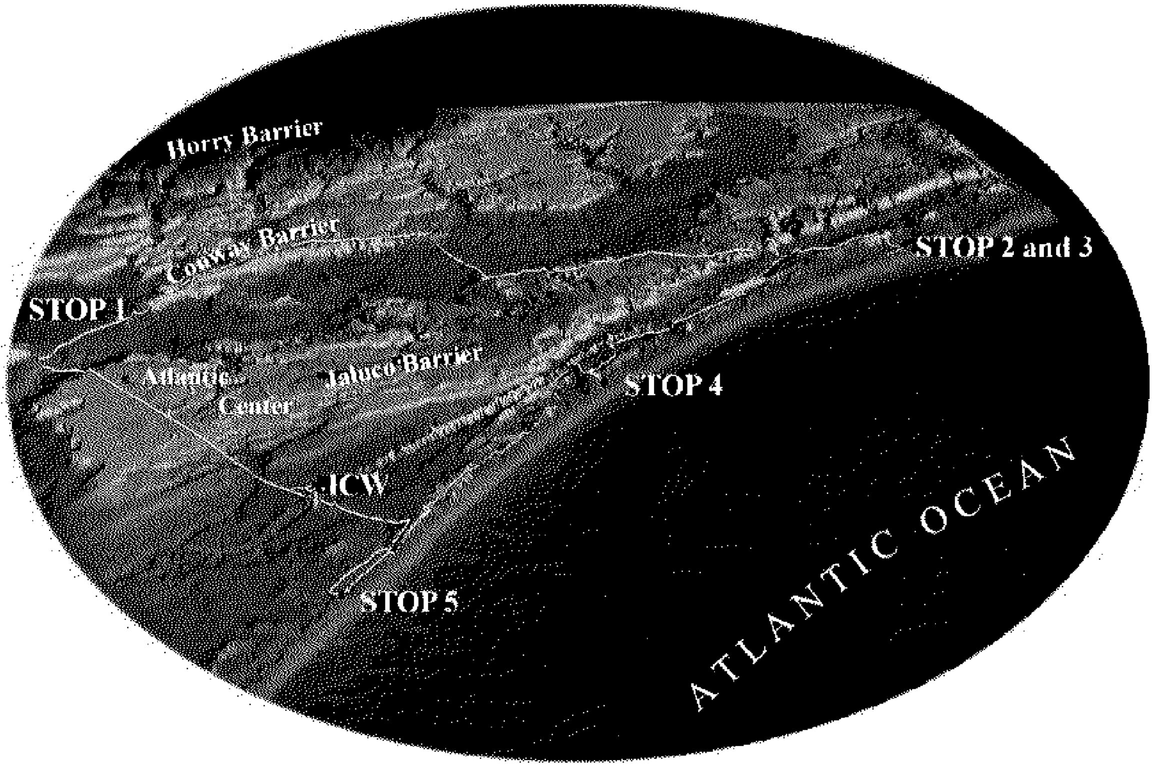
Assateague Shelf and Shore Workshop

26th Annual Meeting

April 6-8, 2000

Program with Abstracts and Field Guide

Compiled and edited by M. Scott Harris



Hosted by:

Scott Harris, Paul Gayes, Eric Wright, Patricia Donovan-Ealy

Center for Marine and Wetland Studies
Coastal Carolina University
Conway, South Carolina

Foreword

Welcome to the 26th meeting of the Assateague Shelf and Shore Workshop (ASSW) and to Conway, South Carolina! We want to thank you for participating in this year's workshop, and also to welcome you to the farthest point south the meeting has been held. If you are interested in hosting next year's meeting, please speak with one of the workshop hosts or one of the long-term associates of ASSW.

We are honored to be hosting this year's workshop. With the multitude of renourishment programs, coastal geomorphologies, and tourist attractions, the Grand Strand of South Carolina provides a timely backdrop for this year's meeting. The Center for Marine and Wetland Studies (CMWS) at Coastal Carolina University (CCU) works closely with several groups in the region on various coastal issues. Major beach renourishment and monitoring programs and an extensive program initiative by the US Geological Survey (USGS) Coastal and Marine Geology Program gives us the opportunity to highlight some of the research being conducted in this region and nationally.

In the traditional format for ASSW, Friday's schedule consists of talks and open discussions. Complimentary to the talks, formal posters and informal displays may be found throughout the Atlantic Center. The informal displays represent much of the work being conducted regionally by the CMWS. In your wanderings, we welcome you to explore our "new" facilities.

On Saturday, the field trip will take us across the lower Coastal Plain and along the active coastal zone. We will be going to the undeveloped Waites Island, demonstrating the BERM long beach-profiling techniques, and presenting materials associated with the multitude of beach nourishment and framework geology studies in this region. CCU, the USGS, SC Department of Natural Resources (DNR), Minerals Management Service (MMS), US ACOE, SC Office of Coastal Resource Management (OCRM), and South Carolina Sea Grant Consortium are currently conducting these studies on change and influence in the coastal zone in response to beach renourishment projects conducted over the last three years.

Many thanks and kudos to several key people who helped make this year's workshop possible. The University and CMWS have provided additional funds to upgrade our reception to the Aquarium in Myrtle Beach, as well as logistical support for the facilities and boats. The South Carolina Sea Grant Consortium has provided funding for several registrants and provided a majority of guidebook costs. At the University, Margo Saunders has been on the logistical forefront and Howie Mulcahy has kept databases and the web site together; thanks to Pat Donovan-Ealy and her entourage of students who have put together many of the informal displays around the Center; Neal Gielestra and Jamie Phillips have done a fantastic job at making the new facilities presentable; and thanks to the facilities and cleaning staff for making keeping the place clean through it all. As with many of the Workshops, Cy Galvin has been a wonderful asset in providing guidance throughout the process, as were last year's hosts at the University of Delaware. Thank you all.

Enjoy the 26th Annual Meeting of the Assateague Shelf and Shore Workshop!

Scott Harris　　Paul Gayes　　Eric Wright　　Patricia Donovan-Ealy

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Past Workshops

Assateague Shelf and Shore Workshops Since 1974

Year	Location	Sponsor Org.	Sponsors
1974	CERC, Ft. Belvoir, Va.	CERC	(M.Field/D.Duane/H.Palmer/D.Swift)
1975	Ocean City/Assateague Isl.	CERC	(Field/?)
1976	Sandbridge/Currituck, Va.	VIMS	(V.Goldsmith/W.Hobbs)
1977	Lewes, DE	UDL	(T.Dalrymple/?)
1978	Wallops Isl., VA	UVA	(J.Fisher/?)
1979	Manteo, NC	FRF	(C.Mason/B.Birkemeier/A.De Wall)
1980	Brigantine, NJ		(E.Maurmeyer/S.Farrell)
1981	Wallops Isl., VA	PSU	(R.Slingerland/Guber)
1982	Chincoteague, VA	VIMS/USGS	(W.Hobbs/B.Mixon)
1983	Seaville, NJ	Rider	(Nadeau)
1984	VA Beach, VA	ODU	(M.Byrnes/?)
1985	Nags Hd., NC	FRF	(C.Mason/S.May/H.Klein)
1986	Lewes, DE	DNREC	(B.Henry/E.Maurmeyer/W.Carey/T.Pratt/M.Chryzastowski)
1987	Assateague Is., VA/McCabe House	UMD	(S.Leatherman)
1988	Suffolk Co., Long Isl., NY		(A.Terchurian)
1989	No Meeting		
1990	Sandy Hook, NJ	Rutgers	(G.Ashley/N.Psuty/S.Halsey/S.Farrell)
1991	Wallops Isl., VA	VIMS	(S.Kimball/M.Fenster/B.Dolan)
1992	Duck, NC	FRF	(C.Miller/B.Birkemeier)
1993	Solomons Isl., MD	MGS	(R.Kerhin/?)
1994	Ocean City/Assateague, MD	USGS-CMGP	(J.Williams/H.Cichon/C.Kraft)
1995	Stockton, NJ	Stockton St.	(S.Farrell)
1996	Beaufort, NC	Duke Un.	(R.Thieler/O.Pilkey)
1997	Towson, MD	MGS	(R.Kerhin)
1998	Fairfax, VA	GMU/USGS/Gal	(R.McBride/J.Williams/C.Galvin)
1999	Lewes, DE	UDL/DGS	(J.Wehmiller/K.Ramsey)
2000	Conway, SC	CCU	(S.Harris/T.Gayes/E.Wright/P.Donovan-Ealy)

26th Assateague Shelf and Shore Workshop

Schedule of Events

Center for Marine and Wetland Studies
Atlantic Center Academic Village
Coastal Carolina University

Thursday April 6th

6:00 to 9:00 p.m.	Registration and Reception	*Ripley's Aquarium*

Friday April 7th

8:00 a.m.	Registration	*CCU's Atlantic Center Academic Village*
9:00	Welcome	
9:20 to 12:00	Talks *with break*	
12:00 to 1:30	*Lunch*	
1:30 to 3:00	Posters	
3:00 to 4:00	Tours of Atlantic Center	
4:00 to 4:45	Discussion of ongoing studies along the Mid-Atlantic	
4:45	Continuation of Discussions at Liberty and Dinner	

Saturday April 8th

8:00	Muster at Atlantic Center for coffee and field trip
8:30	Depart Atlantic Center for STOP 1
1:30	Conclusion of Morning Field Trip and Lunch at Damon's

For those who need to start on the way home, we will guide and/or shuttle you back to the Atlantic Center and/or airport for departure. Those remaining (up to 24 people) are invited to join us on a cruise up the Intracoastal waterway aboard Coastal Carolina University's R/V *Coastal II.*

Saturday Afternoon

~3:00	Depart the dock at the Waterway Village
6:30	Return to dock and head to dinner

If you will be staying over on Saturday evening and would like to join us for dinner, please talk with Scott and we will make a decision where to go after the cruise.

Friday, April 7th, 2000

8:00 Registration
9:00 Introductions

Scott Harris	*Assistant Professor of Marine Science*
Valgene Dunham	*Dean, College of Natural and Applied Sciences*

Talks (see abstracts for additional authors and more details)

9:20	***Paul Gayes***	INTRODUCTION TO COASTAL STUDIES IN SOUTH CAROLINA
9:40	***Bob Van Dolah***	DREDGING SAND BORROW SITES IN SOUTH CAROLINA: A REVIEW OF PHYSICAL AND BIOLOGICAL EFFECTS
10:00	***Kelvin Ramsey***	THE HURRICANE OF OCTOBER 21-24,1878: THE HURRICANE OF RECORD FOR THE DELAWARE BAY AND RIVER
10:20	*Break*	
10:40	***Spencer Rogers***	THE RECENT CAPE FEAR HURRICANES: COASTAL SHORELINE IMPACTS ON DEVELOPMENT
11:00	***Michael Fenster***	STORMS AND SHORELINE CHANGE: SIGNAL OR NOISE
11:20	***Donna Milligan***	CLASSIFICATION OF DUNE SYSTEMS WITHIN THE VIRGINIA CHESAPEAKE BAY
11:40	***Tom Cronin***	CLIMATIC VARIABILITY RECORDED IN CHESAPEAKE BAY SEDIMENTS

Posters (see abstracts for more details)

•	***Brian Batten***	Erosion criterion Applied to a Shoreline Adjacent to a Coastal Inlet
•	***Frank Buonaiuto***	Slope Distribution along Ebb-Tidal Shoals of East, Gulf, and Great Lakes Inlets
•	***Pat Donovan-Ealy***	Myrtle Beach Renourishment Monitoring: Nearshore Hardgrounds and Borrow Site Assessments
•	***Pat Donovan-Ealy***	Arcadian Shores Beach and Borrow Site Monitoring
•	***Vicki Lynn Ferrini***	Multibeam Sonar: A Tool for Investigating Shallow Water Sedimentary Environments
•	***Maria Honeycutt***	Influence of Antecedent Geology and Modern Shoreface Processes on Shoreline Change, Delaware and Maryland
•	***Pam Jutte***	Biological and Physical Recovery of a Sand Borrow Area Used for Beach Nourishment in Cherry Grove, South Carolina
•	***Joe Liddicoat***	Magnetostratigraphy of Atlantic Coastal Plain Sediments in South Carolina
•	***Kimberly K. McKenna***	Using the "Stack-Unit Mapping" Method for Evaluating Delaware's Offshore Sand Sources, Hen and Chickens Shoal
•	***Tara Miller***	Beach Profiles of Disequilibrium: Variations on a Theme
•	***William C. Schwab***	Marine Geologic Mapping of the nearshore region off Northern South Carolina
•	***David B. Scott***	Trend Analysis of Hurricane Landfalls in the Northwest Atlantic Ocean: Historic and Late Holocene Occurrences and Application to Risk Analysis
•	***Eric Wright***	Inner Shelf Stratigraphy and Sand Resources Seaward of Pawleys Island, South Carolina

3:00 to 4:00	Tours of the Atlantic Center
4:00	Discussion
~4:45	End of Day

Abstracts

(In order of appearance in the Schedule)

SAND BORROW SITES IN SOUTH CAROLINA: A REVIEW OF PHYSICAL AND BIOLOGICAL EFFECTS

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Over the past ten years, six sand borrow sites that were dredged for beach nourishment projects in South Carolina were studied to evaluate the rate of recovery in physical condition, biological condition, or both. One site was located in a high salinity tidal river behind the front beach and the rest were located in shoals or shallow sand bottom areas seaward of the beaches being nourished. Sand volumes dredged from these sites ranged from approximately 150,000 to 3,100,000 yd^3. The majority of sites showed evidence of relatively slow refilling rates (5.5 to 12 yrs), with only the smallest site having a refilling rate of less than two years. Four of the borrow sites were studied to evaluate changes in surficial sediment composition and biological condition over a 1-2 year period following dredging. Two of these areas showed a significant and persistent increase in the percentage of silt/clay content (> 10-20%) after dredging. These areas also exhibited significant changes in the infaunal communities that had not recovered to pre-dredging conditions within the study period. The other two borrow areas were also altered after dredging, but both sites had largely recovered with respect to surficial sediment composition and benthic condition within one year. The most persistent biological effect observed at all sites after dredging was an overall change in composition of species and types of dominant taxa present. Site location, depth of excavation, and/or the type of dredge used were considered to be the primary factors influencing the rate of recovery in the borrow areas studied.

THE HURRICANE OF OCTOBER 21-24,1878: THE HURRICANE OF RECORD FOR THE DELAWARE BAY AND RIVER

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On October 21, 1878, a hurricane crossed the island of Cuba and headed east of Key West, Florida. On the evening of October 22, it made landfall north of Cape Lookout, North Carolina as a low Category 2 hurricane with winds around 100 mph. The storm picked up speed after landfall and moved northward at a rate of greater than 40 mph and maintaining tropical storm force wind speeds of greater than 60 mph with gusts much higher. On the morning of October 23, it passed up the western side of the Chesapeake Bay near the cities of Baltimore and Annapolis, Maryland, Wilmington, Delaware, and Philadelphia, Pennsylvania. By the late afternoon it had reached Albany, New York and turned eastward and passed out to sea north of Boston, Massachusetts on the morning of October 24.

The storm caused a wide swath of devastation sinking or driving aground ships in the Atlantic, and in the Chesapeake and Delaware Bays. Wind damage was great: unroofing houses, knocking down church steeples, uprooting trees, and in some places destroying buildings. Storm surge created by east-southeast winds blowing into the entrance of Delaware Bay at the same time as a perigean high tide caused massive flooding along the Delaware Bay and River, and along the riverfronts in the cities of Wilmington, Delaware, and Philadelphia, Pennsylvania.

Along a section of coast along the lower Delaware River this storm surge was in the form of a surge wave perhaps as high as five to eight feet above high tide (greater than 12 feet above sea level) that crashed onto shore flooding miles inland and destroying buildings along the coast. The area that this wave hit experienced dramatic coastal change where freshwater swamps and streams became tidal streams over the course of just a few years where new inlets formed in the bay-front barriers.

Over 100 fatalities were the result of the hurricane, many of them the result of drowning in shipwrecks. Damage estimates in 1878 dollars likely topped $10,000,000 which equates to over $150,000,000 in 1999 dollars. This storm may well be the hurricane of record for the Delaware Bay and River region and provides a model for a worst-case scenario for a modern hurricane. If such a storm were to occur today there would be flooding of riverfront development areas in Wilmington, Delaware and along the industrial riverfront of Philadelphia. In addition, wind damage would cause massive disruption of traffic from downed trees, downing of numerous power lines, and much damage to houses. A hurricane of greater strength would create a storm surge in the Delaware River that would cause catastrophic flooding.

THE RECENT CAPE FEAR HURRICANES: COASTAL SHORELINE IMPACTS ON DEVELOPMENT

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Cape Fear in North Carolina has recently served as a magnet for most of the landfalling hurricanes in the Atlantic. Since 1996 the area has been in the eyes of Hurricanes Bertha, Fran, Bonnie and Floyd, as well as, brushed by Dennis and Irene. Peak wind speeds at the coast have been estimated to have reached 115 mph but onshore measurements were generally less than 100 mph and wind damage to development was moderate to light. Storm surge conditions have been considerably more severe with measured return frequencies of 5-, 12-, 37-, 75- and 120- years along 65 miles of shoreline north of Cape Fear. The latter two storms, Hurricane Floyd in 1999 and Fran in 1996 are of particular interest since they approached or exceeded storm surge design conditions for 50 miles of developed coastline. Wave, erosion, and storm surge impacts on coastal development will be described. North Carolina was a pioneer state in planning and design for hurricanes and shoreline erosion. Success and failures of those efforts will be discussed, including at least 4 beach nourishment projects that were in place from 1 to 30 years.

STORMS AND SHORELINE CHANGE: SIGNAL OR NOISE

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Coastal managers, planners, scientists and engineers routinely use mathematical models to assess shoreline trends. Over the past decade, linear regression of shoreline positions over time (using photographic and map data) has become the method of choice to assess the long-term shoreline migration history and to predict future movement at a particular beach. However, the results generated by mathematical maximization procedures such as regression, discriminant, and principal component analysis are particularly sensitive to errant data and the use of such data can lead to incorrect results and faulty interpretations. The question we pose in this talk is: When do shoreline position data lose quality, cease to provide germane information, bias trend analyses or, in statistical jargon, become outliers? More specifically, (1) what constitutes a temporal outlier in a shoreline change data set and can we detect shoreline position outliers quantitatively, (2) what coastal processes produce outliers, (3) are there patterns to the distribution of outliers that can be used to assess large sets of shoreline data, and, (4) once detected, how do we decide to include or delete outliers from shoreline change analyses?

For the temporal shoreline outlier analyses we used the null hypothesis (statement of equality) that episodic, large magnitude coastal storms do not directly control "long-term" shoreline movement. Rather, shoreline changes occur as a result of the synergistic interaction of day-to-day processes or longer-term processes such as sea-level rise or fall. Under this scenario, storms tend to displace the shoreline systematically landward, but shorelines "quickly" return to their pre-storm position. Failure to reject the null hypothesis would suggest that storms are indeed outliers and produce shoreline positions which deviate from the "true" long-term migration trend. Rejection of the null hypothesis for the alternative hypothesis would indicate that storm-influenced data points are not outliers and that storms control the long-term shoreline trends. (For this work, we define storm-influenced data points as those in which a storm with deep water wave heights = 1.8 m had occurred at least two weeks prior to a photogrammetric flight.)

Results from linear regression (studentized) residual analysis of shoreline trends along the storm-influenced Outer Banks of North Carolina showed that only 7 of 144 shoreline positions (< 5%) were identified as potential outliers at the 95% confidence interval (CI) and 3 additional positions were significant at the 90% CI (< 7%). Moreover, only 2 of the 10 identified outliers occurred during the period of photo data; the remaining outliers occurred during the period of map data. Hindcast analyses showed that none of the identified outliers correspond to storm dates (photos). These results suggest that storm-influenced data do not yield significant variability unaccounted for by the regression model.

Finally, if we did not delete storm-influenced data from the shoreline change analysis, would we reduce our ability to predict the future accurately? Using a confidence interval analysis to test predictions at two locations on Hatteras Island, we found that, at the 95% CI, the range of uncertainty in the storm versus non-storm prediction varies only slightly (projected 30 yr). Therefore, (1) including storm-influenced data does not appear to impair predictions of future shoreline positions, (2) the impact of any particular storm does not exert as strong of an influence on the trend estimate as does the combination of many storms, and (3) shoreline trends are, in fact, controlled by the cumulative effect of many storms over time. These conclusions corroborate the validity of the shoreface retreat model over time scales shorter than geologic time (i.e., decades to centuries).

CLASSIFICATION OF DUNE SYSTEMS WITHIN THE VIRGINIA CHESAPEAKE BAY

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The Coastal Primary Sand Dune Protection Act was enacted in 1980 in eight Virginia localities with open-Bay shorelines. Prior to adoption of the Act, and until our present research effort, the dune resources in the lower Chesapeake Bay were never fully identified, enumerated, or classified. Natural Bay dune systems are relatively rare when compared with the extent of other critical estuarine habitats. Of the approximately 4,800 miles of tidal shoreline in Virginia's portion of the Chesapeake Bay, we have identified only 51 miles as dunes/potential dunes (this constitutes approximately 1% of the Virginia tidal shoreline). Of the 51 miles of dunes that we have preliminarily identified, a significant amount of those that have been assessed on-site are classified as man-made or man-influenced systems- reducing further the shore footage of natural dunes.

Dunes provide important functions and values to both littoral marine systems (as habitat for flora and fauna) and the adjacent landward environments (erosion control and protection from storm events). Management of these critical and rare areas is inconsistent partly because of the legal definition of a coastal primary sand dune which may not always be supported by coastal plain geology. According to the Act, dunes must meet three criteria:

- substance (a mound of unconsolidated sandy soil contiguous to mean high water)
- morphology (landward and lateral limits are marked by a change in grade from >10% to <10%)
- character (dunes must support specific plant species or communities which are named in the Act)

This definition generally is more accurate when applied to ocean coastal primary dunes since their morphology is more consistent over a shoreline reach than Bay and river dunes which vary within the landscape. In addition, man-influenced and man-made dunes can further complicate the definition criteria. For Bay and river dunes, the definition often excludes contiguous areas of importance such as secondary dunes and maritime forests.

In order to provide the basis for sound resource management and consistency within the dune management program, this project set forth to:

- determine the extent of the existing dune systems around Chesapeake Bay,
- determine morphologic changes of selected dune systems and the factors that influence their evolution,
- develop a geology-based classification of dune system types based on influencing factors, and determine the connection between primary and secondary dunes.

Potential dune sites were located using low-level, oblique aerial video and mapped on topographic maps. Once potential dune systems were delineated from aerial imagery analysis, these sites were visited to verify vegetation types and coastal zone profile. A representative beach profile was taken at each site to characterize the primary and secondary dune features within 100 feet of the shoreline. The historical evolution of the selected dune systems was ascertained using historical vertical aerial imagery. Utilizing collected field data, a Chesapeake Bay dune classification is being developed. This classification is based on factors that are unique to certain dune systems and which have a basis in the dune field evolution, vegetative zones, lateral and vertical extent of primary and secondary dune features as well as anthropogenic impacts. Sites are categorized initially into natural, man-influenced, or man-made. Then the geologic underpinnings of the system are determined as well as the fetch exposure and shore orientation of the site. Its morphologic setting is assessed as an isolated accreting feature, creek mouth barrier, a spit, or a dune field. The nearshore gradient and the existence of bars is noted as is the site's relative stability. Elevation and distance from mean low water of the primary and secondary dune crests and the back of the jurisdictional dune are also determined from the site profile. Sediment data taken at each site provide the mean grain size at mean high water.

The historical evolution analysis has shown that man's influence is pervasive. The dune fields on either side of Smith Point in Northumberland County have evolved, in part, a result of channel jetty construction at the Little Wicomico River. The large dunes west of Ocean Park in Virginia Beach evolved due to beach nourishment. The large dune ridge at the distal end of Willoughby Spit in Norfolk was built as part of a large 1985 beach nourishment project. A subsequent breakwater installation has accreted a wide beach and created dunes seaward of the original dune construction.

Preliminary analysis of the categorized data has shown that the average width of the dunes that exist against upland regions tend to be wider than sites that are formed in front of a marsh. The analysis of field data is ongoing and will provide additional relationships between dune features.

CLIMATIC VARIABILITY RECORDED IN CHESAPEAKE BAY SEDIMENTS

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We are investigating the Chesapeake Bay Holocene paleoclimatic record to determine patterns and impacts of climate variability over various timescales and to relate these to the ecosystem history of the bay and the eastern United States. Sediment coring in Chesapeake Bay off the Potomac River mouth, the Parker Creek-Calvert Cliffs area, and the Rhode River area by the R/V *Marion-Dufresne* on June 20 - 22, 1999 was carried out as part of the IMAGES V cruise to the North Atlantic Ocean and adjacent seas. Micropaleontological and geochemical records from *Marion-Dufresne* cores, and cores taken in prior years on the R/V *Kerhin*, contain evidence for:

- Multi-decadal and decadal variability in bay temperature and salinity over the past millennium;
- Possible climate "teleconnections" to ENSO and North Atlantic climate processes;
- Holocene vegetation changes over millennial, centennial and perhaps decadal timescales;
- Sustained 15th and 16th century periods of regional drought;
- Centennial-scale climate variability during the early Holocene (7,500-5,800 yr BP);
- Large impacts on Chesapeake Bay phytoplankton and benthos during climatic extremes.

The relationship between late Holocene mid-Atlantic precipitation, Chesapeake Bay salinity and temperature, and regional and hemispheric climate processes will be discussed.

EROSION CRITERION APPLIED TO A SHORELINE ADJACENT TO A COASTAL INLET

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The potential for erosion (or accretion) by cross-shore transport processes was evaluated by the ratio of the wave height to the product of the wave period and the grain settling speed (*i.e.* the Dean Number, N_o). Values of N_o were compared to a two-year series of volume changes for a shoreline downdrift of a stabilized barrier inlet (Shinnecock Inlet, New York). Surveys were taken at a biweekly to monthly interval and hourly wave measurements were available for 10 m of water from a local gauge maintained by the U.S. Army Corps of Engineers (USACE, 1999). Initially, N_o was calculated using wave data five days prior to the date of beach surveys. Established criteria for prediction of accreted ($N_o < 3.2$) or erosive beaches ($N_o \geq 3.2$)(Kraus *et. al*, 1991) were then applied to the data, resulting in 60% agreement. While this method did not provide a satisfactory parameterization of the data, it correctly predicted all instances of accretion. Discrepancies in applying the criteria occurred when wave conditions remained in the accretionary range of the criteria ($N_o < 3.2$) for several days after erosive events occurring on a time scale from 24 to 48 hr. Recalculation of N_o with particular attention to specific storm events throughout the winter storm and hurricane seasons resulted in 97% agreement between the observed changes and the criterion.

REFERENCES:

Kraus, N.C., Larson, M., and Kreibel, D.L. (1991) Evaluation of beach erosion and accretion predictors. Proc. Coastal Sediments '91, ASCE, 572-587.

USACE. (1999) U.S. Army Corps of Engineers, Waterways Experiment Station, Prototype Measurement and Analysis Branch. URL: http://sandbar.wes.army.mil/public_html/pmab2web/htdocs/ny001.html

SLOPE DISTRIBUTION ALONG EBB-TIDAL SHOALS OF EAST, GULF, AND GREAT LAKES INLETS

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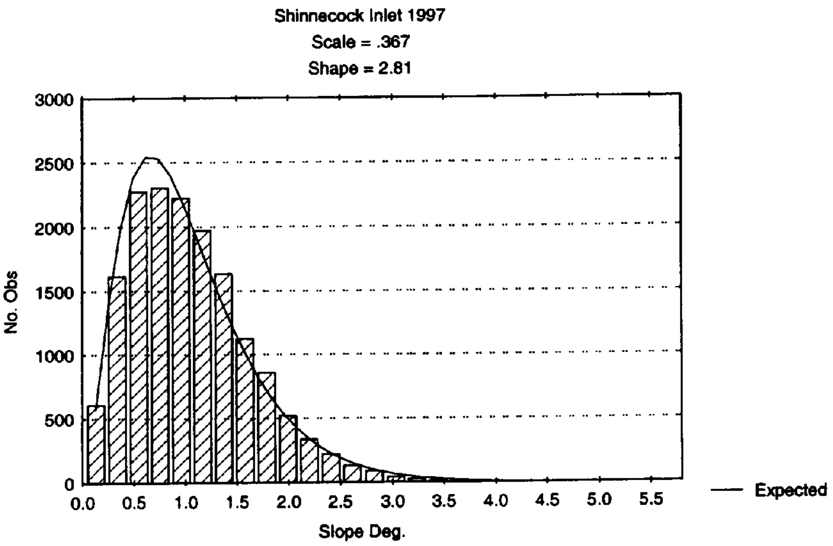
US Army Corps of Engineers Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) data for 13 inlets were analyzed to interpret scalar and temporal variability of slope distributions of ebb-tidal shoals. The airborne-mounted system obtains depth measurement to a horizontal position accurate to 3 m and a vertical position accurate to 0.15 m. The inlets examined were Shinnecock, Moriches, Ft. Pierce, St. Lucie, Lake Worth, and Hillsboro on the East Coast; Ponce de Leon, New Pass, East Pass, and Perdido Pass on the Gulf Coast; and New Buffalo, Ludington, and St. Joseph harbors in the Great Lakes. The selected inlets encompass varying energy regimes, with mean wave heights from 0.4 to 1.6 m and tidal amplitudes ranging from 0.18 to 0.88 m.

The variation in slope of the ebb-tidal shoal, for the majority of the inlets, was well represented by a gamma function (Figure 1). Gamma distributions are characterized by shape and scale parameters. For our inlets shape parameters ranged from 0.36 to 2.81, and scale parameters ranged from 0.36 to 1.87. Larger scale and shape values will result in a wider distribution and an increase in the most probable slope. St. Joseph Harbor, MI demonstrated both temporal and scalar stability, with distribution parameters remaining relatively constant under a wide range of grid resolutions from August 1997 through June 1998.



Myrtle Beach Renourishment Monitoring: Nearshore Hardgrounds and Borrow Site Assessments

Patricia Donovan Ealy[1], Paul T. Gayes[1], Mike Lowiec[1], Wayne Baldwin[1], Pam Cox Jutte[2], Bob Van Dolah[2]
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In April through December 1997, the US Army Corps of Engineers began construction on Reach 2 (Myrtle Beach) of the Grand Strand Renourishment Project which to placed 2.5 million cubic yards of sand on the beach above –5' NGVD. Concern that nearshore hardbottom areas would be covered by offshore-migrating sand from the nourishment project prompted a bottom mapping study by the Center for Marine and Wetland Studies (CMWS) at Coastal Carolina University and the Marine Resources Division of the South Carolina Department of Natural Resources (SCDNR). The bottom mapping was ancillary to the larger study to monitor the physical and biological recovery of the offshore borrow site and the behavior of the beach fill.

In an effort to monitor changes to hardbottom areas in the nearshore, the CMWS and SCDNR selected 13 hardbottom sites to focus attention. Sonar collected and processed by the CMWS in November 1997 was false-colored to help delineate areas of hardgrounds based on sediment sample groundtruthing. An underwater video system was developed at the CMWS and deployed in August and November 1999 to groundtruth the sonar imagery. Statistical correlation exists between the sonar backscatter values and the underwater video coding. One year after nourishment, significant changes to several nearshore hardgrounds are visible in the sonar, including both influx of sand and sediment evacuation over previously high backscatter (hard) areas. In addition to sonar mapping, RoxAnn bottom characterization surveying conducted pre- and post-nourishment at four SCDNR-MRD nearshore control sites, where video imagery was collected along BERM profiles, also indicates changes to the nearshore environment. A lens of finer grained (softer) material moved onto the existing, harder material shortly after sand-placement at BM 5350 as evidenced in the RoxAnn E2 (hardness) values as well as the November 1999 (USGS) sonar imagery.

Two offshore borrow sites were dredged for the Myrtle Beach reach of the Grand Strand Nourishment Project. The total fill dredged from these sites, based on measured constructed beach fill, was 2.25 million cubic yards. Although accurate calculations for volume removed from the borrow sites are not available, this study calculated the volume change between the pre- and one-year post dredging condition to be 1.25 million cubic yards. This value represents a higher than average infilling for the Cane North and South borrow sites relative to other offshore borrow areas in the state (Van Dolah *et al.*, 1999).

ARCADIAN SHORES BEACH AND BORROW SITE MONITORING

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The Arcadian Shores Community along the northern coast of South Carolina nourished approximately 1.5 km of beach in May-June 1999. The Center for Marine and Wetland Studies at Coastal Carolina University has been active in monitoring the behavior of the beach fill and the offshore borrow site used for the project. The USACOE design template called for building a beach of varying width at 9' NGVD, sloping at a 1/5 gradient to 3' NGVD, and then to a natural grade of -5' NGVD at varying slopes along the coast. BERM survey data has been compiled in ArcView and BMAP software to compare volume and contour changes between pre, post, and 3 months post beach survey datasets with favorable results. Volume calculations for the entire nourished beach using ARC/INFO TIN modeling estimates 480,000 yd^3 of sand was added initially to the Arcadian Shores beach and nearly 94% of sand placed in the design template was still present three months after sand placement. The high retention behavior observed is very similar to that experienced at north Myrtle Beach Reach of the Grand Strand Nourishment Project 3 month post-placement survey. A significant volume of sediment was deposited below the toe of the fill template. The TIN modeling of the profiles from the Arcadian Shores project area suggests a similar movement of sand from the middle shoreface supporting the upper beach fill. The construction of the Myrtle Beach Phase of the nourishment did not result in a large volume of sand placed on the middle shoreface. Although the templates were similar, the loss from Myrtle Beach was about 10% higher than North Myrtle Beach during the first year. This is due to the difference between the design template and the actual construction. Behavior of beach fills of similar design may vary significantly as volumes placed on the middle shoreface vary with construction. Though the design of the Arcadian Shores template is considerable larger than the adjacent Myrtle Beach and North Myrtle Beach projects, the rate of re-equilibration during the initial 3 months is similar to the north Myrtle beach project where large overfills on the shoreface occurred.

The borrow site used for the Arcadian Shores Reach is located approximately 9 km offshore, just seaward of the North Myrtle Beach borrow site. Detailed bathymetric surveys from the pre-dredging and intermediate post-dredging activities show that approximately 696,200 yd^3 were removed from the southeastern end of the borrow area. Vibracores taken from the borrow site before dredging operations showed 0.5-1.5 ft of usable nourishment material overlying a stiff, silty-clay. One year post construction bathymetry and vibracores have been collected in March 2000 to document the characteristics of the sediment infilling the borrow site. This will provide a more detailed documentation of the Arcadian Shores borrow site than the other four sites associated with recent nourishment projects along the Grand Strand.

MULTIBEAM SONAR: A TOOL FOR INVESTIGATING SHALLOW WATER SEDIMENTARY ENVIRONMENTS

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Multibeam sonar is similar to side-scan sonar in that sound is projected perpendicular to the ship track such that the area being ensonified is narrow in the along-track direction and wide in the across-track direction. However, in contrast to side-scan, the sound received by a multibeam sonar system is used to derive depth information. The fan-like beam arrangement provides continuous coverage of the bottom while the ship is underway at speeds of up to 10 knots. In the fall of 1998 the Marine Sciences Research Center became the first academic institution in the US to acquire a Simrad EM3000 Multibeam Echosounder. The transducer is hull-mounted and has a swath width of approximately 4 times the water depth, with vertical accuracy of 5 cm. The system is designed for shallow water surveys (up to a depth of about 100 m), and operates at a frequency of 300 kHz, providing very high resolution information about the bottom.

This echosounder simultaneously provides information about water depth and backscatter intensity, which is joined with navigational information (DGPS) and digitally recorded on a SUN workstation. The system is supplemented with a POS/MV attitude sensor which provides a means to monitor and correct for ship motion (pitch, roll and heave). Data processing, map creation, and 3-D visualization is done with a suite of programs designed by the Ocean Mapping Group at the University of New Brunswick. The calibrated backscatter intensity is used to produce imagery similar to side-scan sonar and can be used to identify changes in sediment type and/or texture. The depth information is used to create contour maps, color-coded depth maps, and 3-dimensional sun-illuminated representations of bottom morphology.

Fine-scale bathymetry is essential to studies in coastal areas, and has traditionally been the hardest data to collect. Multibeam technology permits rapid acquisition of high-resolution bathymetric data which can be used to investigate a range of issues including benthic habitat assessment, sedimentary processes, and bathymetric change. The identification of sedimentary features such as sandwaves and scour marks around obstructions can be used as indicators of the nature and direction of dominant flow. Other features identified through multibeam imagery can be used to assess anthropogenic impacts on the environment including the response of the environment to dredging and coastal stabilization.

Surveys to date include 35 miles of the Hudson River, parts of Long Island Sound, some Long Island inlets and embayments, nearshore areas off southwest Washington, northern California, and the Gulf coast of Florida. In most areas the multibeam data are supplemented with grab samples that are used to ground-truth the imagery. We will present examples of how this kind of data has increased our understanding of coastal processes.

INFLUENCE OF ANTECEDENT GEOLOGY AND MODERN SHOREFACE PROCESSES ON SHORELINE CHANGE, DELAWARE AND MARYLAND

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With billions of dollars worth of property threatened by coastal erosion, there is a great need to identify, predict, and mitigate against this hazard. Setbacks are the primary regulatory tool used by state and local agencies to limit construction in hazardous coastal areas. The setback is typically based on some multiplier of the annual erosion rate, but is only as effective as the input data, analysis methods, and scientific understanding of the rates. The National Flood Insurance Program is considering incorporating erosion estimates for determining coastal flood hazards; however, current forecasting methods are neither uniform nor standardized. A certain degree of variability in methodology is warranted given the diversity of coastal environments and governing sediment-transport processes, however some basic standards are necessary.

The antecedent geologic framework, across which the modern shoreline is transgressing, has emerged as a critical variable in analyses of long-term coastal evolution, as well as in evaluation of short-term response due to great storms. Despite this, analyses of shoreline-change data rarely address this variable in any direct or systematic manner. This study attempts to improve erosion models by estimating prediction uncertainty in forecasts generated from several common methods, and by integrating the geologic framework into analyses of erosion trends. The study focuses on the Delaware-Maryland coast, and addresses several questions: (1) Does antecedent geology affect the rate of shoreline retreat? (2) Do other large-scale, interannual processes affect erosion rates in a predictable manner? (3) Based on these results, is there an ideal way to calculate erosion rates that provides reliable forecasts for use in establishing setbacks or determining flood hazards?

A three-dimensional, geologic model for the Delaware and Maryland Atlantic shoreface is being constructed from available core data, previously uninterpreted 3.5 kHz seismic-reflection profiles and side-scan sonar data, and new CHIRP seismic profiles to be collected in the extreme nearshore zone and back-barrier bays. Spatial and temporal trends in historical shoreline (HWL) data and nearshore bathymetric profiles will be examined, with statistical tests used to identify any correlation between erosion rates, volumetric changes, and antecedent geology. Long-term trends should reflect the greatest influence of the framework, particularly in areas where the modern shoreline intersects relict shorelines. There should also be evidence of temporal changes in recession rates as shoreface erosion cuts through variably resistant units, although complete resolution of these changes from existing datasets may be difficult.

BIOLOGICAL AND PHYSICAL RECOVERY OF A SAND BORROW AREA USED FOR BEACH NOURISHMENT IN CHERRY GROVE, SOUTH CAROLINA

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The Myrtle Beach Renourishment Project placed nearly 6.5 million yd^3 of sand on over 25 miles of beaches in 1996-1998. Physical and biological data from the Cherry Grove offshore borrow site, dredged with a hopper dredge, were collected for 1.25 years before the initiation of dredging and for two years after dredging. Both spatial and temporal controls were utilized to assess recovery of the site. Physical characteristics, including mean phi size of sand, sediment composition, and organic matter content showed signs of recovery to pre-dredging conditions within three months after dredging operations, with complete physical recovery occurring within one year after dredging. More than 46,000 benthic infaunal organisms, representing 415 taxa were collected during the study period. No significant changes in faunal abundance values or number of species per grab were observed after dredging activities. Changes in higher taxonomic structure and dominant species were observed at the borrow site until six months after dredging occurred, when the site had recovered to pre-dredging conditions. Diversity indices were similar between control and dredged areas throughout the study. Areas of undisturbed sediments and biota left by the hopper dredge most likely resulted in the rapid recovery observed at the offshore borrow site.

MAGNETOSTRATIGRAPHY OF ATLANTIC COASTAL PLAIN SEDIMENTS IN SOUTH CAROLINA

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Paleomagnetic polarity narrows the ages of sediments for which biostratigraphic, aminostratigraphic and radiometric data are available. The polarity at localities in the Santee Lms near the bottom of the Martin Marietta Orangeburg quarry, Warley Hill Fm at Wilson Landing on the Santee River, and Sawdust Landing Fm in the bluffs of the upper Santee River is normal after thermal demagnetization. Reverse polarity is recorded in the middle Eocene Chapel Branch Member of the Santee Lms at Santee State Park. The member is in the *Cubitostrea selloeformis* zone and its dinoflagellates correlate with nannofossil zone NP17 of Martini (1971). Regional correlations constrain the unit to the lower part of zone NP17 and therefore to the upper part of magnetic anomaly Chron C18r (41.2-40.1 Ma) or to Subchron C18n-1r (39.6 Ma; after Berggren and others, 1995). A Rb-Sr date of 40.4±0.8 Ma reported by Harris and Fullagar (1989) from glauconite grains collected nearby in the Chapel Branch Member and an inferred biostratigraphic position low in zone NP17 together suggest correlation with anomaly Chron C18r at 40.3-40.1 Ma. Reverse polarity in the mid-Pliocene Duplin Fm near Summerton is consistent with that known from Pinecrest beds 6 through 8 in the faunally equivalent Pinecrest beds 5 through 9 at the APAC pit in Florida (Jones and others, 1991; M. Campbell, 1998). Regional correlations constrain the Duplin Fm in South Carolina to foraminiferal zone N20 of Blow (1969) and to the lower part of nannofossil zone NN16 of Martini (1971; both after M. Campbell, 1998). Consequently, the Duplin Fm is placed in either Chron C2Ar at 3.8-3.55 Ma or Subchron C2An-2r (3.35-3.2 Ma) or C2An-1r (+/-3.15-3.05 Ma; after Berggren and others, 1995; M. Campbell, 1998). The Canepatch and Waccamaw Fms near Myrtle Beach have normal and reverse polarity, respectively, that place their ages as younger (Canepatch) and older (Waccamaw) than 0.73 Ma.

USING THE “STACK-UNIT MAPPING” METHOD FOR EVALUATING DELAWARE’S OFFSHORE SAND SOURCES, HEN AND CHICKENS SHOAL

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Delaware’s Atlantic coast beaches are popular tourist destinations and as such, maintenance of the beaches is important for the economy of the state. In order to maintain wide, sandy beaches in the areas where beach width has been decreasing, beach replenishment has been implemented. With continued usage, offshore supplies of beach-quality sand have been dwindling. In addition, some areas where potential good-quality sand is found are within former artillery firing ranges. With greater demands for sand for the eroding beaches of Rehoboth Beach and Dewey Beach, the State and the U.S. Army Corps of Engineers (COE) have intensified their search for quality sand. The offshore region known as Hen and Chickens Shoal is a bathymetric high that extends from the tip of Cape Henlopen approximately 10 miles (18.5 kilometers) to the southeast and is considered a possible sand source by the COE (1996). In this study, the stack-unit mapping method was used to determine the spatial relationship of the lithologic units and the suitability of the sediments for beach replenishment along the Delaware Atlantic shoreline. Forty-four vibracores from the shoal area and twenty-nine cores from the surrounding inner continental shelf were extracted from the Delaware Geological Survey core repository database. The log descriptions were evaluated for sediment type, grain size, layer thickness, and number of layers. The lithologic units for each core log were evaluated and each was assigned a lithologic category symbol (G, S, L, or M) based on the grain size description and textural analyses (if available). Each unit was then measured in feet and assigned a thickness symbol (0 to 5, 10, 15, 20, 25, or 30). The criteria for determining the resource potential (E, G, F, or P) include the suitability of the sediments with the native beach textural composite, the thickness of the unit, and its proximity to the sea floor surface (for extraction purposes). Sites with Good (G) or Excellent (E) ratings contain sediments that match the native beach sand composite (coarse to medium sand (1.5 to 0.5 phi)) and are considered to be potential resources. Those with Fair (F) ratings are considered marginal at best either because the sand is finer than that of native beach sand, or contains too much silt. Sites with Poor (P) ratings should not be considered. This study finds that most of the cores taken from the crest of the Hen and Chickens Shoal contain material too fine for beach replenishment. Of the few cores that are rated as excellent sand sources, one was from the crest (Oj13-02) and the other two (Oj24-02 and Oj33-01) are found along the flanks of the shoal near Rehoboth Beach. An area that could be suitable as a sand resource is located on the inner platform north of the Indian River Inlet. Cores Pj14-02 and Pj25-02 are rated as Excellent (E) sand sources and the surrounding cores contain sand within their upper-most sections. These cores are located within a Late Pleistocene and Holocene offshore paleovalley.

BEACH PROFILES OF DISEQUILIBRIUM: VARIATIONS ON A THEME

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A long-term beach-surveying program conducted along the South Carolina coast has generated an extensive database of beach and shoreface behavior along a broad (200 km) section of coastline. Profiles have been collected using a sled-based surveying system at 300 locations since 1993. Profiles typically extend from the dune offshore to well beyond the calculated depth of closure for the area. In areas of recent beach nourishment projects, additional surveys have been collected to assess the behavior of artificial beaches in the region. This extensive database has been used to analyze the nature of profile behavior within the region.

Defining an "equilibrium profile" from the database, utilizing standard forms of expressions, produces variable levels of success in representing the range of beaches shaped by similar wave climate, tidal range and sediment size in the study area. In many locations, the profile of the beach and shoreface has evolved away from an "equilibrium profile" in response to natural and human induced perturbations. These disturbances include the influence of hard engineering structures (i.e. seawalls, groins, etc.), beach nourishment, and outcrop of antecedent geologic framework. A graphical analysis of the deviation from the local "equilibrium profile" in disturbed areas was used to project beach response to removal of the disturbing influence (seawalls, groins, cessation of beach nourishment). A similar analysis was used to project deviations from existing behavior where older indurated deposits will soon be intersected by the eroding shoreface.

Resolution of Large and Small-Scale Climatic/Sea-Level Fluctuations and their Holocene Coastal Response: Northeastern North Carolina

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The Albemarle-Pamlico Embayment is a large Quaternary basin with a detailed Holocene record. A data base has been developed that includes >2,500 km network of high-resolution seismic, side-scan sonar, and ground-penetrating radar profiles; 120 (15-40m) drill core holes, 487 (2-10m) vibracores, 117 (6-18m) wash bores, and 634 (0.5-1m) hand cores; and 499 radiocarbon age dates (313 SRR; 186 literature). Integration of these sedimentologic, seismic, and chronostratigraphic data have enabled deciphering the complex stratigraphic record of non-steady state conditions through the Holocene within the shallow, micro- to nannotidal estuarine system and intimately coupled, wave-dominated barrier island system.

The general post-glacial, sea-level transgression was frequently interrupted by both large-scale (centennial to millennial) and small-scale (annual to decadal) sea-level fluctuations driven by some combination of changes in climatic and oceanographic processes and resulted in multiple erosional and depositional events that extensively modified the depositional record. Episodes of lowered sea level caused channel incisement and erosional truncation within the estuarine system and erosion of the barrier island system. Subsequent coastal flooding led to deposition within the new accommodation space by estuarine sediments and remobilization of the barrier islands. The underlying paleodrainage framework and availability of sand on the shoreface and inner shelf led to formation of either complex, wide, accretionary barrier segments dominated by progradational beach ridges and back-barrier dune fields or simple, narrow overwash barriers. Most complex, sediment-rich barrier segments are related to trunk stream valleys or interfluvial headlands, whereas sediment-starved, overwash barrier segments are mostly related to tributary stream valley-fills along the flanks of drainage basins.

MARINE GEOLOGIC MAPPING OF THE NEARSHORE REGION OFF NORTHERN SOUTH CAROLINA

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Coastlines with limited sand supplies, such as much of the Atlantic margin of the United States, are significantly influenced by the geologic framework beneath and seaward of the littoral zone. This antecedent geology can determine the morphology of the shoreface/inner shelf and strongly influence modern beach behavior. A better understanding of sediment dynamics in coastal areas can be attained by mapping the surface sediment distribution and subsurface stratigraphy of the lower shoreface and inner continental shelf.

In November 1999, the United States Geologic Survey, in cooperation with Coastal Carolina University, began a program to produce geologic maps of the nearshore regime off Northern South Carolina utilizing high-resolution sidescan-sonar, interferometric (direct phase methods) swath bathymetry, and sub-bottom profiling systems. The study area extends from the ~7m isobath to about 10km offshore (water depths </= 12m). The goals of the investigation are to determine regional scale sand resource availability needed for planned beach nourishment programs, to investigate the roles that the inner-shelf morphology and geologic framework play in the evolution of this coastal region, and to provide baseline geologic maps for use in proposed biologic habitat studies.

In this report, we present the sidescan-sonar imagery and swath bathymetry of the nearshore area off Myrtle Beach (between Little River and North inlets). For the first time, the collection of swath bathymetric data on a regional scale in extremely shallow water (<11m) was possible through the use of an interferometric sidescan-sonar system. The data products presented here were produced onboard ship; in effect, this is a "dockside" cruise report.

TREND ANALYSIS OF HURRICANE LANDFALLS IN THE NORTHWEST ATLANTIC OCEAN: HISTORIC AND LATE HOLOCENE OCCURRENCES AND APPLICATION TO RISK ANALYSIS

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Singleton Swash on the South Carolina coast provides an extended record of storm events for this coast. Using experience gained by looking at traces of a known storm in the area, Hugo, which occurred in 1989, we were able to confidently pick out storm horizons from the sediments that have been accumulating in Singleton Swash since 5000 years ago. We found that although our record went back 5000 years the most intense storm activity occurred since 1800 years ago with major storm strikes on this location every 300-400 years. No storms were detected prior to that except two giant storms at about 5000 years ago. These storms were detected primarily by content of offshore forminiferain marsh sediments at selected intervals except the two giant storms that had thick (10 cm) sand layers with offshore foraminifera. It has been suggested that the position of the Bermuda High plays a role in the hurricane storm tracks in the Atlantic and our data combined with that of others appears to confirm this with most hurricanes before 2000 years hitting the Gulf Coast when the High was in a southerly position. After 2000 years ago when the Bermuda High moved up over Bermuda, we observe storms more frequently on the Atlantic coast.

INNER SHELF STRATIGRAPHY AND SAND RESOURCES SEAWARD OF PAWLEYS ISLAND, SOUTH CAROLINA,

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Identifying sand resources for beach renourishment remains a critical need for maintaining South Carolina shorelines. This study investigates the sand resources seaward of Pawleys Island, South Carolina as part of the South Carolina Task Force on Offshore Resources and Critical Habitats funded by the Minerals Management Service INTERMAR program. To identify resource sites, approximately 150 trackline-miles of high-resolution seismic and side-scan sonar data, and 96 vibracores were collected. High-resolution seismic reflection profiling data suggests a thin sediment cover (< 8 ft, typically < 3 ft) over the entire study area, overlaying lithified, southward-dipping seismic units located along the southern flank of the Cape Fear Arch. Thicker sediment deposits occurred within bathymetric highs located to the southeast of Pawleys Island. The constructed side-scan mosaic reveals high return values (coarse sand, shell hash or rock) along the southern half of the study area and low return values along the northern half of the study area (finer sand or mud). Based upon the interpretation of the geophysical data, vibracore collection was focused in the area to the southeast of Pawleys Island. Lithology of the region consists of marine sand overlaying back-barrier muddy sand to clay and thin brackish to freshwater peat. Sediment analysis of subsamples from the vibracores outline a 0.6 square mile area where the surficial sediment contains less than 10% mud and possesses Ra values of lower than 1.25 in the top 1' interval of sediments. Assuming a conservative depth of 1 ft, this borrow area would provide over 500,000 cubic yards beach compatible material for nourishment in the Pawleys Island area.

Saturday, April 8th, 2000

Introduction

The field trip this weekend will start in Conway, South Carolina (Figure 1), continue south along the Grand Strand from the Waites Island at the state line, and end just south of Myrtle Beach. The embayment centered on Myrtle Beach is Long Bay. It extends from Cape Fear, North Carolina approximately 130 km (80 mi) to the Santee River mouth. Geologically, this section of coast mirrors Onslow Bay in North Carolina, with exposed Cretaceous and Tertiary rocks dipping to the south-southwest south of the state line.

The shelf off Myrtle Beach is sediment starved and has a tidal range inshore of approximately 1.5 m to 2.1 m (5 to 7 ft). Hydrodynamically, this coastal zone falls within Hayes' transitional zone. Geomorphically, the coast is predominately headland attached with few inlets. Tides today will be rising, peaking at +5.1 ft at 11:30 a.m. offshore, with an approximate lag of 45 minutes behind Waites Island.

General Geologic Framework

The geologic framework of the Grand Strand's lower coastal plain and continental shelf consists of indurated to unconsolidated Cretaceous, Tertiary, and Quaternary formations at or near the surface (Figures 2 and 3). The low-relief coastal plain and continental shelf (Figure 4) have moderately thin (up to 10 m) to non-existent sediment cover.

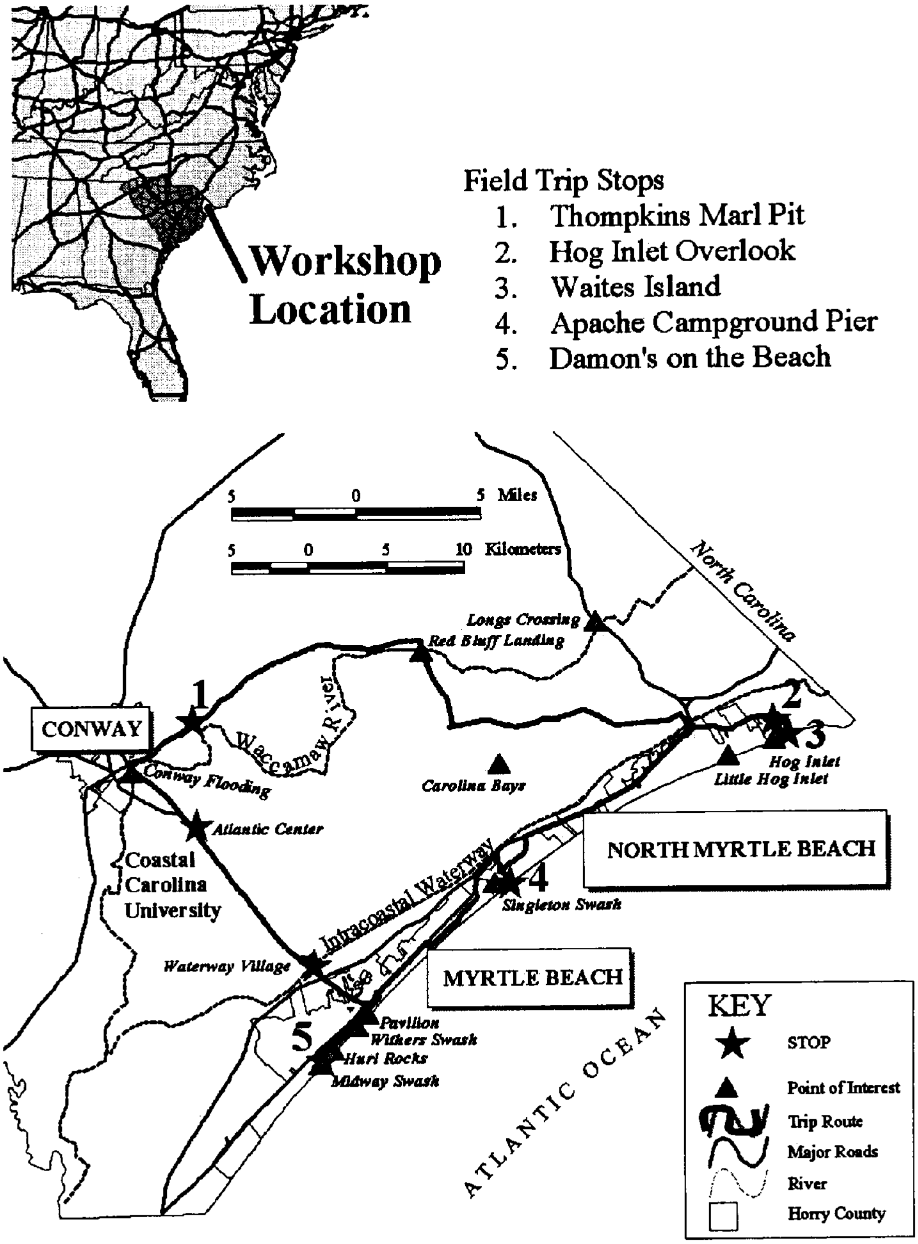
Repeated sea level rise and fall throughout the Quaternary has resulted in deposition of a series of prograding beach ridge deposits (Figures 5 and 6) and backbarrier deposits of varying age (Figure 7) over a stratigraphically variable pre-Quaternary surface. Stratigraphic variability is important because of variations in mechanical stability of the deposits as they are exhumed in the rivers and shoreface during transgression or storm events. Pleistocene units are being truncated at the coast in the vicinity of Myrtle Beach and form headlands with 7 to 10-m relief within one to two hundred meters inland. Some late-Tertiary/early-Quaternary units form indurated coquina beds which crop out at sea level on the beach. Inlets and swashes occupy paleoincisions are the only low zones extending back into the headland, creating high to extreme risk zones in these low lying areas.

Coastal Hazards

Hurricanes (Figure 8), chronic shoreline changes (Figure 10), earthquakes (Figure 9), and flooding (Figure 29) have been identified as potential hazards in this region. Six hurricanes passed close to Horry County between 1880 and 1990 *(Lennon*, et al., *1996)*, with an additional four in the last ten years. Shoreline erosion rates range from an average of 0.4 to 0.96 ft/yr (Anders *et al.*, 1990) from north to south in the region. Generally, erosion rates increase in the vicinity of ancient paleoincisions and south of the Cretaceous-Tertiary boundary at the Myrtle Beach Jet Port. Evidences for earthquake activity are abundant in the unconsolidated sediments of Horry County. The number of sand blows (Figure 9) identified in the region is high and range in age from 200 to 2000 years old. Because much of the lower coastal plain in this region is covered with poorly drained soils, flooding is a common threat. Hurricane Floyd caused discharge values to increase from approximately 3000 ft^3/day to over 22,000 ft^3/day in a few weeks.

Recent Projects

The South Carolina State Beach Front legislation and tourism dictates the need for renourishment and coastal studies in the Grand Strand. Within the last five years, three phases of renourishment have been completed and subsequently monitored. The Surfside/Garden City, Myrtle Beach, and Cherry Grove phases were completed in 1998, 1997, and 1997, respectively. Since 1993, the USGS through SC OCRM (formerly SC Coastal Council) has funded beach profiling in the South Carolina coastal zone. This type of program directly benefits the states needs by helping provide scientific data for the management decision-making process.



Field Trip Stops

1. Thompkins Marl Pit
2. Hog Inlet Overlook
3. Waites Island
4. Apache Campground Pier
5. Damon's on the Beach

Figure 1. The field trip starts at Coastal Carolina University's Atlantic Center. Key stops are numbered and points of interest (POI) are labeled. This section of coast is called the Grand Strand and continues from about the North Carolina/South Carolina border down to Winyah Bay at the southwest edge of the map. The route lies wholly within Horry County.

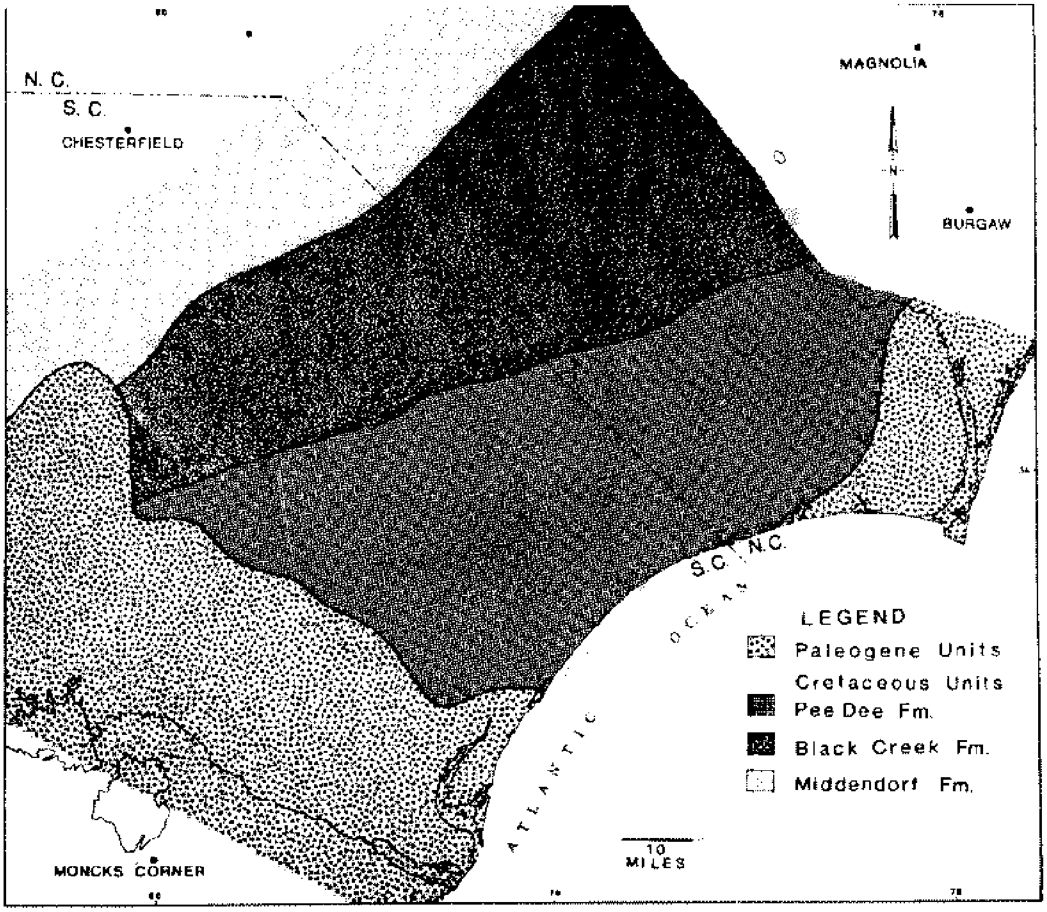


FIGURE 3. *Geologic map of pre-Neogene surface in southeastern North Carolina and northeastern South Carolina.*

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Figure 2. The stops are located on the southern side of the Cape Fear Arch. This feature straddles the North Carolina and South Carolina border and is surrounded by younger units. In the region we are visiting today, Cretaceous, Tertiary, and Cenozoic consolidated to semi-consolidated rocks crop out in the creeks, rivers, and the shoreface (*from DuBar* et al., *1974).*

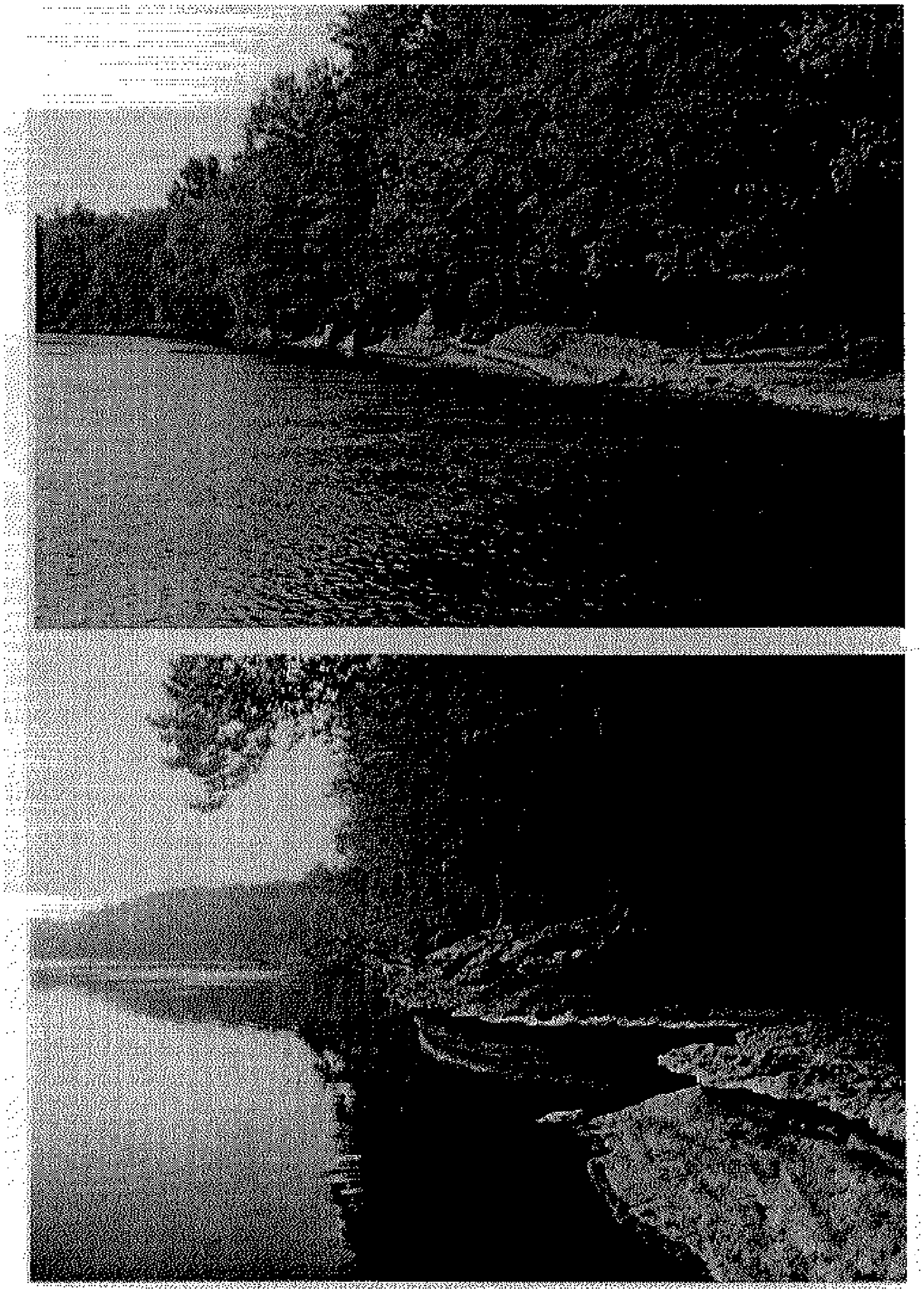


Figure 3. Along the Pee Dee River to the south and west of Conway, the Cretaceous is exposed above stream level. These rocks are similar to those that crop out at sea level and offshore. *(photos from fall 1999, M.S. Harris)*

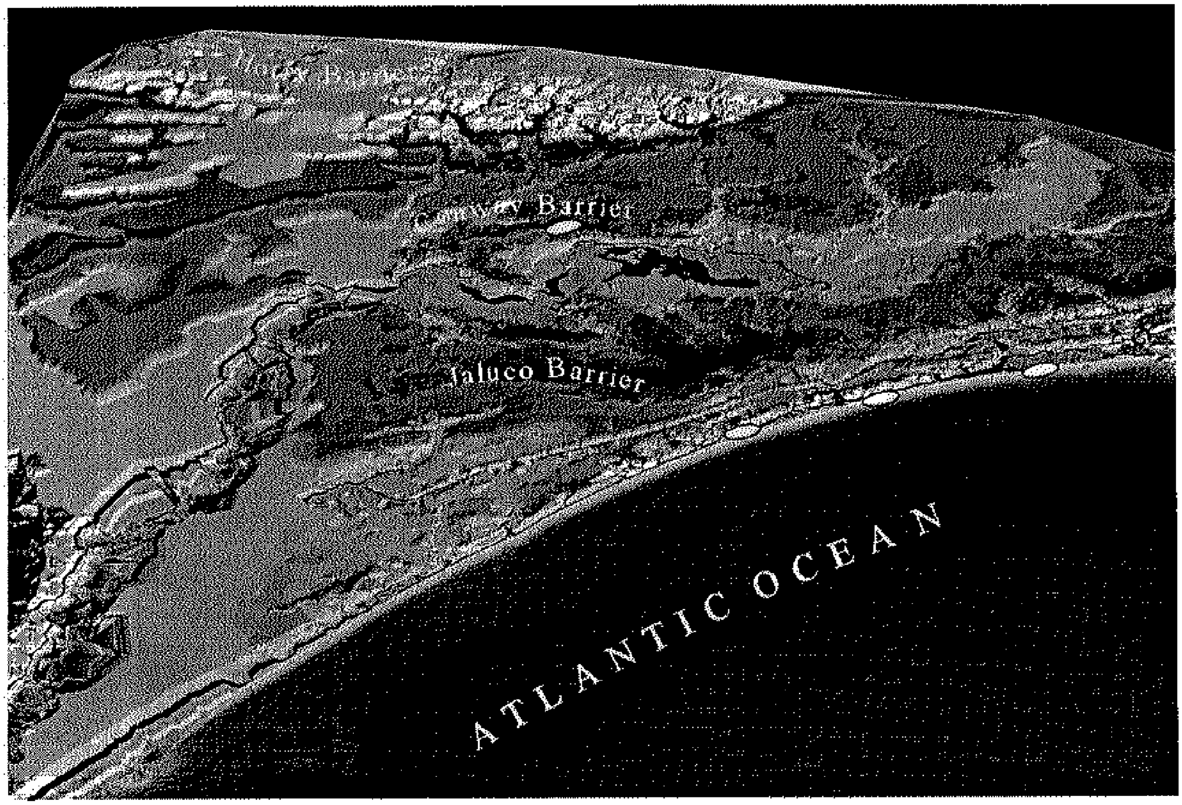


Figure 4. The continental shelf and lower coastal plain have very little relief in this region. Pleistocene barrier island ridges are being truncated at or near the beach in the Grand Strand region of South Carolina's Coast. (*the grid was created using line contours from 1:24,000 hypsography provided by SC DNR* http://www.dnr.state.sc.us/gisdata *and NOAA point bathymetry provided by C. Pollini at USGS Woods Hole).*

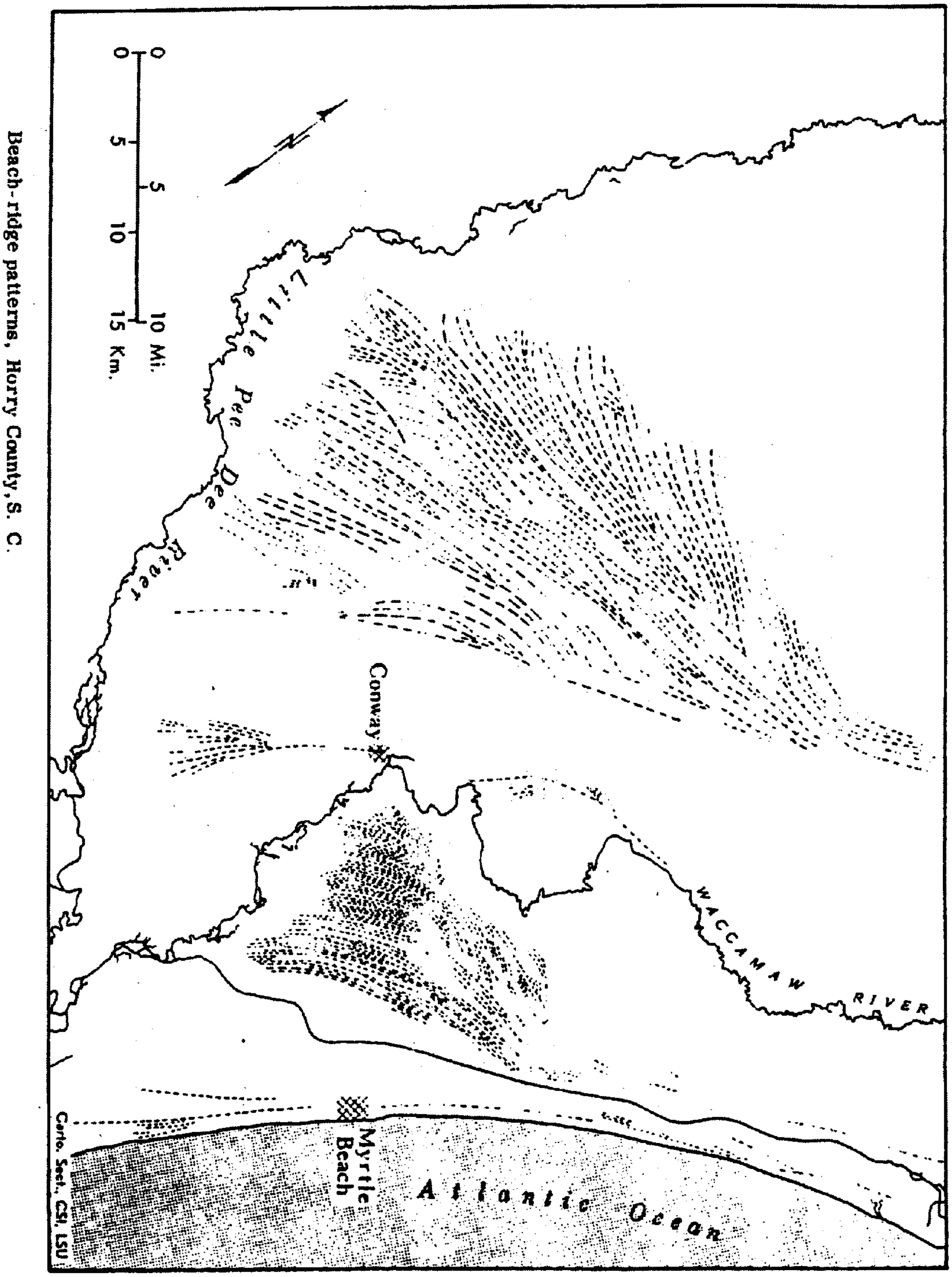


Figure 5. Individual beach ridges outline the trends of the Jaluca, Conway, and Horry barriers on shore. Notice the angular truncation of the Pleistocene barriers near the coast and bends in the Waccamaw related to constructive geomorphic features *(from DuBar* et al., *1974).*

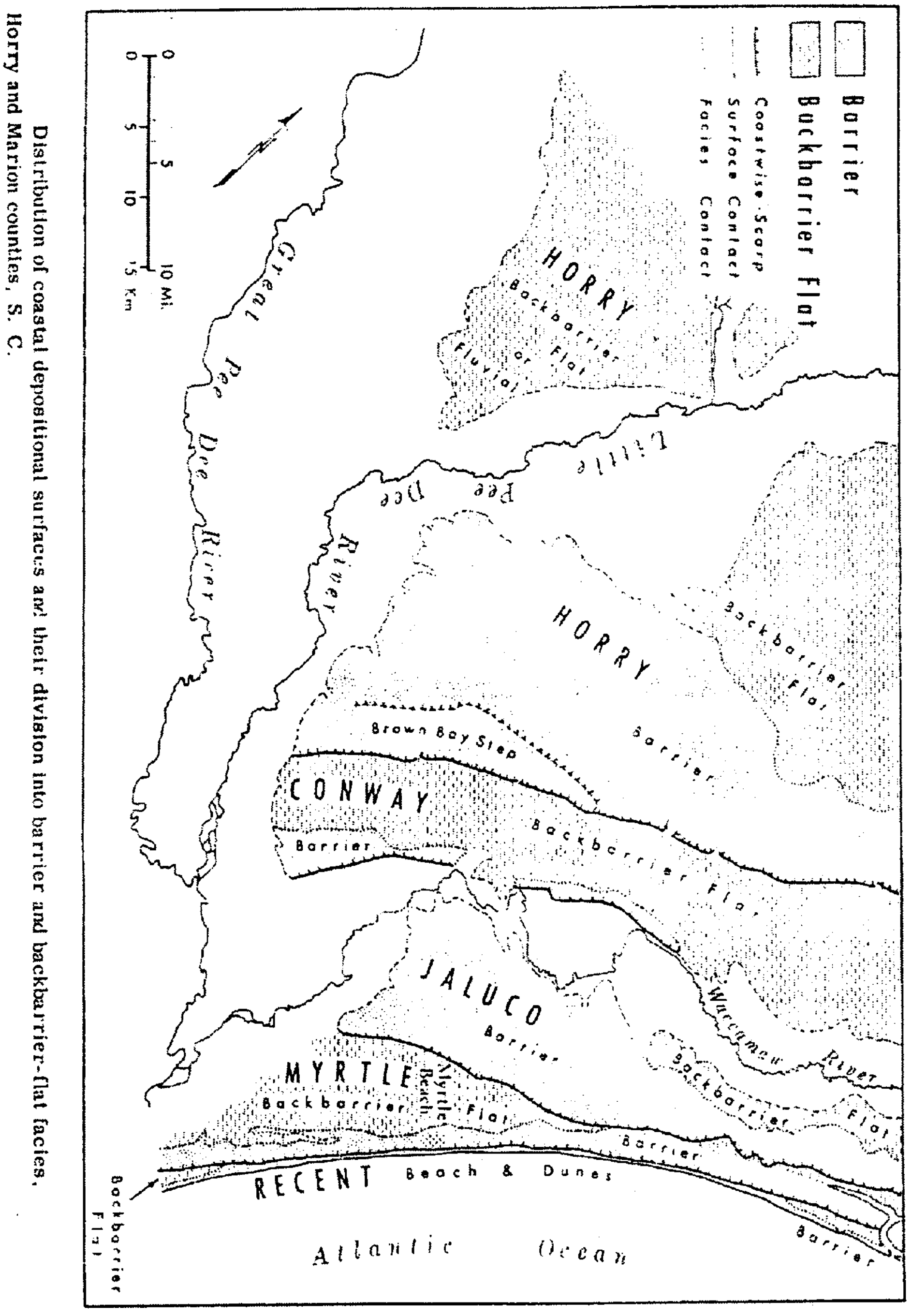


Figure 6. The individual named emergent barriers along the Grand Strand coastline. Lithified and partially lithified shelf facies of these units crop out in the shoreface (generally to the south) and fill paleochannels from the ancestral Waccamaw and Pee Dee Rivers *(from DuBar* et al., *1974).*

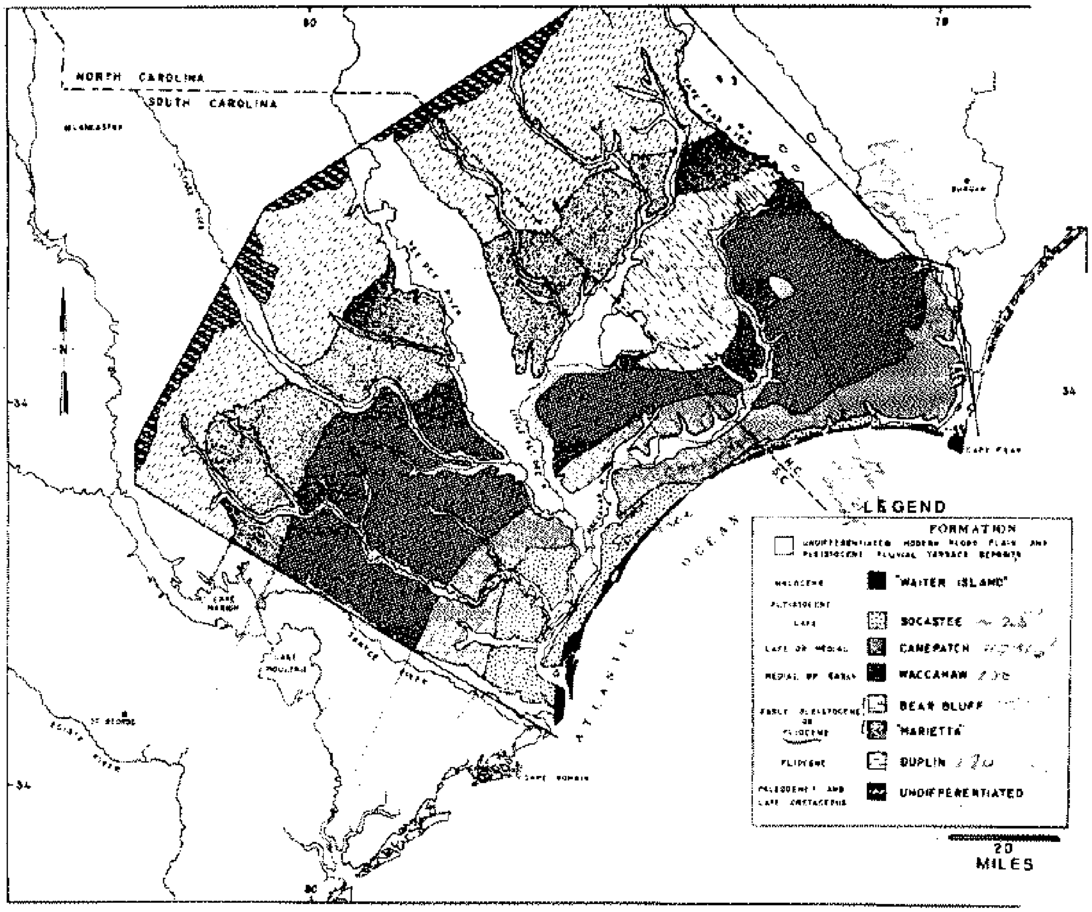
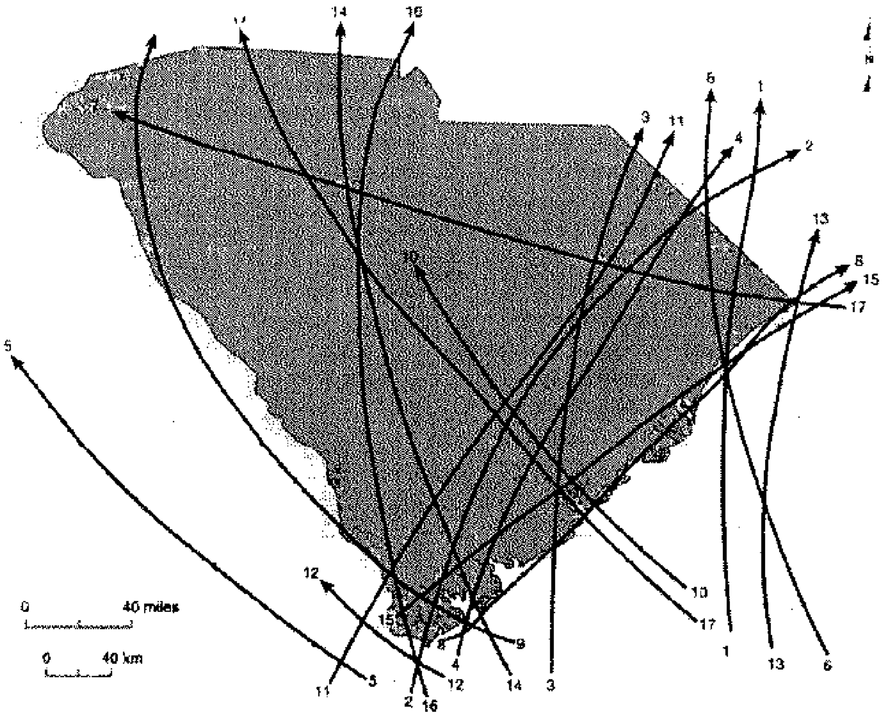


FIGURE 4. *Generalized geologic map of Neogene formations in southeastern North Carolina and northeastern South Carolina.*

Figure 7. The geology of the surficial deposits is depicted. The higher relief along the northern coast is due to truncation of the Canepatch and Socastee units *(from DuBar* et al., *1974).*

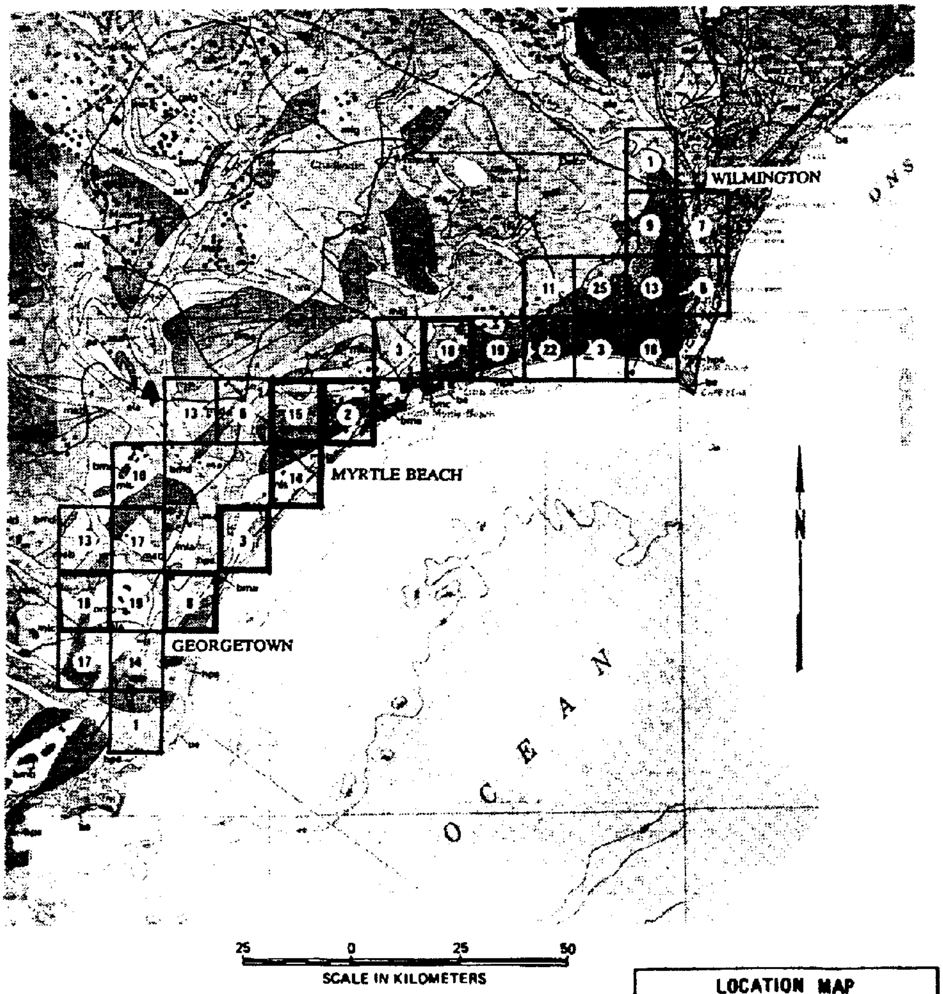


(1)	1883	MH	
(2)	1885	EH	
(3)	1893	MH	
(4)	1894		
(5)	1898	EH	
(6)	1899	MH	
(7)	1906	GH	
(8)	1910	GH	
(9)	1911	MH	
(10)	1916		
(11)	1928	GH	
(12)	1940	MH	
(13)	1954	GH	Hazel
(14)	1959	MH	Gracie
(15)	1966	MH	Alma
(16)	1979		David
(17)	1989	GH	Hugo

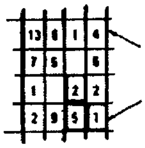
MH	major
GH	great
EH	extreme

(*from Lennon* et al., *1996)*

Figure 8. Hurricanes making landfall along the South Carolina coastline between 1880 and 1989. Since hurricane Hugo impacted Charleston in 1989 *(Lennon* et al., *1996).* In the last five years, the northern coast has been brushed by hurricanes Bertha, Fran, Bonnie and Floyd. Although wind damage created problems in the northeast section, the largest problems associated with Floyd in 1999 was severe rapid flooding from the higher regions and then flooding from the main channel weeks later.



EXPLANATION

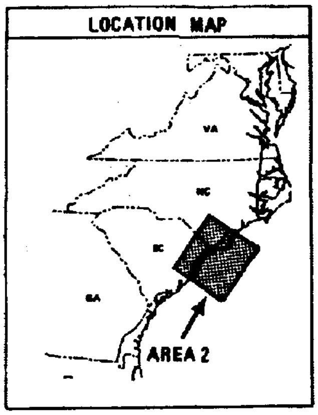


The black outlines shown on the geologic map represents USGS 7.5 minute topographic quadrangles which were used for all site reconnaissance work. The number of evaluated locations per quadrangle is shown in the circle. Any quadrangle containing a SIL site is outlined in heavy bold lines.

This plate was constructed from the following two USGS geologic maps:

1) **Johnson and Peebles, 1986, Quaternary Geology, Hatteras 4° x 6° Quad., U.S., 1:1,000,000, Map I-1420 (NI-18).**

2) **Colquhoun and Others, 1987, Quaternary Geology, Savannah 4° x 6° Quad., U.S., 1:1,000,000, Map I-1420 (NI-17)**



FIGURE

Figure 9. Earthquakes pose a documented risk in this region, even to the point for the necessity of earthquake insurance to secure loans in some cases. The black dots within the dark-edged quadrangles represent the occurrence of sand blows resulting from liquefaction of sands in the subsurface and eruption at the surface. The age of these features groups at approximately 1800 +/- 200 ka (*Amick* et al., *1990).* At STOP 1, microfaulting and possible liquefaction features are visible in some areas.

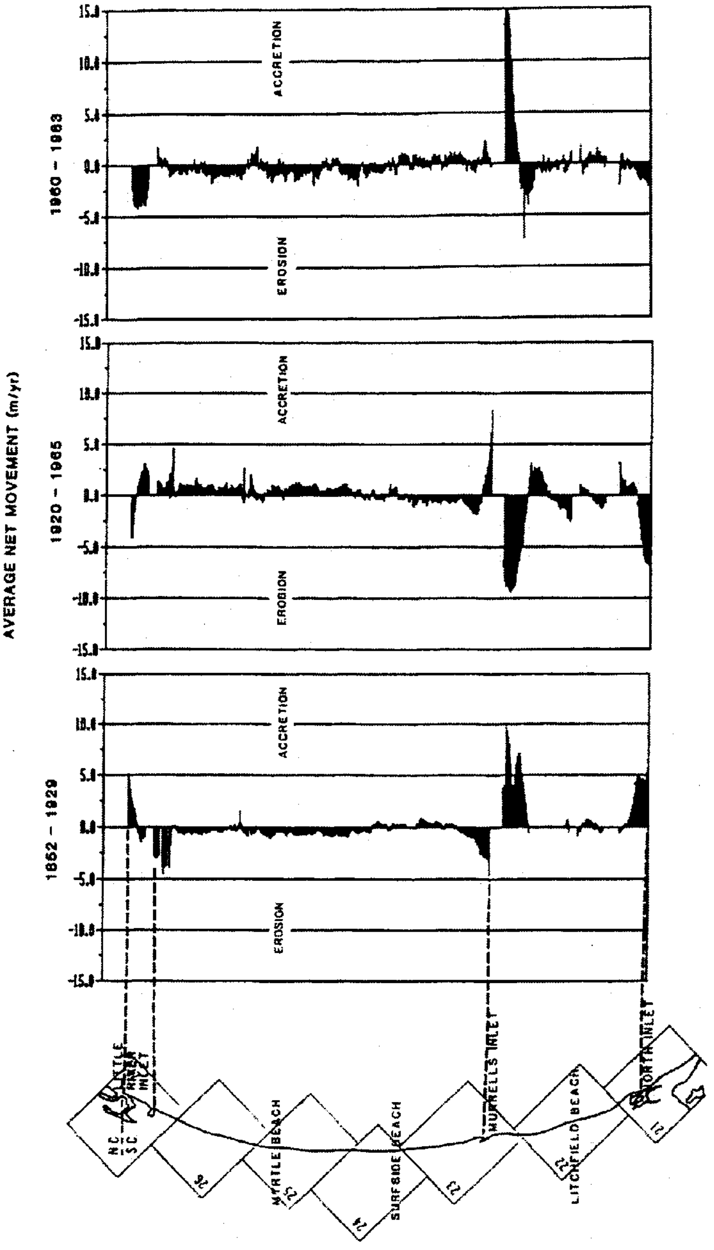


Figure 45. Temporal division of average net shoreline movement data for coastal reach 6

Figure 10. Average shoreline movements for the Grand Strand have been calculated by Anders *et al.* (1990). High rates of change identify inlets (northeast is to the left). Erosion rates are approximately 0.4 ft/yr at STOP 2 and 3, and increase to 0.68 ft/yr at STOP 4 and 0.96 ft/yr at STOP 5 *(Lennon* et al., *1996).* The change in rate along the coast closely corresponds with truncated geomorphic features seen in Figure 6 and 7 and the position of the Cretaceous and Tertiary boundary.

ROAD GUIDE

The road guide provides a log of miles between individual stops. Figure 1 is the overview map and general travel circuit for the day. Each stop location map contains an orthophotograph and road map. Stops 2 and 3 are listed together. Between Stop 4 and Stop 5, we may alter the directions depending on traffic.

Points of interest (POI) are identified on the overview map and descriptions and images may be found towards the end of the field guide.

Please be careful, as we have many tourists from out of town in a new and exciting place. They may also have not seen the sun since last year when they visited, so sunglasses are recommended.

To Stop 1. Thompkins Marl Pit (Figure 11)

0.0 miles	The field trip starts at 1270 Atlantic Avenue at Coastal Carolina University's Atlantic Center Academic Village.
0.3	Leave the Atlantic Center and turn west (right) onto Route 501.
0.7	Bear right onto 501 Business towards Downtown Conway.
3.5	*Proceed over Waccamaw River (Point of Interest 1) and into downtown Conway.*
3.8	Turn Right at second light onto 4th Avenue/Route 905 north.
3.9	*Pass over Kingston Lake*
4.0	*Historic Railway*
6.6	Turn left into Thompkins Pit entrance during the regular work week.
6.8	Turn left into back entrance to pit on non operating days. It is the next dirt road just past landowner's blue house.

The purpose of visiting Thompkins Marl Pit is to see the relation of an ancient barrier strand system to the underlying stratigraphic framework. The relationship between underlying Cretaceous and Tertiary rocks (Figure 12) in the region is well demonstrated in the pit, although the Cretaceous is currently visible only beneath the lake.

The pit is situated on the Conway Barrier at a surface elevation of approximately 7 m (23 ft).

As we leave and head northeast on Route 905, the Waccamaw River is just through the woods to the right. Upstream over the next couple of miles, large meander scrolls are visible in the false color infrared images (Figure 27).

STOP 1. Thompkins Marl Pit

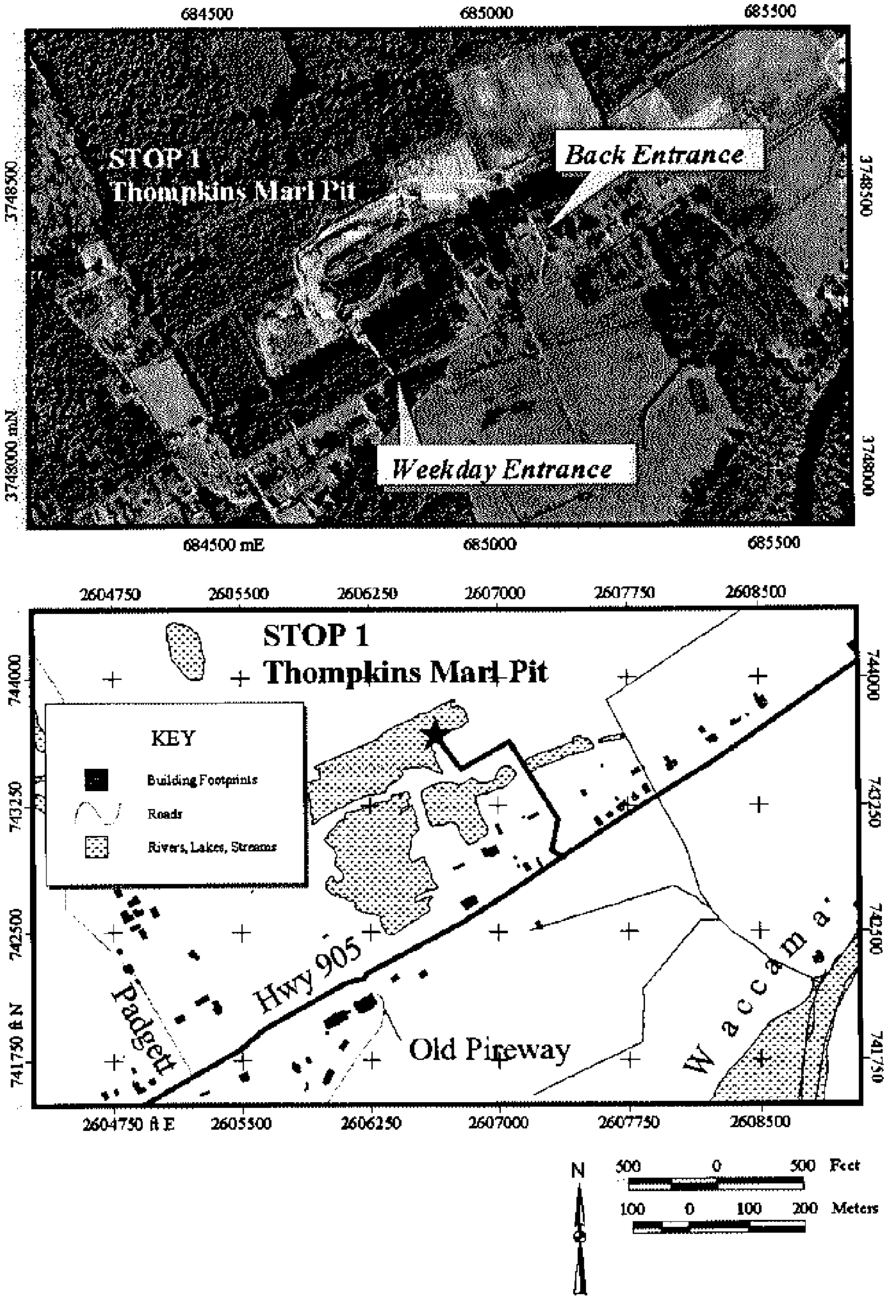
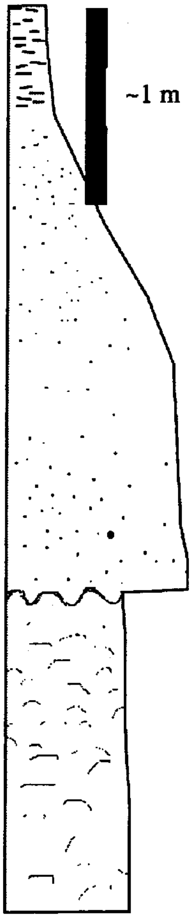


Figure 11. The Thompkins Marl Pit is situated on the crest of the narrow Conway Barrier. In the northern corner of the pit, a 2-m to 3-m Pleistocene backbarrier system rests unconformably on late Tertiary or early Quaternary shelf deposits. An ancient paleoincision cuts across the site and contains organic rich sediments and scattered boulders.

Thompkins Marl Pit Schematic Geologic Section



MUD and SANDY MUD with coarse fraction scattered throughout; gray to mottled gray with red, contact gradational with lower sand unit; coarse fraction increases with depth [estuarine/backbarrier deposits].

SAND and MUDDY SAND grading down into SAND; very light brown to gray with some mottling; cross-bedding increases with depth [estuarine/higher energy backbarrier].

SAND; very light brown, white, and mottled red; trough-cross stratification and planar beds common; small faults visible in some portions of the pit, with possible weak sand blows [tidal inlet/flood-tidal delta sands].

The lower portion of the surficial unit rests unconformably on the underlying marl deposits. In portions of the pit, this contact is in the form of a peat-lined paleovalley/channel.

SANDY to MUDDY SHELL; Indurated to semi-indurated materials. [Late-Pliocene to Early Pleistocene shelf]

Figure 12. A schematic cross-section for Thompkins Marl Pit. The upper Quaternary barrier facies is generally stripped to expose the underlying fossil beds.

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To Stop 2. Hog Inlet Overlook: Waites Island, Hog Inlet, Cherry Grove

0.0 mi	Leave Thompson Marl Pit and turn north (left) on Route 905.
9.3	Cross "over" Conway Bypass (under construction)
	POI - Carolina bays are abundant to the east
10.4	Turn east (right) on Route 31 at Branton's Corner
10.7-13.0	*the flood plain for the Waccamaw under water after post-Floyd flooding*
10.8	Proceed over Waccamaw River (POI 2) and to Route 90
14.3	Turn left on Route 90 and head north
16.6	*Smack Daddy's Sportsman Lounge*
17.3	*Bombing range road*
19.4	*stay to right on Route 90*
21.0	*entrance to mining company*
22.1	*La Belle Amie Vineyards, Horry County's only Winery*
23.6	Turn right on Route 17 south towards the coast
24.1	Go over Intracoastal waterway swing bridge and stay in left lane
	This next intersection and turn is confusing--BE CAREFUL
24.2	Bear left to Route 17 north and make an immediate left on Little River Neck Road in front of the Hampton Inn
24.2	Continue under bridge and follow Little River Neck Road
27.5	Continue on unpaved road through the back and left of the *cul-de-sac*
27.9	Turn right before gate
28.1	Turn right at "WHOA"
28.2	Pull over to left under clean forest for overlook to Waites Island, Hog Inlet, and Cherry Grove (north to south, respectively)

From the overlook , a clear view of Hog Inlet, Waites Island, and Cherry Grove is possible (Figure 13). The principle reason for stopping here is so that we can discuss changes in the inlet through time and to discuss island geology and inlet changes (Figure 16). Stop 3 is on the island, and from there we will see the demonstration of the BERM program.

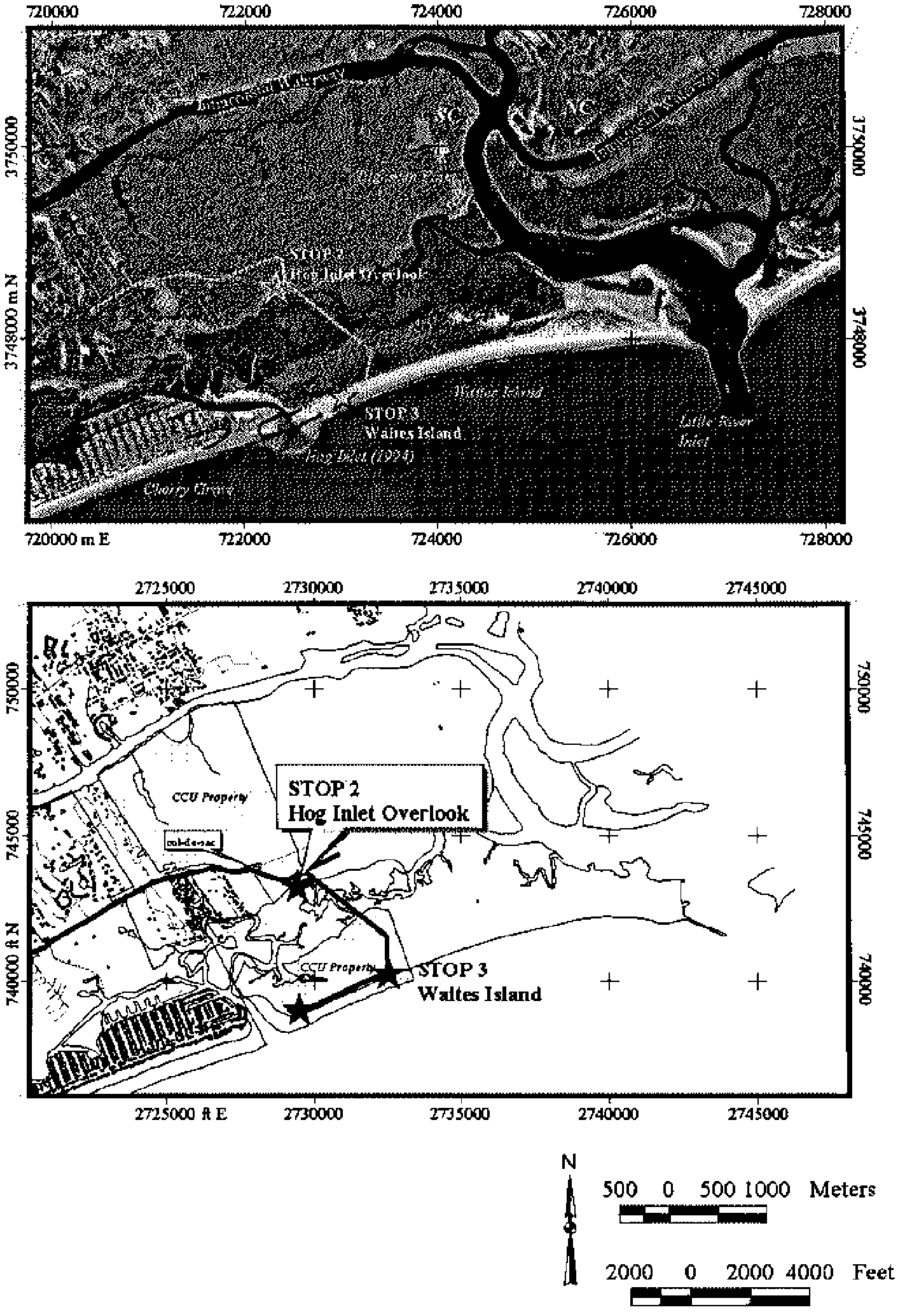


Figure 13. STOP 2 and STOP 3 are located on the Waites Island Tract, property donated to the University by Mrs. Tilghman. STOP 2 overlooks the island, inlet, and Cherry Grove from approximately 7 m above the marsh. Little River Inlet to the north of Waites Island connects the Intracoastal waterway to the ocean here.

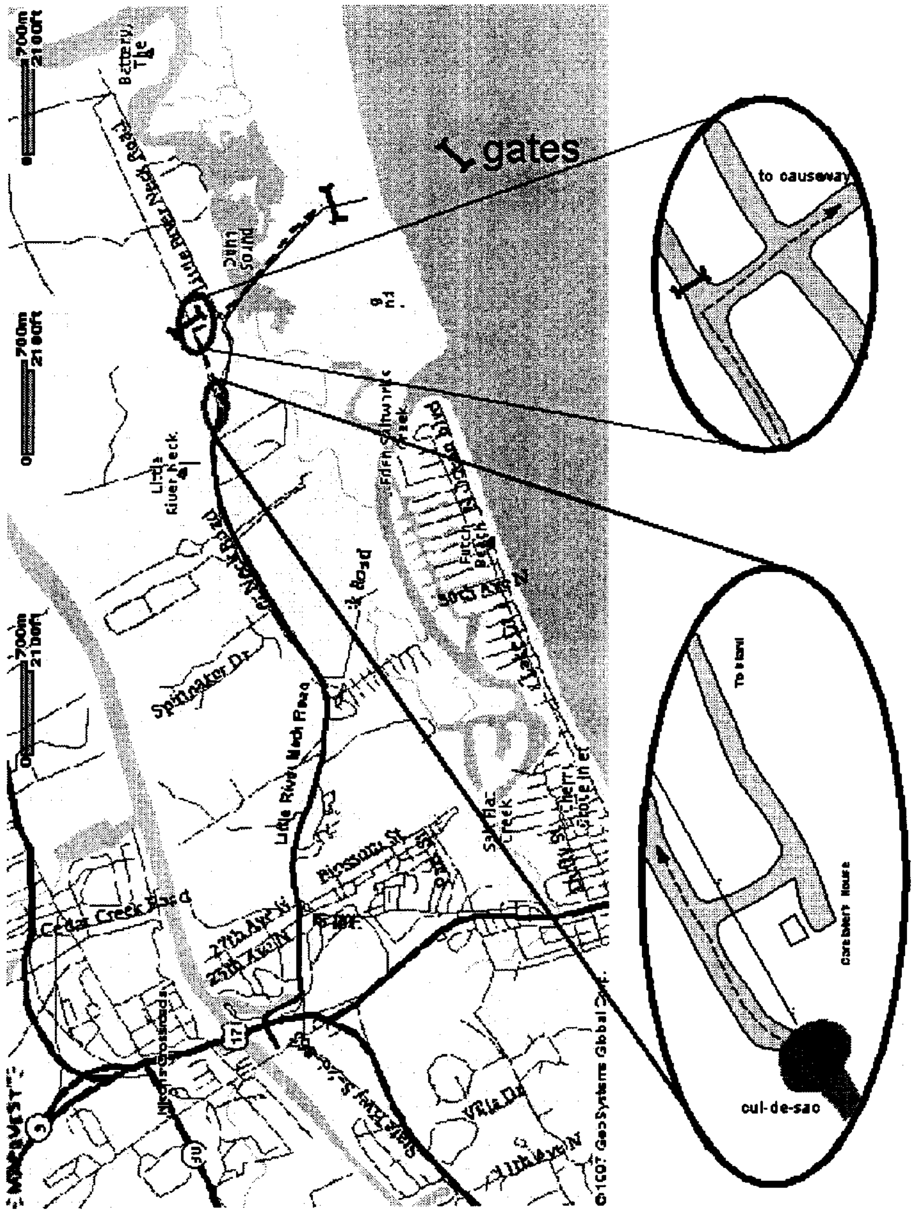


Figure 14. Detailed location map for access to the Waites Island tract.

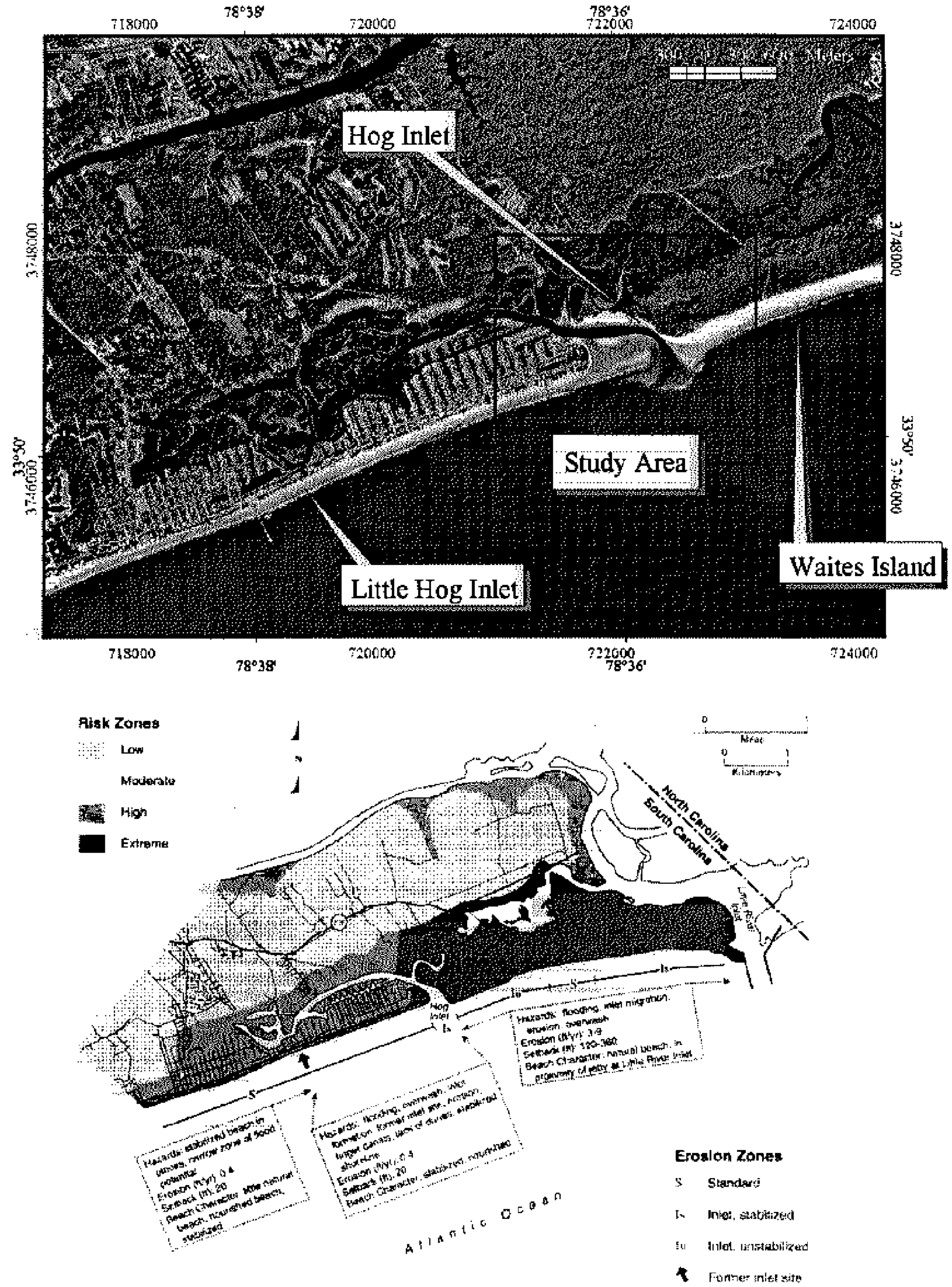


FIG 1. Waites Island, Cherry Grove, and northern North Myrtle Beach

Figure 15. The upper view focuses on Hog Inlet and the separation between the developed section of Cherry Grove to the southwest and undeveloped Waites Island to the northeast. Little Hog Inlet was closed and development of Cherry Grove increased. The tidal prism through Hog Inlet was also increased. The lower view shows the Risk zones and Erosion zones for this section of coast. The erosion rate is 3-9 ft/yr on Waites and 0.4 ft/yr to the south *(Lennon* et al., *1996).*

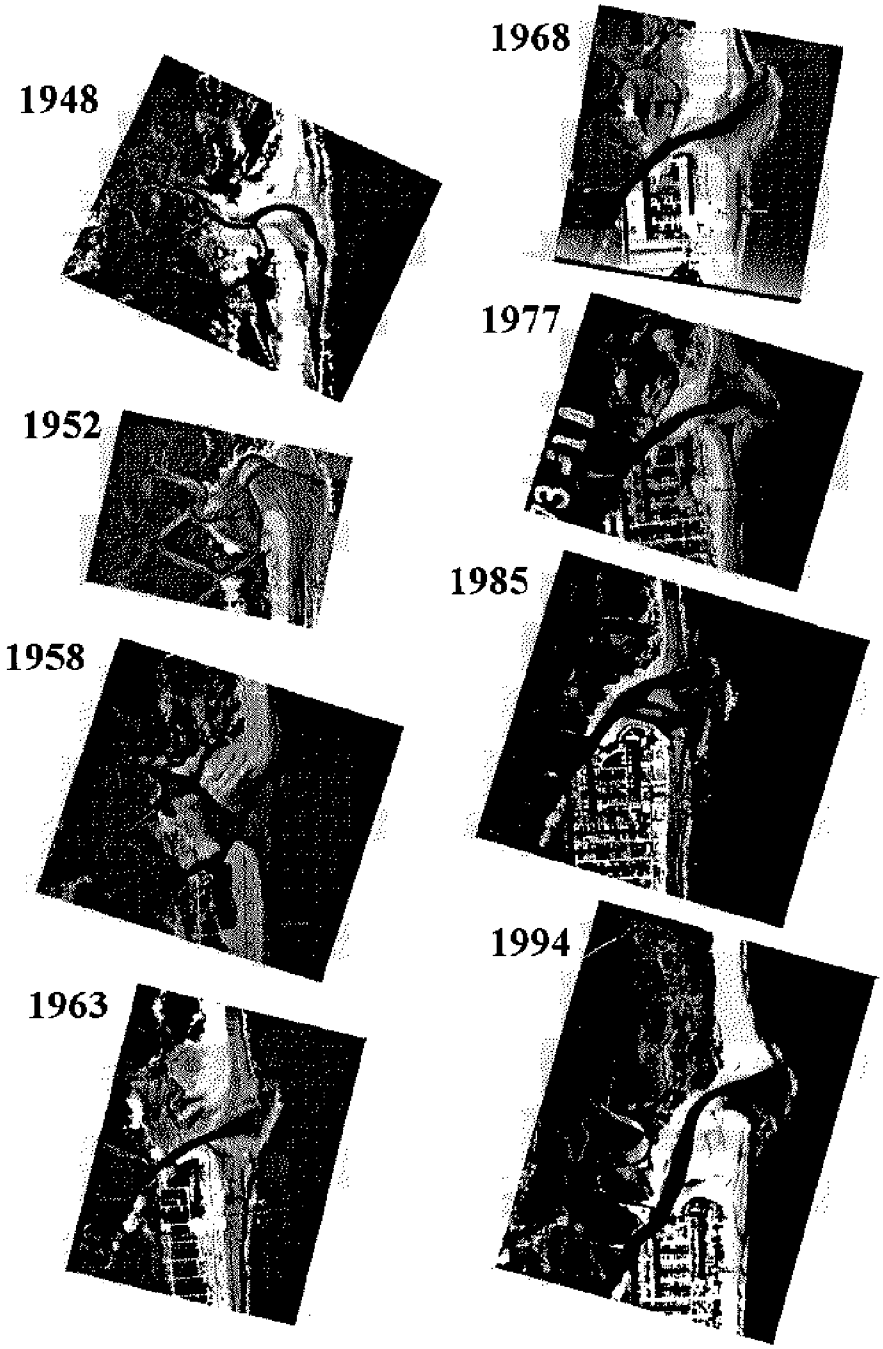


Figure 16. Scaled views of Hog Inlet from 1948 to 1994. An image from 1998 may be seen in Figure 17. The orthophotograph in the location maps are from 1994. Note the change in the nature of the inlet in the late 1950's after Little Hog Inlet was closed by hurricane Gracie in 1957. This series of photographs was scaled by Gene Smith for a senior research project at CCU.

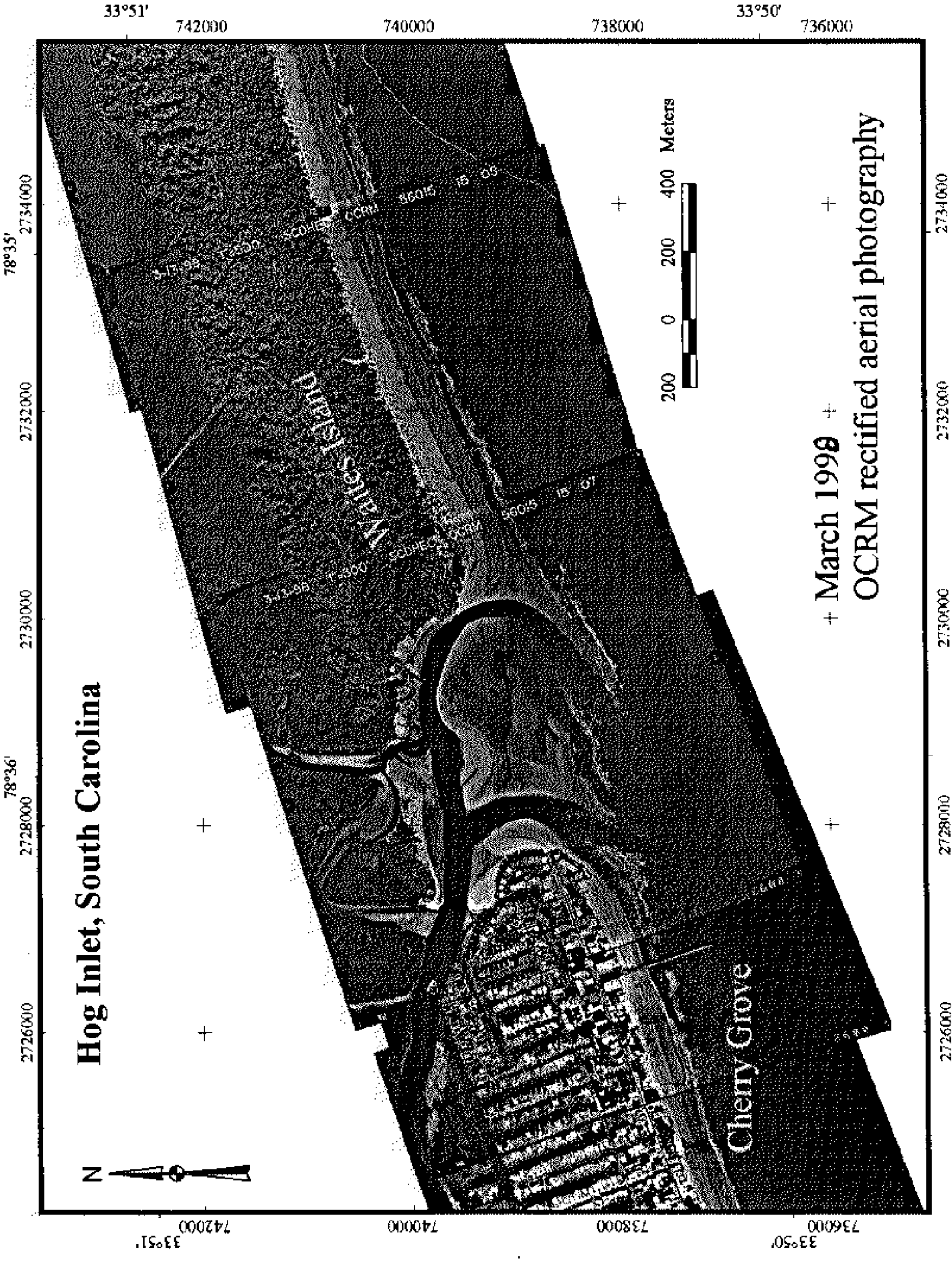


Figure 17. In 1998, the Office of Coastal Resource Management of South Carolina contracted for rectified digital aerial photographs. These are specifically isolated to the coast for jurisdictional purposes. In the two years since this photograph, a substantial spit has prograded southwest from Waites Island into Hog Inlet. Likewise, the inlet is encroaching upon Cherry Grove.

To Stop 3. Waites Island Proper

0.0 mi	Make a U-turn and head back up road
0.1	Turn right at intersection
0.2	Drop down escarpment and head across causeway to island
0.7	Enter onto Island
0.9	Parking area adjacent to beach
1.5	Turn south and walk/ride to inlet

High Tide on 8 April 2000 is at approximately 11:39 a.m. and will reach a maximum 5.1 feet. Cherry Grove is +10 minutes and Springmaid Pier is -26 minutes. There is an approximate 45 minute delay from the beach to the causeway behind Waites Island.

The BERM program is responsible for occupying over 300 benchmarks annually and helping SC OCRM determine set back lines for jurisdictional purposes. Consisting of a sled-mounted mast with prisms and a land-based total station (Figure 18), data are recorded at bench marks into Hypack surveying software. Long beach profiles are then constructed from processed data (Figure 19) and plotted to scale for each bench mark.

For renourishment surveys (Figure 20), additional or more closely-spaced bench marks are used to more accurately document the volume of sand placed in the design template for the project. In several cases in this region, sediment volume exceeded project design by filling regions outside of the design, often below -9 ft NGVD.

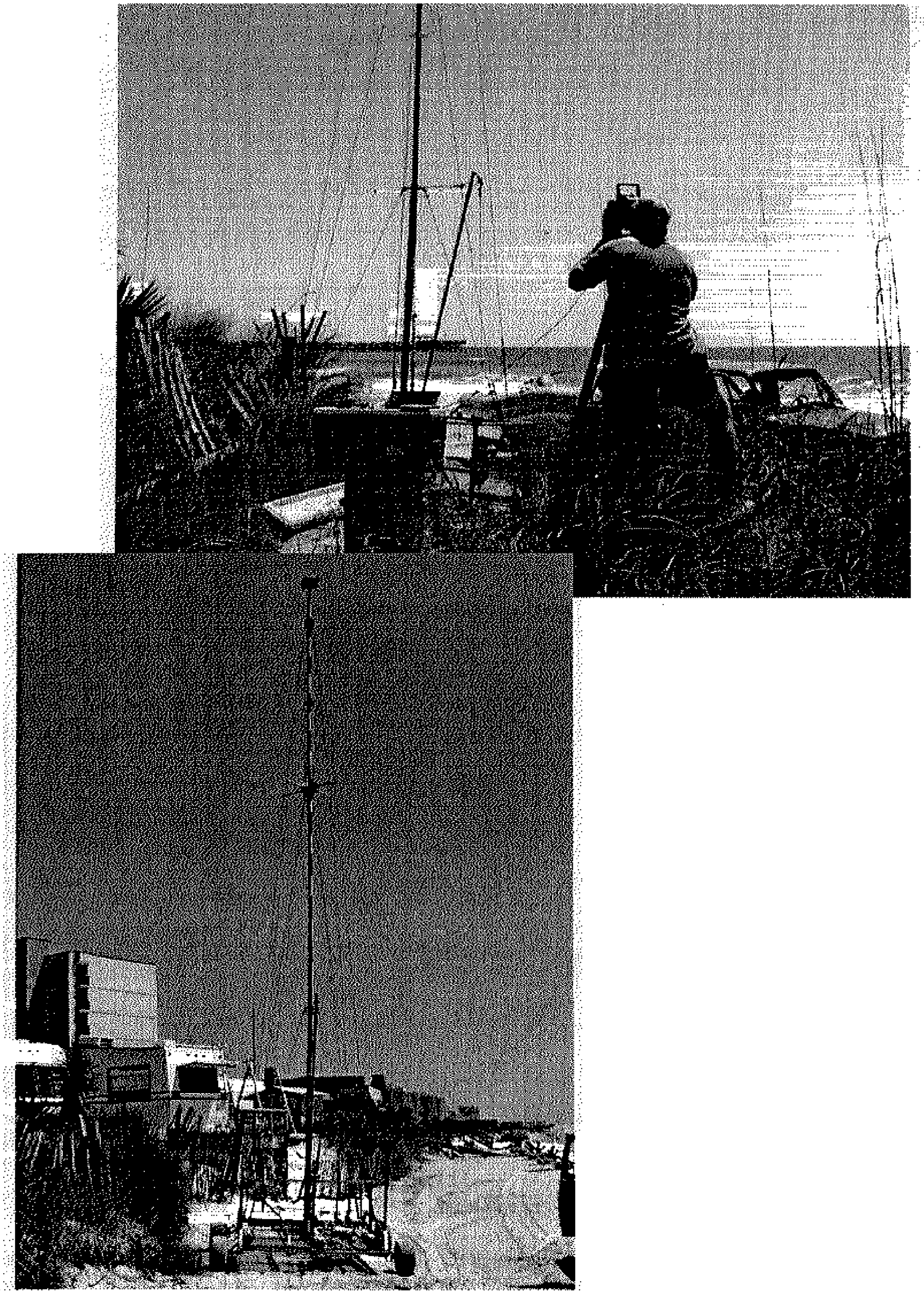


Figure 18. The US Geological Survey has funded the Beach Erosion and Resource Monitoring (BERM) beach-profiling program. This program is used to aid OCRM in preparing jurisdictional set back lines for South Carolina. The survey cart below was designed and built by Neal Gielstra and Paul Gayes. Joey Jenkins is on the total station above.

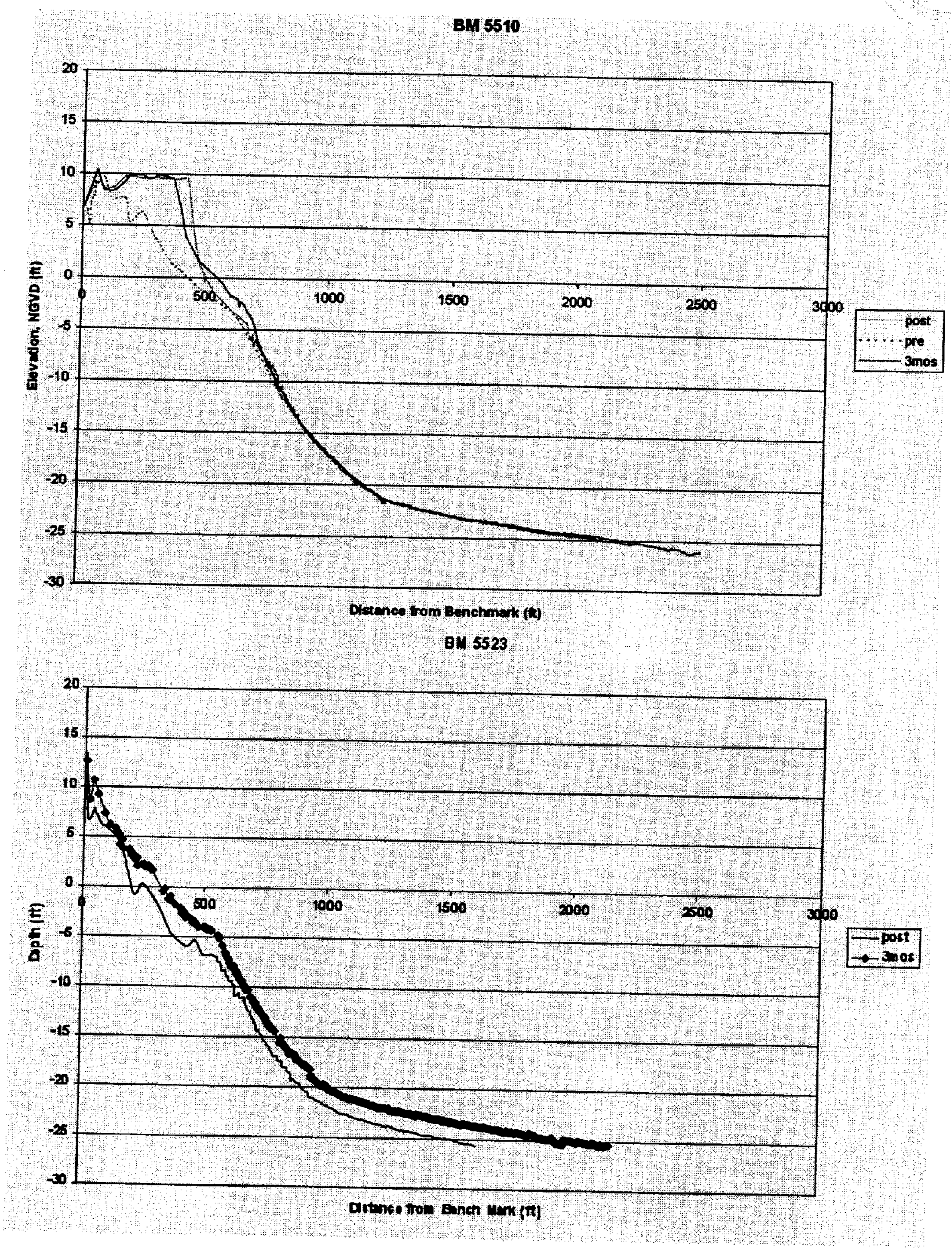


Figure 19. The BERM program occupies approximately 320 stations annually across the entire populated coastal zone of South Carolina. These two benchmarks from the Arcadia Shores region to the South were reoccupied both before and after beach renourishment. The advantage of long profiles is that movement of sediments in water depths below -15 to -20 ft NGVD can be measured providing more accurate measurement of the active sediment prism. Note the lack of change and the distinct change below -20 ft in the two benchmarks.

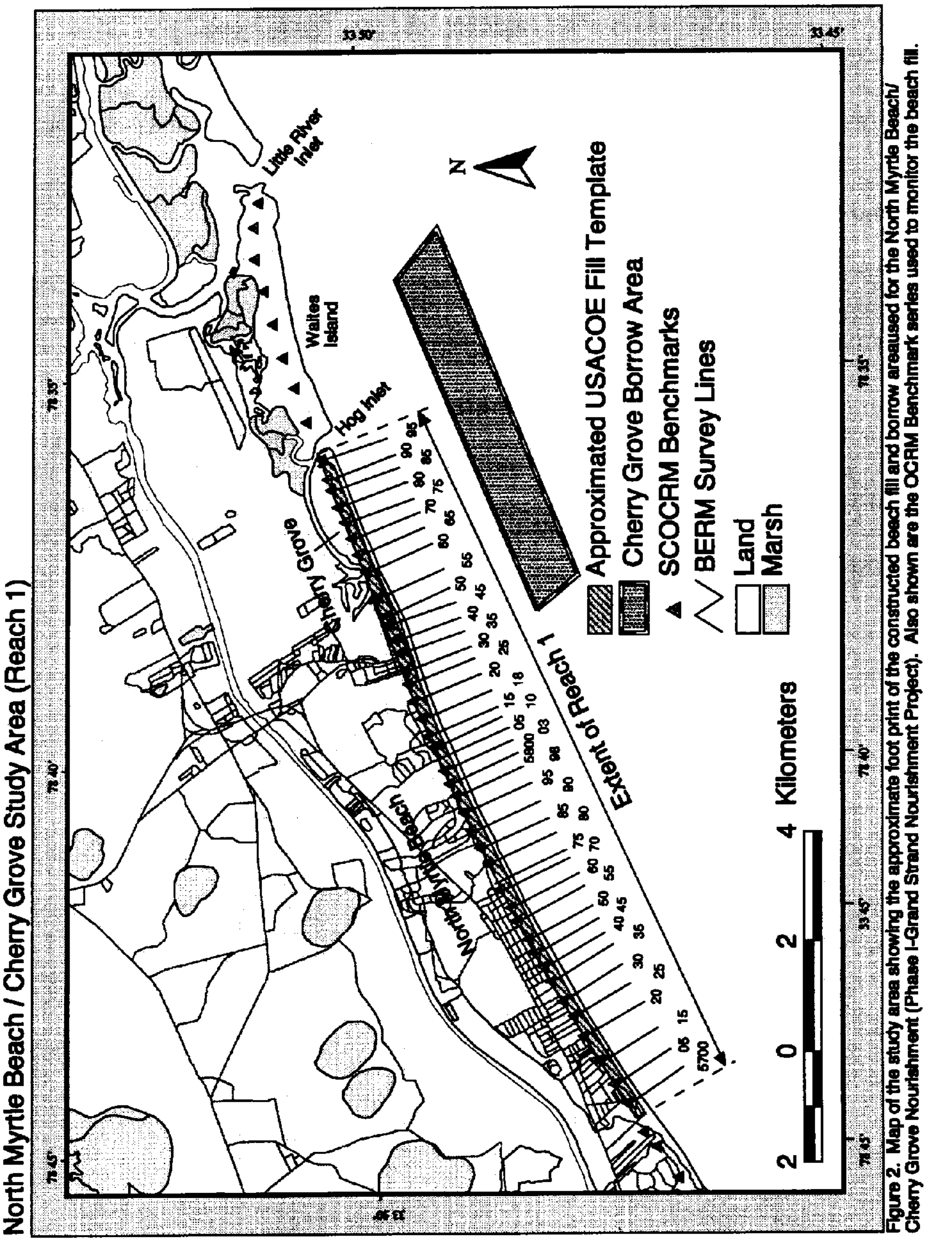

North Myrtle Beach / Cherry Grove Study Area (Reach 1)

Figure 2. Map of the study area showing the approximate foot print of the constructed beach fill and borrow areaused for the North Myrtle Beach/ Cherry Grove Nourishment (Phase I-Grand Strand Nourishment Project). Also shown are the OCRM Benchmark series used to monitor the beach fill.

Figure 20. Reach 1 renourishment site in North Myrtle Beach. The borrow area off Cherry Grove is marked. Detailed long profile surveys have been extremely helpful in determining a more accurate representation of the sediment added to the active system. Note the elliptical carolina bays to the northeast.

To Stop 4. Apache Campground Pier and Arcadian Shores

0.0 mi	Head off Island, continue across causeway to mainland
1.5	Get back on main road
4.8	Cross over from Little River Neck Road and bare to the left to 17 South
5.6	Merge onto Route 17 heading south to Myrtle Beach
11.5	Pass Briarcliff Acres
13.1	Turn left on Kings Road before Conway bypass construction
14.9	Turn left into Apache Campground. Proceed to gate and to Public Pier

Arcadia Shores

The main purpose of this stop (Figure 21) is to see the distinct change from the renourished beaches to the southwest, and the unrenourished beaches to the northeast. Figure 22 depicts the Arcadian Shores nourishment project area and Figure 23 identifies the borrow area in relation to the renourishment area.

The terminus for the Conway Bypass intersects Route 17 just to the west. In the pit excavated adjacent the waterway for the new road, layers of Cretaceous boulders are separated by estuarine mud. To the east, these boulder beds are found in what appear to be tidal inlet or flood-tidal delta sands. These boulders have distinct patterns, identical to those found offshore exposed at the seafloor. Boring clams, corals, and other shelf fauna are associated with these boulders. Depending on lateral continuity of these units, they likely crop out beneath sea level off shore.

STOP 4. Apache Campground Pier

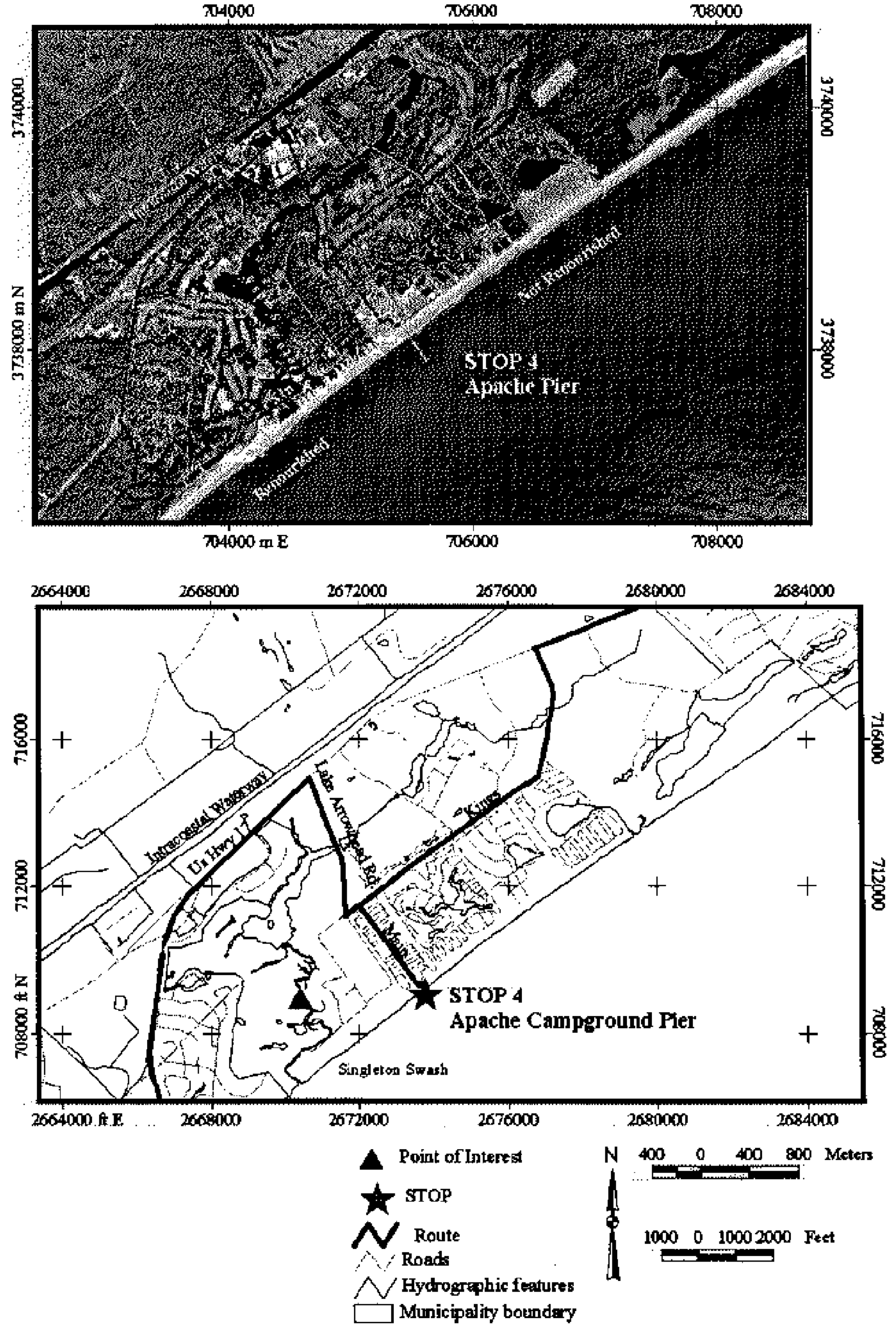
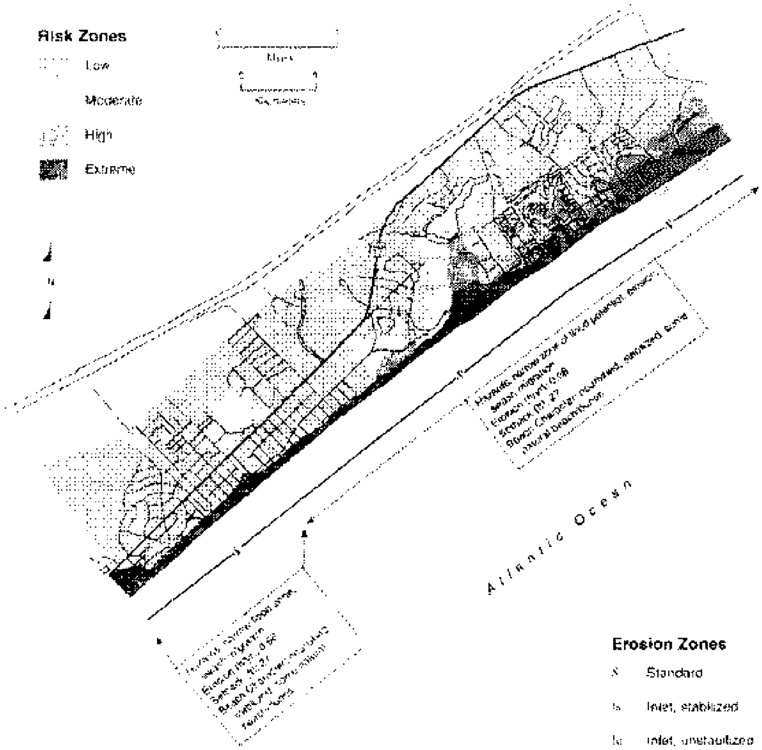


Figure 21. STOP 4 is located at the Apache Campground Pier. Not only is it the "longest pier on the east coast," but it also is the dividing line between the renourishment project to the south and the unrenourished section of coast to the north. Note Singleton Swash to the southeast and the series of small ponds situated between old barrier ridges. These swashes are commonly flooded during storms and have been cored to document evidence for large storm surge events.



ure 5. Myrtle Beach, White Point Swash to Canepatch Swash

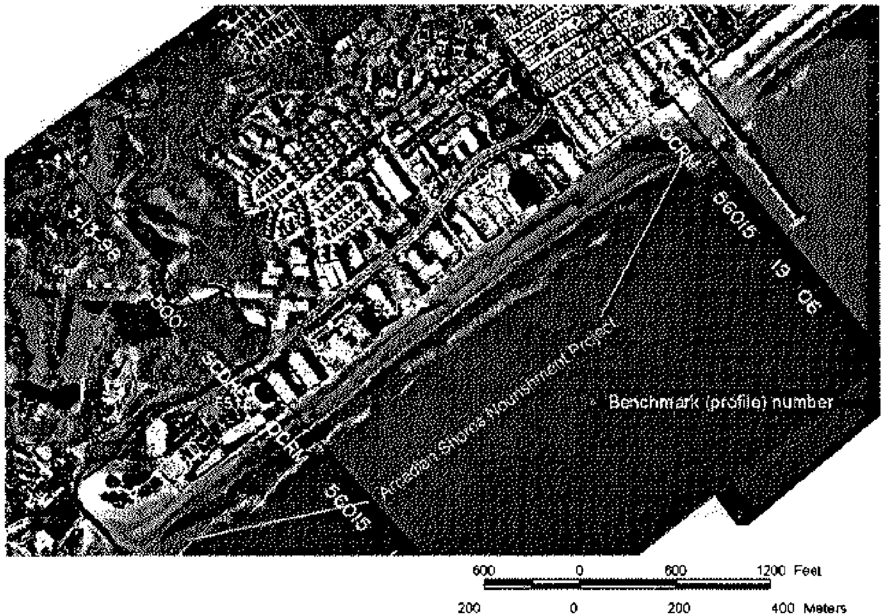


Figure 22. Erosion rates in this zone are approximately 0.68 ft/yr *(Lennon* et al., *1996).* Notice the elevation difference as you drive from the beach inland through the campground. You will cross the swash to the southwest as you go back out to Route 17.

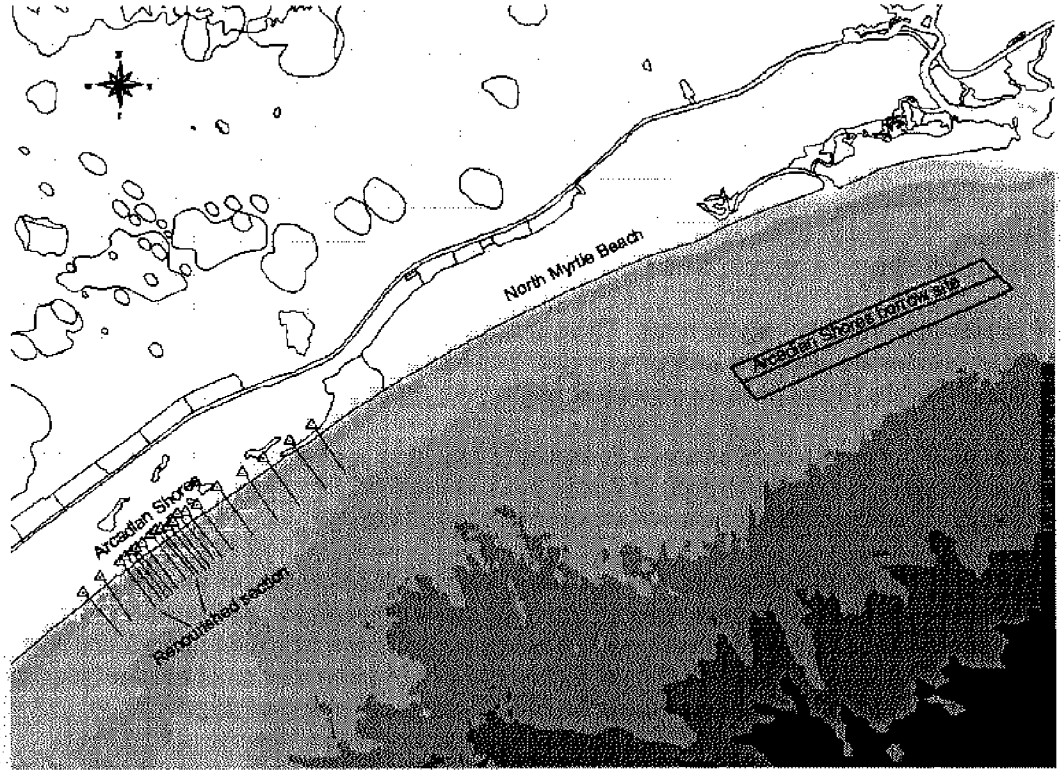


Figure 23. The borrow site for the Arcadian Shores project was located offshore Cherry Grove.

To Stop 5. Myrtle Beach South

0.0 mi	Turn left out of Apache Campground on Kings Road
0.1	Turn right on to Lake Arrowhead Road
	0.4 Cross over Singleton Swash headwater
0.8	Turn left onto Route 17 south
1.4	Veer left onto 17 Business
2.6	Turn left into Dunes community (WATCH for TRAFFIC)
3.3	Turn left at new intersection
	4.3 Cross over swash
5.3	Turn left
	9.9 Withers Swash
	11.0 Pass Hurl Rock public parking area
11.9	Turn left into Damon's at 2985 South Ocean Boulevard and the approximate K/T boundary (unconformable).

Travel between STOP 4 and STOP 5 may be modified due to traffic downtown. This route was chosen in order to point out the elevation changes between the residential area to the north and the hotel and pavilion district to the south. We should arrive at STOP 5 sometime between 1:00 and 1:30 for continued discussions and lunch. Lunch is on your own.

Several low swashes are crossed along the route. These areas create high to extreme risk coastal zones (Figure 25). The swashes are also the source of increased bacterial runoff into the coastal ocean during summer rainstorms and the source of beach closings during certain periods.

To the north of STOP 5, Hurl Rock (Waccamaw Formation?) used to be exposed with one to two meters relief in the beachface prior to renourishment. It is now buried beneath the fill and not visible. These types of rocky exposures are common along the beach and nearshore in this region.

Renourishment along this section of coast received sediment from two separate borrow sites (Figure 26). Infaunal communities have been monitored to determine if the renourishment projects have had a negative impact on live ground communities. Side-scan sonar, RoxAnn bottom characterization surveys, and towed cameras (Figure 26) have been utilized to document recovery of these regions after renourishment projects are completed. Long beach profiles collected using the BERM system are also used (Figure 26) to document changes in the nearshore zone and identify sediment volume changes down to -25 ft NGVD.

STOP 5. Damon's on the Beach

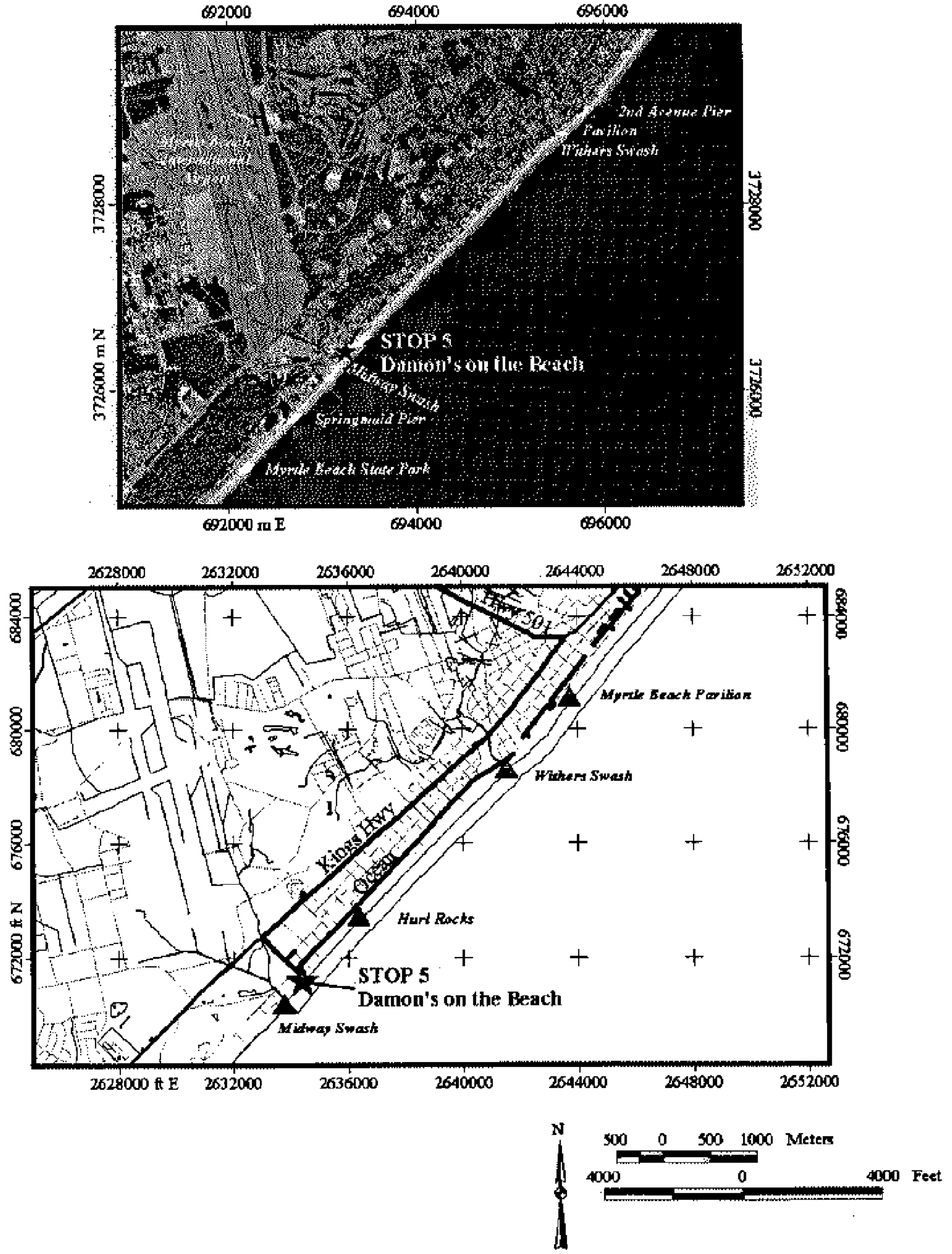
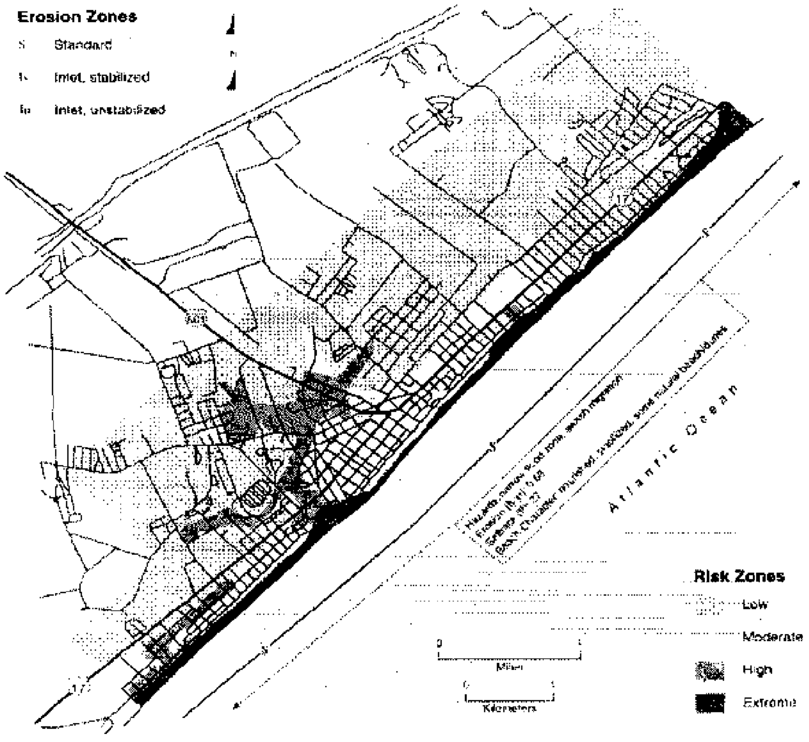
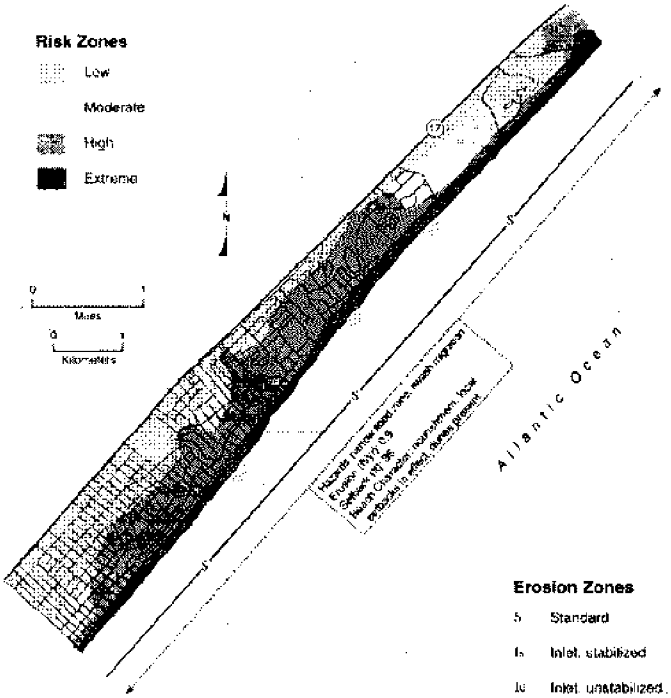


Figure 24. STOP 5 is located just seaward of the Myrtle Beach International Jetport.



MAP 4. Myrtle Beach, Canepatch Swash to Midway Swash



MAP 5. Midway Swash to Surfside to Garden City

Figure 25. Erosion rates change in the vicinity of STOP 5, increasing from 0.68 ft/yr northward to 0.9 ft/yr southward. This change coincides with the exposure of less resistant Tertiary rock to the south and more resistant Cretaceous rock to the north.

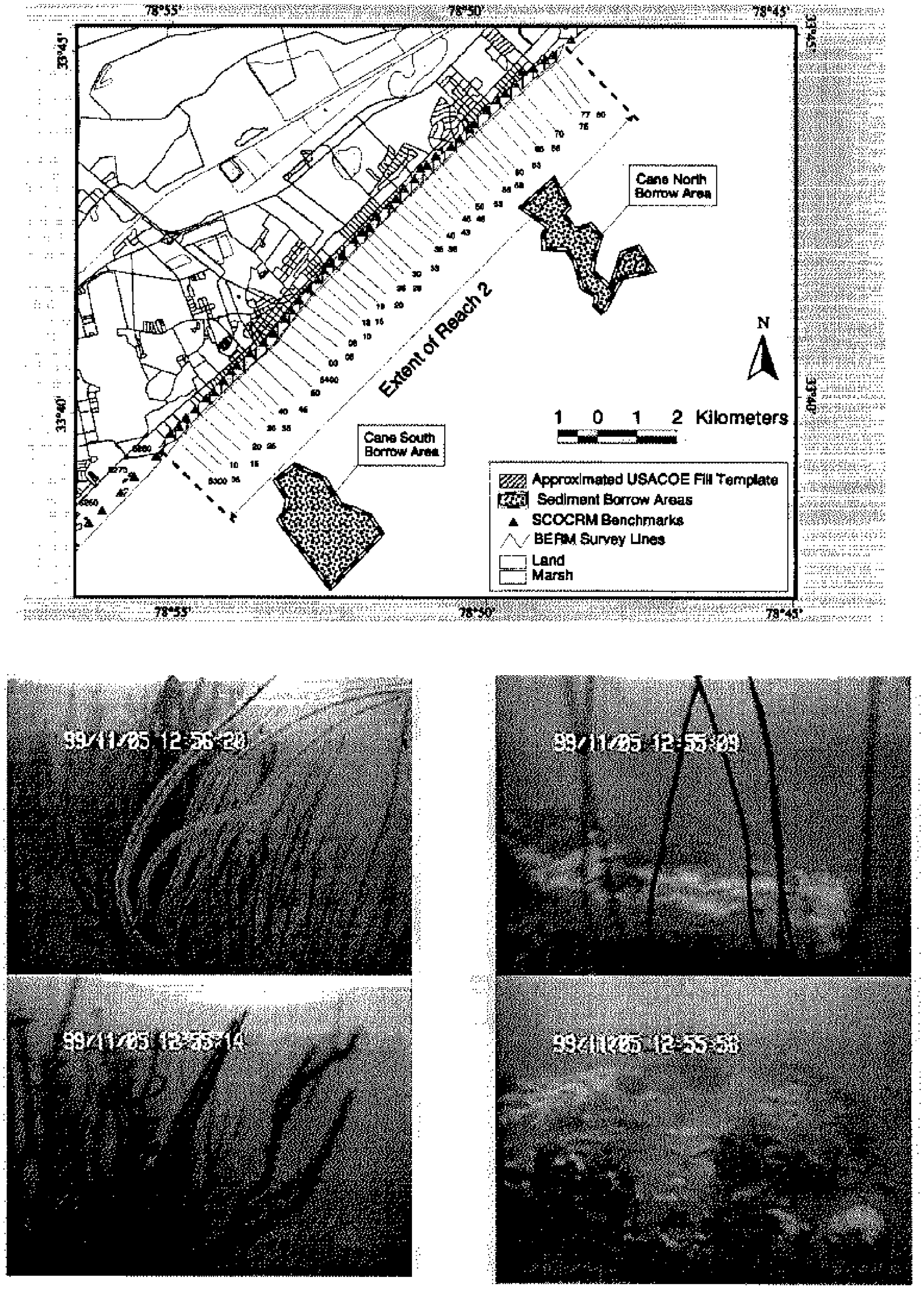


Figure 26. Two borrow sites were used for the renourishment of Myrtle Beach. Under a grant from and in conjunction with the SC Department of Natural Resources, hard ground regions are mapped using side-scan sonar and RoxAnn bottom characterization surveys. Impacts on live bottom communities have been studied using underwater video. Corals and sponges, in the video clips above, characterize the hard ground communities.

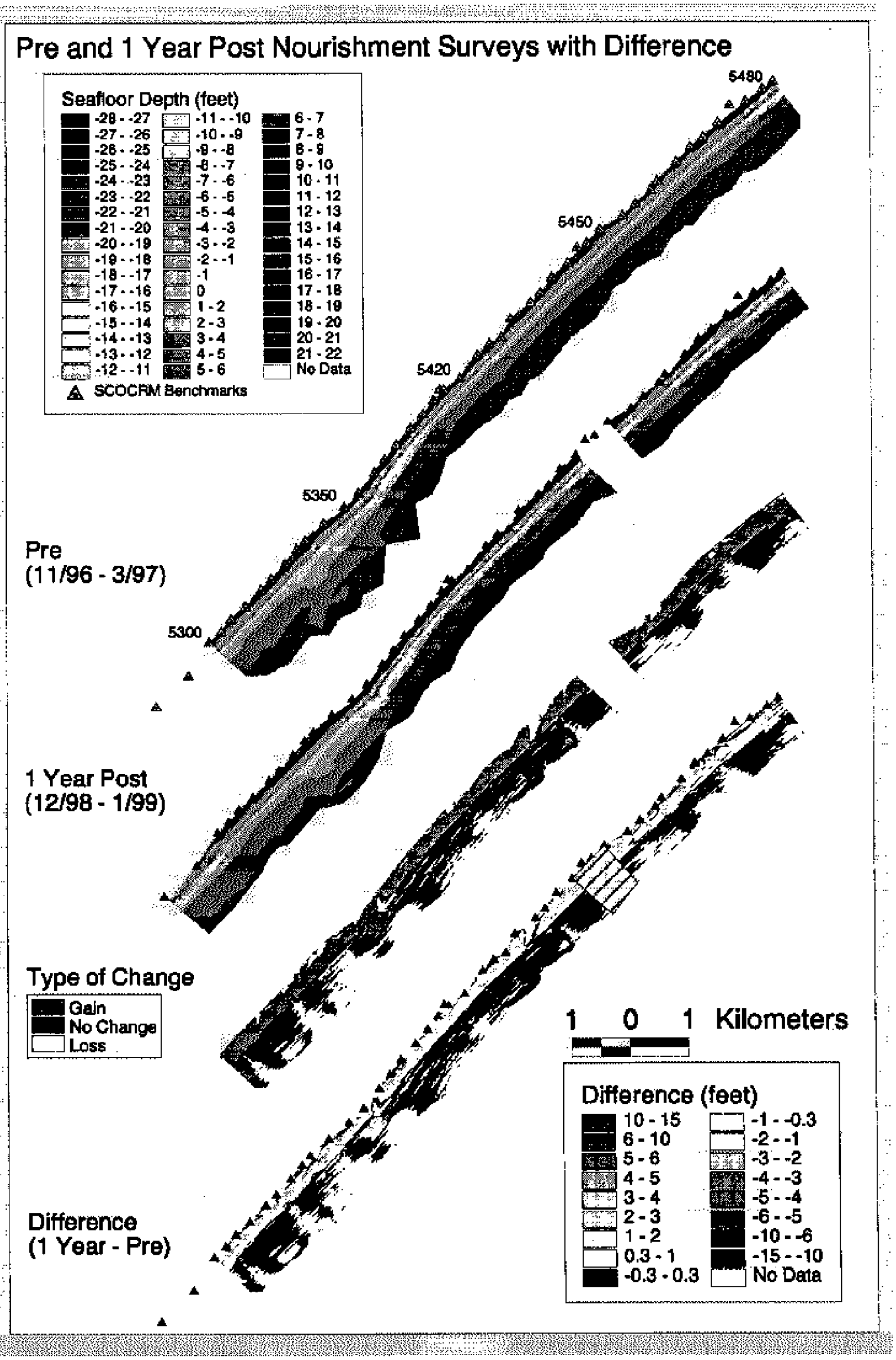


Figure 27. Long beach profiles collected before and after renourishment are used to calculate cut and fill differences through time. ARC/INFO (createtin), ArcView (spatial analyst), and ISRP calculations were all within 5 to 8% of one another. We continue to use ArcView and ARC/INFO methods for calculating volumes.

Points of Interest (POI)

Waccamaw River at Conway

Conway is a river town. It was built on the north bank of the river where deep water met the high banks. Tobacco and lumber were the two major supplies that were loaded here and transported to Georgetown for shipment around the world.

The Waccamaw River is a blackwater river with a drainage basin entirely within the lower and middle coastal plain. Beginning at Lake Waccamaw in North Carolina, the river meanders between several sets of emergent Quaternary barrier islands and cuts down to Tertiary and Cretaceous rocks in its bed.

The drainage basin of the Waccamaw River covers approximately 1652 mi^2. Large wide flood plains with abundant meander scars are typical to the river (Figure 28). During low flow conditions, the river at Conway is tidally influenced and net negative outflow rarely occurs (Figure 29 and 30). Average discharge for the river here at Conway was 1062 ft^3/s in 1997 and 2928 ft^3/s in 1998, with peaks around 15,000 ft^3/s (Figure 30). Last year during Hurricane Floyd, the river crested with an approximate discharge of 25,000 ft^3/s at Conway

Rivers and Streams in the Waccamaw River drainage basin (HUC# 03040206) include: Bogue Swamp, Brown Marsh Swamp, Buck Creek, Elkton Swamp, Grisset Swamp, Gum Swamp, Intracoastal Waterway, Juniper Creek, Lake Waccamaw, Seven Creeks, Simpson Creek, Slap Swamp, Waccamaw River, Western Prong, and White Marsh (EPA, http://www.epa.gov/surf3/hucs/03040206/).

Waccamaw River at Red Bluff

As we head from the Thompkins Marl Pit to Waites Island, we will cross the Waccamaw River at Red Bluff. The river level is high now due to rains a few weeks ago. After Hurricane Floyd September 15th, the river took over a month to crest With several large rainfall events in addition to Floyd, it was not until late in November 1999 that the river had receded.

When crossing the Waccamaw River flood plain, dark stains on the trunks of the trees indicate the water depth. The flood covered this road continuously across the flood plain for over two months.

Carolina Bays

Carolina bays are unique environments that are widely distributed on the lower coastal plain. Our travel route today has enveloped the major distribution of them in Horry County (Figure 30). From the air, sand rims are distinct set against the dense undergrowth in the interior of the bays.

Waccamaw River at Longs

A 50-year water level record at Longs (Figure 30; USGS data) was extremely helpful in determining the rating curves for the river after Hurricane Floyd.

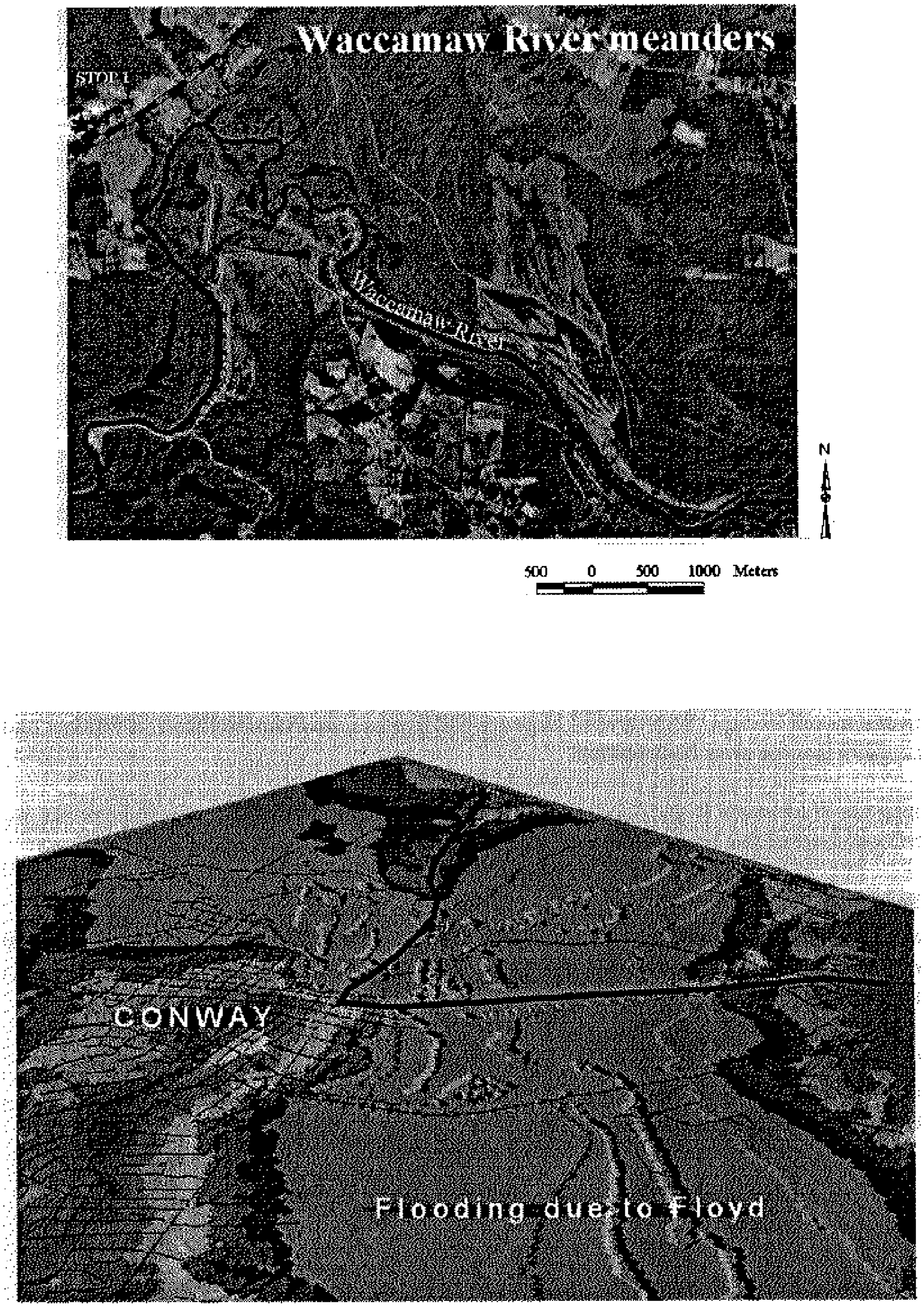


Figure 28. The black water Waccamaw River is restricted to the Coastal Plain. Situated between barriers between 400 ka and 750 ka, this river has created large sequences of meander scars in its flood plain (above). Between September and November, the Waccamaw River at Conway covered the entire flood plain.

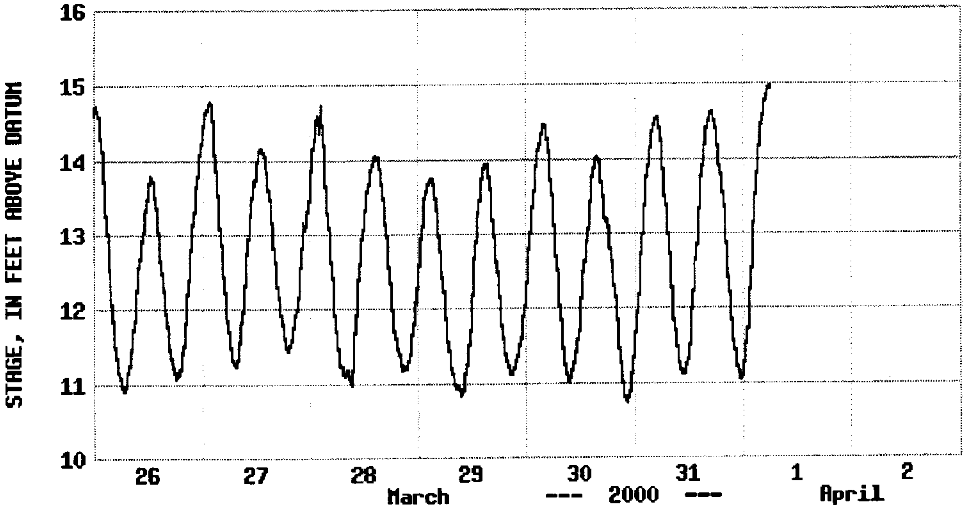
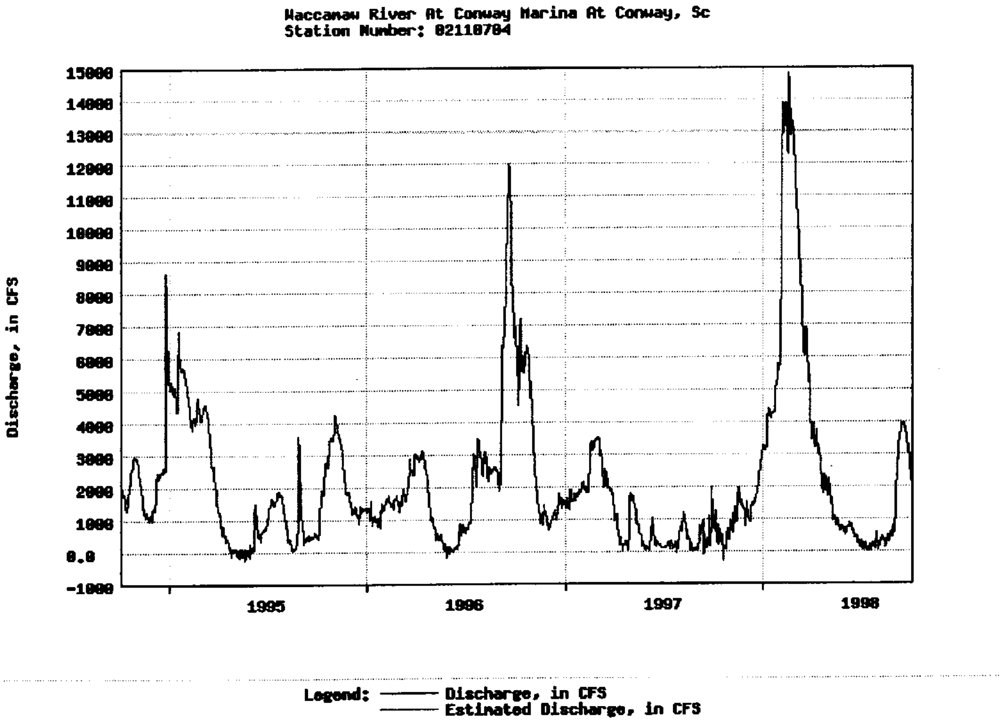


Figure 29. The river flow through Conway during low to moderate flow conditions (below: source: *USGS and SCDNR*). As discharge increases during a flood, the tidal phase is overpowered. As a dominant lumber and tobacco shipping district in the 19th Century, many old barges and canal boats have been uncovered along the banks of the Waccamaw. This old boat is just off to the right as you cross over Kingston Lake on 905 and is visible only at a quick glance by car at low water (*1999, Harris*).



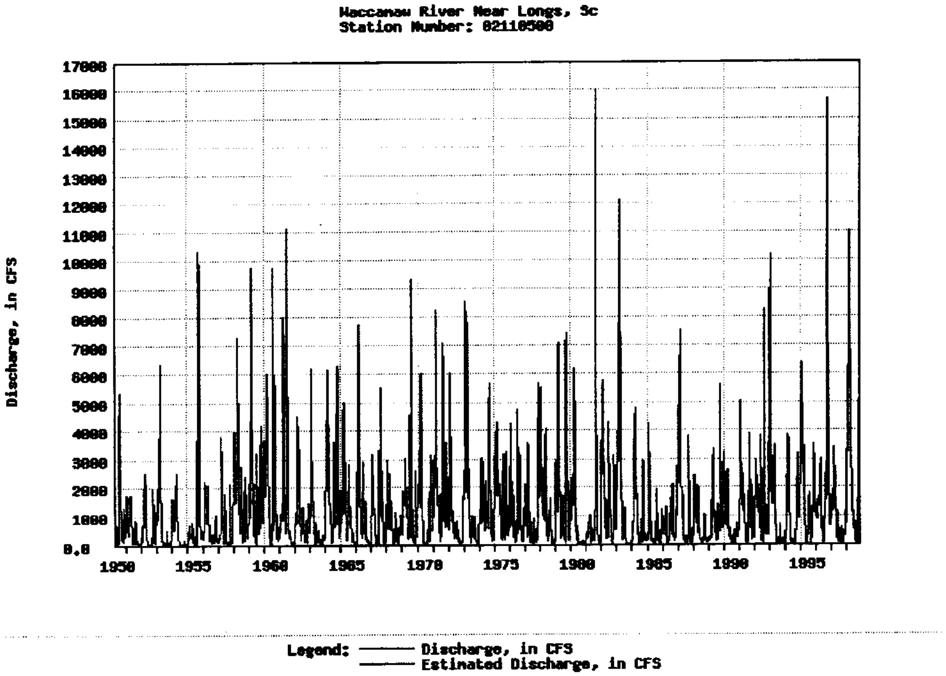


Figure 30. Volume discharge for the Waccamaw River at Conway (above) and at Longs (below). Normally, river discharge at Conway is between 1000 and 3000 cubic feet per second (CFS), but during either the late Winter or late Summer it may increase to 15,000 CFS. After Hurricane Floyd, discharge of the river went up over 25,000 CFS and took three months to go back to normal. The record for Longs (below) is from 1950 to 1998. Data are from the USGS web site at http://www.usgs.gov/.

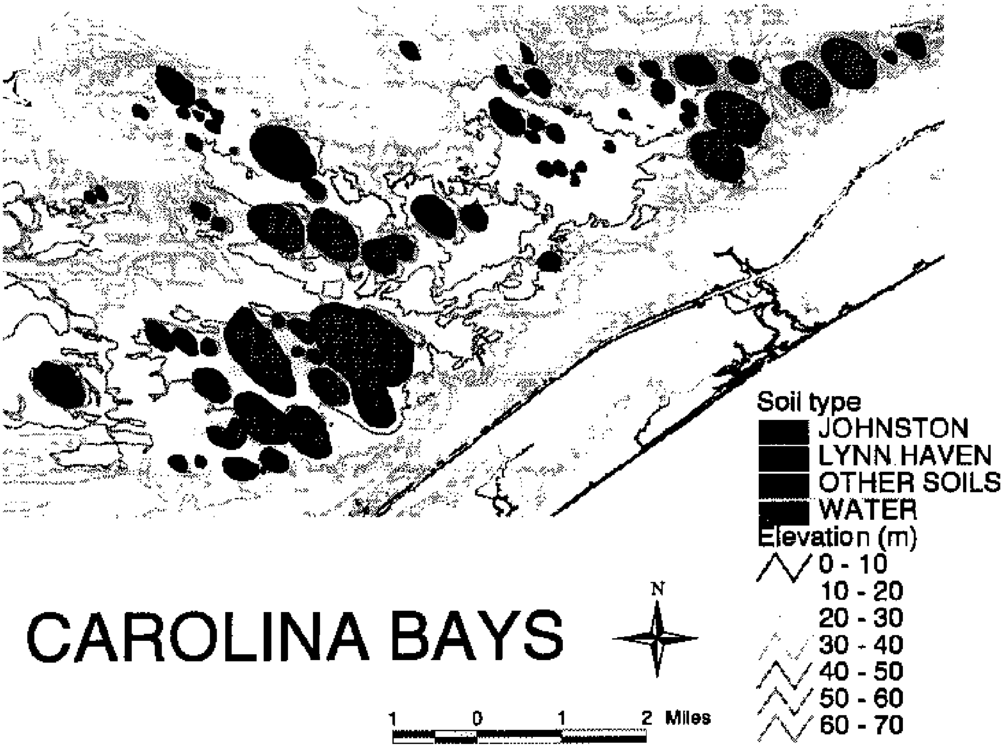


Figure 31. Carolina bays are ubiquitous across the lower coastal plain of the Grand Strand. Primarily on the Jaluca barrier, they commonly occur in Johnston, Lynn Haven, and other soils (*Wright, Ray, and Carter, CCU*).

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