--
11	onshore	--	234.6	12.2	67.9	$< 10^{-3}$	10-131
	offshore	--	51.2	20.9	65.3	$< 10^{-5}$	100-320
	total	51°	46.4	8.7	17.4	$> .10$	--
12	onshore	--	238.6	10.9	67.9	$< .015$	161-324
	offshore	--	68.6	22.6	66.5	$< 10^{-5}$	16-126
	total	8°	77.9	12.1	24.1	$> .85$	--
13	onshore	--	163.1	25.5	79.6	$< 10^{-5}$	114-251
	offshore	--	341.8	15.8	87.7	$< 10^{-5}$	290-61
	total	240°	165.2	9.7	19.4	$> .60$	--
14	onshore	--	180.0	18.5	84.0	$< 10^{-5}$	86-241
	offshore	--	336.3	24.3	86.8	$< 10^{-5}$	274-78
	total	260°	291.1	10.4	21.0	$> .30$	--

Currituck area are composed of dune beds dipping in response to the major onshore (northeast) and offshore (northwest and southwest) wind components. However, the bed orientation is further modified by the shoreline and dune orientation (Fig. 4): This dependence on the shoreline orientation appears to be one of the clearest trends apparent in these data, and one which differs from data reported in other coastal areas (Goldsmith, 1973). This difference in the importance of shore orientation is probably due to the coastal-stabilization program in the area. Since the 1930's, these dunes have been artificially heightened by a program of repetitive sand fencing and dune grass plantings (Dolan, 1973) resulting in an anomalously narrow but high foredune continuous along much of this coastline. This dune configuration has modified the normally direct relationship between wind direction and dip of beds, resulting in a polarized azimuth distribution of dune crossbeds.

EFFECTS ON THE MANAGEMENT OF COASTAL AREAS

The foredune ridge is the primary defense mechanism of natural coastal areas against both the erosional and overwash effects of storms and surge. Effective planning has traditionally protected the integrity of the dune under the assumption that it is nourished and replenished by wind-blown sand from the beachface. The present study on Currituck Spit indicates the importance of the back-island areas as a sand source to the foredune (Fig. 4). Leatherman (1976) also showed the importance of offshore winds in furnishing sand to the foredunes and beaches, sand derived from the interior of Assateague Island, Maryland-Virginia. If a back-island area has a high degree of commercial or residential development, the supply of sand needed to maintain the protective foredune is removed. If natural processes are to be maintained, corridors must exist in the back-island for the free movement of windblown sand.

The strongly polarized distribution of dip direction in foredune cross beds, which is anomalous with respect to other coastal areas (Goldsmith, 1973), suggests that the artificially heightened foredune results in a different dune geometry. Such a geometry may be less stable and less resistant to erosion from natural forces (e.g., wave attack) and from stresses exerted by people, than is a dune geometry having more evenly distributed, and therefore,

FOREDUNE CROSS BED DIP ANGLES & AZIMUTHS
CURRITUCK SPIT, VA. /N.C.

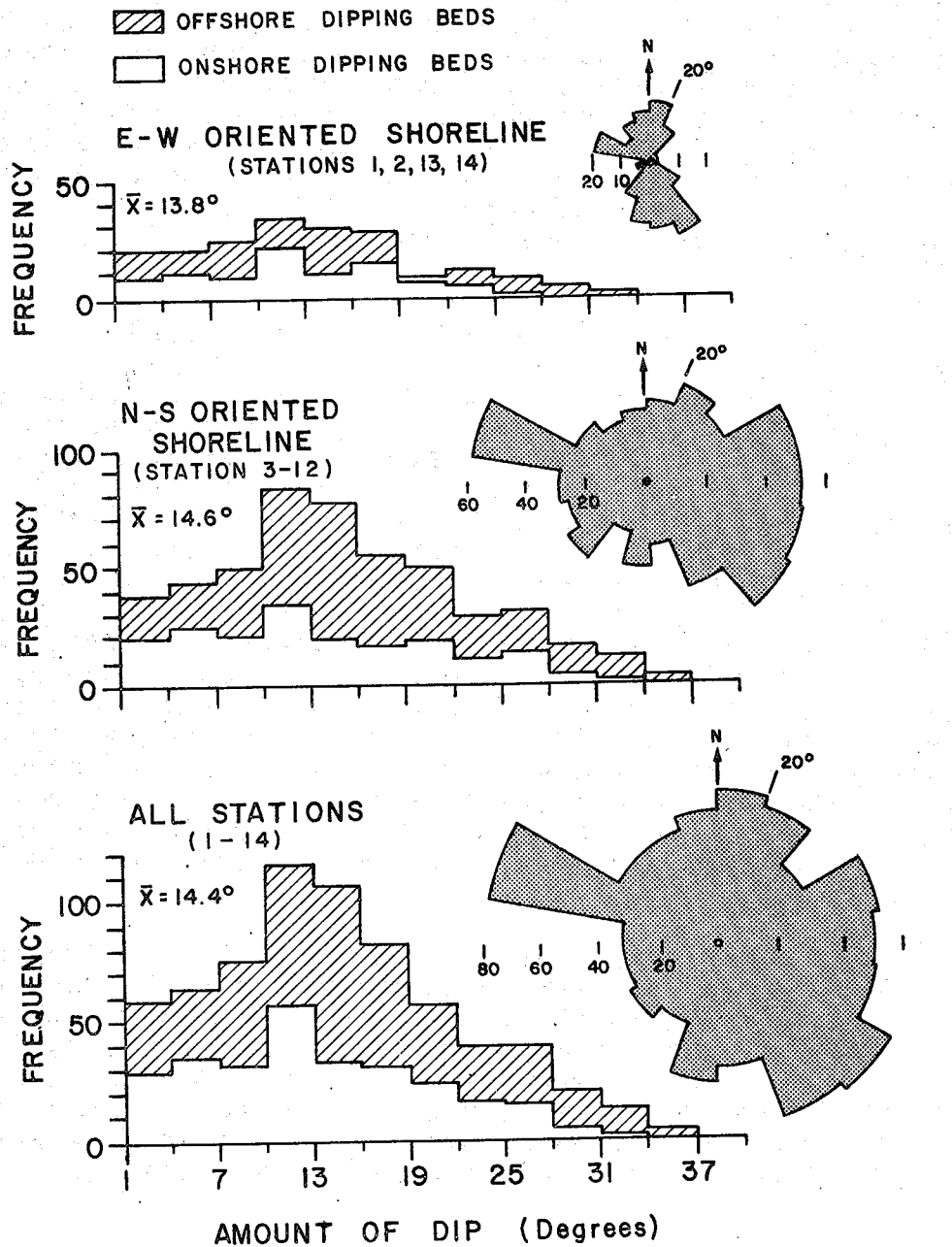


Figure 4.

"interlocking" beds. This has yet to be studied. The important point, however, is that the internal dune geometry is different in highly managed areas than it is in areas where natural processes are in effect. The results of coastal management need to be recognized for enhanced preservation of these areas, as well as improved design of the coastal developments inevitable in some areas.

CONCLUSIONS

The internal geometry of the foredune ridges in the Currituck Spit area shows two distinct modes of bedding, which are aligned to the onshore and offshore directions. In general, high-angle dips are more abundant in the offshore-dipping beds. The high-angle offshore bedding is the result of talus deposition seaward of wave-cut dune scarps. This offshore dominance suggests that the backshore of the barrier islands is also a major source of sediment for dune formation, rather than the beach alone.

The strongly polarized orientation of bedding in the foredune (i.e., dipping perpendicular to shoreline orientation) is probably a result of the artificially heightened but narrow continuous foredune ridge maintained along much of this coastline since the 1930's.

REFERENCES

- Curray, J., 1956. The analysis of two-dimensional orientation data, *J. Geol.* V. 64, p. 117-131.
- Dolan, R., Godfrey, P.J., Odum, W.E., 1973. Man's Impact on the Barrier Islands of North Carolina, in *American Scientist*, V. 61, March-April 1973, p. 152-162.
- Goldsmith, V., 1973. Formation and internal geometry of vegetated coastal sand dunes: *J. Sed. Petrol.*, V. 43, p. 1128-1142, VIMS Contrib. No. 521.
- Goldsmith, V., 1975. Eolian sedimentation in coastal areas. Chapter 4 in Davis, R.A. (ed.), *Coastal Sedimentation*, Edwards Bros., Mich., VIMS Contrib. No. 533. VIMS Printing, 1975.
- Goldsmith, V., Sturm, S., Thomas, G., 1977. Variations in Beach Erosion and Accretion Trends at Virginia Beach, Virginia, and Vicinity: Final Report CERC Contract DACW-72-C-0008 and CERC Tech. Memo No. (in press), C.E.R.C., U.S. Army Corps of Engs., Ft. Belvoir, Virginia; VIMS SRAMSOE No. 122.
- Leatherman, S., 1976. "Quantification of Overwash Processes," Ph.D. Dissertation, Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia.

A REVIEW OF GRAIN SIZE AND MINERALOGY DATA

FROM THE LITERATURE¹

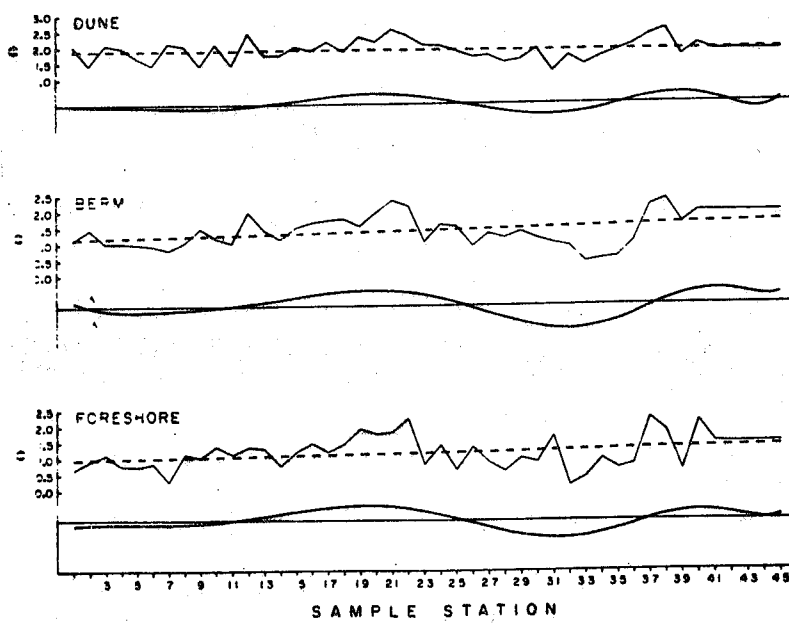
Victor Goldsmith

Beach sedimentological studies of the Outer Banks have been made by Swift, et al. (1971), Swift, Dill and McHone (1971), Shideler (1973a, 1973b, 1973c, 1974), and Sabet (1973). These studies, which show that the interpretation of coastal processes from grain size and mineralogical data in this area is a very complex problem, are summarized in Figure 1. In general, the sand composing the beach and dunes south of Rudee Inlet is relatively uniform with Mean (ϕ) \approx 1.0 to 2.0 (0.5 to 0.25 millimeters); Standard Deviation \approx 0.8 (0.6 millimeters) along the berm and 0.5 (0.7 millimeters) in the dunes (Shideler, 1973b). The major exception is the addition of a coarse red (-2. to 1. ϕ), iron-stained quartz and feldspar sand component. The northern limit of this coarse red sand varies dramatically between Corolla and Duck (discussed by Thomas, et al., this volume). This area is referred to locally as the "area of treacherous red sands" because of its adverse affect on four-wheel drive vehicles traveling the beach. (Also see Farrell, this volume.)

The sand behavior of Virginia Beach has been studied by Harrison and Alamo (1964), who tabulated the settling velocities of sand in the vicinity of Rudee Inlet, and by Tuck (1969). Tuck suggested that a reversal in the slope grain-size relationship occurs under storm conditions on the beach coincident with profile changes, and that such a reversal is generally present in the "zone of shoaling waves" part of the beach at Virginia Beach. The slope-grain size relationship referred to here is the increase in beach slope with

¹Much of this section is taken from a report (in press) to the Coastal Engineering Research Center of the U.S. Army Corps of Engineers (Goldsmith, et al., 1977).

MEAN DIAMETER



STANDARD DEVIATION

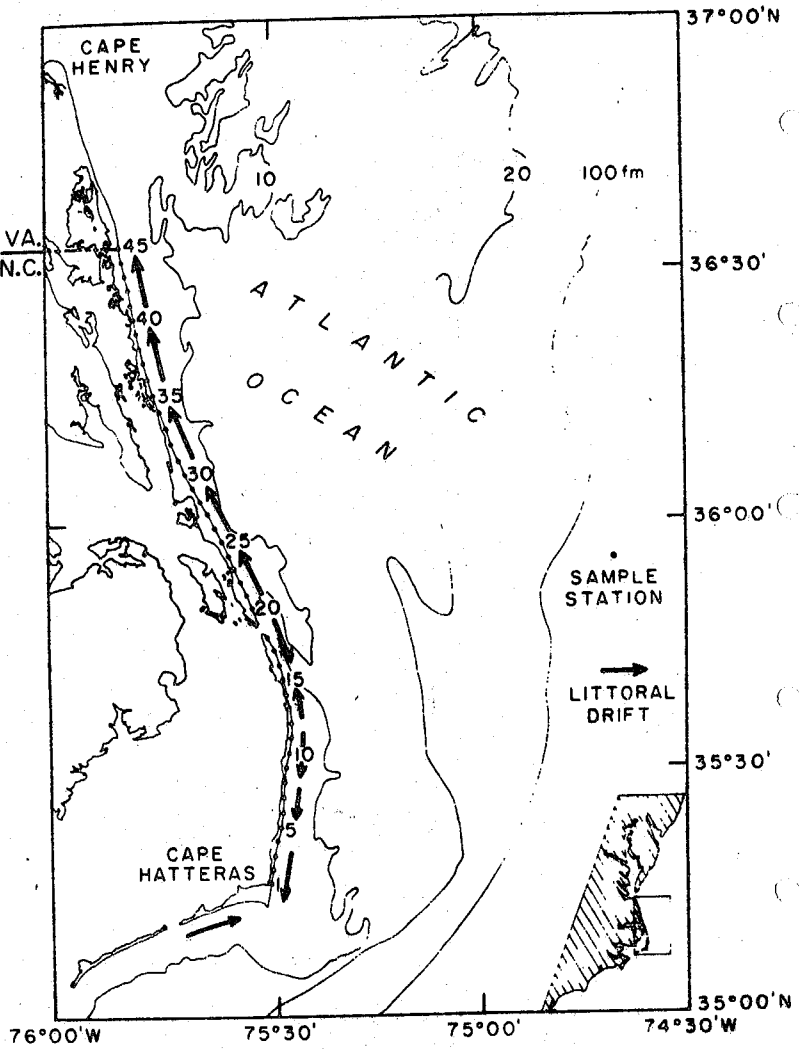
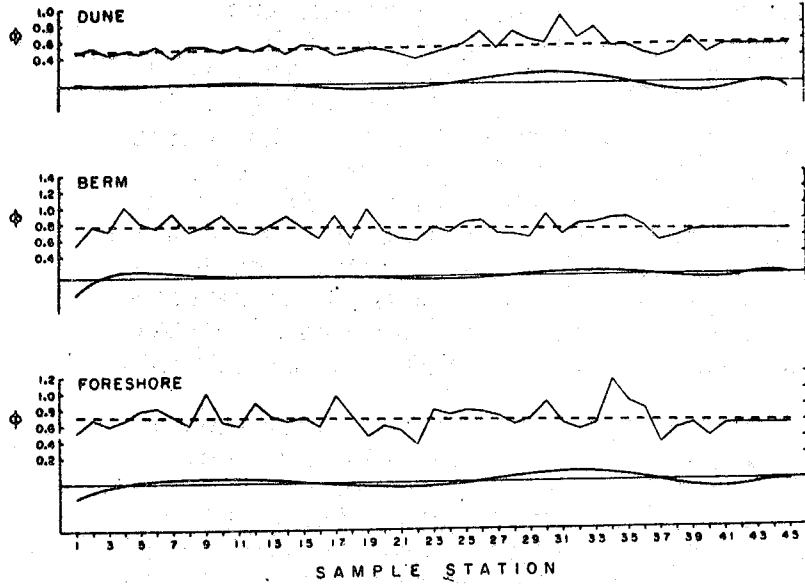


Figure 1. Grain size data, Cape Henry to Cape Hatteras, and longshore transport direction (arrows) hypothesized by Shideler (1973b).

increase in grain size. As noted by Tuck (1969) and Thomas, et al. (this volume), there are many exceptions to this relationship.

Mineralogical data between Cape Henry and Cape Hatteras are detailed by Swift, et al., 1971, who indicate very complex relationships. They are summarized in Figure 2.

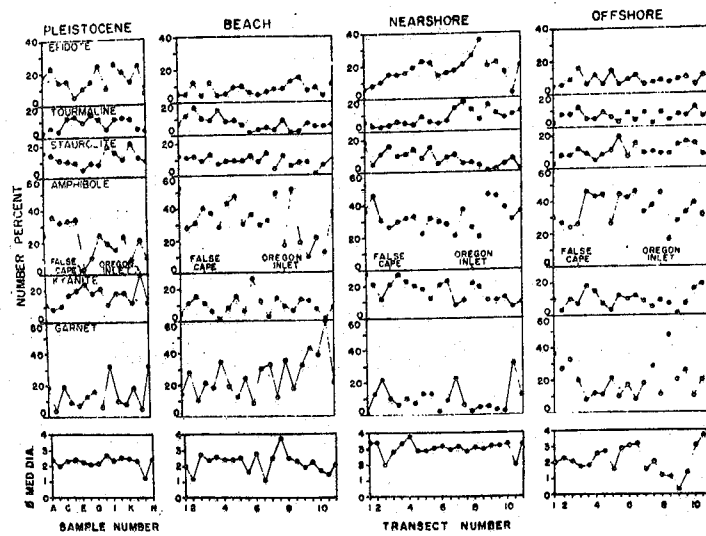
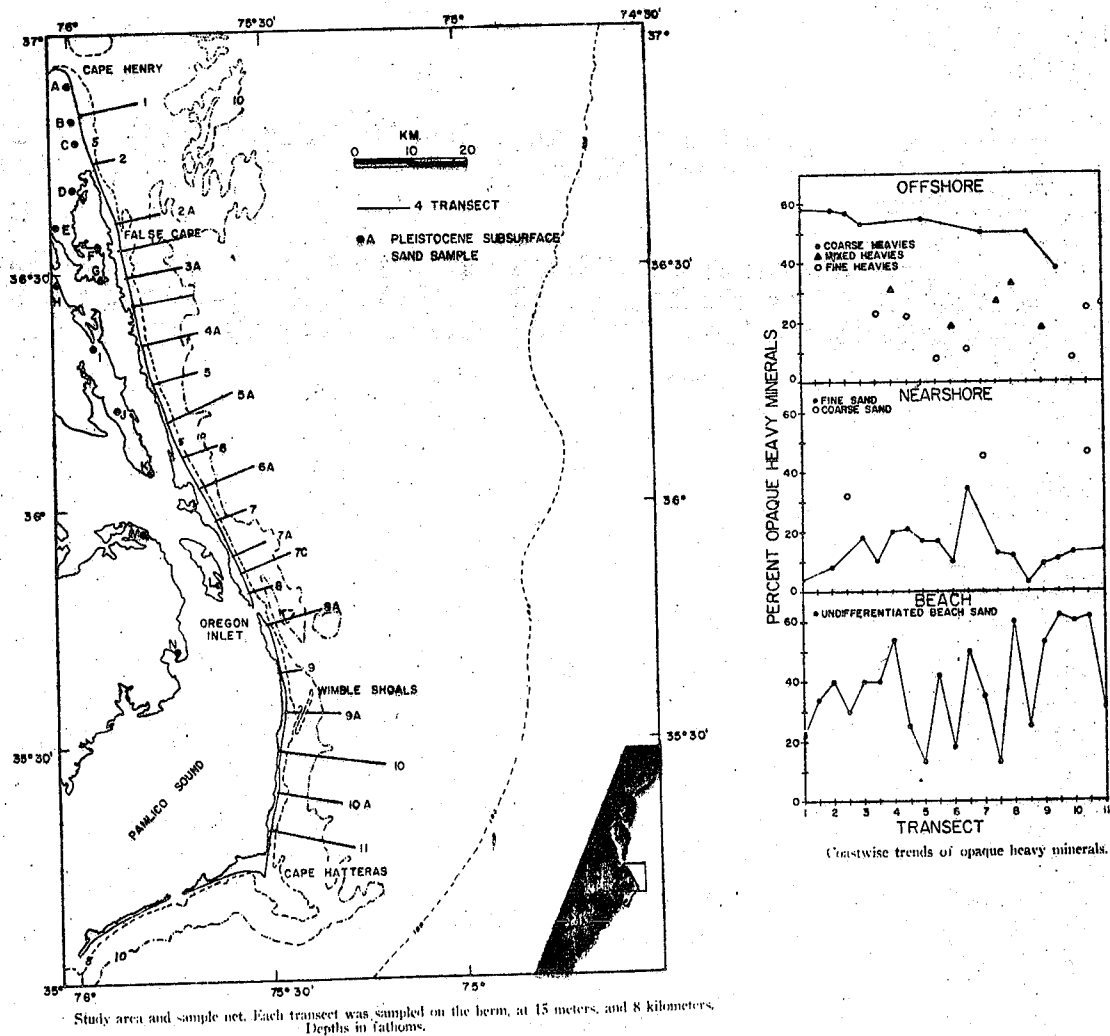


Figure 2. Mineralogical data, Cape Henry to Cape Hatteras (from Swift Dill, and McHone, 1971).

REFERENCES

- Goldsmith, V., Sturm, S., Thomas, G., 1977. Variations in Beach Erosion and Accretion Trends at Virginia Beach, Virginia, and Vicinity: Final Report CERC Contract DACW-72-C-0008 and CERC Tech. Memo No. ___ (in press), C.E.R.C., U.S. Army Corps of Engs., Ft. Belvoir, Virginia; VIMS SRAMSOE No. 122.
- Harrison, W., and Morales-Alamo, R., 1964. Dynamic Properties of Immersed Sand at Virginia Beach, Virginia, Technical Memorandum 9, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Washington, D.C., Dec.
- Sabet, M.A., 1973. Textural Trend Analysis of Coastal Barrier Sediments Along the Middle Atlantic Bight, North Carolina--Some comments, Sedimentary Geology, Vol. 10, pp. 311-312.
- Swift, D., Dill, C., and McHone, J., 1971. Hydraulic Fractionation of Heavy Mineral Suites on an Unconsolidated Retreating Coast, Journal of Sedimentary Petrology, Vol. 41, pp. 683-900.
- Swift, D., Sanford, R., Dill, C., Jr., and Avignone, N., 1971. Textural Differentiation of the Shoreface During Erosional Retreat of an Unconsolidated Coast, Cape Henry to Cape Hatteras, Western North Atlantic Shelf, Sedimentology, Vol. 16, pp. 221-250.
- Shideler, G.L., 1973a. Evaluation of a Conceptual Model for the Transverse Sediment Transport System of Coastal Barrier Chain, Middle Atlantic Bight, Journal of Sedimentary Petrology, Vol. 43, pp. 748-764.
- Shideler, G.L., 1973b. Textural Trend Analysis of Coastal Barrier Sediments Along the Middle Atlantic Bight, North Carolina, Sedimentary Geology, Vol. 9, pp. 195-220.
- Shideler, G.L., 1973c. Textural Trend Analysis of Coastal Barrier Sediments Along the Middle Atlantic Bight, North Carolina--Reply, Sedimentary Geology, Vol. 10, pp. 313-316.

Shideler, G.L., 1974. Evaluation of Textural Parameters as Beach-Dune Environmental Discriminators Along the Outer Banks Barrier, North Carolina, Southeastern Geology, Vol. 15, pp. 201-222.

Tuck, D.R., Jr., 1969. Major Environmental Variables Affecting Grain Size Distribution in the Shoaling-Wave Zone Under Storm Conditions at Virginia Beach, Virginia, M.S. Thesis, Virginia Institute of Marine Science, Gloucester Point, Va.

BEACH SLOPE AND GRAIN SIZE CHANGES:

CURRITUCK COUNTY, NORTH CAROLINA¹

George R. Thomas, Victor Goldsmith and Susan C. Sturm

Eight trips to the Currituck County ocean front (February 1975 to September 1976) revealed low-gradient, broad beaches for the first 30 kilometers south of the Virginia-North Carolina State line (Figs. 1 and 2). (The VIMS-CERC Currituck County reconnaissance stations, at intervals of 6.4 kilometers starting at the Virginia-North Carolina State line, are indicated on Figure 1.) The next 8 to 9 kilometers of beach encompasses the southern part of Currituck County (the area of the now closed Caffey Inlet in upper Dare County) and beaches just north of the Duck Field Research Facility. This section is represented by narrow, steep beaches with dune scarps, and copious amounts of coarse sand, locally known as "treacherous red sands" because of the difficulty of driving. However, these sands were beginning to show farther north in 1976.

Over the 19 months data were taken in quarterly reconnaissance trips to this area, little change was observed in the beach widths. The steepness of beach-face slopes decreased slightly (Fig. 2) and beach-face sand grain size remained about the same (Fig. 3). Figure 4 compares the beach-face slope angle to the beach-face sand grain size.

Field observations indicate the measured high angle beach faces represent convex-upward accretional berm conditions, and the low angle beach-face slope angles

¹Much of this is excerpted directly from a report to be published by the Coastal Engineering Research Center, U.S. Army Corps of Engineers, which sponsored this research.

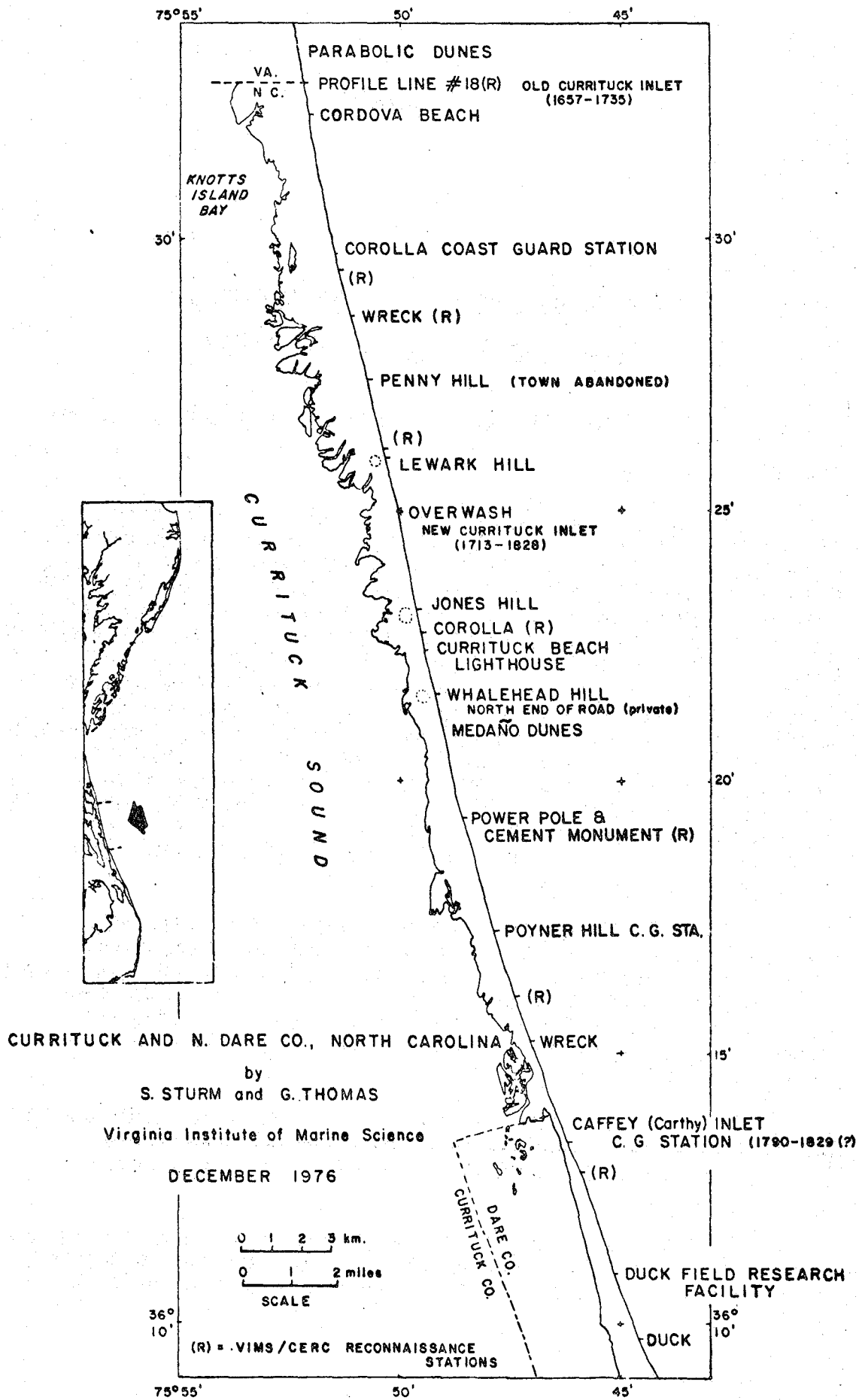


Figure 1. Map of Currituck County, North Carolina.

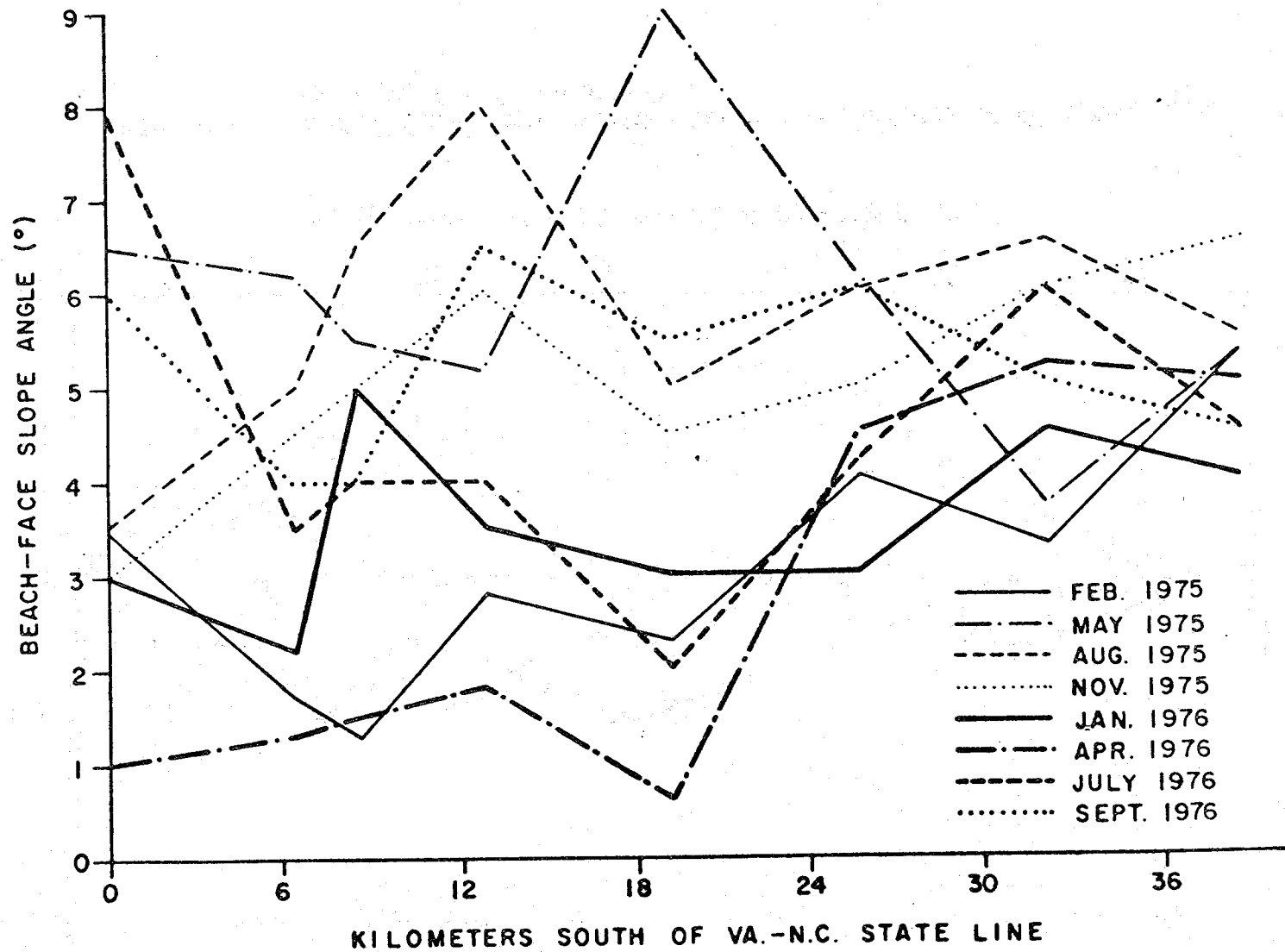


Figure 2. Beach-face slope angle versus distance in Currituck County, North Carolina.

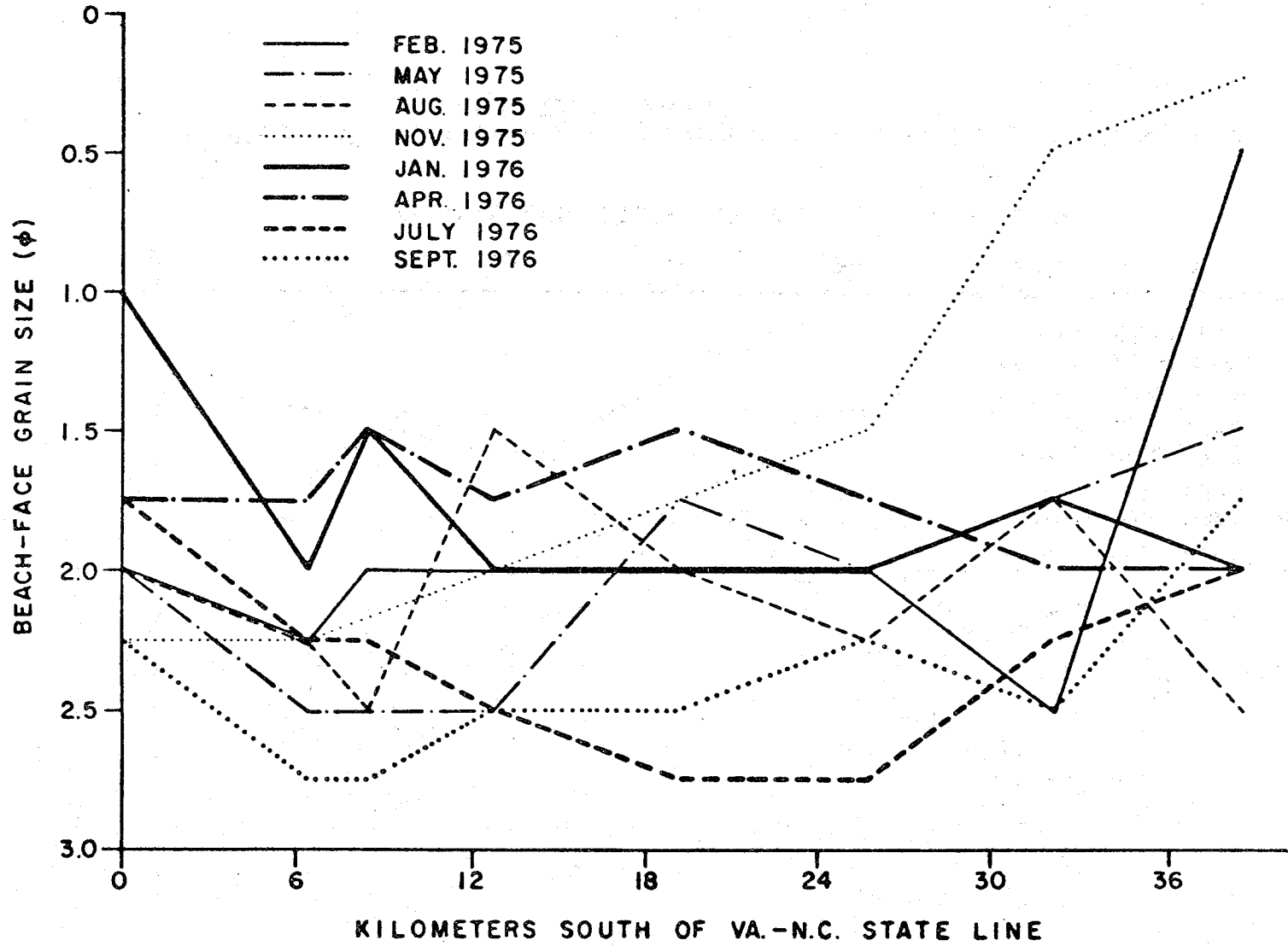


Figure 3. Beach-face sand grain size versus distance in Currituck County, North Carolina.

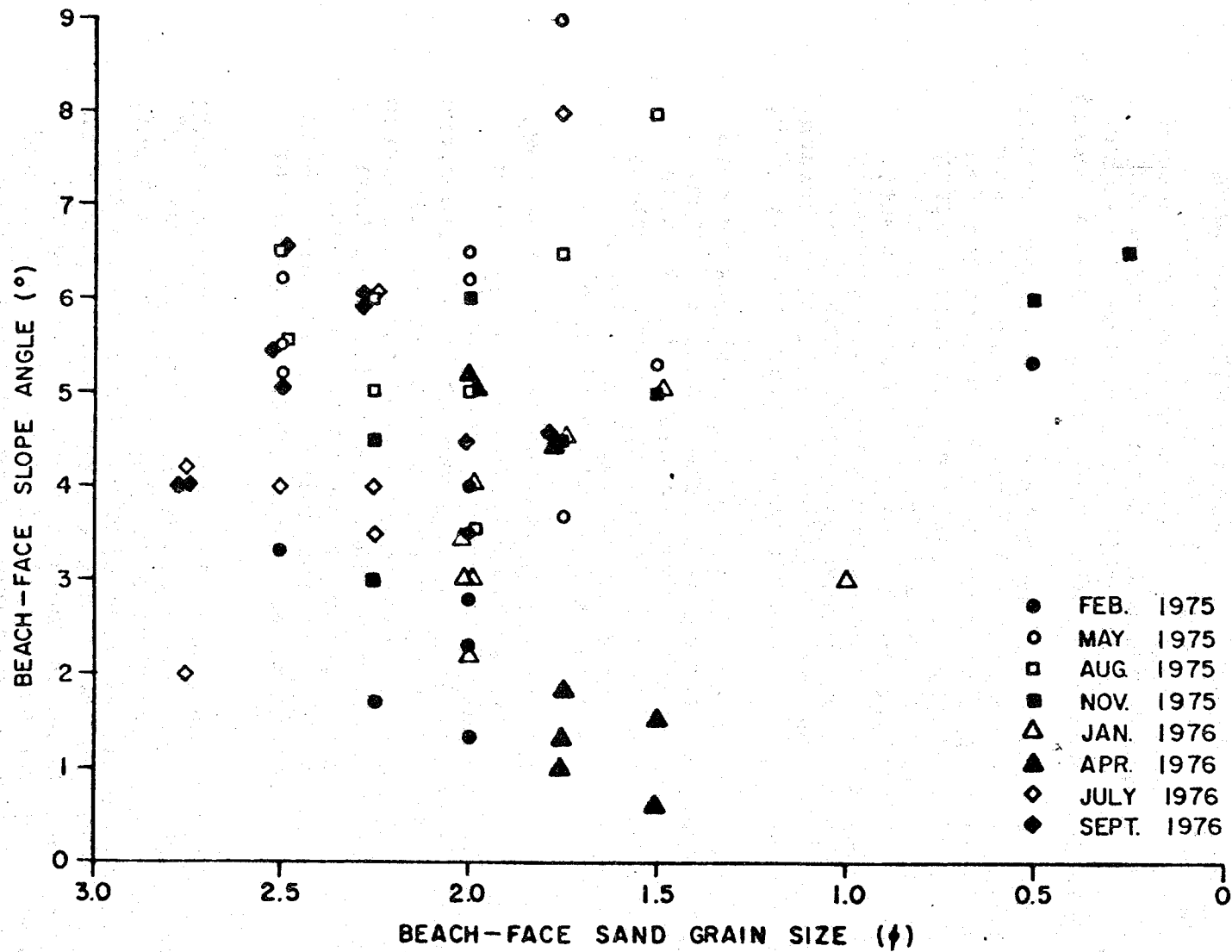


Figure 4. Beach-face slope angle versus beach-face sand grain size in Currituck County, North Carolina.

represent concave erosional beach profile lines. The lowest-angle beaches (i.e., erosional) were measured in April 1976, February 1975, July 1976, and January 1976, and the steepest beaches (i.e., accretional) were measured in May 1975, August 1975, September 1976, and November 1975. These data are thus suggestive of seasonality with erosional beaches in winter and early spring (with one exception in July 1976) and accretional beaches in late spring, summer and fall. (See Frisch, this volume.)

Richardson (1977) has summarized beach erosion occurrences between 1 November and 30 April for the U.S. east coast (Maine to Virginia) from the U.S. Weather Service records. This tabulation indicates a fall storm period (November and December) and a late winter-early spring storm period (March and April), with a lull in January. Thus, these Currituck County beach slope data generally fit other beach erosion seasonality data, with these Currituck data having two exceptions, a fall storm season later than usual in 1975, and a summer storm in July 1976.

The large variations in grain size were observed to be due to longshore variations in the coarse red sand. These fluctuations, which ranged between 4 and 20 kilometers north of Duck, were quite visible during monthly aerial overflights. There was no apparent relation between grain size and beach-face slope (Fig. 4).

The new C.E.R.C. Research Pier of the U.S. Army Corps of Engineers is located in northern Dare County, North Carolina, approximately 5 kilometers south of the Currituck-Dare County line and approximately 42 kilometers south of the Virginia-North Carolina State line. In general, the beaches in this immediate vicinity are narrow and steep with very apparent dune scarps (greater than or equal to 3 meters) reached by every storm. These beaches do not resemble, in morphology or response, those closer to the Virginia State line or those in southeast Virginia.

Generally, a representative beach in Currituck County would be expected to have a beach-face slope of from 2.5° to 6.5° and a sand grain size ranging from 2.5 to 1.5 phi, with both parameters varying widely. The northern two-thirds of Currituck County has a rather broad beach, with low dunes, and has an increasing amount of coarse red sand showing on the beach surface. (The description and origin of this red sandy-gravel is discussed in Farrell, in this volume.)

REFERENCES

Goldsmith, V., Sturm, S., Thomas, G., 1977. Variations in Beach Erosion and Accretion Trends at Virginia Beach, Virginia, and Vicinity: Final Report CERC Contract DACW-72-C-0008 and CERC Tech. Memo No. ___ (in press), C.E.R.C., U.S. Army Corps of Engs., Ft. Belvoir, Virginia; VIMS SRAMSOE No. 122.

Richardson, W.S., 1977. Forecasting Beach Erosion Along the Oceanic Coastlines Northeast and Mid-Atlantic States, Masters Thesis, School of Marine Science, The College of William and Mary, Williamsburg, Va., 121 pp.

SOME DEFORMATION STRUCTURES IN RECENT BEACH SANDS

Carl H. Hobbs, III

Structures similar to those described by van der Linger and Andrews (1969) have been observed and studied on coastal environments in Alaska, Massachusetts, Virginia, and North Carolina. On the beaches of the Currituck Spit - Cape Hatteras area of Virginia and North Carolina, and Plum Island, Sand Neck, Nauset, and Crane Beaches, Massachusetts, parallel zones of highly disturbed and contorted sediment layers have been found within otherwise undisturbed normal beach and dune sediments. It has been noted that the zones of disturbed sediment occur in regions where vehicles (beach buggies) are operated on the beaches and dunes. Trenches excavated across the strike of such tire tracks indicate that the passage of a vehicle of even moderate weight across unconsolidated sands causes disruption of the natural layered structure. These linear zones of deformation, which could be preserved in the stratigraphic record, are termed autogenetic structures.

During field investigations on the barrier islands of Alaska's Copper River Delta, the northeast coast of the Gulf of Alaska, and the uninhabited barrier islands of Virginia's Eastern Shore, structures similar to those formed by beach buggies but, in fact, formed by aircraft operations on the beach were observed. The only discernable differences between the deformation structures caused by the aircraft and beach buggies are the discontinuous nature of the airplane tracks and the existence of an ephemeral, smaller third parallel band of deformation which is caused by the aircraft's third wheel.

Because of the similarity of causative forces generated by beach buggies driving and airplanes landing and taxiing on beaches and other areas of unconsolidated sediment, both types of deformation structures should be called by the common name of autogenetic structures.

Reference Cited

van der Lingen, G.J., and P.B. Andrews. 1969. Hoof-print structures in beach sand: *Journal of Sedimentary Petrology*, Vol. 39, pp. 350-357.

A PRELIMINARY INVESTIGATION ON THE ORIGIN OF THE
"TREACHEROUS RED SANDS", CURRITUCK SPIT, NORTH CAROLINA

Kathleen Farrell

INTRODUCTION

The treacherous red sands of North Carolina's beaches are a mixture of a reddish sandy-gravel washed inshore during isolated storm events, and a fine quartz sand presumably deposited by long-shore currents. The geographical distribution of the red sands has not been mapped, but they appear to be a discontinuous deposit along the beaches of Currituck Spit in the vicinity of northern Dare and southern Currituck Counties.

The coarseness and emplacement of this sediment on the beach at high tide causes a high degree of permeability when the tide drops, resulting in immediate drainage downwards of interstitial water towards the lowered water table. Without the internal support of fluid pressure in these coarse gravels and sand these sediments collapse when acted upon by outside forces. Therefore a vehicle traveling across this deposit may sink. Hence, these sands are considered "treacherous".

SEDIMENTOLOGY

Five short sediment cores (15 cm long) were taken at 100 meter intervals along a beach 4 km south of Corolla, North Carolina (Fig. 1). Sieve analyses showed a bimodal distribution. Each distribution was represented by a distinct lithology: a fine sand lithology lacking any red color and concentrated between 1 phi and 2.5 phi size, and a red sandy-gravel lithology which was also represented in the coarser phi sizes of the sand fraction.

The sand fraction is dominantly composed of about 90% angular and clear quartz grains, and about 10% of shell, trace minerals, rock fragments, and possibly feldspar grains. Some of the quartz grains are iron stained and more rounded than the clear quartz grains, and look like relict shelf sediment. The color of the sand fraction is extremely light brown since red sand lithologies made up a small percentage of the grains in the coarser sand sizes. Heavy minerals are present in trace amounts and consist of epidotes,

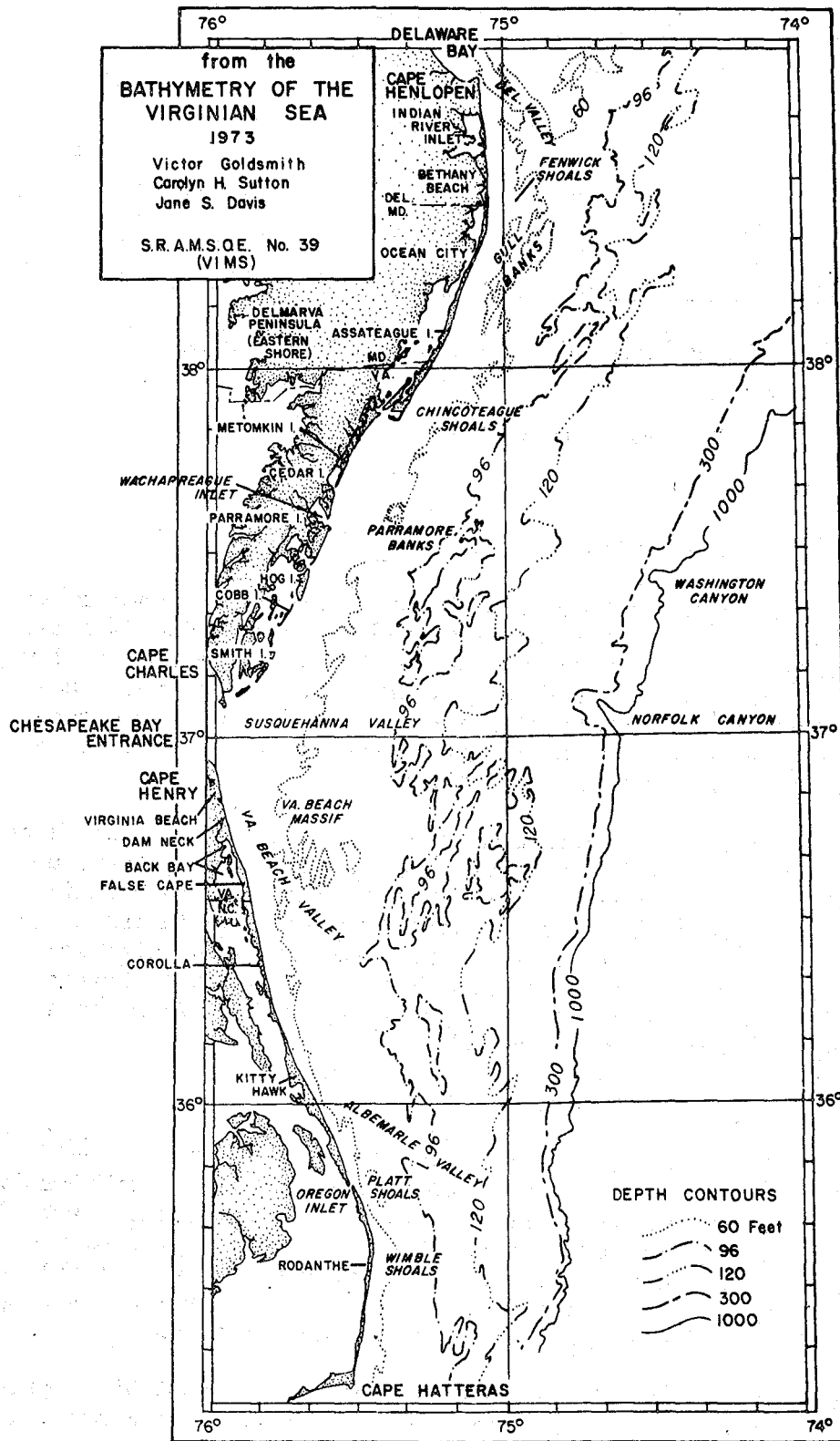


Figure 1. Bathymetry of the Virginian Sea; contours in feet (1 foot = 0.305 meter).

garnets, hornblende and a few grains of ilmenite, staurolite, kyanite, sillimanite and gold. Blue quartz is also present, indicative of a Piedmont origin (S.C. Clement, Geology Dept., William & Mary, personal comm.). Large mica flakes are noticeably present. This heavy mineral suite indicates a metamorphic-igneous source area, namely the Piedmont and Appalachian highlands to the west.

The gravel fraction differs from the sand fraction in color, composition and texture. All of the constituent grains are highly polished. A particle count of a beach sample showed that the gravel fraction consists of approximately 65% quartz, 13% feldspar, 9% rock fragments, 8% shell and 5% flint or chert. The overall reddish brown color of the coarse fraction is attributed to: (a) iron coatings on the feldspar and quartz grains; (b) feldspar grains that are pink, red, orange or brown all the way through; and (c) quartz grains that are tinted purple or pink.¹

DISCUSSION

Both the fine quartz sand and the "treacherous" red sandy-gravel were originally derived from the Piedmont and Appalachian highlands, as indicated by their composition. However, on the basis of their respective textures and regional distributions, one can conclude that the two lithologies were not transported simultaneously, and were initially subject to different transporting hydraulic regimes. The well sorted angular quartz sand is part of a continuous deposit of quartz sand that appears to stretch from Cape Henry to Cape Hatteras on Outer Bank beaches. The highly rounded gravelly-mixture containing a noticeable amount of feldspar has a patchy distribution along Currituck Spit beaches. It can be inferred that the feldspar must have originally been rapidly eroded, transported, deposited and buried because feldspar usually cannot survive long periods of weathering (Folk, 1974).

On the basis of textural and mineralogic studies, Swift (1969) indicates that the sediments of the Mid-Atlantic Bight are derived from either erosion of headlands and subsequent longshore transport, or by wave erosion from the shoreface. Longshore transport of eroded nearshore sediment is the mechanism suggested here for the origin, transport and deposition of the fine quartz sand since Cape Henry lacks an obvious source (i.e., cliffs, etc.). However the high angularity and clearness of many of the quartz grains suggests that these grains have not been extensively reworked.

¹ It is difficult to distinguish quartz from feldspar because of the iron stain on many of the grains and the lack of cleavage due to rounding.

The net longshore current transport is towards the south in Currituck and Dare Counties, North Carolina (Goldsmith, et al., 1977).

An offshore source is postulated for the origin of the treacherous red sandy-gravel, since extensive observations indicate that longshore currents are not transporting red gravels down the North Carolina coast.

Recall that during the Pleistocene, eustatic sea level changes occurred. During low stands of the sea, rivers, ancestral to our present shelf drainage systems, cut channels across the present continental shelf, depositing characteristic riverine facies such as channel gravels. It is possible that such hypothetical gravel deposits could survive erosion by the transgressive-regressive sea fluctuations of the Pleistocene.

The Holocene transgression began 14,000 years ago and sea level rose rapidly until about 7000 B.P., when the rise became more gradual and continues to the present day (Milliman and Emery, 1968). The submerged gravel deposit now supplying the treacherous red sand is probably on the present shoreface. Large waves appear to be actively eroding the bottom and redepositing these gravels onshore.

A relict channel with the potential of supplying the red gravel may be located on the shelf in the vicinity of Albemarle Sound. Shideler and Swift (1972) suggest that an ancestral Albemarle fluvial channel may have trended eastward along the coastal plain near the present mouth of Albemarle Sound during a period of widespread shelf emergence during the late Tertiary or early Pleistocene. Detailed bathymetry (Goldsmith, et al., 1973) indicates the presence of a relict channel in this vicinity. A structure contour map of the Miocene-post Miocene basal unconformity indicates widespread erosion of undulatory topography during this emergence and the probable localization of the ancestral channel at the 70 to 80 fathom contour lines (Fig. 2). Other evidence supporting the existence of this channel include: 1) relict beach ridges in the vicinity of the proposed channel (Fisher, 1967), 2) "anomalous textural properties of sediment comprising the barrier island chain near this location" (Swift, et al., 1971), 3) the fluvial character of strata overlying the site of the proposed channel (Shideler and Swift, 1972), and 4) statistical analyses of barrier sediments show local cyclicity near the present mouth of Albemarle Sound (Shideler, 1973). Shideler reports that the cyclical nature of the sediment at the mouth of the Sound reflects textural variations in the barrier source materials derived from a "heterogeneous Pleistocene substrate."

CONCLUSIONS

The "treacherous red sands" in northern Dare and southern Currituck County beaches acquired its' name from the addition of a reddish coarse sand-gravelly component to the relatively uniform

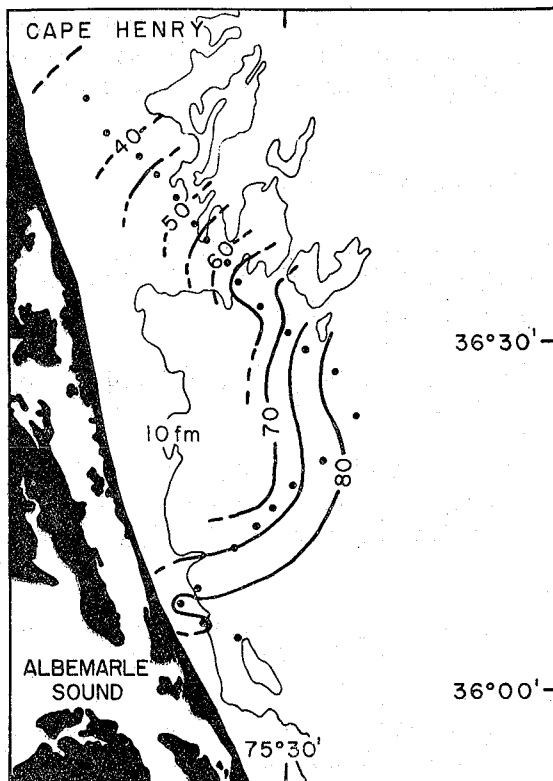


Figure 2. Structure contour map on reflector R1, which comprises the inferred Miocene and post-Miocene boundary. Contours are presented as meters below sea level. (From Shideler & Swift, 1972, Fig. 7)

medium-size clean quartz sand composing the Currituck Spit, Virginia/ North Carolina beaches. The reddish sandy-gravel is composed of (very approximately) 65% quartz, 13% feldspar, 9% rock fragments, 8% shell and 5% flint or chert. However, this composition varies with wave and beach conditions (see Thomas, et al., this volume).

Evidence suggests that the heterogeneous red gravel being supplied to the barrier beaches of Currituck Spit, North Carolina near Currituck Sound is derived from an offshore pre-Pleistocene or Pleistocene channel of the ancestral Albemarle River.

It would be interesting to map the regional distribution of the red gravel and trace this lithology to its source, and possibly verifying the Albemarle Channel as the source.

REFERENCES CITED

- Fisher, J.J. 1967. Development pattern of relict beach ridges, Outer Banks barrier chain. Thesis, University of North Carolina, 250 pages, unpublished.
- Folk, Robert L. 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, Texas.
- Goldsmith, V., S.C. Sturm, and G.R. Thomas. 1977. Variations in beach erosion and accretion trends at Virginia Beach, Virginia, and vicinity. Final Report to C.E.R.C., U.S. Army Corps of Engineers.
- Goldsmith, V., C.H. Sutton, and J. Davis. 1973. Bathymetry of the Virginian Sea. VIMS SRAMSOE No. 39.
- Milliman, J.D. and K.O. Emery. 1968. Sea level during the past 35,000 years. *Science*, Vol. 162, pp. 1121-1123.
- Shideler, G.L. 1973. Textural trend analysis of coastal barrier sediments along the middle Atlantic Bight, North Carolina. *Sedimentary Geology*, Vol. 9, pp. 195-220.
- Shideler, G.L. and D.J.P. Swift. 1972. Seismic reconnaissance of post-Miocene deposits, Middle Atlantic Continental Shelf - Cape Henry, Virginia to Cape Hatteras, North Carolina. *Marine Geology*, Vol. 12, pp. 165-185.
- Swift, D.J.P. 1969. Inner shelf sedimentation: processes and products. In: D.J. Stanley (ed.), The New Concepts of Continental Margin Sedimentation. AGI short course lecture notes, Washington, pp. 4:1-4:46.
- Swift, D.J.P. 1971. Textural differentiation on the shore face during erosional retreat of an unconsolidated coast, Cape Henry to Cape Hatteras, western North Atlantic Shelf. *Sedimentology*, Vol. 16, pp. 221-250.

AEOLIAN GRADING OF SAND ACROSS TWO BARRIER
ISLAND TRANSECTS, CURRITUCK SPIT, VIRGINIA-NORTH CAROLINA

Andrew L. Gutman

INTRODUCTION

Textural studies of sands have been conducted in order to understand the environments of deposition of ancient geologic formations in connection with the search for stratigraphic oil traps (Friedman, 1961; Mason and Folk, 1958). Ahlbrandt (1974), however, concluded that the structures of deposits are more definitive of an ancient aeolian environment than are the textures. Both Ahlbrandt (1974) and Sharp (1965) found that textural analyses of sand were useful in detailed analyses of known depositional environments.

Two very different depositional environments are evident on Currituck Spit (Fig. 1). A cross-barrier transect near Corolla, North Carolina includes a low, sparsely vegetated foredune ridge, shifting sands on the aeolian flat and a large unvegetated medano (i.e., sand hill) (Fig. 29-3). To the north, in False Cape State Park a second transect crosses subenvironments quite different from those to the south. Here there are high multiple-ridge foredunes, dense aeolian flat shrub thickets, and large vegetated parabolic dunes (Fig. 29-4). Since textural parameters may be able to differentiate environments of deposition, a detailed sampling and analyses of sediment deposits across two transects was conducted with the hope that the textural parameters might indicate the geologic processes responsible for the differences in the subenvironments of the north and south transects, and help clarify the role that aeolian sand transport plays in the overall sediment dynamics of a barrier island.

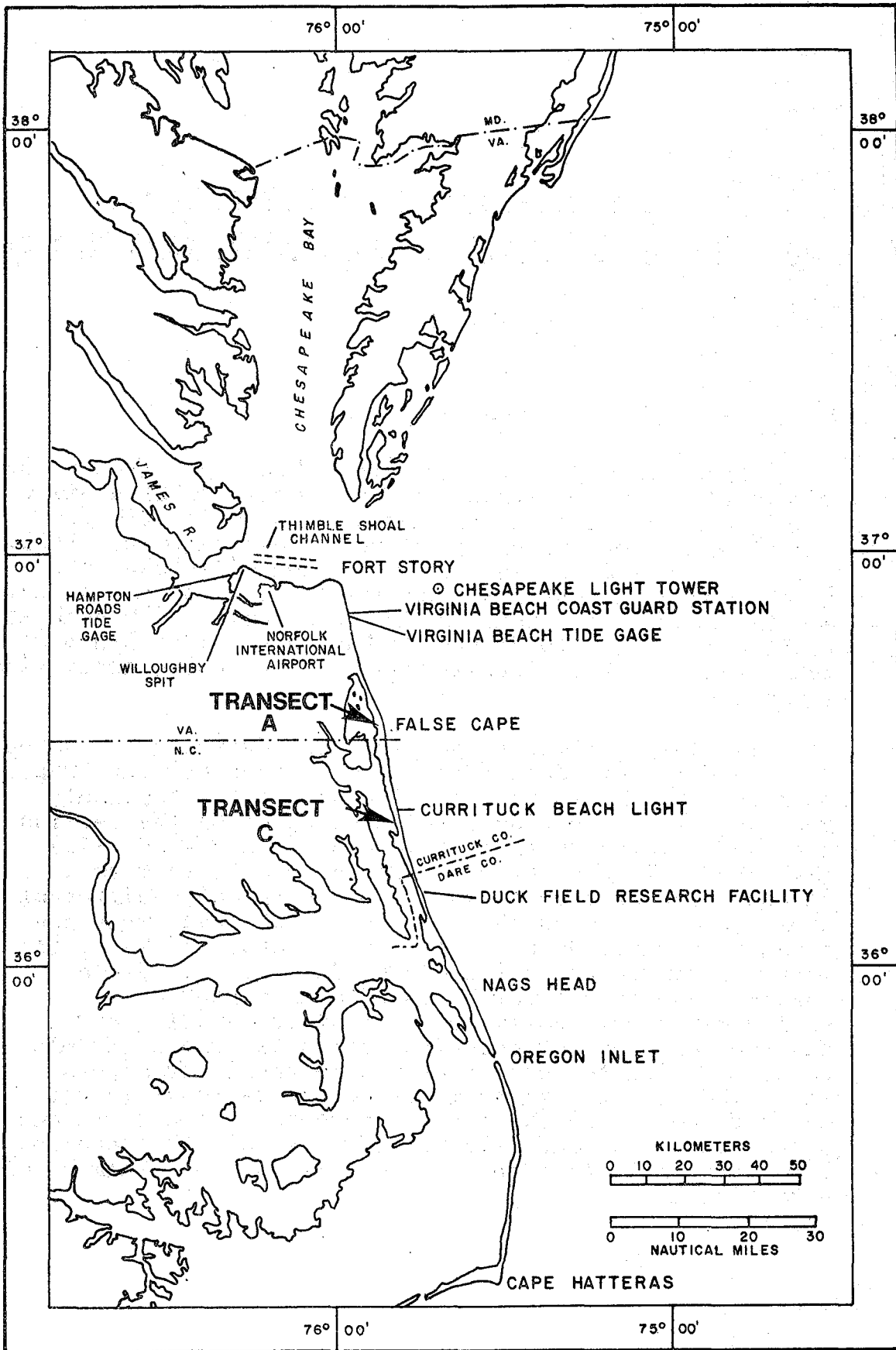


Figure 1. Regional location map showing two transects sampled.

FIELD PROCEDURE

Field work for this study was conducted between January 1976 and January 1977, as part of an investigation into the role of aeolian processes in the sediment dynamics of a barrier island (Gutman, 1977). The field work consisted of sampling along two cross-barrier transects (Fig. 1); one in False Cape State Park, Virginia, and the other just south of Corolla, North Carolina. The two transects were sampled on the same day, as close to the time of low tide as possible.

Starting at the low water mark samples were collected across the transect at irregular intervals. In general the same number of samples were collected across the two transects however the distance between samples varied according to the width of the subenvironments that the transects crossed. The northern transect was 0.6 kilometers long with a wider and higher foredune system and a wider aeolian flat, than the southern transect which was 0.45 kilometers long.

At each sampling site (Fig. 2) on the transect two samples were gathered. A surface sample was collected by scraping the top layer of sand onto a sheet of cardboard and then storing it in a sample bag. This sample was supposed to represent the most recent response of the sediment to the wind regime. In all cases sampling was conducted after a fairly long period (~ 48 hours) of winds above the threshold velocity for sand movement from a constant direction. Table 1 lists the wind data from the Currituck Light Station for the 96 hour period prior to each of the two sampling periods. Notice that one sampling was conducted after a period of onshore winds while the other sampling was after a period of offshore winds. After collection of the surface sample a 2.54 cm diameter 5.0 cm deep core was taken at the same site and stored in a coded sample bag. This sample was supposed to represent many sedimentation units, though in many cases it may not, due to the long duration of the unidirectional winds prior to sampling.

At each transect, samples were gathered at the low water mark, berm, beach dune interface, foredune crest, midway down the landward foredune slope, and across the aeolian flat (Fig. 2). Then samples were collected along the slope, at the crest, and at the base of the slip face, of a large dune. After completion of both transects the samples were taken back to the laboratory for analyses.

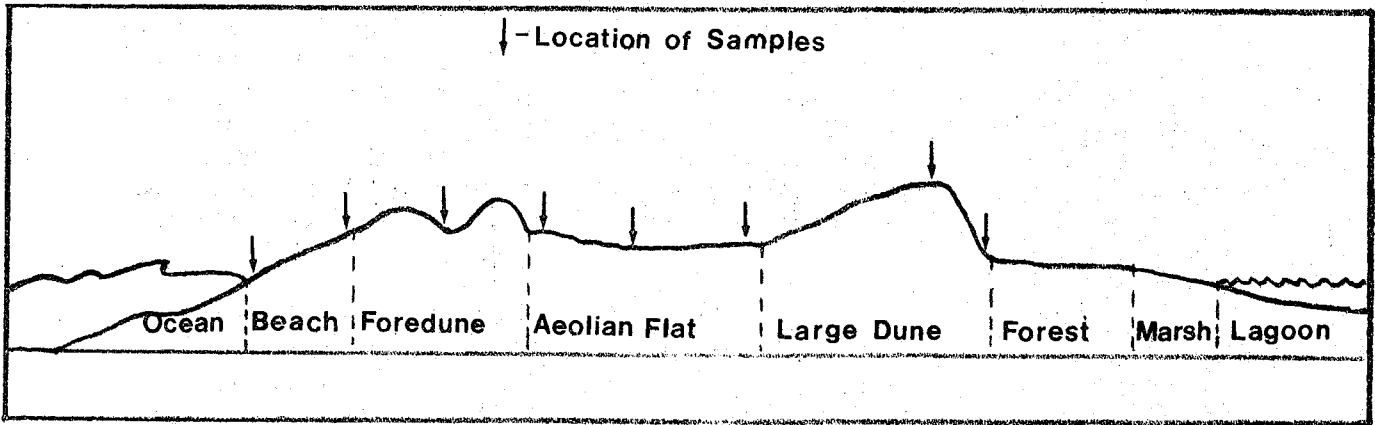


Figure 2. Profile of barrier island showing the location of samples on transect

Table 1.

Wind Data Prior to Sediment Sampling for Sand Grading Study.

WIND DIRECTION AND SPEED DATA
DIRECTIONS 0-360 DEG. FROM TRUE NORTH, SPEEDS MPH

STATION-COROLLA LIGHT

DATE/ HOUR	1		4		7		10		13		16		19		22		MAX.		VECTOR AV.	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
1/ 6/76	16	255	14	245	14	255	8	255	18	235	20	225	22	215	24	235	30	215	16	236
2/ 6/76	22	245	12	235	12	235	4	275	16	65	24	65	26	75	24	65	32	55	5	74
3/ 6/76	20	65	26	75	24	65	24	75	20	65	26	55	26	55	82	65	28	75	30	64
4/ 6/76	26	65	26	65	32	55	32	55	32	45	32	55	36	55	34	55	42	45	31	55
5/ 6/76	36	55	36	55	32	55	36	45	38	55	30	45	32	35	38	35	42	55	34	47
6/ 6/76	24	35	20	35	20	35	20	35	8	65	6	85	8	165	10	165	28	35	10	50

35-5

Sampling Conducted June 6, 1976 Following Period of Onshore Winds.

15/ 2/76	12	95	16	85	12	115	6	145	12	185	20	215	26	215	24	235	34	215	9	183
16/ 2/76	28	235	26	245	22	245	20	255	16	245	18	235	18	215	26	225	24	215	21	237
17/ 2/76	26	235	22	235	30	235	26	235	22	245	20	235	16	185	18	225	34	235	21	231
18/ 2/76	16	220	18	225	18	225	20	215	22	215	32	205	34	215	36	235	46	215	24	219
19/ 2/76	18	265	16	265	16	275	20	305	10	285	18	255	14	235	18	235	26	295	14	264
20/ 2/76	20	265	14	355	7	345	6	55	8	75	8	125	10	160	8	178	23	255	0	358

Sampling Conducted February 20, 1976 Following Period of Offshore Winds.

TEXTURAL ANALYSES

Grain size distributions for all samples were determined with the Rapid Sediment Analyser at the Virginia Institute of Marine Science. After oven drying, splits of samples were obtained using a Otte splitter. Several splits were necessary to get an optimum 5-15 gram sample size for the settling tube.

The Virginia Institute of Marine Science Rapid Sediment Analyser (RSA) is modelled after the unit designed by Zeigler, et al. (1960) at Woods Hole. The falling velocity of particles over a one meter drop is measured by a pressure transducer which sends a signal to a recording unit. Templates prepared from the tables of Zeigler and Gill (1959) are then used with a Gerber variable scale to determine from the record, sizes of ten percentiles along the curve. For simplicity and because the most important aspect of the study was detecting relative changes of texture, the grain size parameters from the settling tube were determined from the hydraulic radius.

The data from the settling tube analyses was input into a computer for calculation of mean, standard deviation, skewness and kurtosis. Many different methods for calculating these four moments have been proposed. The graphic method of Folk and Ward (1957) was chosen for all calculations. McCammon (1962) found that the mean derived by this method had an efficiency of 88% relative to the result of the moment method, while the standard deviation had an efficiency of 79%. The graphic method is also much simpler and the ability to discriminate environments of deposition by the graphic method of Folk and Ward (1957) has been shown by many authors (Friedman, 1961; Mason and Folk, 1958; Ahlbrandt, 1975; Anan, 1971).

Graphic Mean: A measure of the average size of the sand particles was determined according to the relation:

$$\bar{x} = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

where:

ϕ = phi unit corresponding to some percent level on the cumulative frequency curve.

Graphic Standard Deviation: A measure of the sorting of the sediment, was calculated according to the relation:

$$\sigma = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

A low value of σ indicates well sorted, while a high value indicates poorly sorted sediment.

Graphic Skewness: A measure of the symmetry of the grain size distribution about the mean, was determined according to the formula:

$$sk = \frac{\phi 16 + \phi 84 + 2 \phi 50}{2 (\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2 \phi 50}{2 (\phi 95 - \phi 5)}$$

Symmetrical curves have $sk = 0.0$; those with an excess of coarse sediment are negatively skewed, while those positively skewed indicate an excess of fine sediment.

Graphic Kurtosis: Is a quantitative measure of the departure from normality of the grain size distribution. Kurtosis measures the ratio between the sorting of the tails and the central portion of the probability curve. Kurtosis was calculated according to the formula:

$$kg = \frac{\phi 95 - \phi 5}{2.44 (\phi 75 - \phi 25)}$$

A normal curve has a kg of 1.0. Curves with kurtosis greater than 1.0 are said to be leptokurtotic, that is the central portion is better sorted than the tails. A kg less than 1.0 indicates a platyleurtotic curve where the tails are better sorted than the central portion.

After computer calculation of the grain size parameters plots of the moments (Figs. 3-8) were generated on a calcomp plotter.

RESULTS

False Cape Transect

Figures 3 and 4 are plots of the four grain size moments versus distance across the barrier for a set of samples taken after a period of intense southwest (Fig. 3) and northeast winds (Fig. 4). Notice that neither figure indicate any clear cross barrier trends in the grain size moments. Only samples gathered in the foreshore where deposition is primarily by waves is there any marked change in the grain size characteristics. In this area the beach sand showed a coarser (about 1.0 phi), more poorly sorted (standard deviation about 0.49) sediment with a skewness indicating a tail of coarse sand (-0.1).

Landward of the zone of wave activity where aeolian processes are dominant the sand becomes very uniform in grain size characteristics across the barrier. This aeolian sand has a mean size of about 1.8 phi, is well sorted (standard deviation $\sim .3$) and a positive skewness ($\sim .3$) indicating a tail of fine material. These general grain size characteristics are to be expected for aeolian deposited sand. What is surprising however is the lack of any clear grading of sand across the transect, at least for Figure 4. If we assume that the beach is the source of sand for aeolian deposition then it would follow that samples gathered at increasing distances from the source should show the following:

- 1.) Mean grain size should decrease (phi increase) because finer sand should be differentially transported farther inland.
- 2.) Standard deviation should decrease as sand becomes finer and more uniform in size.
- 3.) Skewness should become increasingly positive as normal curve becomes skewed towards the fines.
- 4.) Kurtosis may become leptokurtotic as the central part of the curve becomes better sorted.

Examination of Figures 3 and 4 indicate no such changes at the False Cape transect for either onshore or offshore winds.

A TRANSECT (FALSE CAPE, Va.) FOLLOWING OFFSHORE WINDS

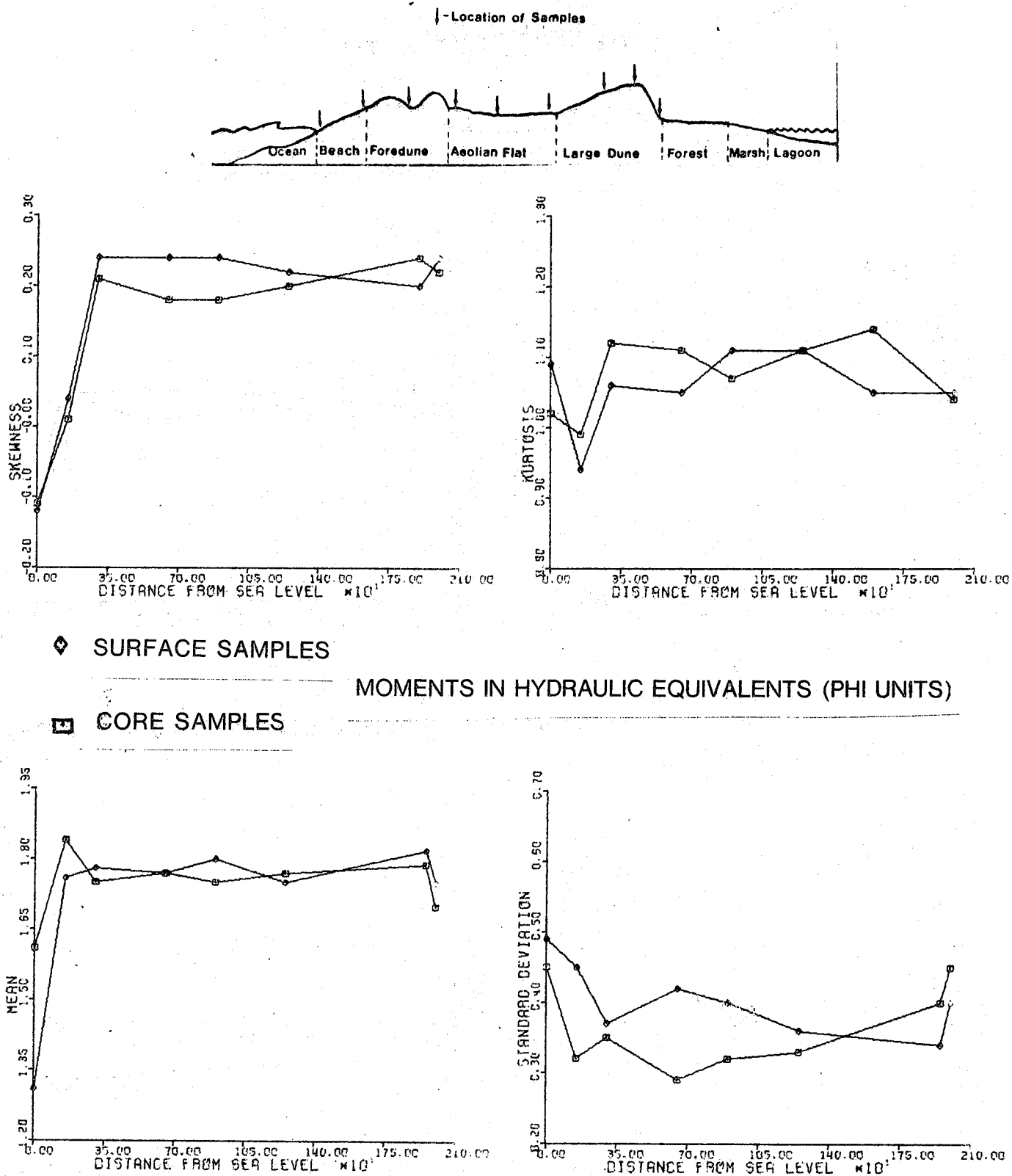
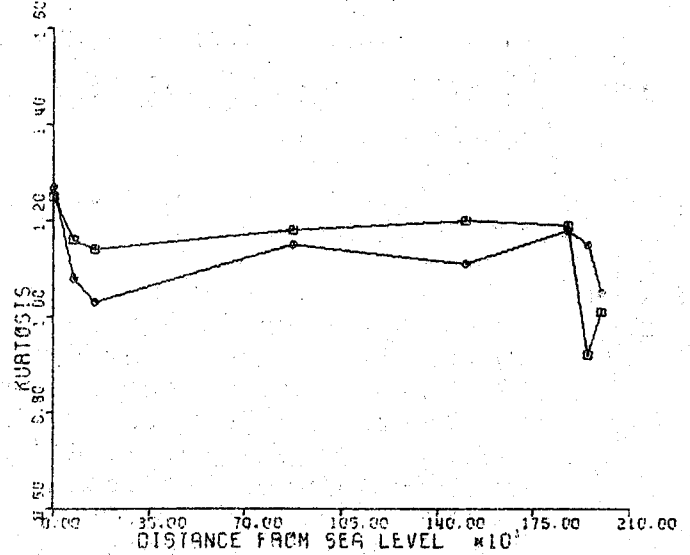
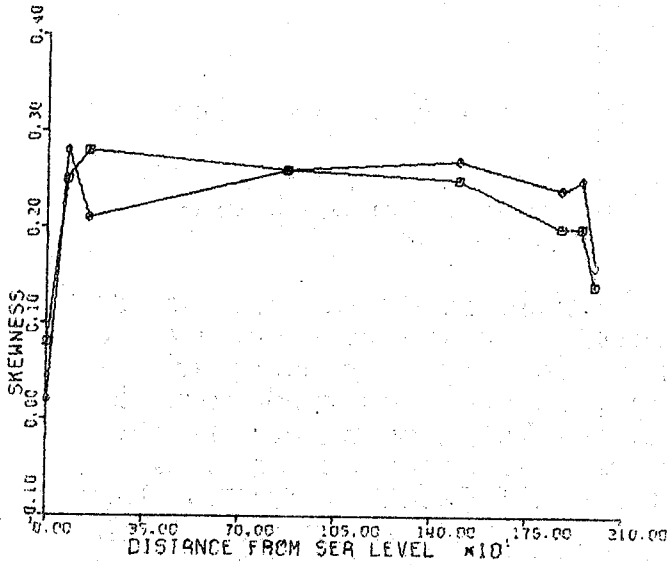
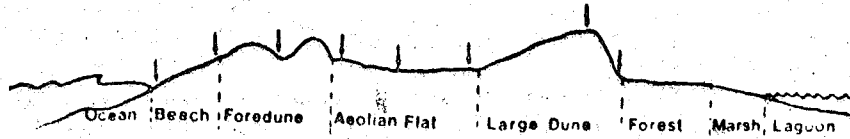


Figure 3. Grain-size moments across Transect A in False Cape State Park, Virginia.

A TRANSECT (FALSE CAPE, Va.) FOLLOWING ONSHORE WINDS

Location of Samples



◆ SURFACE SAMPLES

MOMENTS IN HYDRAULIC EQUIVALENTS (PHI UNITS)

□ CORE SAMPLES

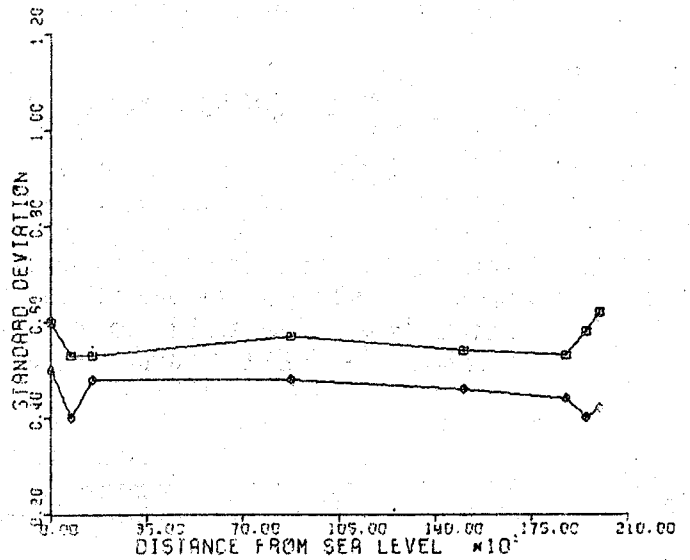
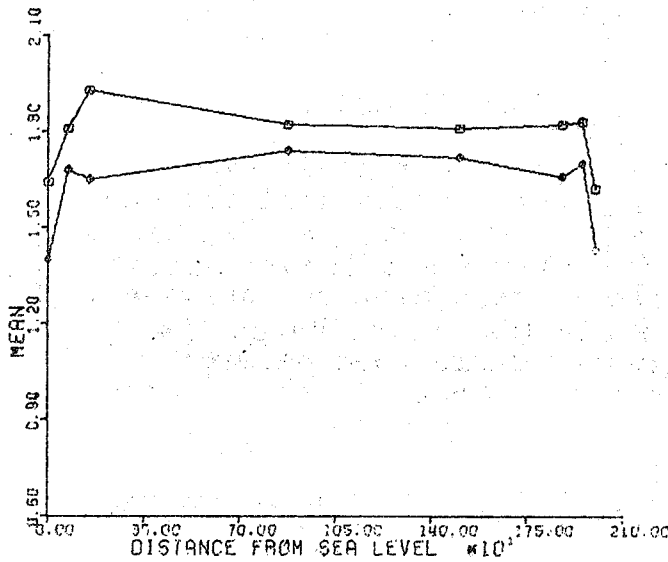


Figure 4. Grain-size moments across Transect A in False Cape State Park, Virginia.

It is especially surprising that after a period of onshore winds (Fig. 4) none of these grading characteristics were evident. This lack of any obvious trend may be due to any of the following:

- 1.) Mechanical problems with the Rapid Sediment Analyser.
- 2.) Sampling design.
- 3.) Inadequate wind speeds to transport and thus grade the sand.
- 4.) Simply that there is no aeolian cross-barrier grading of sand.

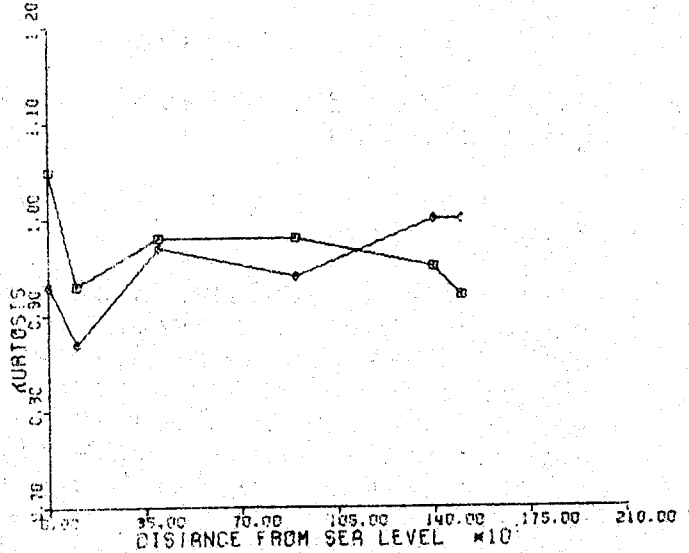
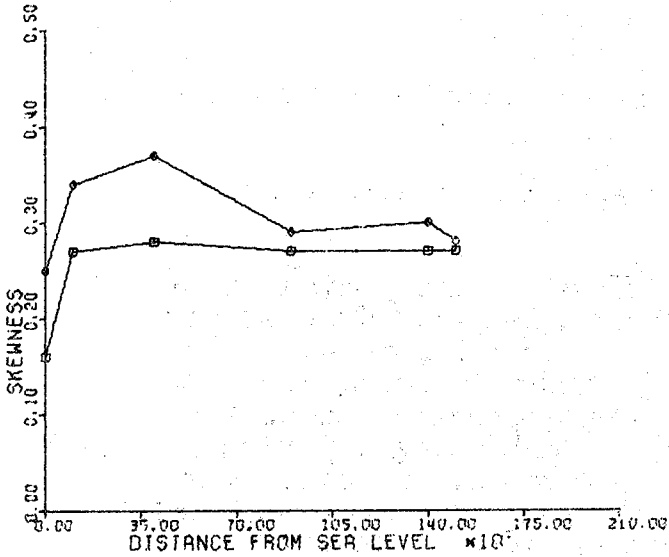
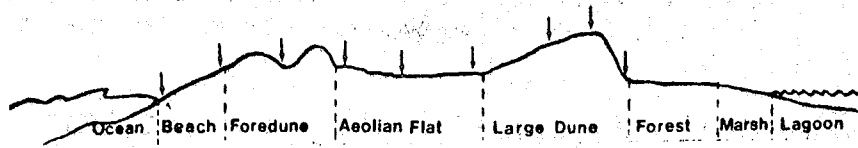
A field examination of the transect during high winds reveals a high (3-5 meters) multiple ridge foredune system with a thick growth of dune grasses, impeding most, if not all, transport to the interior. Further downwind from the sand source a very thick shrub thicket growing across the entire aeolian flat is effectively eliminating any flux of sand between the beach and the interior, or across the barrier island. Figure 29-4 is an aerial photograph of this area showing the general distribution of vegetation. Field measurements of sand transport during 15.6 m/s (35 m.p.h.) onshore winds indicated a zero transport rate across the dunes and aeolian flat. There is little cross-barrier sand transport in the False Cape region due to the presence of vegetation, so there could be no grading of sand. Therefore, it is suggested that this accounts for the lack of a change in trend in Figures 3 and 4.

WHALEHEAD HILL TRANSECT, SOUTH OF COROLLA

Figures 5 and 6 are plots of the four grain size moments versus distance across the Whalehead Hill transect south of Corolla (Fig. 1), for the same dates as Figures 3 and 4, respectively. Figure 5 (following offshore winds) shows a slight seaward decrease in mean size and skewness, towards a fine tail in surface samples, relative to the Barbour's Hill transect. A greater difference between transects is that there is no great change in the moments at Whalehead Hill-offshore winds for the foreshore surface samples, even though the core sample at the foreshore does show typical wave-deposited sand characteristics. It is suggested that the relatively small mean grain size of

C TRANSECT (COROLLA, N.C.) FOLLOWING OFFSHORE WINDS

- Location of Samples



◆ SURFACE SAMPLES

MOMENTS IN HYDRAULIC EQUIVALENTS (PHI UNITS)

□ CORE SAMPLES

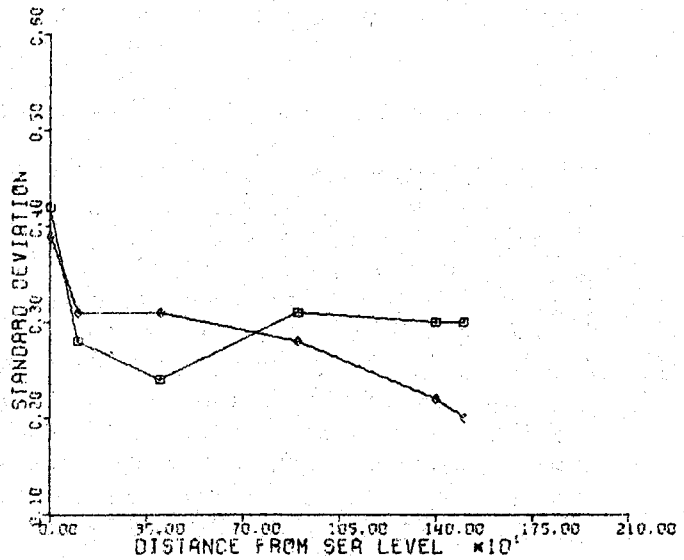
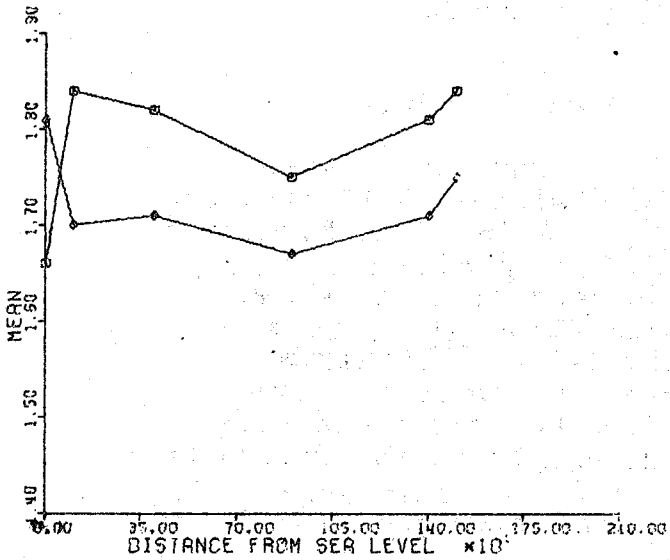
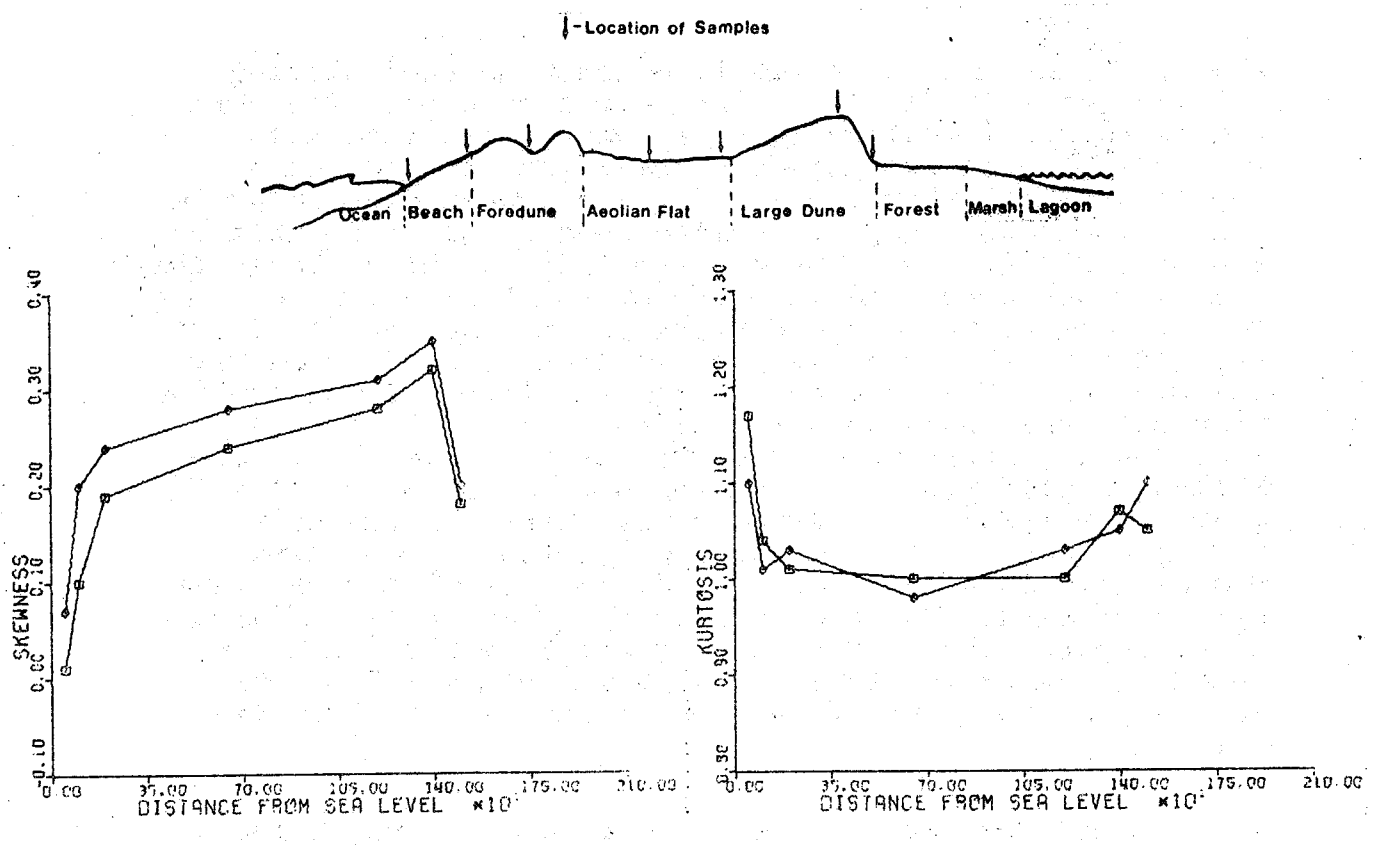


Figure 5. Grain size moments across Transect B south of Corolla, North Carolina.

C TRANSECT (COROLLA, N.C.) FOLLOWING ONSHORE WINDS



◆ SURFACE SAMPLES

■ CORE SAMPLES

MOMENTS IN HYDRAULIC EQUIVALENTS (PHI UNITS)

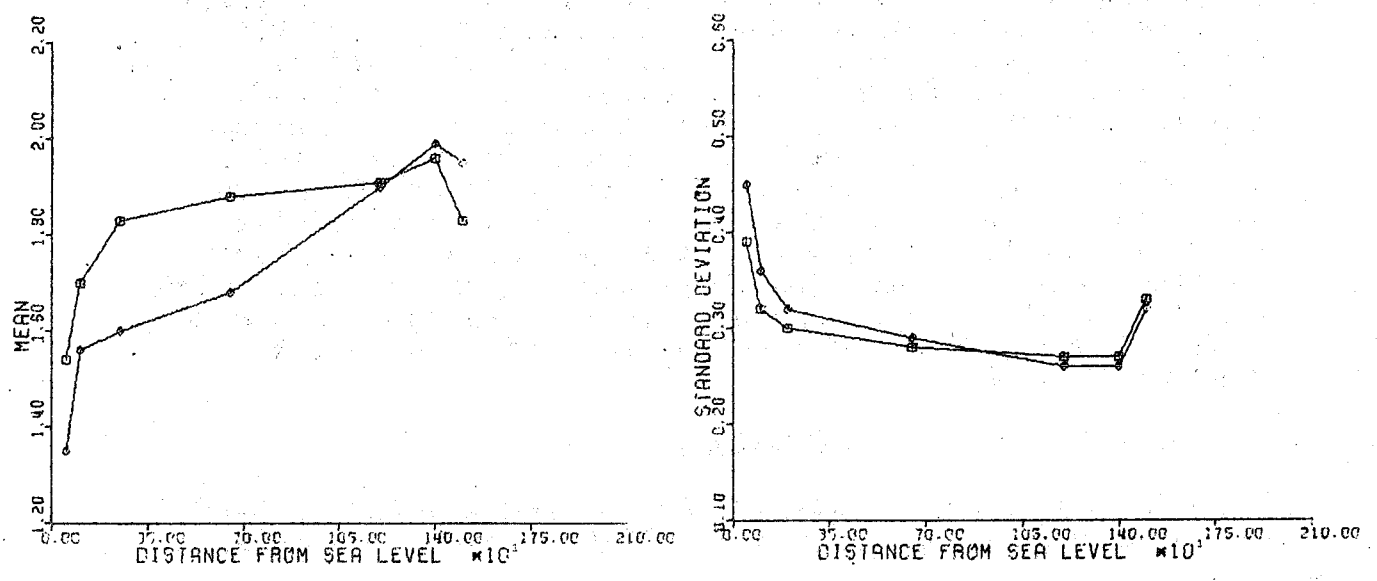


Figure 6. Grain-size moments across Transect B south of Corolla, North Carolina.

the surface sample is a result of aeolian sand blowing off the dunes and aeolian flat onto the beach. The core sample in the foreshore zone may have penetrated the recent layers of aeolian deposition into typical wave deposited sand, therefore giving a somewhat coarser grain size. The deposition of aeolian sand is not indicated by the Barbour's Hill grading diagram (Fig. 3) even though the sampling was conducted for Figures 3 and 5 on the same day. This is due to the large differences in the amount of sand carried onto the beach in the two areas. Sand transport measurements of sand blowing from the foredune and aeolian flat onto the beach during 11 m/sec (24 m.p.h.) winds from the southwest were conducted at both areas. At the Whalehead Hill transect the transport rate was about 0.07 g/cm/sec while at the Barbour's Hill transect was only 0.01 g/cm/sec. For a one hour period and a one meter width, this is equivalent to a difference of over 20 kilograms of sand. The explanation for this large difference in transport rate is the lack of thick aeolian flat and foredune vegetation in the Whalehead region which does not inhibit the flux of sand as it does in the Barbour's Hill region.

Figure 6 contains plots of the four moments after a period of onshore winds (Table 1). Notice that in the first three moments there is a slight trend of increasing phi values across the barrier from the ocean beach, indicating some of the expected changes in grain size characteristics as the sediment is carried across the barrier under the influence of the onshore winds. The mean grain size decreases slightly, the sorting improves, and the skewness increases towards the fine tail as would be expected. Kurtosis does not indicate any clear trend. The cross-barrier trends in Figure 6 are not pronounced, but they do correlate with known transport measurements and vegetation characteristics. As indicated in Figure 29-3, the extent of vegetation and height of foredunes south of Corolla is much less than in False Cape. Due to this lack of vegetation there was a flux of sand, which extended a distance of approximately .5 km in response to both onshore and offshore winds, resulting in aeolian grading of sand.

CONCLUSIONS

- 1.) No pronounced cross-barrier aeolian grading of sand was observed though there were slight trends in samples

gathered on the transect south of Corolla at Whalehead Hill after both onshore and offshore winds.

2.) The complete lack of grading in the Barbour's Hill region is attributed to the effects of a thick vegetation cover which has effectively stabilized the interior of the barrier spit, and thus precluding aeolian grading of sand.

3.) In the Whalehead Hill region, diagrams of the four moments indicate a greater flux of sand in response to onshore and offshore winds than is evident in the False Cape region. This greater flux is attributed to a lower foredune system and less extensive vegetation.

4.) These grading characteristics corroborate field measurements of sand transport (Gutman, 1977) which indicate that there is a much greater sand transport rate during both onshore and offshore winds in the Whalehead Hill region than to the north in False Cape State Park.

5.) The only pronounced changes across the transect was at the foreshore where wave activity results in a coarser sand in contrast with aeolian deposition farther inland. The ability to discriminate beach and dune depositional environments by grain size analysis confirms the studies of Mason and Folk (1958), Friedman (1961) and Ahlbrandt (1975).

REFERENCES

- Ahlbrandt, T.S., 1975. Comparison of Textures and Structures to Distinguish Eolian Environment, Killpecker Dune Field, Wyoming. *The Mountain Geologist*, Vol. 12, No. 2, p. 61-73.
- Anan, F.S., 1971. Provenance and Statistical Parameters of Sediments of the Merrimack Embayment, Gulf of Maine. Unpublished Ph.D. Thesis, University of Massachusetts, Amherst, Massachusetts, 377 p.
- Folk, R.L., and Ward, W.C., 1957. Brazo River Bar: A Study in the Significance of Grain Size Parameters. *Jour. of Sedimentary Petrology*, Vol. 27, p. 3-26.
- Friedman, G.M., 1961. Distinction Between Dune, Beach and River Sands from their Textural Characteristics. *Journal of Sedimentary Petrology*, Vol 31, No. 4, p. 514-529.
- Gutman, A.L., 1977. Aeolian Coastal Processes: Interaction of Aeolian Sand Transport, Vegetation, and Dune Geomorphology. Masters Thesis (in prep), Virginia Institute of Marine Science, Gloucester Point, Va.
- Mason, C.S., and Folk, R.L., 1958. Differentiation of Beach, Dune, and Aeolian Flat Environments by Size Analysis, Mustang Island, Texas. *Jour. of Sed. Petr.*, Vol. 28, No. 2, p. 211-226.
- McCammon, R.B., 1962. Efficiency of Percentile Measures for Describing the Mean Size and Sorting of Sedimentary Particles. *Journal of Geology*, Vol. 70, p. 453-465.
- Sharp, R.P., 1965. Kelso Dunes, Mojave Desert, California. *Geological Society of America Bulletin*, No. 77, p. 1046-1073.
- Zeigler, J.M., and Gill, B., 1959. Tables and Graphs for the Settling Velocity of Quartz in Water, Above the Stoke's Law. References No. 59-36, Woods Hole Oceanographic Institution, Woods Hole, Mass., 13 p.
- Zeigler, J.M., Whitney, G.G., and Hayes, C.R., 1960. Woods Hole Rapid Sediment Analyser. *Journal of Sedimentary Petrology*, Vol. 30, No. 3, p. 490-495.

