Synthesis of Geophysical and Geologic Data on the North Carolina Shelf and Future Research Needs, NC-BOEM Cooperative Agreement Technical Report

Walsh, J.P., Conery, I., Garmire, K., Mallinson, D. and C. Freeman

Introduction

Hurricane Sandy caused massive surf and high water levels that battered North Carolina in 2012, especially the northern Outer Banks. Significant erosion, ocean overwash and localized flooding led to costly damage and left portions of this economically important coast in a compromised condition for future storms (Fig. 1). As a result of this and other events, many communities in NC are planning for beach nourishment. But, borrow areas in State waters are limited, and sand in federal waters may be critical. Availability of seismic reflection and sediment data varies along NC, and work was needed to find and database relevant information. The primary objective of this NC-BOEM cooperative project was to create an inventory and GIS database of information available on sand resources in the federal Outer Continental Shelf (OCS) offshore (3-8 nautical miles) of North Carolina. The purpose of this technical report is three-fold: 1) to provide an overview of the need for sand resources and thus related data offshore of North Carolina, 2) to review the range of geological and geophysical information and data available and 3) give a prioritization for future research needs in the OCS.

Fig. 1: Hurricane Sandy overwash and dune loss, Kitty Hawk, NC. The area remains vulnerable. Associated Press and Walsh photo, respectively.

Need for Sand Resource Information Offshore of North Carolina

The State of North Carolina has eight counties along the Atlantic Ocean (Fig. 2): Currituck, Dare, Hyde, Carteret, Onslow, Pender, New Hanover and Brunswick as well as a variety of federally managed properties including military and conservation areas. The NC Beach and Inlet Management Plan (2011) provides an excellent overview of the specific lands and activities in different regions of the State and their sizable socio-economic value. Much of the economic activity is associated with tourism, and there are many incorporated and unincorporated towns along the NC coast where the commerce and valuable real estate are concentrated (Fig. 2). The environmental and ecological sustainability of the ocean shoreline is another factor that must be considered for ecosystem services, resources and economic prosperity. For example, the compatibility of sand placed on the beach is important, not only to extend the life of a nourishment project but also for ecological purposes, such as the maintenance of suitable habitat for sea turtles and some bird species (NC BIMP, 2011).

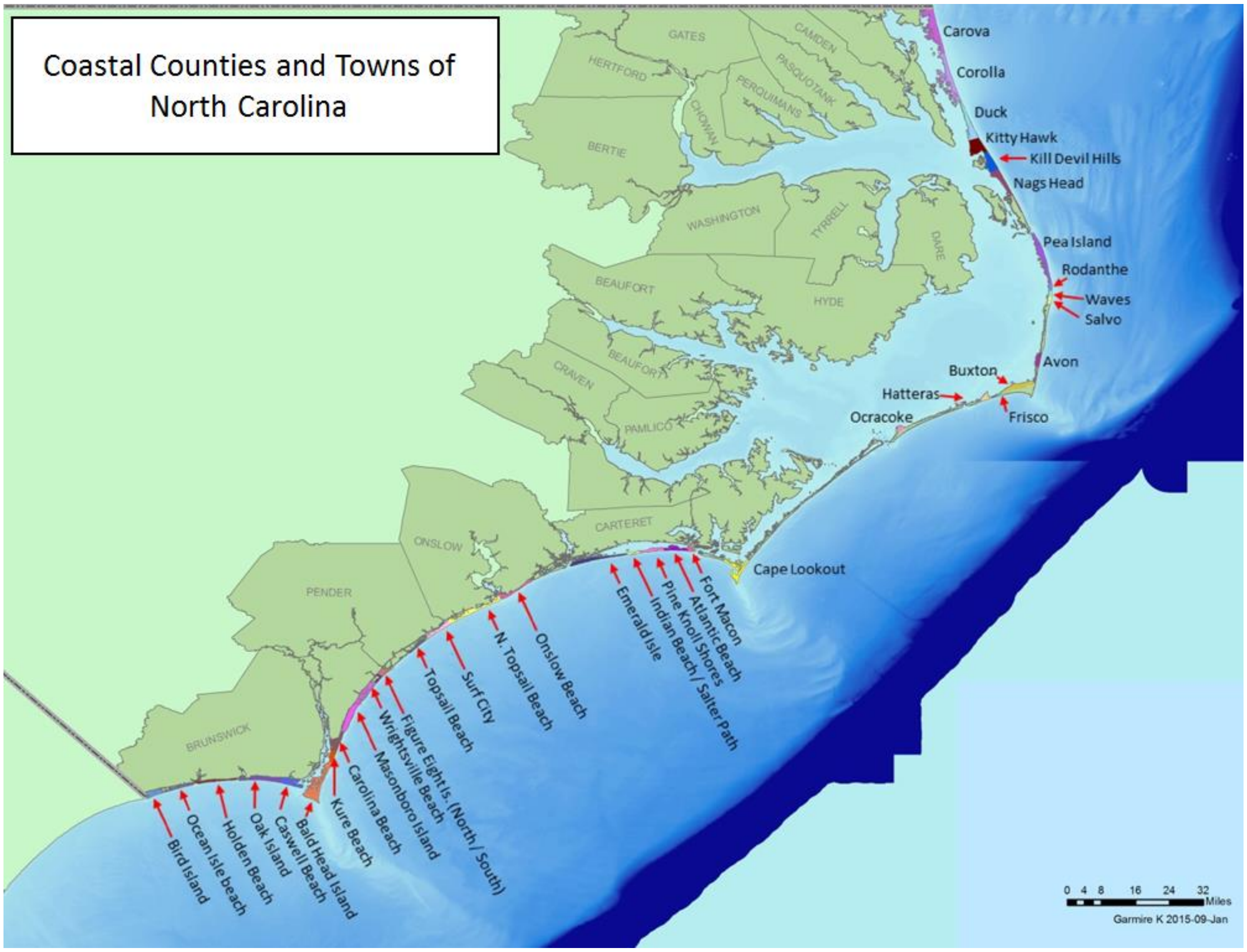


Fig. 2: Map of NC coastal counties and towns. Note, the eight oceanfront counties and the numerous incorporated and unincorporated towns.

The NC Division of Coastal Management monitors shoreline erosion to help understand the risk to property and infrastructure, and enable management of coastal development. More specifically, a setback policy is used to limit oceanfront construction, and this approach utilizes the long-term shoreline change rates (https://deq.nc.gov/). The available data highlight widespread erosion along the NC ocean shoreline (Fig. 3), including erosion hot spots, where rates are locally enhanced (e.g., >8 ft/yr), in many communities. Because of continued erosion over the last century and more rapid changes in some localities, there are areas in all coastal counties where nourishment has been conducted or is being considered. Several towns have historically received federal assistance for nourishment from the Army Corps of Engineers (e.g., Coastal Storm Damage Reduction projects). However, each project has its own situation, and continuation is subject to political, economic and storm-related factors. A review of these efforts is beyond the scope of this report. Interested readers are directed to Army Corps of Engineers website: http://www.saw.usace.army.mil/Missions/Coastal-Storm-Damage-Reduction/.

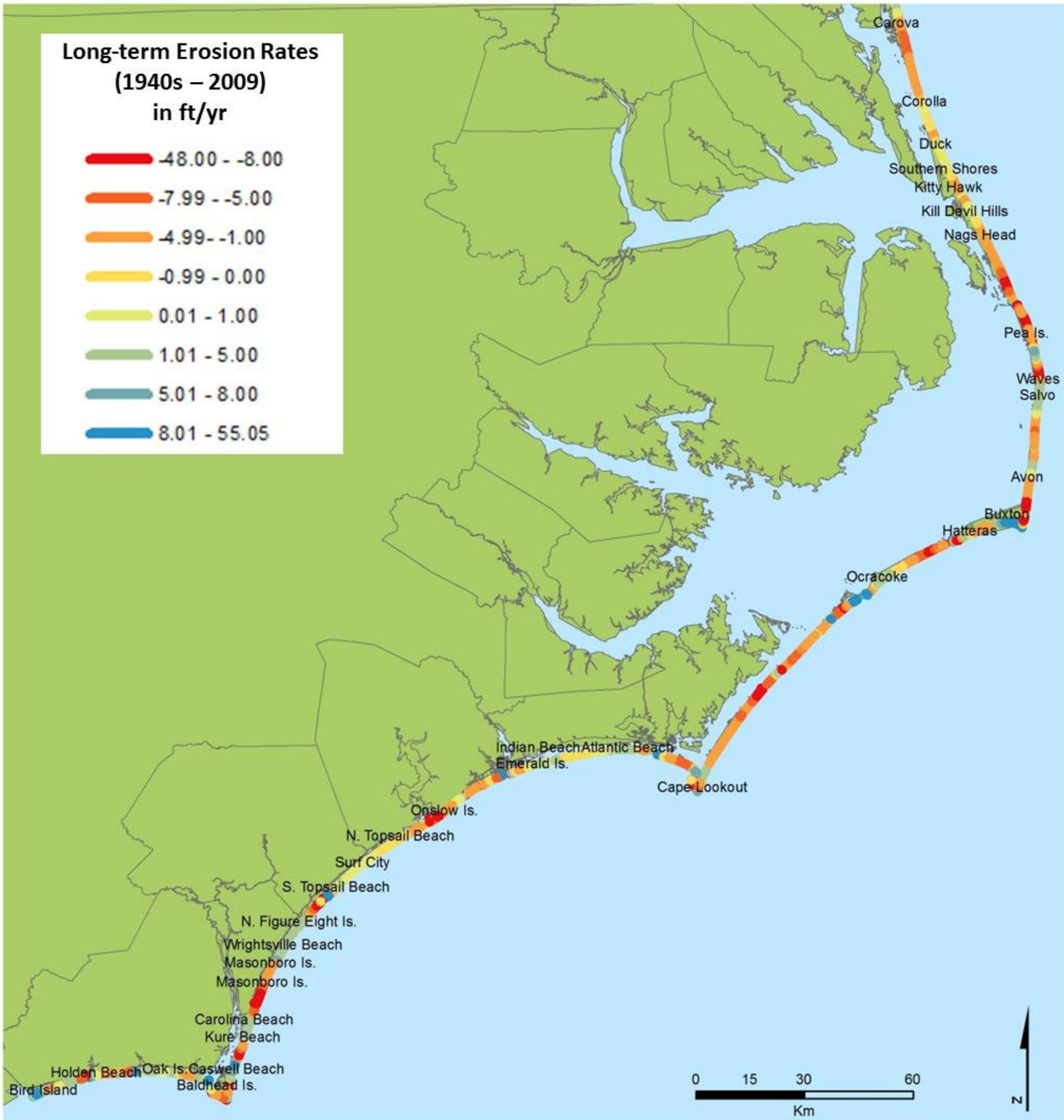


Fig. 3: Long-term (~50 year) oceanfront erosion rates for NC. Data from the NC Division of Coastal Management (2012).

Review of Available Sand Resources Information

Many different entities have conducted seafloor mapping and geological research offshore North Carolina over the last half century. As a result, a wide variety of sediment, seismic, and bathymetric data are available. Much work has focused on the inner shelf within three nautical miles (State waters), and a lesser amount of data is available in the three to eight nautical mile range, the area of federal waters likely utilized for sand resources. The largest data collections (many with large spatial coverage) are available from federal agencies, including the National

Oceanic and Atmospheric Administration (e.g., the National Centers for Environmental Information, formerly the National Geophysical Data Center at https://www.ngdc.noaa.gov/), the U.S. Army Corps of Engineers (e.g., the Field Research Facility; http://www.frf.usace.army.mil/) and the U.S. Geological Survey (http://walrus.wr.usgs.gov), including information in usSEABED and from a large cooperative study conducted in the 2000s. Other data sources include information from academic, private, State and other federal efforts. GIS layers have been obtained or created to map each dataset, and a brief summary is provided in Appendix 1. Figures 4 and 5 show the layers (points, lines or polygons) of the various datasets in northern and southern NC, respectively. FGDC-consistent metadata has also been developed for each to capture as much related information as possible. In addition to the geodatabase of layers being provided to BOEM for serving through federal outlets, map layers also will be served using the NC Coastal Atlas: https://www.nccoastalatlas.org/.

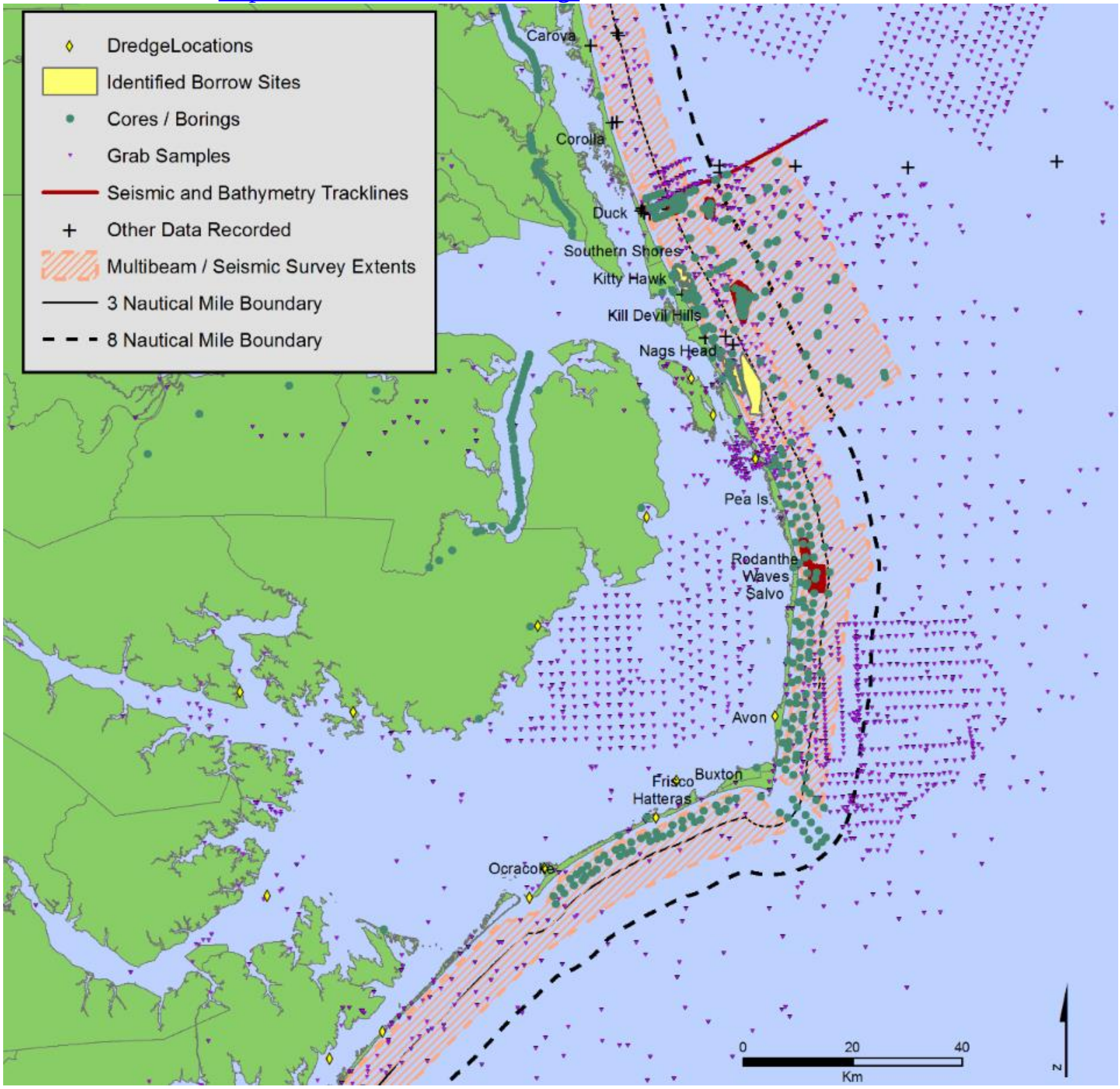


Fig. 4: Data layers of geological or geophysical in northern coastal NC. Note, the focus of this effort was the OCS region (3-8 nm offshore; see boundaries), but some other data is included.

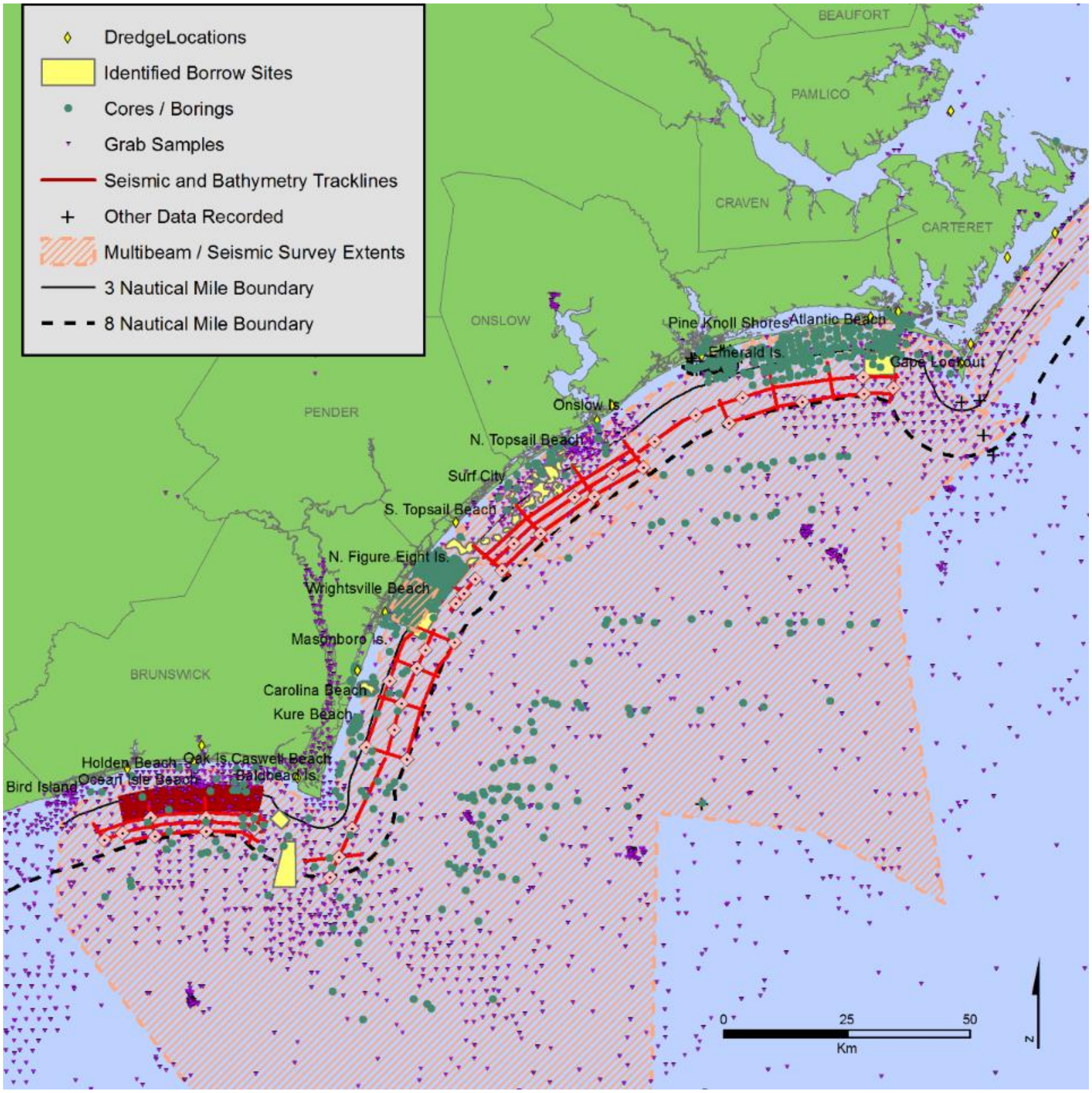


Fig. 5: Data layers of geological or geophysical information in southern coastal NC. Note, the focus of this effort was the OCS region (3-8 nm offshore; see boundaries), but some other data is included. Although a large polygon suggests widespread survey data offshore, in fact, there are only relatively sparse seismic data in the OCS.

Prioritization for Future Data Collection in the Outer Continental Shelf

As noted above, the need for beach nourishment in NC is widespread. Many communities have conducted projects in the past (Table 1), and others are planning future efforts. Because of frequent storms and ongoing sea-level rise, it is anticipated that most if not all communities in NC will be considering nourishment into the future. To minimize costs, it is usually preferred to use a proximal sediment source (e.g., inlet fill); however, in many areas, a sufficiently sized

Table 1: Areas and details of past beach nourishments in North Carolina. Most data obtained from the Program for the Study of Developed Shorelines at Western Carolina University (http://beachnourishment.wcu.edu/) and the NC BIMP (2011).

Location	Past Nourishment	Episodes	Volume (cubic yards)	Cost (2013 Dollars)
Carova	No			
Corolla	No			
Duck	No			
Southern Shores	No			
Kitty Hawk	No			
Kill Devil Hills	No			
Nags Head	Yes	2	4,983,000	43,555,614
Pea Island	Yes	16	7,747,902	29,016,048
Rodanthe	Yes	1	1,620,000	20,300,000
Waves	No			
Salvo	No			
Avon	No			
Buxton	Yes	3	1,812,000	20,942,408
Frisco	No			
Hatteras	Yes	7	887,801	11,590,856
Ocracoke	Yes	5	516,062	4,187,820
Cape Lookout Nat. Sea.	Yes	1	75,700	1,070,520
Fort Macon State Park	Yes	6	808,800	8,768,399
Atlantic Beach	Yes	9	16,285,656	51,512,952
Pine Knoll Shores	Yes	6	2,662,198	36,899,070
Indian Beach	Yes	3	1,384,698	12,608,318
Emerald Isle	Yes	24	4,589,862	48,168,070
Onslow Beach	Yes	1	101,653	745,070
North Topsail Beach	Yes	4	946,000	7,206,177
Surf City	No			
South Topsail Beach	Yes	8	1,615,296	14,716,667
Figure Eight Island North	Yes	7	1,796,235	?
Figure Eight Island South	Yes	13	3,889,016	6,371,434
Wrightsville Beach	Yes	25	15,256,391	66,698,922
Masonboro Island	Yes	3	2,939,530	8,317,308
Carolina Beach	Yes	30	18,108,368	77,409,465
Kure Beach	Yes	6	2,534,790	43,857,251
Bald Head Island	Yes	10	9,992,800	49,011,926
Caswell Beach	Yes	2	2,382,000	22,444,140
Oak Island	Yes	5	3,059,894	34,932,256
Holden Beach	Yes	16	2,227,412	13,356,231
Ocean Isle Beach	Yes	12	3,376,585	20,534,770
Bird Island	No			

source of compatible sand is lacking, and OCS sand resources may be the only option. The nourishment planned for the Town of Duck in 2017 provides an example; details can be found on the Town of Duck web site (http://www.townofduck.com/).

Based on the available data, a prioritization was completed in early 2015 to guide the Atlantic Sand Assessment Project (ASAP; BOEM-funded) data collection in summer 2015. With input from NC scientists, managers and private consultants, it was agreed that reconnaissance data collection was needed in southern NC, where there was sparse data in the OCS (Fig. 4). As can be seen in Fig. 3, extensive geophysical and core data collection has been completed in northern NC, particularly as part of a large USGS cooperative project (Thieler et al., 2013; 2014). Because the 2015 reconnaissance data have yet to be analyzed and because central and southern NC continues to have a limited amount of high-quality geophysical data in federal waters, it is believed that the greatest priority for data collection is south and west of Cape Lookout. However, insights gained from the analysis of recently obtained geophysical and geological data may shift or focus the recommended area for future work.

Conclusions

The need for sand resource data in the OCS offshore NC is substantial as more projects are likely to be planned, and the beach-compatible sand in State waters is limited. Although there has been a variety of geological and geophysical data collected offshore of NC, data are more limited in federal waters, particularly high-resolution seismics offshore southern NC. Based on the distribution of available data, it appears the highest priority area for OCS data collection is from Bogue Banks to the SC border. Analysis of the recently collected ASAP data may help shift attention for additional data.

References

Beach and Inlet Management Plan (BIMP). 2011. NC Division of Coastal Management. https://deq.nc.gov/about/divisions/coastal-management/coastal-management-oceanfront-shorelines.

Boss, S.K., Hoffman, C.W., 2000. Sand resources of the North Carolina Outer Banks, Final Report. Contract Report prepared for the Outer Banks Transportation Task Force and the North Carolina Department of Transportation, 87 pp.

N.C. Division of Coastal Management. 2012. North Carolina 2011 Long-Term Average Annual Oceanfront Erosion Rate Update Study. 125 pp. https://deq.nc.gov/about/divisions/coastal-management/coastal-management-oceanfront-shorelines.

Thieler, E.R., Foster, D.S., Mallinson, D.J., Himmelstoss, E.A., McNinch, J.E., List, J.H., and Hammar-Klose, E.S., 2013, Quaternary geophysical framework of the northeastern North Carolina coastal system: U.S. Geological Survey Open-File Report 2011–1015, http://pubs.usgs.gov/of/2011/1015/.

Thieler, E.R., Foster, D.S., Himmelstoss, E.A., and D.J. Mallinson. 2014. Geologic framework of the northern North Carolina, USA inner continental shelf and its influence on coastal evolution. Marine Geology, 14: 113-130.

Western Carolina University Program for the Study of Developed Shorelines, 2016. Beach Nourishment Data Viewer. http://beachnourishment.wcu.edu/

Appendix 1

Alpine Ocean Seismic Survey, Inc. and Moffat and Nichol, 2012, Vibracore data layers, Bogue Banks Master Beach Renourishment Plan.

Alpine Ocean Seismic Survey, Inc (Alpine), under contract to Moffatt & Nichol and Carteret County, conducted vibracore sampling offshore of Bogue Banks, North Carolina. The majority of the work was conducted using an Alpine model 270 pneumatic vibracore configured to collect 20 foot long cores. The R/V Shearwater was used for deployment of the vibracore system. Five cores inside Bogue Inlet were subsequently collected using an Alpine Mini-Vibracore system configured to collect 10 foot long cores, as deployed off a local spud barge. The purpose of the project was to collect sediment samples for use in characterization of four areas as potential borrow sites for periodic renourishment of Bogue Banks beaches.

Bernstein, D.J., 2001, Short-Term Evolution of Cape Morphology: Cape Lookout and Cape Fear, North Carolina. North Carolina State University Thesis.

Cuspate forelands often occur as a series of seaward projecting capes and their cape–associated shoals. Capes are important physical and ecological discontinuities in a coastline, yet their dynamics are poorly understood. The barrier coastline of North Carolina, consisting of Capes Hatteras, Lookout and Fear, typifies a cuspate foreland coastline. The evolution and morphology of the subaerial cape points at Cape Lookout and Cape Fear, North Carolina were examined through a field-intensive study using Real-Time-Kinematic Global Positioning System (RTK-GPS) from September 2000 to August 2001.

Topographic surveys of the subaerial cape points were conducted to assess changes in volume and shoreline position. Direct observation of waves, currents and bathymetry on cape-associated shoals is extremely difficult and often hazardous. This field-intensive study at Cape Lookout and Cape Fear uses the changing geometry of the subaerial cape point as an easily observed proxy for complex nearshore sediment transport processes at capes. Geo-spatial analysis of topography and shoreline position was used to assess geomorphic trends in volume change and shoreline variability. These results indicate that: 1) Short-term and seasonal changes in shoreline position are a result of changes in nearshore wind and wave energy; 2) variability in shoreline position and morphology increases with distance from the landward end of the cape to the seaward tip; and 3) the seaward tip of the subaerial cape point responds uniquely to changes in the nearshore wind and wave energy, and indicates that this region of the cape point plays a key role in sediment exchange between the subaerial cape and cape-associated shoal. Given the unique behavior of the seaward portion and transitional area of these capes, a previously un-described sequence of morphologic events I call "clipping" plays a dominant role in the transfer of sand from the tip of the subaerial cape point offshore to the adjacent shoals.

Boss, S.K., Hoffman, C.W., and Cooper, B., 2002, Influence of Fluvial processes on the Quaternary geologic framework of the continental shelf , North Carolina , USA: Marine Geology, v. 183, p. 45–65.

Digital, single-channel, high-resolution seismic reflection profiles were acquired from the insular continental shelf of North Carolina, USA along a data grid extending from Oregon Inlet northward 48 km to Duck, North Carolina and from the nearshore zone seaward approximately 28 km (total surveyed area=1334 km^2). These data were processed and interpreted to delineate principal reflecting horizons and develop a three-dimensional seismic stratigraphic framework for the continental shelf that was compared to stratigraphic data from the shoreward back- barrier (estuarine) and barrier island system. Six principal reflecting horizons (designated R0 through R5) were present within the upper 60 m of the shelf stratigraphic succession. Three-dimensional mapping of reflector R1 demonstrated its origin from fluvial incision of the continental shelf during an episode (or episodes) of lowered sea-level. Fluvial processes during development of reflector R1 were responsible for extensive reworking and re-deposition of sediment throughout most of the northern half of the study area. Five seismic stratigraphic units (designated S1 through S5) were tentatively correlated with depositional sequences previously identified from the North Carolina back-barrier (estuarine) and barrier island system. These five stratigraphic units span the Quaternary Period (S1 =early Holocene; S2 =51-78 ka; S3 =330-530 ka; S4 =1.1-1.8 Ma; S5 =earliest Pleistocene). Unit S1 is composed of fine-grained fluvial/ estuarine sediment that back-filled incised streams during early Holocene sea-level rise. The four other stratigraphic units (S2^S5) display tabular depositional geometries, low total relief, and thicken toward the east-southeast as their basal reflectors dip gently between 0.41 m km^{-1} (0.02 degrees) and 0.54 m km^{-1} (0.03 degrees). Knowledge of the three-dimensional subsurface stratigraphic architecture of the continental shelf enhances understanding of the development of shelf depositional successions and provides a framework for development of better Quaternary sea-level data, especially offshore North Carolina where such data are sparse.

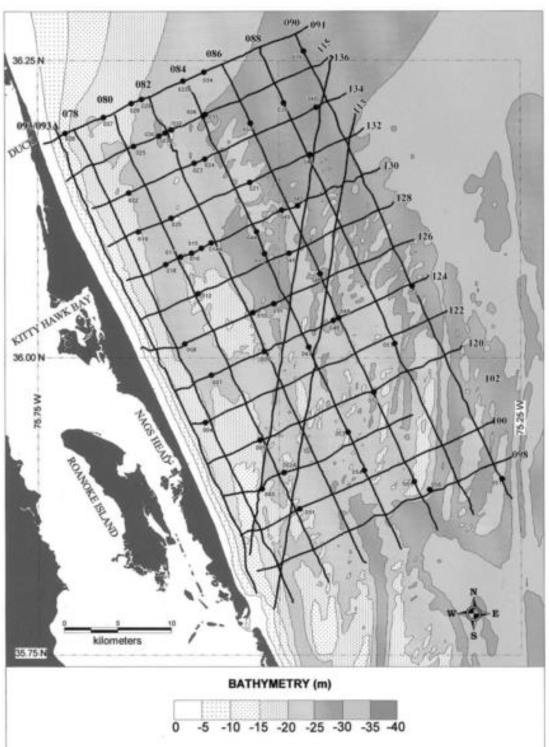


Fig. 1. Location map of the study area offshore of Dare County, NC showing seismic reflection and side scan sonar track lines (black lines) and vibracore locations (solid circles). Contoured bathymetry is at 5-m interval.

Boss, S.K., and Hoffman, C.W., 1999a, Sand Resources of the North Carolina Outer Banks 1st Interim Report: Assessment of Diamond Shoals Study Area: Prepared for the Outer Banks Task Force and the North Carolina Department of Transportation.

A review of available geophysical (single-channel seismic reflection and side-scan sonar records) and sedimentological (core descriptions, images, and textural analyses) data from Diamond Shoals, offshore Cape Hatteras, North Carolina was undertaken on behalf of the Outer Banks Task Force and the North Carolina Department of Transportation to determine the potential of this area as a source of sand for possible beach nourishment programs on the North Carolina Outer Banks. Results of this review are presented as an outline of the stratigraphic architecture of the Diamond Shoals Study Area (DSSA) derived from interpretation of seismic reflection and side-scan sonar data, description of the gross textural attributes of sampled Diamond Shoals sediment, and assessment of potential sand reserves within the DSSA which might be utilized for future beach nourishment programs.

Six major seismic reflectors (designated R0, R1, R2, R3, R4, R5) were correlated throughout the DSSA and form the upper and lower boundaries of five principal stratigraphic units (designated S1, S2, S3, S4, S5). Of these units, only the upper two (S1, S2) are considered accessible to presently available dredging technology, and thus are considered the viable sand resource units in the DSSA.

Stratigraphic unit S1 is the only unit sampled by available cores. This unit has an average thickness of 4 m throughout the DSSA, attaining a maximum thickness in excess of 24 m near the seaward limit of the survey data. Available cores suggest that this unit is typically composed of 95% sand. The sand of unit S1 is dominantly fine sand (0.21 mm) with lesser amounts of medium sand (0.26 mm), shell gravel (sediment coarser than 2.0 mm = 1.5%), and mud (sediment finer than 0.0625 mm = 3.3%). Sediment is typically medium sand across the shoal crest and among seaward megaripple fields.

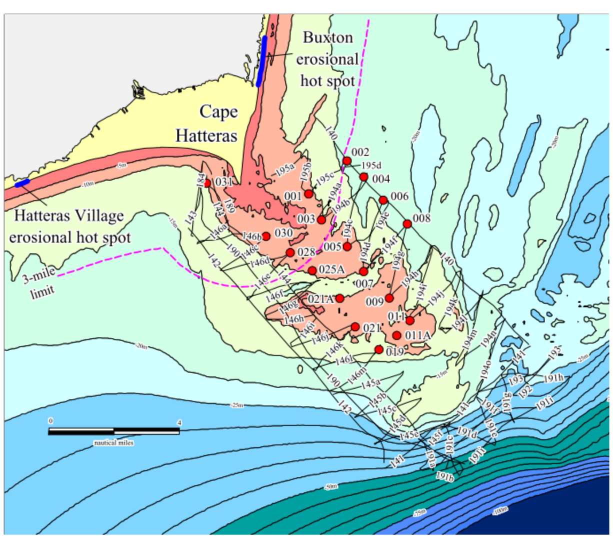


Fig. 2. Detailed location map of Diamond Shoals Study Area (DSSA) showing tracklines of seismic reflection and side-scan sonar profiles (thin lines) as well as locations of vibracores (solid cirlces) used in this sand resource assessment. Bathymetry layer created from NOAA hydrographic data (NGDC, 1999).

Boss, S.K., and Hoffman, C.W., 1999b, Sand Resources of the North Carolina Outer Banks 2nd Interim Report: Assessment of Buxton Study Area: Prepared for the Outer Banks Task Force and the North Carolina Department of Transportation.

A review of available geophysical (single-channel seismic reflection and side-scan sonar records) and sedimentological (core descriptions, images, and textural analyses) data from an area offshore Buxton, North Carolina was undertaken on behalf of the Outer Banks Task Force and the North Carolina Department of Transportation to determine the potential of this area as a source of sand for possible beach nourishment programs on the North Carolina Outer Banks. Results of this review are presented as an outline of the stratigraphic architecture of the Buxton Study Area (BSA) derived from interpretation of seismic reflection and side-scan sonar data, description of the gross textural attributes of sediment in cores collected within the BSA, and assessment of potential sand reserves within the BSA that might be utilized for future beach nourishment programs.

Nine principal seismic reflectors (designated R0 through R8) were correlated throughout the BSA and form the upper and lower boundaries of eight principal stratigraphic units (designated S1 through S8) extending from the seafloor to approximately 60 m sub-sea. Individual seismic units are relatively thin, averaging 5.4 m throughout the BSA. The seismic signatures of units within the BSA are quite variable, ranging from acoustically "transparent" units (i.e. lacking internal reflecting horizons) to units with multiple, closely spaced parallel reflectors. These variations in seismic character are indicative of rather variable geologic or sedimentologic units.

Side-scan sonar records throughout the BSA indicate that seafloor over three-fourths of the study area is characterized by weak acoustic reflectivity. This phenomenon most commonly indicates very fine sand or finer sediment at the seafloor. In addition to imaging of fine-grained sediments, side-scan sonar data from the BSA scanned significant occurrences of low- to highrelief hardbottoms exposed on the seafloor over a good portion of the northernmost quarter of the study area (north of line 022).

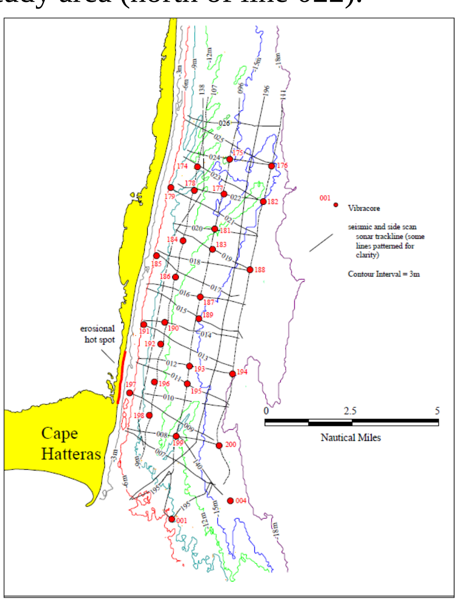


Fig. 2. Detailed location map of Buxton Study Area (BSA) showing tracklines of seismic reflection and side-scan sonar profiles (thin lines) as well as locations of vibracores (solid cirlces) used in this sand resource assessment. Bathymetry from NOAA hydrographic data (NGDC, 1999).

Boss, S.K., and Hoffman, C.W., 1999c, Sand Resources of the North Carolina Outer Banks 3rd Interim Report: Assessment of Frisco-Ocracoke Study Area: Prepared for the Outer Banks Task Force and the North Carolina Department of Transportation.

A review of available geophysical (single-channel seismic reflection and side scan sonar records) and sedimentological (core descriptions, images, and textural analyses) data from an area offshore Ocracoke Island and southern Hatteras Island, North Carolina was undertaken on behalf of the Outer Banks Task Force and the North Carolina Department of Transportation to determine the potential of this area as a source of sand for possible beach nourishment programs on the North Carolina Outer Banks. Results of this review are presented as an outline of the stratigraphic architecture of the Frisco-Ocracoke Study Area (FOSA) derived from interpretation of seismic reflection and side scan sonar data, description of the gross textural attributes of sediment in cores collected within the FOSA, and assessment of potential sand reserves within the FOSA that might be utilized for future beach nourishment programs.

Six principal seismic reflectors (designated R0 through R5) were correlated throughout the FOSA and form the upper and lower boundaries of five principal stratigraphic units (designated S1 through S5) extending from the seafloor to approximately 60 m sub-sea. Individual seismic units vary in thickness from 0 to 31 m (0 – 94 ft). The seismic signatures of units within the FOSA are quite variable, ranging from acoustically "transparent" units (i.e. lacking strong internal reflecting horizons) to units with multiple, closely spaced parallel reflectors. These variations in seismic character are indicative of rather variable geologic or sedimentologic units.

Side scan sonar records throughout the FOSA indicate two sea-floor types. The first is characterized by weak acoustic reflectivity--commonly indicating very fine sand or finer sediment. The second sonogram pattern recognized in the FOSA is a mixture of weak and moderate acoustic returns--indicating both finer and coarser grained sediments. There is little evidence for the development or occurrence of hardbottom areas within the studied area. Only three minor "scarps" of localized extent and minimal relief were observed in the data.

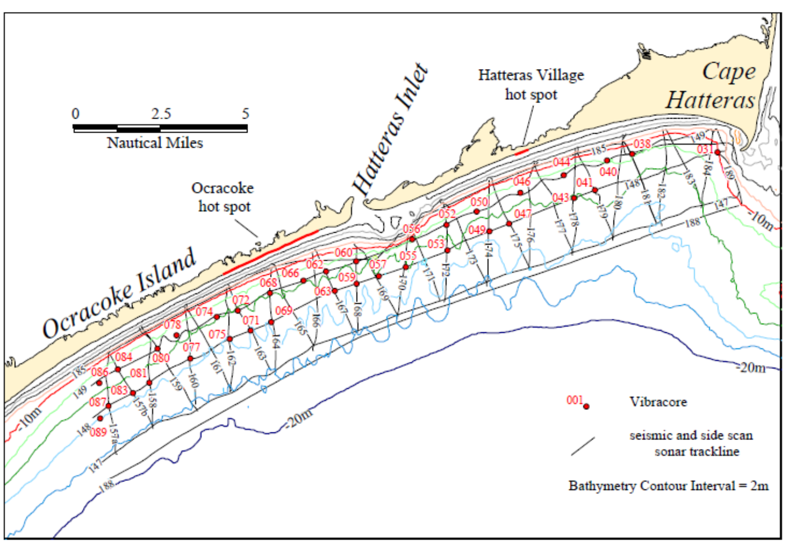


Fig. 2. Detailed location map of Frisco-Ocracoke Study Area (FOSA) showing tracklines of seismic reflection and side-scan sonar profiles (thin lines) as well as locations of vibracores (solid red cirlces) used in this sand resource assessment. Bathymetry from NOAA hydrographic data (NGDC, 1999) and from this study.

Boss, S.K., and Hoffman, C.W., 2000a, Final Report Sand Resources of the North Carolina Outer Banks: Prepared for the Outer Banks Task Force and the North Carolina Department of Transportation.

A preliminary survey to assess the availability and location of sand resources offshore of the Outer Banks was commissioned by the Outer Banks Task Force, beginning in 1994. The primary intent of this survey was to collect reconnaissance data (single-channel, high-resolution seismic reflection and side-scan sonar profiles) to be used to develop baseline information regarding the availability of sand for beach nourishment and the shallow (<100 m depth) stratigraphy and sea-floor characteristics of the continental shelf waters within the jurisdiction of the State of North Carolina (3 nautical miles (nm)). The resulting survey obtained 1,164 km (628 nm) of profile data between 0.5 and 3 nm from shore.

In 1995, geophysical data were supplemented with 121vibracores collected aboard the United States Army Vessel *D/B Snell*. Vibracores ranged in length from 0.62 to 6.14 m and averaged 3.73 m. These provide physical samples of the geologic units exposed within the NC-12 study area. Laboratory grain size analyses were conducted on samples from all vibracores.

During 1999, geophysical and core data were analyzed and synthesized by the North Carolina Geological Survey working with Dr. Stephen K. Boss of the University of Arkansas to generate a working database documenting the general stratigraphy and sand resource potential (including sand volume estimates) offshore of four areas of critically eroding shoreline along the Outer Banks (Pea Island, Buxton, Diamond Shoals, and Frisco-Ocracoke). Results of these analyses are generalized below and presented in detail in this final comprehensive report.

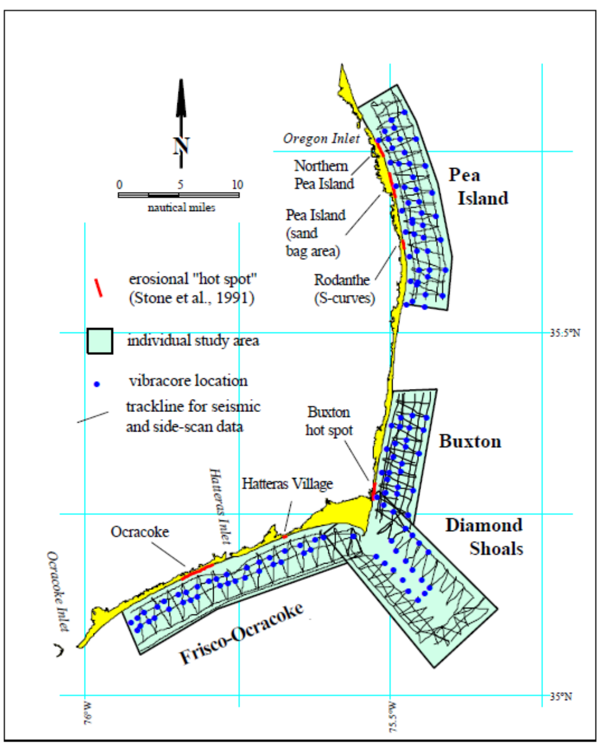


Fig. 1. Location map showing the Outer Banks Task Force sand resource project area. The four principal project areas are labeled along with locations of erosional "hot spot" areas where NC-12 is considered vulnerable to overwash and erosion.

Boss, S.K., and Hoffman, C.W., 2000b, Sand Resources of the North Carolina Outer Banks 4th Interim Report: Assessment of Pea Island Study Area: Prepared for the Outer Banks Task Force and the North Carolina Department of Transportation.

A review of available geophysical (single-channel seismic reflection and side-scan sonar records) and sedimentological (core descriptions, images, and textural analyses) data from an area offshore Pea Island, North Carolina was undertaken on behalf of the Outer Banks Task Force and the North Carolina Department of Transportation to determine the potential of this area as a source of sand for possible beach nourishment programs on the North Carolina Outer Banks. Results are presented as an outline of the stratigraphic architecture of the Pea Island Study Area (PISA) derived from interpretation of bathymetric, seismic reflection, and side-scan sonar data; description of the gross textural attributes of sediment in cores; and assessment of potential sand resources that might be utilized for future beach nourishment programs.

Six principal seismic reflectors (designated R0 through R5) were correlated throughout the PISA and form the upper and lower boundaries of five principal stratigraphic units (designated S1 through S5) extending from the seafloor to approximately 50 m sub-sea. Individual seismic units vary in thickness from 1 to 20 m (0 to 66 ft), but average 6 to 8 m thick. The seismic signatures of units within the PISA are variable, ranging from acoustically "transparent" units (i.e. lacking internal reflecting horizons) to units with multiple, closely spaced parallel reflectors. These variations in seismic character are indicative of variable geologic or sedimentologic units.

Side-scan sonar records indicate a variety of sea-floor types, although the quality of sidescan sonar records suffer from the unique and variable bathymetry of the seafloor within the PISA. As a result, side-scan sonar data from this study area are of limited value in characterizing the seafloor within the PISA.

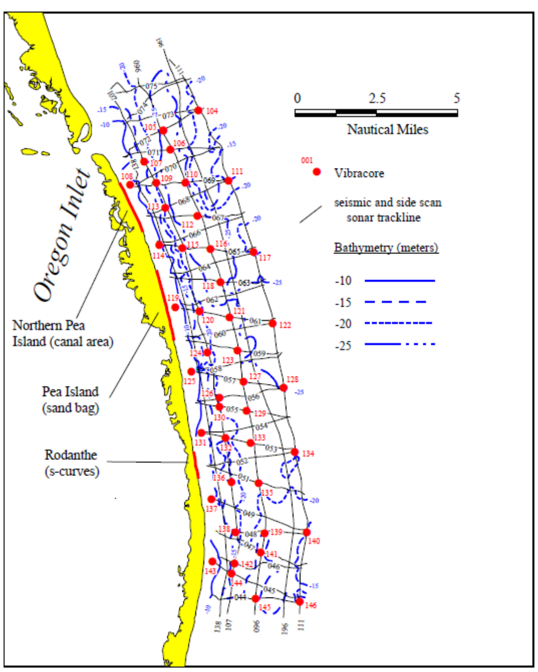


Fig. 2. Detailed location map of Pea Island Study Area (PISA) showing tracklines of seismic reflection and side-scan sonar profiles (thin lines) as well as locations of vibracores (solid cirlces) used in this sand resource assessment. Bathymetry from this study.

Boss, S.K., and Hoffman, C.W., 2001, Geologic Framework Derived from High-Resolution Seismic Reflection, Side-Scan Sonar, and Vibracore Data Offshore Oregon Inlet to Duck, Dare County, North Carolina: Prepared for U.S. Minerals Management Service.

Digital seismic profile data collected offshore of the northern Outer Banks, North Carolina were processed and interpreted to delineate principal reflecting horizons and develop a three-dimensional seismic stratigraphic framework for the insular continental shelf between Oregon Inlet and Duck, North Carolina. Developments in Geographic Information System technology over the past few years made it possible to derive gridded data from a network of intersecting, two-dimensional seismic profiles to provide three-dimensional images of reflecting horizons and seismic stratigraphic units (Boss and Hoffman, 2000). This methodology provides high-quality digital 3-D images of selected horizons of the offshore stratigraphy to be displayed on desktop computers or plotted on large format maps.

Data were analyzed from twenty-three single-channel, high-resolution seismic reflection profiles arranged in an orthogonal grid with profiles spaced at two nautical mileintervals over an area of 338 square nautical miles (1,138 km^2). Eight profiles were oriented parallel with the existing shoreline between Oregon Inlet and Duck, North Carolina and thirteen profiles were oriented perpendicular to shore. Two additional profiles were run diagonally across the grid.

Bureau of Ocean Energy Management, Mapping and Boundary Branch, 2010. Atlantic NAD 83 OCS Blocks Data Layer. Dataset accessed at 2016-01-26 at GSAA Coast & Ocean Portal http://gsaaportal.org/.

This data set contains OCS block outlines in ArcGIS shape file format for the BOEM Atlantic Region. OCS blocks are used to define small geographic areas within an Official Protraction Diagram (OPD) for leasing and administrative purposes. These blocks have been clipped along the Submerged Lands Act (SLA) boundary and along the Continental Shelf Boundaries. Additional details are available from: http://www.boem.gov/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Mapping_and_Data/99-0006.pdf. Because GIS projection and topology functions can change or generalize coordinates, and because shapefiles cannot represent true arcs, these GIS files are considered to be approximate and are NOT an OFFICIAL record for the exact block coordinates or areas. The Official Protraction Diagrams (OPDs) and Supplemental Official Block Diagrams (SOBDs) serve as the legal definition for BOEM offshore boundary coordinates and area descriptions.

Canuel, E., Martens, C., and Benninger, L., 1990, Seasonal variations in ^{7}Be activity in the sediments of Cape Lookout Bight, North Carolina: Geochimica et Cosmochimica Acta, v. 54, no. 1, p. 237–245.

Analysis of lipid biomarker compounds associated with surface sediment (0-0.5 or 0-1.0 cm) deposited monthly in Cape Lookout Bight (CLB), North Carolina, U.S.A. revealed seasonal trends in the relative importance of various sources of organic matter. Seasonality in these sources was reflected through variations of source-specific biomarkers in three classes of extractable lipid components-fatty acids, sterols and hydrocarbons, over an 18 month period. Samples collected during periods of sediment accumulation (winter/spring, generally) showed an increase in the relative abundance of algal-derived components. Summer months were characterized by negligible accumulation of sediment and a threefold increase in fatty acids of bacterial origin (i.e. odd numbered n-alkanoic acids and iso- and anteiso-branched acids). Further evidence for the activity of bacteria during summer months was seen by increases in the 5α(H)-cholestan-3ß-ol to cholest-5-en-3ß-ol ratio. These data indicate that bacterially-mediated processes incorporate organic matter derived from other sources, and accumulated during other times of the year, into biomass. As a result, in situ processes control the composition of preserved organic matter at least as much as temporal changes in the delivery of materials derived from allochthonous sources.

Cleary, W.J., Mcleod, M.A., Rauscher, M.A., Johnston, M.K., and Riggs, S.R, 2000. Digitized sediment grab and trackline layers. Beach Nourishment on Hurricane Southeastern North Carolina , USA : Targeting Shoreface and Tidal Inlet Sand Resources in: Journal of Coastal Research, Special Issue, p. 232–255.

Southeastern North Carolina is a rapidly growing tourist destination. A primary concern of management officials is the environmentally sensitive issue of beach nourishment for hurricane-impacted shorelines. Long term erosion and lack of shoreline recovery has prompted a re-examination of the shoreface and tidal inlets for beachfill quality sand resources. North Topsail Beach and Oak Island are exemplary study sites situated in different geologic settings with contrasting development, erosion, and nourishment histories. In addition to a variety of published and unpublished information, the database for this study consisted of 100 vibracores, 50 km of seismic profiles and 140 km^2 of sidescan-sonar data, petrographic analyses and diver surveys.

North Topsail Beach located adjacent to the New River submarine headland in Onslow Bay, was once extensively developed prior to 1996 hurricanes. This reach fronts a shoreface dominated by hardbottoms some of which crop out just seaward of the surf zone. On some portions of the shoreface sand trapped on the seaward side of the hardbottoms during storms is lost to the beach system. Other losses occur through shore-normal channel-like features that are probable pathways for cross-shore transport. The shoreface in this area has no resource potential. Maintenance dredging of New River Inlet may provide small volumes of material for erosion mitigation but no long term borrow sources are available. Continued development is the focus of debate due to the lack sand resources.

South facing Oak Island in low energy Long Bay is composed of a 3.5 km long Pleistocene subaerial headland segment flanked by two transgressive spits. Caswell Beach, a low relief 4 km barrier extends into the Cape Fear River estuary toward the east while Long Beach a 14km spit extends westward towards Lockwoods Folly Inlet. Chronic erosion is commonplace along Oak Island except near the bordering inlets. The volume of sand retained in the ebb-tidal deltas varies from 7 million m^3 for Lockwoods Folly Inlet to 125 million m^3 for the entrance shoals of the Cape Fear River along Caswell Beach. Initial beach fill requirements are conservatively estimated to be 4.0 million m^3. Material dredged from Lockwoods Folly Inlet will provide only a short-term and localized solution. Dredging activities at the Cape Fear River entrance will play a major role in mitigating the erosion. Activities include the deepening and realignment of the ship channel across the shoreface that will yield 6.6 million m^3 of material. The exact volume of usable material and the volume to be placed on Oak Island is currently being determined.

Significant portions of the shoreface are characterized by outcropping Cretaceous – Paleocene age sandstones and limestones. The sediment cover is variable and consists of 10-300 cm units of muddy sands and gravely muddy sands. The distribution of hardbottoms, the variable thickness, and the muddy nature of the sediment preclude the use of the majority of the shoreface as a long term borrow source. Pockets of 1-2 million m³ of beach fill compatible sands are found along a zone that straddles the outer fringes of the active beach. The only viable long-term borrow source is Jay Bird Shoals at the Cape Fear River entrance. A number of environmental concerns must be addressed before any of these areas can be utilized.

Coastal Planning & Engineering of North Carolina, Inc., 2014. Trackline, bathymetry and vibracore layers with associated raw data. Comprehensive Marine sand search for Towns of Duck, Kitty Hawk, and Kill Devil Hills, NC.

In 2013, Coastal Planning & Engineering of North Carolina, Inc. (CPE-NC) was authorized to provide services in support of the effort by the Towns of Duck, Kitty Hawk, and Kill Devil Hills to obtain the necessary permits and authorizations required for beach nourishment along portions of the three Towns. As part of these efforts, CPE-NC was tasked with conducting a comprehensive marine sand search investigation and borrow area design.

During the comprehensive marine sand search investigation, CPE-NC researchers conducted geophysical (sidescan sonar, magnetometer, sub-bottom and bathymetric) and geotechnical (beach characterization) surveys and compiled these data with existing information supplied by the U.S. Army Corps of Engineers (USACE), the Bureau of Ocean Energy Management (BOEM) and other Federal and non-federal entities.

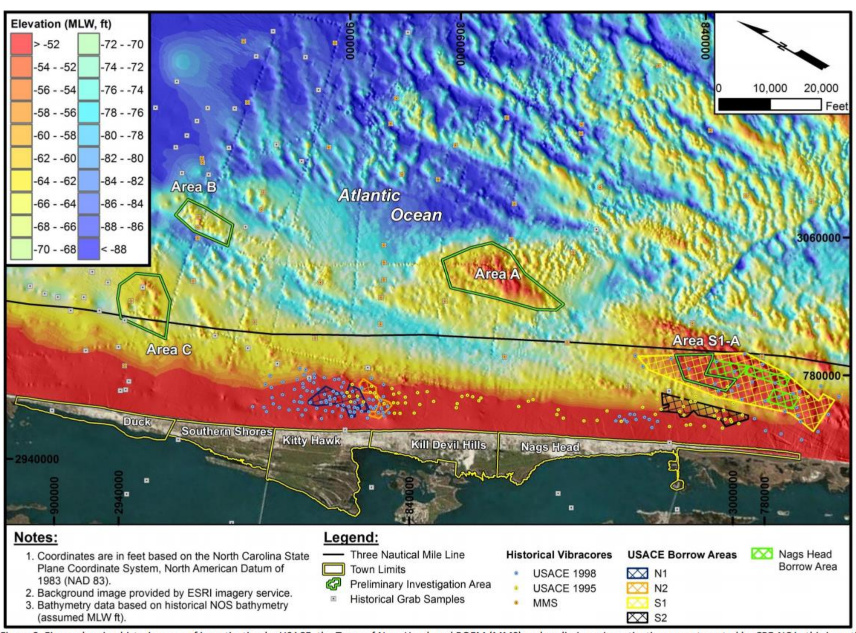


Figure 3. Figure showing historic areas of investigation by USACE, the Town of Nags Head, and BOEM (MMS) and preliminary investigation areas targeted by CPE-NC in this investigation.

Coastal Planning & Engineering of North Carolina, Inc., 2015, Ocean Isle Beach 30-year Beach Management Plan FINAL prepared for Ocean Isle Beach, North Carolina.

One common concern of residents and owners of oceanfront properties at Ocean Isle Beach are the threats of economic losses resulting from damages to structures and their contents due to hurricane and storm activity and the loss of beachfront land due to the ongoing shoreline erosion. In an attempt to reduce the potential damages from storm activity, the federal government authorized and implemented the nourishment of a 3.25 mile segment of the Town's 5.5 miles of oceanfront shoreline. In addition, the Town is actively pursuing the construction of a terminal groin and beach fill that will address shoreline erosion issues along the extreme eastern 0.5 miles of the island. The western portion of the island, covering approximately 1.75 miles from the west end of the federal project to the east shoulder of Tubbs Inlet, is currently unmanaged.

This report explores the existing management strategies, preliminary engineering analysis of an island-wide management program, the capacity of possible borrow sources, and environmental documentation and permitting approaches designed to help develop a single comprehensive, long-term management plan for the Town's entire oceanfront shoreline. This long-term plan was developed using the historical performance of the federal project, the anticipated shoreline protection provided by the yet-to-be constructed terminal groin, and the erosion rates documented along the unmanaged western portion of the island.

The island-wide management plan would utilize the existing borrow area within Shallotte Inlet as the primary borrow source for initial construction of the projects along the east and west ends of the Town as well as periodic nourishment of the entire 5.5 mile ocean shoreline which includes the federal storm damage reduction project. Current estimates indicate approximately 645,000 cubic yards of material will be needed every 5 years to maintain the Town's oceanfront shoreline once all shoreline management plans are implemented.

Coastal Science and Engineering, 2011. Vibracore data layers. Coastal Engineering & Geotechnical Analyses for Beach Nourishment Nags Head North Carolina.

This report is prepared in connection with the Nags Head, North Carolina, beach nourishmentproject. It follows preliminary planning and design work initiated by the Town of Nags Head in 2005 and extensive research and planning by the US Army Corps of Engineers (USACE) in connection with the federal Dare County beaches final feasibility report and environmental impact statement on hurricane protection and beach erosion control (USACE 2000). The final design report provides the basis and rationale for a proposed ~4-million-cubic-yard (±15 percent) beach nourishment project encompassing 10.1 miles of ocean shoreline along Nags Head on Bodie Island, north of Oregon Inlet (Figs 1.1–1.2). The purpose of the project is to restore a protective beach for a minimum of ten years, replace sand lost during the period of delay in the startup of the federal Dare County beach erosion control project, and expand the recreational beach for the benefit of the community.

Cudaback, C., and Largier, J., 2001, The cross-shelf structure of wind- and buoyancy-driven circulation over the North Carolina inner shelf: Continental Shelf Research, v. 21, no. 15, p. 1649–1668.

Circulation and transport over the North Carolina shelf were studied as part of an interdisciplinary Co-OP studying 1994. Shipboard data and moored instruments reveal two

important influences on the density distribution. Winds in the area reverse every few days, driving upwelling and downwelling circulation alternately, and a low-salinity coastal buoyancy current from Chesapeake Bay is present only during downwelling. Empirical orthogonal functions reveal that variability in temperature and cross-shore circulation is dominated by upwelling and downwelling, while patterns in salinity and along-shore circulation are primarily due to the buoyancy current. The observed density distribution goes through a cycle, showing each influence in turn. After a period of equatorward winds, the thermocline bends downward at the nearshore end, and a coastal wedge of low-salinity water is observed. When the winds turn poleward, the thermocline bends upward and the low-salinity water moves offshore. This cycle repeats four times during our study period with modest variations.

Culver, S.J., Farrell, K.M., Mallinson, D.J., Horton, B.P., Willard, D. a., Thieler, E.R., Riggs, S.R., Snyder, S.W., Wehmiller, J.F., Bernhardt, C.E., and Hillier, C., 2008, Micropaleontologic record of late Pliocene and Quaternary paleoenvironments in the northern Albemarle Embayment, North Carolina, U.S.A.: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 264, no. 1-2, p. 54–77.

Micropaleontological data provide a strong actualistic basis for detailed interpretations of Quaternary paleoenvironmental change. The 90m-thick Quaternary record of the Albemarle Embayment in the mid-Atlantic coastal plain of the USA provides an excellent opportunity to use such an approach in a region where the details of Quaternary environmental change are poorly known. The foraminiferal record in nine cores from the northern Outer Banks, east of Albemarle Sound, North Carolina, indicates the deposition of subhorizontal, mostly open-marine early to late Pleistocene units unconformably upon a basement of late Pliocene reduced-oxygen, fine-grained, shelf-basin deposits. Pollen data record several warm-cool fluctuations within the early to mid-Pleistocene deposits. Diatom data indicate that some fresh and brackish-water units occur within the generally open-marine Pleistocene succession. A channel cut by the paleo-Roanoke River during the last glacial sea-level lowstand occurs in the northern part of the study area. Pollen indicates that the basal fluvial valley fill accumulated in cooler than modern climate conditions in the latest Pleistocene. Overlying silts and muds accumulated under cool climatic, estuarine conditions according to diatom and pollen data. Radiocarbon ages from the estuarine deposits indicate that the bulk of these sediments accumulated during the latest Pleistocene. The estuarine channel-fill deposits are overlain by Holocene open-marine sands deposited as the rising sea transgressed into the estuary approximately 8.5 to 9.0 kyr BP. Within the barrier island drill cores of this study, fully marine sedimentation occurred throughout the Holocene. However, immediately west of the present barrier island, mid- to late Holocene estuarine deposits underlie the modern Albemarle Sound. The islands that currently form a continuous barrier across the mouth of Albemarle Sound have a complex history of Holocene construction and destruction and large portions of them may be less than 3 kyr old. The barrier island snds overlie open-marine sands of Colington Shoal in the north and to the south overlie fluvial and marine sand filling paleo-Roanoke tributary valleys. The Pleistocene sediments underlying the northern Outer Banks study area are mainly of open inner to mid-shelf origin. If, as is likely, sea level continues to rise, a return to such environmental conditions is likely in the near future.

Curators of Marine and Lacustrine Geological Samples Consortium. The Index to Marine and Lacustrine Geological Samples (IMLGS). NOAA National Centers for Environmental

Information. Dataset accessed at 2016-01-26 at doi:10.7289/V5H41PB8.

Data include basic collection and storage information. Lithology, texture, age, principal investigator, province, weathering, metamorphism, glass remarks, and descriptive data are included for some samples, at the discretion of the curator.

The Index provides links to view and download related data and images in the long-term archive, at participating institutions, and includes reciprocal links to the National Science Foundation (NSF) sponsored Rolling Deck to Repository (R2R). R2R also maintains a Linked Data version of the IMLGS in cooperation with NOAA.

Several thousand samples in the Index also link to the NSF supported System for Solid Earth SAmple Registration (SESAR) by IGSN, the Marine Geoscience Data System (MGDS) and PetDB. The Index is endorsed by the Intergovernmental Oceanographic Commission, Committee on International Oceanographic Data and Information Exchange (IODE-XIV.2). Look for data from the Index to Marine and Lacustrine Geological Samples, and for data digitized under the NOAA Climate Database Modernization Program (CDMP), in the NSF-funded GeoMapApp, and in the GRID-Arendal Continental Shelf Programme.

Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Office for Coastal Management (OCM), 2014, Unexploded Ordinances in US Waters as of February 2014 Data Layer. Dataset accessed at 2016-01-26 at http://marinecadastre.gov/nationalviewer/.

Unexploded ordnance (or UXOs/UXBs, sometimes identified as UO) are explosive weapons (bombs, bullets, shells, grenades, land mines, naval mines, etc.) that did not explode when they were employed and still pose a risk of detonation, potentially many decades after they were used or discarded. While "UXO" is widely and informally used, munitions and explosives of concern (MEC) is the current preferred terminology within the remediation community. This is NOT a complete collection of unexploded ordnance on the seafloor, nor are the locations to be considered exact. The presence and locations of the unexploded ordnance have been derived from graphical representations recorded on NOAA Raster Navigation Charts. These data are intended for coastal and ocean planning. Not for navigation.

Eastern Division Conservation Science Office of the Nature Conservancy and usSEABED. Draft Shallow Sediment Type Data Layer. Dataset accessed at 2016-01-26 at GSAA Coast & Ocean Portal: http://gsaaportal.org/.

Interpolated grid of sediment size for the South Atlantic Bight Marine Assessment near shore (to 200 meter depth) area. The interpolation was done using point data from U.S. Seabed and other sources.

Eastern Division Conservation Science Office of the Nature Conservancy modified from Southeast Area Monitoring and Assessment Program's (SEAMAP) Bottom Mapping Project. Benthic Habitats – Hardbottom Data Layer. Dataset accessed at 2016-01-26 at GSAA Coast & Ocean Portal: http://gsaaportal.org/.

This data product maps the location of hardbottom habitats within the seafloor environments of the South Atlantic Bight inside a 1 x 1 minute grid. Hard bottom habitat refers to live corals/coral reefs, underwater rocky vertical outcrops, exposed flat pavements colonized by marine invertebrates, shallow drowned slopes supporting macroalgae and hard bottom/gravel mixed substrates. These habitats are associated with diverse marine communities are considered Essential Fish Habitat (EFH) for a wide variety of species that are commercially and recreationally important throughout the South Atlantic Bight. The total area of hardbottoms mapped in this dataset is limited to the areas where studies have occurred; therefore this is not a complete representation of regional hardbottom resources.

The Nature Conservancy's objective for this project is to create an updated version of the 1 x 1 minute grid that was originally developed during the Southeast Area Monitoring and Assessment Program's (SEAMAP) Bottom Mapping Project from 2001. TNC used the protocols previously defined by SEAMAP to classify data records as: Hardbottom [HB] (clear evidence of hardbottom habitat), Potential hardbottom [PH] (possible evidence of hardbottom habitat) or Not hardbottom [NH] (no evidence of hardbottom habitat being present). Data records incorporated into this database include all data records from the SEAMAP Bottom Mapping Project except those that include information from trawls and dredges due to a more conservative methodology used to assess hardbottom occurrences as well as several other data records that have been updated with more current information for those specified spatial locations. The database also added new datasets available since the publishing of the original SEAMAP hardbottom dataset. The source citation list later in this document provides additional information about how each dataset was incorporated. Information is summarized at the 1x1 minute grid scale which classifies each polygon that contains a survey record as either "Hardbottom" – cells that have one or more occurrence of HB, "Potential hardbottom" – cells that do not have a HB occurrence but have one or more PH occurrence or "Surveys with no identification of hardbottom" – cells that do not have any HB or PH occurrences but have one or more NH occurrence within that 1x1 minute gridded area.

Feasibility Report and Final Environmental Impact Statement on Coastal Storm Damage Reduction: Surf City and North Topsail Beach North Carolina Appendix R, 2003.

The following pages contain the reports of surveys in both the offshore borrow areas and in the nearshore of the project area. These surveys and reports were conducted and prepared by consultants under contract to the U.S. Army Corps of Engineers, Wilmington District. Note that due to size, attachment 4 is only being provided electronically, and as a seperate document. The scanned reports, prefaced by title pages are listed as follows: 1. Attachment 1 – An Assessment of the Availability of Beach Fill Quality Sand Offshore North Topsail Beach and Surf City, NC, HDR Engineering of the Carolinas, with William J. Cleary, PhD., March 2003, 113 pages 2. Attachment 2 – High-Resolution Remote Sensing of Potential Hard Bottom Habitats: Topsail Island, NC July 2006, Greenhorne & O'Mara Inc., and Geodynamics LLC, 75 pages 3. Attachment 3 – High-Resolution 3D Bathymetric Assessment of Potential Hard Bottom Habitats: Topsail Island, Surf City and North Topsail Island, NC January / February 2007, Greenhorne & O'Mara Inc., and Geodynamics LLC, 60 pages 4. Attachment 4 – Surf City / North Topsail Beach, N.C. Shore Protection Project, Hardbottom Resource Confirmation and Characterization

Study, Anamar Environmental Consulting, Inc., June 2008, 233 pages.

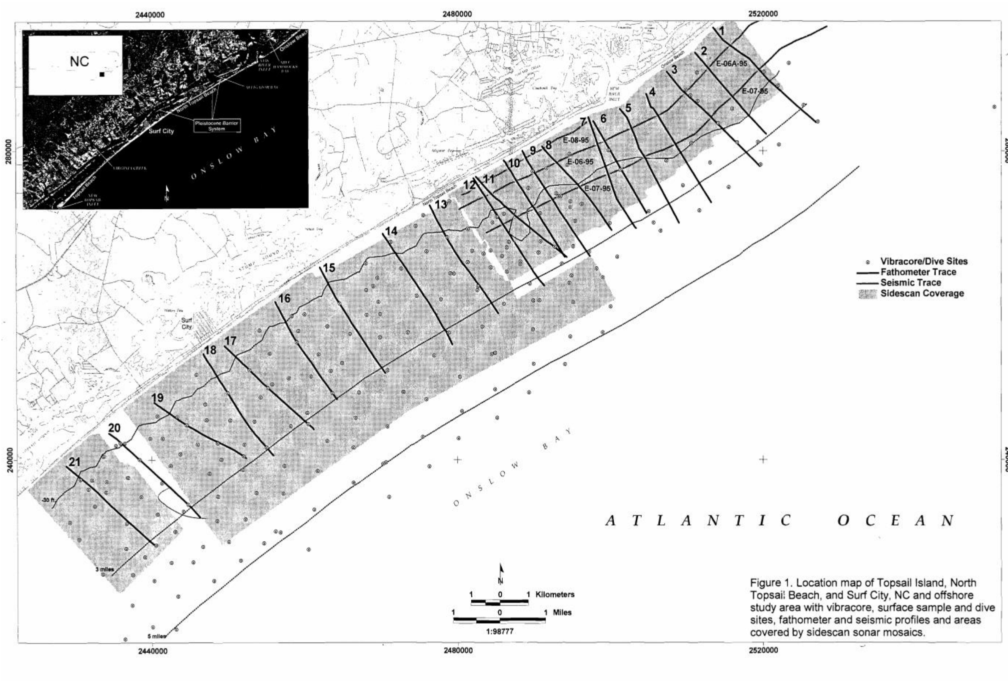


Figure 1. Location map of Topsail Island, North Topsail Beach, and Surf City, NC and offshore study area with vibracore, surface sample and dive sites, fathometer and seismic profiles and areas covered by sidescan sonar mosaics.

Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI), Coastal and Marine Resource Assessment (CAMRA), 2005. Coral, Coral Reef and Live Hardbottom EFH-HAPC Data Layer. Dataset accessed at 2016-01-26 at GSAA Coast & Ocean Portal http://gsaaportal.org/.

Essential Fish Habitiat (EFH) that is judged to be particularly important to the long-term productivity of populations of one or more managed species, or to be particularly vulnerable to degradation, should be identified as "habitat areas of particular concern" (HAPC) to help provide additional focus for conservation efforts. As a result of the Sustainable Fisheries Act Amendment to the Magnuson-Stevens Fishery Conservation and Management Act in 1996 the Councils and the NMFS have been mandated to use an ecosystem approach in managing the Nation's Fisheries. The Council has taken the first step with the approval of the Habitat Plan identifying and describing in detail essential fish habitat (EFH) for species managed throughout the South Atlantic and with the approval of the Comprehensive Habitat Amendment amending all existing FMPs to include descriptions of EFH and EFH-habitat areas of particular concern (EFH-HAPCs).

Freeman, C.W., Bernstein, D.J., Sumners, B.W., and Hill J.C., 2012, Final Descriptive Report: Bogue Banks Master Beach Nourishment Plan Carteret County, North Carolina. Geodynamics contracted through Moffat and Nichol for Carteret County, NC Sand Resource Surveys.

Geodynamics was contracted by Moffatt & Nichol to perform a high-resolution survey of the seafloor surface and sub-bottom for two select areas along the southeast coast of North

Carolina. The first site was focused on the Ocean Dredged Material Disposal Site (ODMDS) within the Morehead City Federal Navigation Project, located in both State and Federal ocean jurisdictions. The second site was Borrow Area Y offshore of the Town of Emerald Isle, located completely within State waters. To accurately assess the nature of sediments at these locations, multibeam bathymetry, multibeam backscatter, and seismic (sub-bottom) data was collected at both sites. The multibeam bathymetry data was collected in accordance with IHO Order 1a requirements to provide accurate seafloor elevations and seabed information to determine and assess discrete sand resources. The multibeam backscatter was used to identify areas of possible hardbottom/rock outcrops, areas of possible archaeological concern, bedforms, and likely surface sediment type. To understand volumes and underlying geology, reflectors were identified using the seismic data. The geophysical portion of the survey was acquired by Coastal Carolina University (CCU) and is reported within this report. All data was collected and processed in accordance with the State Regulations 15A NCAC 07H .0312 –Technical Standards for Beach Fill Projects (NCDCM, 2007) and all BOEM requirements.

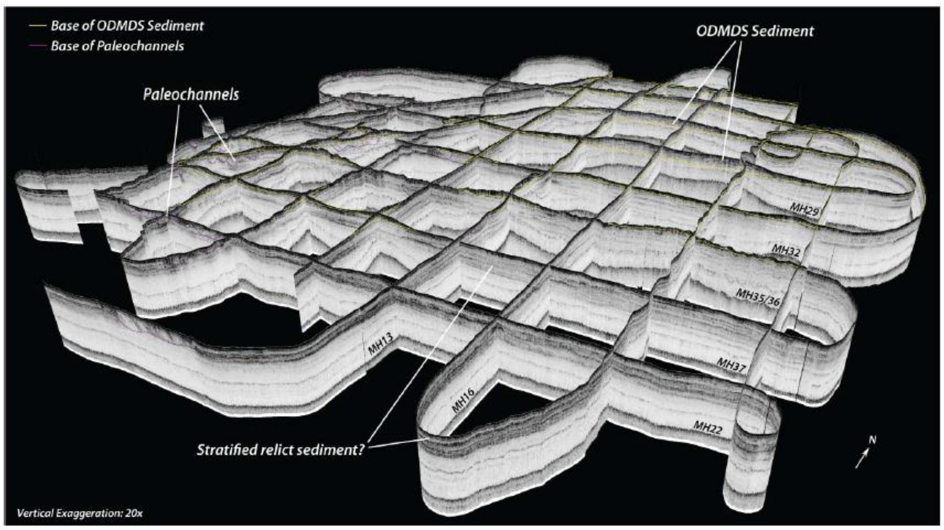


Figure 56. 3-D Perspective view of Chirp sub-bottom data from the Morehead City ODMDS survey area. The yellow horizon represents the base of ODMDS sediment; the purple horizon represents the base of paleochannel incision.

Finkl, C.W., and Hobbs, C.H., 2009, Mining Sand on the Continental Shelf of the Atlantic and Gulf Coasts of the U.S.: Marine Georesources & Geotechnology, v. 27, no. 3, p. 230–253.

Essentially all marine mining along the East and Gulf coasts of the U.S. is for sand used in beach nourishment projects. The current minimal commercial production of sand and aggregate may increase as conventional, on-shore sources become exhausted or are lost to competing land use. Studies published in the late 1990s document a history of nearly 900 individual episodes of beach nourishment having a total cost in excess of $2_109 with several hundred million cubic meters of sand placed along over 645 km (400 mi) of shoreline. As exemplified by studies in Florida, prospecting for sand for use in beach nourishment can begin before site specific needs are identified. A full prospecting starts with assimilation of pertinent literature, local knowledge, and an understanding of the geologic and geomorphic settings in which suitable deposits of sand or aggregate occur. High-resolution seismic profiling follows to outline the three dimensional extent of the sand bodies. Finally, vibratory cores are collected to verify the interpretation of the seismic data and to provide samples for geotechnical, especially granulometric, analyses. The actual method of production often is determined by the local availability of different dredge types. Because the mining of marine sands disturbs meaningful areas of the sea floor, environmental concerns must be considered. While it generally is assumed that dredged areas will be left barren, it is possible to assess the likely rate of recolonization. The disruption of bottom habitat also can affect feeding and spawning areas for fishes and other organisms. Alteration in local currents and wave transformation processes need to be modeled and their consequences assessed.

Finkl, C.W., Jarrett, T., Willson, K., Andrews, J.L., Forrest, B.M., Ph, D., and Larenas, M., 2008, Topsail Beach, North Carolina: Marine Sand Search Investigations to Locate Sand Sources for Beach Nourishment: Prepared by Coastal Planning & Engineering of North Carolina, Inc.

To meet the needs of the Interim (Emergency) Beach Nourishment Project, the Town of Topsail Beach authorized Coastal Planning & Engineering of North Carolina, Inc. (CPE-NC) to conduct a marine sand search investigation. Due to the urgent need for fill material, the goal of this investigation was to identify and develop a suitable borrow area as quickly and cost effectively as possible.

The classic CPE-NC three (3) phased approach to sand search investigations was modified for this investigation. During Phase I, borrow areas previously identified by the USACE were reviewed. Historic data indicated that the most promising area was located within USACE Borrow Area A. In order to maintain cost effectiveness and efficiency, the portion of the borrow area located landward of the State/Federal boundary was identified for further investigation. Phase II investigations consisted of a geophysical survey of the area identified during Phase I. In May 2006, joint seismic reflection profiling, sidescan sonar, magnetometer and bathymetric survey were conducted. Phase III investigations consisted of a vibracore survey of a further refined area that was developed using geophysical data collected during Phase II. In October 2006, twenty (20) vibracores were collected. The results of the geophysical and vibracore surveys indicated that the material within Borrow Area A1 had percent silt values in excess of those allowed by the State of North Carolina and in general was too fine to meet the Town's performance goals. A second three phase sand search investigation was initiated by the Town in January 2007.

Vibracore data collected by the USACE was re-examined to determine if the data indicated any additional potential sand resource areas. Based on this review, an area outside of New Topsail Inlet was identified for Phase II investigations. In February 2007, joint seismic reflection profiling, sidescan sonar, magnetometer, and bathymetric surveys of the New Topsail Inlet ebb tidal delta were conducted. Twenty-three (23) vibracores were collected in June/July 2007, from the areas with the highest probability of containing beach quality sand based on the geophysical data. These investigations resulted in the identification of a sand source that was coarse enough to meet the performance goals of the project and to satisfy all State requirements. A Phase III investigation of this area was conducted between October and December 2007. Seismic reflection profiling, sidescan sonar, bathymetric and magnetometer survey data was collected for this survey. The Phase III results were used to refine and further develop the New Topsail Inlet sand source into Borrow Area X.

Geodynamics LLC under contract for the USACE Wilmington District through Greenhorne & O'Mara, 2007. Sidescan Sonar Mapping of Potential Hard Bottom Areas in the Nearshore Zone of Bogue Banks, North Carolina GeoTiff.

Hydrographic surveys using sidescan sonar provide detailed information of the seafloor which are used for nautical charting, geological investigations as well as high-resolution data for various coastal engineering projects and benthic habitat assessments (to name just a few applications). Modern digital sidescan technology allows for the acquisition of 100% seafloor imagery coverage and seafloor textural information in a swath up to 300m depending on the resolution required for the project. In the case of the Bogue Banks project, which was deemed as a recon level survey, we set the high frequency band (600kHz) to 200m and the low frequency (300kHz) to 300m. The final product of swath-based seafloor imagery surveys allow the end user to resolve morphological features on the seafloor, in the form of pixel intensities (0-255), of varying size and frequency. In addition, these spatially dense surveys are easily imported into a Geographic Information Systems (GIS) database that allow users to analyze various morphological, physical and environmental data from a single project specific database.

Geodynamics LLC, a geologic and oceanographic services firm, was requested by G&O to prepared a survey design and cost estimate on 11/06/06. On 6/6/07 the project was contracted by the United States Army Corps of Engineers (USACE) Wilmington District through Greenhorne & O'Mara, Inc. The object of the project was to collect high-resolution sidescan sonar data along the 25 mile stretch of Bogue Banks, North Carolina from the surfzone to approximately - 40' MLLW. The main objective of the survey was to collect and mosaic high-resolution sidescan sonar data to image potential hard grounds and to classify the data such that potential sites could be easily identified for further investigation. These surveys made use of an EdgeTech 4200 HFL sidescan sonar system using differential corrections (RTCM format) from a Trimble BOB system input into an Applanix POS MV 320 v4 intertial navigation system. Due to strict time frames established by the client the data was collected during the first available weather window, which along Bogue Banks is any winds from the N and NE quadrants and seas less than 2'. The first day of data acquisition took place on 7/2/07 with forecasted winds to be out of the NE but winds were more easterly; only one line of data was collected. The next window took place on 7/21 and 7/22/07. Since this fell on a weekend boat traffic and boat wakes became a problem which is outlined further in the final report.

Geodynamics LLC contracted by USACE Wilmington District, 2013. Bathymetry, trackline coverage, backscatter, and sediment thickness data layers. Multibeam & Geophysical Survey of Designated Borrow Areas Offshore NC12 Rodanthe, North Carolina.

Geodynamics was contracted by the USACE Wilmington District to perform a high-resolution survey of the seafloor surface and sub-bottom for a potential borrow area offshore highway NC12 near Rodanthe, North Carolina. The survey area is comprised of 2 individual sites totaling 5.23 (nautical miles) nmi^2, and located approximately 0.5 to 3.0 nmi offshore "S-Turns" at the northern portion of Rodanthe, NC. To accurately assess the nature of sediments at these locations, multibeam bathymetry, multibeam backscatter, and seismic (sub-bottom) data were collected. The multibeam bathymetry data was collected in accordance with IHO S-44, USACE standards for navigation and dredging requirements and the State Regulations 15A NCAC 07H .0312 – Technical Standards for Beach Fill Projects to provide accurate seafloor elevations and details needed to evaluate discrete sand resources. The multibeam backscatter was used to identify areas of complex seafloor morphology, areas of possible archaeological concern, bedforms, and likely surface sediment type that can be used to interpolate ground truth data being collected across the survey areas. To understand volumes and underlying geology, reflectors were identified using the seismic sub-bottom data. All data was collected and processed in accordance with the State Regulations 15A NCAC 07H .0312 – Technical Standards for Beach Fill Projects.

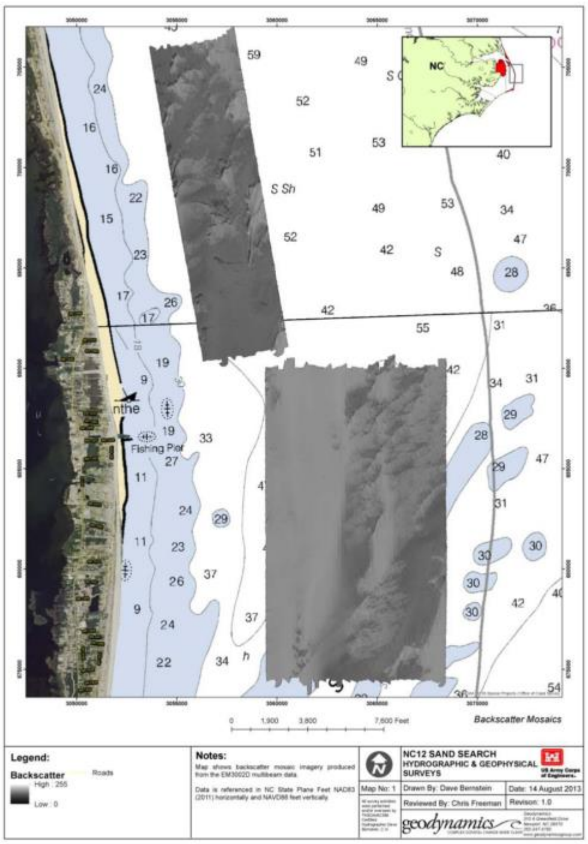
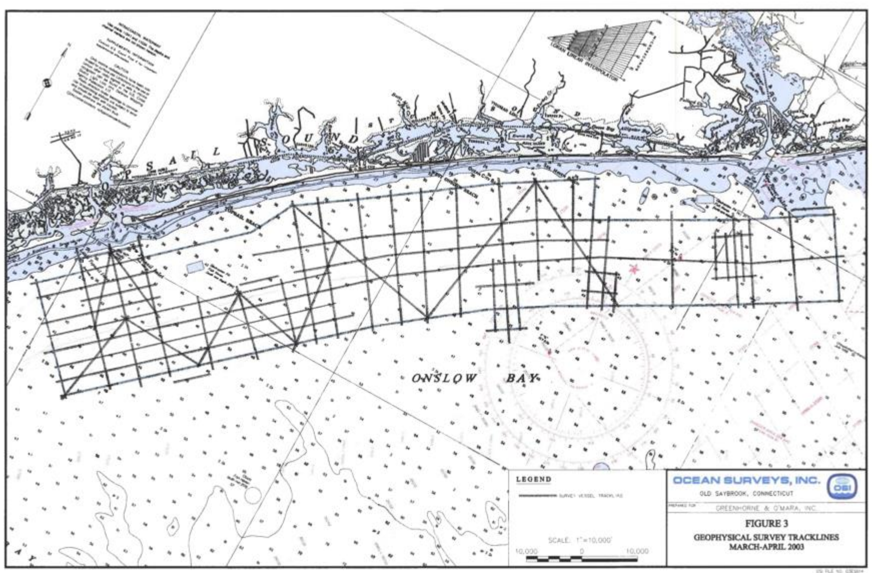


Figure 22. Multibeam backscatter imagery processed in Fledermaus. Lighter colors represent higher backscatter reflectivity which typically equates to material that is harder or coarser in nature.

Greenhorne & O’Mara, Inc. and Ocean Surveys, Inc., 2004, Vibracore data layer. Final Report Marine Geophysical Investigation for the Evaluation of Sand Resource Areas Offshore Topsail Island North Carolina. Prepared for U.S. Army Corps of Engineers Wilmington District. Data accessed on 2016-01-26 at http://www.saw.usace.army.mil/Portals/59/docs/coastal_storm_damage_reduction/TBGRR/Appx_C1_Geotech_Attachment1.pdf

During the period 27 March to 17 April 2003, Ocean Surveys, Inc. (OSI) conducted a marine geophysical investigation to search for and evaluate potential sand resource (borrow) areas offshore Topsail Island, North Carolina (Figure 1). The area designated for investigation covers the inner continental shelf from approximately Rich Inlet to just northeast of New River Inlet, and lies seaward of the 30 foot depth contour extending 5 nautical miles (nm) offshore. Topsail Island is a barrier island that forms the coastline in the central portion of Onslow Bay and contains numerous public beaches including Topsail, Onslow, Sea Haven, and North Topsail Beaches among others. Several small towns and developments dot the island which stretches from New Topsail Inlet at the southwest end to New River Inlet at the northeast tip and occupies territory in both Pender and Onslow Counties, respectively. This work is part of the continuing effort to replenish the oceanfront of Topsail Island with sand for shoreline stabilization and the protection of property and man made structures from storms. This investigation was performed under contract with Greenhorne & O’Mara, Inc. (G&O) for the Wilmington District (WD) of the U.S. Army Corps of Engineers (USACE).



Gutierrez, B.T., Voulgaris, G., and Thieler, E.R., 2005, Exploring the persistence of sorted bedforms on the inner-shelf of Wrightsville Beach, North Carolina: Continental Shelf Research, v. 25, no. 1, p. 65–90.

Geological studies offshore of Wrightsville Beach, North Carolina reveal subtle large-scale regions of coarse sand with gravel and shell hash (widths between 100 and 200m and negative relief of _1m) that trend obliquely to the coast. It was previously suggested that these regions serve as conduits for sand exchange between the shoreface and inner shelf during storm-associated downwelling. Consequently they were classified as rippled scour depressions. More recently, the role of alongshore flows and self-organization as a result of inhibited settling of fine sand has been discussed. In this study, 45 days of near-bed current measurements were analyzed using benthic boundary layer and sediment transport models to examine the role of along- and cross-shore flows in driving sediment transport at this site. The wind climate was found to be a dominant influence on near-bed flows. Six distinct sediment transport events were recognized. During these events, sediment transport models show that bedload transport is directed mainly in the cross-shore direction, while suspended sediments are directed alongshore to the southwest. Current observations during these sediment transport events provide no evidence of cross-shore sediment transport caused by steady downwelling currents. Instead, benthic boundary layer model results are used to show that differences in bed roughness between the coarse areas of the seabed within the ‘‘rippled scour depressions’’ and the finer areas of the inner shelf are more pronounced during increasingly energetic wave and current conditions. The enhanced difference in roughness results in increased turbulence intensities over coarse regions inhibiting the deposition of the fine sand that is resuspended over the shelf during these events relative to finer areas over the shelf. Findings from this study contribute to explaining the observed long-term persistence of these features.

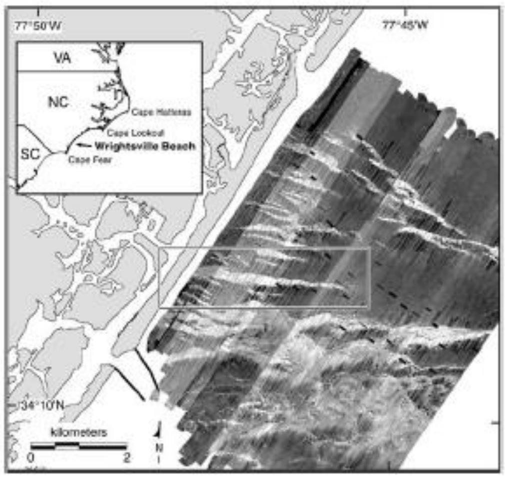


Fig. 1. A sidescan sonar mosaic covering the lower shoreface and inner-shelf offshore of Wrightsville Beach, North Carolina denote the presence of organized high backscatter (lighter areas) regions extending from the shoreface onto the inner shelf. These linear features correspond to very coarse sand and shell-hash providing a reflective surface compared to the darker areas, which are typically comprised of fine-to-medium sand. Outlined area denotes the inner-shelf region investigated in this study. Modified after Thieler et al. (2001).

Harris, M.S., Sautter, L.R., Johnson, K.L., Luciano, K.E., Sedberry, G.R., Wright, E.E., and Siuda, A.N.S., 2013, Continental shelf landscapes of the southeastern United States since the last interglacial: Geomorphology, v. 203, p. 6–24.

The wide, sediment-starved continental shelf and modern coastal areas of the southeastern United States retain well-preserved but scattered remnants of a submerged paleolandscape. This paper presents a conceptual model of stratigraphic deposition and landscape formation since the last interglacial on the continental shelf of South Carolina, with portions of North Carolina, Georgia, and Florida (USA). Data for this study include multibeam bathymetry surveys, sidescan sonar mosaics, high-resolution subbottom profiles, and ground-truth surveys from −250 m to the modern tidewater region. Four bathymetric zones are recognized with eleven landforms and landform indicators. The described zones range in depths from the modern shoreline, across the shelf, and over the shelf edge to−250 mMSL. Relative sea level curves are presented for the area and discussed in conjunction with cultural and climatic events. The potential for preservation of Paleoamerican sites is high at the shelf edge between −130 m and −45 m, with Archaic and later occupations likely in depths of less than −25 m. Prominent vantage points for Paleoamericans (>11 kya) would have existed at the shelf edge, and tidewater resources would have been available nearby for a period of almost 6 ka. Rapid transgression rates (>60 km/ka) after the sea level rose over the shelf edge make preservation of tidewater sites less likely on the outer and middle shelf. Searches for the earliest Paleoamericans should focus on promontories at the edge of the shelf and along future discoveries of paleoincisions on the shelf. Mapping and delineating this paleolandscape and associated unconsolidated sedimentary deposits interspersed with rocky plains and ledges will continue to be a priority to marine archeologists, coastal managers, fishery scientists, and marine spatial planners over the next several decades.

HDR Engineering of the Carolinas with William Cleary, 2003, Vibracore and Grab Sample Location Layer. An Assessment of the Availability of Beach Fill Quality Sand Offshore North Topsail Beach and Surf City, NC.

The United States Army Corps of Engineers (USACE) Wilmington District office is currently preparing a general evaluation report for storm reduction projects along the Town of North Topsail Beach and Surf City, NC. The focal point of the report is the availability of sufficient quantities of beach fill material for the initial project construction and subsequent maintenance during the next 50 years. The USACE Wilmington District has conducted a number of investigations in the Topsail Island area. McQuarrie (1998) and HDR (2002) provided additional information on the unproven sand resource potential of the area offshore of Topsail Beach. The HDR (2002) indicated several potential existing target areas that may contain significant quantities of beach fill material.

It was speculated that a similar sand resource potential would exist off the remainder of Topsail Island; however, the nature of the sedimentary cover was poorly known. In the interest of locating the most economical and environmentally acceptable borrow sites that could support the proposed projects, information of the availability of beach quality material, or its nonavailability, was needed. Therefore, site-specific assessments of each area were necessary. The goal of the investigation was the identification and delineation of suitable borrow sites that contained compatible material for the nourishment projects. An equally important objective was the identification of areas of environmentally sensitive hardbottoms.

Herbert, J.R., 1978, Post-Miocene Stratigraphy and Evolution of Northern Core Banks, North Carolina. Duke University, Thesis.

Fifty-one auger holes ranging from 4.6 m to 36.6 m (15 to 120 ft.) in depth were used to investigate the Quaternary sediments beneath that section of Core Banks north of New Drum Inlet. Five major lithologic units, the Yorktown Formation, Core Creek sand, Atlantic Sand, Diamond City Clay and Core Banks sand, were observed in eight of the auger holes. Particular emphasis was placed on the study of the Holocene Core Banks sand. Eight Holocene depositional environments were recognized in the Holocene sediments. They are overwash and submerged backbarrier sand flat, tidal creek, channel margin, main channel, inlet floor, lagoonal, sound island, and flood-tidal delta environments.

Hill, J.C., Driscoll, N.W., Weissel, J.K., and Goff, J. a., 2004, Large-scale elongated gas blowouts along the U.S. Atlantic margin: Journal of Geophysical Research B: Solid Earth, v. 109, no. 9, p. B09101.

In May 2000 we surveyed a series of en echelon, asymmetric depressions along the outer shelf off Virginia and North Carolina using high-resolution chirp and side-scan sonar. The features, which are elongated parallel to the shelf edge and have steep landward walls, are _4 km long, 1 km wide, and up to 50 m deep. On the basis of internal stratal geometry interpreted from chirp profiles, the depressions do not appear to result from simple, down-to-the-east, normal displacement along deep-seated faults or structure. Rather, the depressions seem to have been excavated primarily by gas expulsion, creating large-scale asymmetric gas escape structures that have been termed ‘‘gas blowouts.’’ Gas appears to have been trapped beneath a shelf edge delta that is a few tens of meters thick and exhibits internal soft sediment deformation suggestive of progressive downslope (seaward) creep. These new data suggest the blowouts occurred when thin-skinned deformation and creep of the surficial deltaic sediment layers combined with updip/ upslope gas migration, ultimately leading to gas pressure in excess of the overburden. The location of the expulsion craters along the shelf edge and their elongated, asymmetric shapes strongly suggests a causal relation between the downslope creep of the delta and the expulsion event. We suggest a positive feedback between upward migration of gas-rich fluids through the low-stand delta and the downslope creep processes. While the complex interplay between differential permeability, overpressure, and upslope fluid migration remains poorly understood, we suggest such interactions may play an important role in controlling slope stability.

Hine, A.C., and Snyder, S.W., 1985, Coastal lithosome preservation: evidence from the shoreface and inner continental shelf off Bogue Banks, North Carolina: Marine Geology, v. 63, p. 307–330.

Seismic and vibracore data from the continental shelf as well as borehole data from an adjacent barrier island indicate that the migrating shoreface, responding to rising sea level, has nearly completely removed the entire coastal sedimentary record in northern Onslow Bay, North Carolina. This process was active throughout the Quaternary and even the late Tertiary as middle Tertiary sediments and rocks directly crop out on the sea floor in vast areas of this shelf sector. Seaward of Bogue Banks (a Holocene barrier island located along northern Onslow Bay) seismic sequences have been truncated by the modern shoreface which extends to about 12 m depth. Correlations with borehole data on the island indicate that these sequences are Pleistocene and Holocene in age. The Holocene sequences contain numerous channels which are interpreted to be relict tidal inlets. However, none extends vertically lower than the shoreface indicating that landward translation of the shoreface would remove most of even the deepest Holocene coastal lithosomes, parts of the Pleistocene and even a portion of the Tertiary.

The middle and inner portions of the continental shelf have been incised by numerous channels. Channel facies are an important component of shelf sedimentary and stratigraphic sequences and comprise about one-third of northern Onslow Bay. Similar seismic infilling facies and vibracore data as well as the poor preservation potential of the tidal inlet throats indicate that the channels were lower coastal plain streams. The infilling sediments are mostly muds with some sands and shells. Dates from shells via the amino acid racemization technique are Pleistocene in age. These channels, with some having multiple infilling events, assume greater importance when one recognizes that essentially they alone hold the vast majority of the Quaternary record of numerous sea-level fluctuations.

Hoffman, C.W., and Brooks, R.W., 2013, Data Layers of Minerals Management Service vibracores from offshore northern Dare County, North Carolina. Included in USGS Quaternary Geophysical Framework of the Northeastern North Carolina Coastal System Open-File Report 2011-1015.

The northeastern North Carolina coastal system, from False Cape, Virginia, to Cape Lookout, North Carolina, has been studied by a cooperative research program that mapped the Quaternary geologic framework of the estuaries, barrier islands, and inner continental shelf. This information provides a basis to understand the linkage between geologic framework, physical processes, and coastal evolution at time scales from storm events to millennia. The study area attracts significant tourism to its parks and beaches, contains a number of coastal communities, and supports a local fishing industry, all of which are impacted by coastal change. Knowledge derived from this research program can be used to mitigate hazards and facilitate effective management of this dynamic coastal system.

The North Carolina Geological Survey (NCGS) collected 56 vibracores totaling about 300 meters in August, 1996 offshore of Dare County, North Carolina. This work was performed under cooperative agreement 14-12-0001-30348 between the NCGS and U.S. Minerals Management Service (MMS) as part of an investigation to delineate potential sand resource deposits in federal waters for use as beach nourishment.

Inman, D.L., and Dolan, R., 1989, The Outer Banks of North Carolina : Budget of Sediment and Inlet Dynamics Along a Migrating Barrier System: Journal of Coastal Research, v. 5, no. 2, p. 193–237.

The Outer Banks are barrier islands separating Pamlico, Albemarle and Currituck Sounds from the Atlantic Ocean. These barriers are transgressing landward, with average rates of shoreline recession of 1.4 m/yr between False Cape and Cape Hatteras. Oregon Inlet, 63 km north of Cape Hatteras, is the only opening in the nearly 200 km between Cape Henry and Cape Hatteras which bounds the Hatteras Littoral Cell. Oregon Inlet is migrating south at an average rate of 23 m/yr and landward at a rate of 5 m/yr. The net southerly longshore transport of sand in the vicinity of Oregon Inlet is between one-half and one million m3/yr. Oregon Inlet is the most dynamic physical feature within the Hatteras Littoral Cell. The combination of waves and tidal currents deposit ebb-tide bars offshore of the entrance and form extensive tidal islands, bars and shoals in Pamlico Sound. These deposits lag behind as the inlet migrates. The offshore deposits are gradually returned to the beach by waves and reincorpor-ated into the littoral drift system. The flood-tide inlet deposits in the sound are eventually rein-corporated into the landward migrating barrier as the inlet moves to the south. The integrity of the landward side of the transgressing barrier is maintained by washover deposits, wind-blown sand deposits, and inlet deposits. Averaged over the 160 km from False Cape to Cape Hatteras, sealevel rise accounts for 21% of the measured shoreline recession of 1.4 m/yr. Analysis of the budget of sediment indicates that the remaining erosion of 1.1 m/yr is apportioned between overwash processes (39%), long-shore transport out of the cell (22%), windblown sand transport (18%), inlet deposits (10%), and removal by dredging at Oregon Inlet (11%). This analysis indicates that the barrier system moves as a whole, so that the sediment balance is relative to the moving shoreline (Lagrangian grid). Application of a continuity model to the budget suggests that, in places, the barrier sys-tem is supplied with sand from the shelf.

Lee, G., 2002, Examination of diffusion versus advection dominated sediment suspension on the inner shelf under storm and swell conditions, Duck, North Carolina: Journal of Geophysical Research, v. 107, no. C7, p. 3084.

The sedimentary processes of a cape-associated shoal are an integral component of the sediment budget of the surrounding cuspate foreland shoreline. The manner in which sediment is delivered to a shoal and the fate of this sediment, once delivered, have important implications to shoreline management and yet remain largely unstudied. Modern sedimentary processes and the recent depositional history of Cape Lookout Shoal, a large cape-associated shoal in the mixed-energy environment of the North Carolina continental shelf, were examined in a field-intensive study through high-resolution seismic profiles, hydraulic probes, near-bottom current meters, sediment grab samples, and detailed bathymetric surveys. Our findings indicate that: (1) the sediment budget of the up-drift littoral cell is coupled directly to Cape Lookout Shoal, (2) the sedimentary processes of the shoal remain active down its entire length but at a diminishing level with distance from the shore, and (3) the shoal serves as a long-term sink for littoral-zone sediment and limits sediment exchange between adjacent littoral cells and shelf regions. We present evidence suggesting that the position and morphology of Cape Lookout Shoal are not controlled by underlying erosion-resistant strata and that the shoal appears to have developed in the late Holocene after the shelf was scoured by the transgressing shoreface.

Lentz, S., Guza, R.T., Elgar, S., Feddersen, F., and Herbers, T.H.C., 1999, Pressure gauge data layer from Momentum balances on the North Carolina inner shelf: Journal of Geophysical Research, v. 104, no. C8, p. 205–218.

Four months of moored current, pressure, temperature, conductivity, wave, and wind observations on the North Carolina shelf indicate three dynamically distinct regions: the surf zone, the inner shelf between the surf zone and the 13-m isobath, and the midshelf. In the surf zone the along-shelf momentum balance is between the cross-shelf gradient of the wave radiation stress and the bottom stress. The linear drag coefficient in the surf zone is about 10 times larger than seaward of the surf zone. On the inner shelf the along-shelf momentum balance is also frictional; the along-shelf wind stress and pressure gradient are balanced by bottom stress. In the cross-shelf momentum balance the pressure gradient is the superposition of roughly equal contributions from the Coriolis force (geostrophy) and wave setdown from shoaling, unbroken surface gravity waves. At midshelf the along-shelf momentum balance is less frictional and hence flow accelerations are important. The cross-shelf momentum balance is predominantly geostrophic because the greater depth and smaller bottom slope at midshelf reduce the importance of wave setdown. The cross-shelf density gradient is in thermal wind balance with the vertical shear in the along-shelflow in depths as shallow as 10 m. The dominant along-shelf momentum balances provide a simple estimate of the depth-averaged, along-shelf current in terms of the measured forcing (i.e., wind stress, wave radiation stress divergence, and along-shelf pressure gradient) that reproduces accurately the observed cross-shelf variation of the depth-averaged, along-shelf current between the surf zone and midshelf.

Lentz, S., 2001, Current and Pressure data layer from The Influence of Stratification on the

Wind-Driven Cross-Shelf Circulation over the North Carolina Shelf: Journal of Physical Oceanography, v. 31.

Wind-driven, cross-shelf circulation is studied using current observations spanning the 90 km wide North Carolina shelf. Most of the shelf is less than 40 m deep. Current measurements were made at five sites within 16 km of the coast from August through October or early December 1994 and at mid- and outer-shelf sites from February 1992 through February 1994. In both studies the water column was stratified in summer and often unstratified during fall and winter. The presence or absence of stratification had a profound influence on the wind-driven, cross-shelf circulation over this shallow shelf. When the water column was stratified, the wind-driven cross-shelf circulation was consistent with a twodimensional upwelling/downwelling response. Over the mid and outer shelf, near-surface and near-bottom crossshelf transports had similar magnitudes but opposite directions and were approximately equal to the Ekman transports associated with the alongshelf wind stress and bottom stress, respectively. Wind-driven cross-shelf transports decreased toward the coast over a cross-shelf scale of ø10 km, suggesting that upwelling and downwelling were confined near the coast during stratified conditions. Stratification may be maintained in the region of transport divergence near the coast by a balance between vertical mixing and buoyancy forcing. When the water column was unstratified the wind-driven cross-shelf circulation at all mooring sites was substantially reduced relative to the stratified response for moderate to strong wind stresses (| ts | . 0.1 N m22); consistent with an Ekman depth greater than the water depth. The dependence of the cross-shelf transport on wind stress and water depth is roughly consistent with an unstratified, two-dimensional model where the eddyviscosity profile depends on the stress and distance from the boundaries. Both observations and model results suggest that during unstratified conditions much of the divergence or convergence in the wind-driven crossshelf transport, and hence the associated upwelling and downwelling, occurs near the shelfbreak on this shallow shelf.

Mallinson, D., Riggs, S., Thieler, E.R., Culver, S., Farrell, K., Foster, D.S., Corbett, D.R., Horton, B., and Wehmiller, J.F., 2005, Late Neogene and Quaternary evolution of the northern Albemarle Embayment (mid-Atlantic continental margin, USA): Marine Geology, v. 217, no. 1-2, p. 97–117.

Seismic surveys in the eastern Albemarle Sound, adjacent tributaries and the inner continental shelf define the regional geologic framework and provide insight into the sedimentary evolution of the northern North Carolina coastal system. Litho and chronostratigraphic data are derived from eight drill sites on the Outer Banks barrier islands, and the Mobil #1 well in eastern Albemarle Sound.Within the study area, parallel-bedded, gently dipping Miocene beds occur at 95 to N160 m below sea level (m bsl), and are overlain by a southward-thickening Pliocene unit characterized by steeply inclined, southward-prograding beds. The lower Pliocene unit consists of three seismic sequences. The 55–60 m thick Quaternary section unconformably overlies the Pliocene unit, and consists of 18 seismic sequences exhibiting numerous incised channel-fill facies. Shallow stratigraphy (b40 m bsl) is dominated by complex fill patterns within the incised paleo-Roanoke River valley. Radiocarbon and amino-acid racemization (AAR) ages indicate that the valley-fill is latest Pleistocene to Holocene in age. At least six distinct valley-fill units are identified in the seismic data. Cores in the valley-fill contain a 3–6 m thick basal fluvial channel deposit that is overlain by a 15 m thick unit of interlaminated muds and sands of brackish water origin that exhibit increasing marine influence upwards. Organic materials within the interlaminated deposits have ages of 13–11 cal. ka. The interlaminated deposits within the valley are overlain by several units that comprise shallow marine sediments (bay-mouth and shoreface environments) that consist of silty, fine- to medium-grained sands containing open neritic foraminifera, suggesting that this area lacked a fronting barrier island system and was an open embayment from ~10 ka to ~4.5 ka. Seismic data show that initial infilling of the paleo-Roanoke River valley occurred from the north and west during the late Pleistocene and early Holocene. Later infilling occurred from the south and east and is characterized by a large shoal body (Colington Island and Shoals) and adjacent inlet fill. Establishment of a continuous barrier island system across the bay-mouth resulted in deposition of the latest phase of valley-fill, characterized by estuarine organic-rich muds.

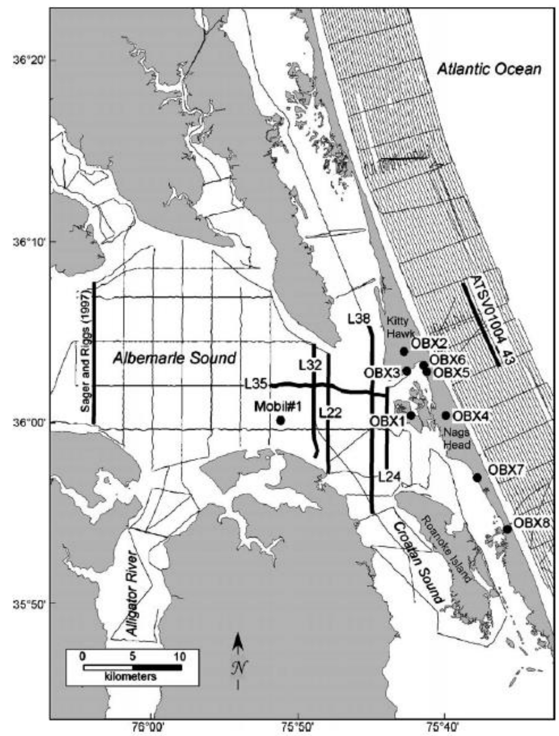


Fig. 2. Map showing the location of all seismic lines (gray lines) from eastern Albemarle Sound and the offshore area. Bold lines with line labels are discussed and presented in this paper. Also shown are the locations of OBX cores (OBX-2 though -8) presented and discussed in this paper.

McNinch, J.E., and Wells, J.T., 1999, Sedimentary processes and depositional history of a cape-associated shoal, Cape Lookout, North Carolina: Marine Geology, v. 158, p. 233–252.

The sedimentary processes of a cape-associated shoal are an integral component of the sediment budget of the surrounding cuspate foreland shoreline. The manner in which sediment is delivered to a shoal and the fate of this sediment, once delivered, have important implications to shoreline management and yet remain largely unstudied. Modern sedimentary processes and the recent depositional history of Cape Lookout Shoal, a large cape-associated shoal in the mixed-energy environment of the North Carolina continental shelf, were examined in a field-intensive study through high-resolution seismic profiles, hydraulic probes, near-bottom current meters, sediment grab samples, and detailed bathymetric surveys. Our findings indicate that: (1) the sediment budget of the up-drift littoral cell is coupled directly to Cape Lookout Shoal, (2) the sedimentary processes of the shoal remain active down its entire length but at a diminishing level with distance from the shore, and (3) the shoal serves as a long-term sink for littoral-zone sediment and limits sediment exchange between adjacent littoral cells and shelf regions. We present evidence suggesting that the position and morphology of Cape Lookout Shoal are not controlled by underlying erosion-resistant strata and that the shoal appears to have developed in the late Holocene after the shelf was scoured by the transgressing shoreface.

McNinch, J.E., and Luettich, R.A., 2000, Current meter data layer from Physical processes around a cuspate foreland: Implications to the evolution and long-term maintenance of a cape-associated shoal: Continental Shelf Research, v. 20, no. 17, p. 2367–2389.

Understanding across-margin transport has long been recognized as crucial for wise management of our coastline and shelf waters. Issues related to sewage outfalls, nutrient and pollutant dispersal, carbon export, and shoreline sediment budgets all require an understanding of these processes. Across-margin transport of water and sediment at cuspate foreland headlands has been largely unrecognized, and the processes responsible for this export unappreciated. We examined physical process on Cape Lookout Shoal, a cape-associated shoal on the North Carolina continental shelf, through numerical modeling and field observations of near-bottom currents. The cuspate foreland setting of the northern South Atlantic Bight has been previously characterized as wave-dominated with a principal alongshore directed sediment transport and physical circulation forced by wave and wind-driven currents along the inner and mid-shelf. Our fndings instead suggest that a seaward-directed, tidal-driven headland flow may play a significant role in the direction of net sediment transport on the shoal and ultimately its location and long-term maintenance. The shoal's location relative to the promontory-induced residual eddies and the region of active deposition differs from traditionally held ideas on sedimentary processes at headland-related sand banks. In addition, the headland flows may also serve as a first-order mechanism for rapidly exporting nearshore and estuarine waters to the outer-shelf.

McNinch, J.E., Wells, J., and Drake, T., 2001, The Fate of Artifacts in an Energetic, Shallow-Water Environment: Scour and Burial at the Wreck Site of Queen Anne’s Revenge: Southeastern Geology, v. 40, no. 1, p. 19–27.

A poor understanding of the physical environment often hinders management of marine artifacts. A study was conducted of an early-18th-century shipwreck to test whether the wreckage could have settled through ~3.5 m of substrate. Results indicate that the wreck could have settled via episodic scour processes driven by storms and tidal inlet migration. A numerical model, modified to include characteristics of the underlying geology, predicts continued scour under moderate waves. Scour processes appear to have been interrupted by an erosion-resistant underlying layer, so that the wreck now remains exposed, subject to degradation. A generalized approach to predict burial or exposure of other shallow-water artefacts is developed.

McNinch, J., 2013, Vibracore Data Layer collected from nearshore off of Duck, North Carolina in 2005. Included in USGS Quaternary Geophysical Framework of the Northeastern North Carolina Coastal System Open-File Report 2011-1015.

The northeastern North Carolina coastal system, from False Cape, Virginia, to Cape Lookout, North Carolina, has been studied by a cooperative research program that mapped the Quaternary geologic framework of the estuaries, barrier islands, and inner continental shelf. This information provides a basis to understand the linkage between geologic framework, physical processes, and coastal evolution at time scales from storm events to millennia. The study area attracts significant tourism to its parks and beaches, contains a number of coastal communities, and supports a local fishing industry, all of which are impacted by coastal change. Knowledge derived from this research program can be used to mitigate hazards and facilitate effective management of this dynamic coastal system.

This GIS layer contains the station navigation for vibracores collected in the Outer Banks in May and July of 2005. These cores, which were used to verify interpretations of high-resolution seismic-reflection profiles, can be used to provide useful information about the framework geology of the nearshore region.

Meisburger, E.P., and Williams, S.J., 1987, Trackline and grab sample data layer from Late Quaternary Stratigraphy and Geological Character of Coastal and Inner Shelf Sediments of Northern North Carolina: Coastal Sediments.

The Quaternary stratigraphic section and sedimentary character of the barrier coast and shelf of Northern North Carolina was investigated using deep borings and vibracores, grab samples, continuous seismic reflection profiles, sidescan sonar, and self-contained underwater breathing apparatus (SCUBA) observations. Analyses of the cores and te geophysical data show that the Quaternary secion is composed of four lithologic units having fairly distinct seismic signatures, mineralogy, and faunal compostion. Grab samples and sidescan sonographs reveal that shoreface and shelf sediments are generally of finer grain size and better sorted than the coarse textured beach. Exceptions are the mesoscale shoals, exhibiting relief up to 10 m on the sheld which are composed of medium to coarse shelly sands. Sidescan and SCUBA diver observations show megaripple bedforms overlie about 30 percent of the area, predominantly on the shoal flanks, while smaller scale ripples are very common on the shoreface. The bedform patterns and sediment texture distributions confirm that the transgressive sand sheet is in equilibrium with the modern storm-dominated hydraulic regime.

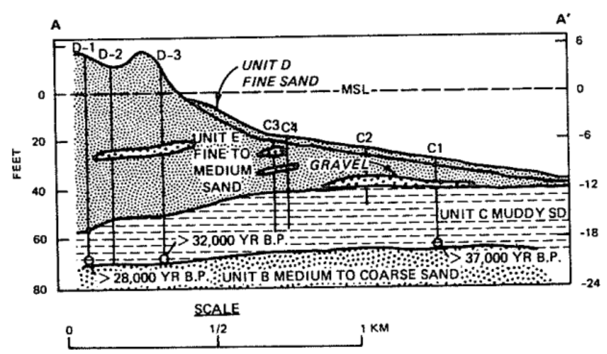


Figure 4. Cross Section of the Barrier and Shoreface Based on Borings and Cores on Transect A-A'. See Fig. 2 for location. Modified from Field et al. (1979).

Michel, J., 2004, Regional Management Strategies for Federal Offshore Borrow Areas, U.S. East and Gulf of Mexico Coasts: Journal of Coastal Research, v. 20, no. 1, p. 149–154.

With the increased demand for Federal sand and gravel resources on the outer continental shelf, the Minerals Management Service (MMS) is developing strategies for environmentally sound and fiscally responsible management of the resource. A process is needed for planning, decision making, and coordination among stakeholders. Two workshops were conducted in Texas and New Jersey to solicit input from Federal, State, and local government representatives, university researchers, and private companies on key issues. Based on the results of the workshop, it was recommended that sand management task forces be established in each state, starting with those states that can provide a strong technical and administrative lead and have a high level of interest in accessing Federal borrow sites. Sand management task forces would be responsible for planning, coordinating, and facilitating the use of OCS sand for beach nourishment and coastal restoration projects. MMS's responsibilities include taking the lead in the design and funding of long-term monitoring studies of the impacts of dredging OCS sand, sponsoring workshops on technical and policy issues, and providing a clearinghouse for dissemination of studies and findings on actual environmental impacts, focusing on key issues such as cumulative impacts.

Miselis, J.L., and McNinch, J.E., 2006, Calculating shoreline erosion potential using nearshore stratigraphy and sediment volume: Outer Banks, North Carolina: Journal of Geophysical Research: Earth Surface, v. 111, no. 2.

Despite the acknowledged influence of coastal geological framework on the behavior of beaches and barrier islands and a wealth of geological and bathymetric observations from the inner shelf, quantitatively connecting those observations to shoreline behavior has been difficult. Nearshore geologic and morphologic variability described by recent research is not well represented by conventional geologic parameters, such as mean grain size and shoreface slope, used in most shoreline change models. We propose that total nearshore sediment volume, as calculated to a continuous seismic reflection surface, provides a flexible and robust metric for use in the prediction of shoreline change. This method of determining the volume of sediment in the nearshore accounts for threedimensional sandbar morphologies and heterogeneous seafloor sediments. The decadalscale shoreline change rate for northeastern North Carolina is significantly correlated to the volume of sediment in the nearshore when a geologically defined base is used in volume determinations, suggesting that the shallow stratigraphic framework of transgressive coasts is an important influence on decadal shoreline behavior. Nearshore sediment volume was overestimated when an arbitrary depth-constant baseline was used and was not correlated to decadal shoreline change. This implies that a volume metric which accounts for both framework geology and variable seafloor morphology better represents the geologic character of the shoreface and may help to improve existing models of shoreline change. An empirical model of regional shoreline erosion potential demonstrates the importance of incorporating nearshore sediment volume, shallow framework geology, and surface morphology when predicting seasonal to decadal shoreline evolution.

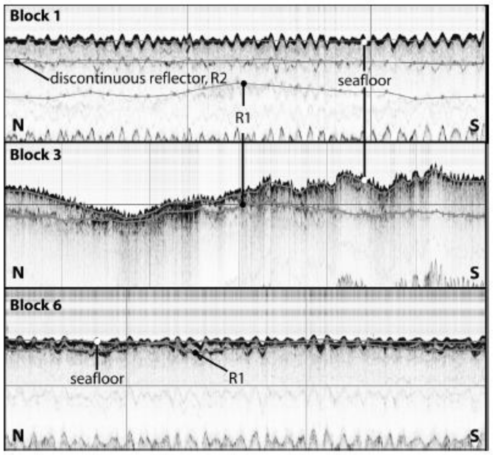


Figure 5. Seismic reflection data collected at 1750 m s^{-1} in 5 km segments. Block 1: a typical seismic profile from the northern region of the survey area. Note the presence of two reflection surfaces here, R1 being the lower of the two. Block 3: a seismic profile collected near Kitty Hawk, North Carolina, showing a shore-oblique bar in cross section in the southern part of the profile. Note that R1 is exposed at the surface of the seafloor just to the north of the shore-oblique bar. Block 6: a seismic profile typical of those collected near Nags Head, North Carolina, and in the southern region of the survey area. Note that the discontinuous reflector, R2, is missing from the profile.

Moslow, T.F., 1977, Quaternary Evolution of Core Banks, North Carolina from Cape Lookout to New Drum Inlet. Duke University Thesis.

Forty-six auger and wash-bore holes were drilled along a 36 km segment of Core Banks, North Carolina, to examine the Quaternary geologic history of a typical mid-Atlantic barrier island. Particular attention has been focused on the Holocene evolution of Core Banks including its origin, landward migration and overall response to a transgressing sea. Fifteen holes penetrated to a Tertiary basement. All 46 were drilled through the Holocene sequence. Six lithologic units were identified.

Ten depositional environments were identified within the Holocene sediments. In five isolated sections the Holocene stratigraphy is completely reworked by tidal inlets that opened, migrated and closed sometime during the past 4,000 years. Arcuate, relict flood-tidal deltas on the soundside of Core Banks are found in association with each of these inlets.

The southernmost four to five km of Core Banks, including Cape Lookout, has been formed by spit accretion during the past 4,000 years. Here a regressive sequence of overwash sands overlying shoreface deposits occurs within the Holocene.

Core Banks probably originated as part of an elongating spit or by mainland beach detachment on the nearshore shelf about 15,000 years ago. From this time and position, Core Banks has steadily migrated landward in response to a rising sea. Rates. of landward migration were calculated using Holocene C-14 dates and projected locations of paleoshorelines.

Paleoshorelines were located using the assumption that the entire shoreface has moved and changed its configuration with the rising sea level according to the Swift concept of shelf evolution. Core Banks has migrated about 6.7 km landward over the past 7,000 years. From 7,000-4,000 BP, the island migrated at rates ranging from 98 m to 79 m per century. This migration slowed to less than 1 m per century ~p to about 755 BP.

Murray, A.B., and Thieler, E.R., 2004, A new hypothesis and exploratory model for the formation of large-scale inner-shelf sediment sorting and “rippled scour depressions”: Continental Shelf Research, v. 24, no. 3, p. 295–315.

Recent observations of inner continental shelves in many regions show numerous collections of relatively coarse sediment, which extend kilometers in the cross-shore direction and are on the order of 100m wide. These ‘‘rippled scour depressions’’ have been interpreted to indicate concentrated cross-shelf currents. However, recent observations strongly suggest that they are associated with sediment transport along-shore rather than cross-shore. A new hypothesis for the origin of these features involves the large wave-generated ripples that form in the coarse material. Wave motions interacting with these large roughness elements generate near-bed turbulence that is greatly enhanced relative to that in other areas. This enhances entrainment and inhibits settling of fine material in an area dominated by coarse sediment. The fine sediment is then carried by mean currents past the coarse accumulations, and deposited where the bed is finer. We hypothesize that these interactions constitute a feedback tending to produce accumulations of fine material separated by self-perpetuating patches of coarse sediments. As with many types of self-organized bedforms, small features would interact as they migrate, leading to a better-organized, larger-scale pattern. As an initial test of this hypothesis, we use a numerical model treating the transport of coarse and fine sediment fractions, treated as functions of the local bed composition—a proxy for the presence of large roughness elements in coarse areas. Large-scale sorted patterns exhibiting the main characteristics of the natural features result robustly in the model, indicating that this new hypothesis offers a plausible explanation for the phenomena.

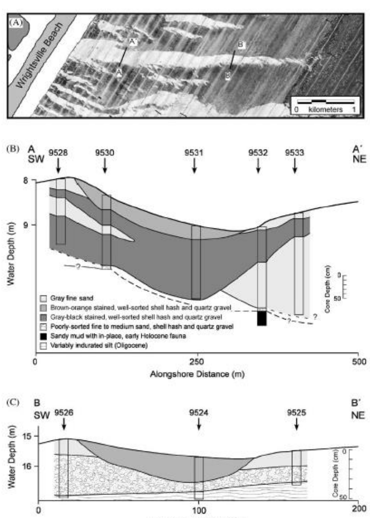


Fig. 2. Map and cross-sections showing the morphology and stratigraphy of a sorted bedform on the shoreface and inner continental shelf off Wrightsville Beach, North Carolina. (A) Sidescan sonar image and locations of cross-sections. In this image, high acoustic backscatter sediments (generally coarse material such as shell hash and gravel) are shown as light- to white-colored. Low acoustic backscatter sediments (generally fine sand) are shown as dark to black. (B) and (C) Cross-sections of the sorted bedform shown above. Morphology and stratigraphy are based on vibracores (core locations indicated by numbered arrows), bathymetric mapping, and diver observations.

National Centers for Environmental Information Multiple Investigators, 2015, Marine Geology Data Archive Layer. Dataset accessed at 2016-01-26.

Marine Geologic data compilations and reports in the NCEI archive are from academic and government sources around the world. Over ten terabytes of analyses, descriptions, and images of sediment and rock from the ocean floor and lakebeds are available. Examples of data available include sediment/rock composition, physical properties, petrology/mineralogy, geochemistry, paleontology, paleomagnetism, x-rays, photographs, and other imagery. All reports and data, regardless of format, are accessible via the Marine Geology Digital Inventory and/or linked to the Index to Marine and Lacustrine Geological Samples (IMLGS). Searches offer free, immediate download of digital data, many images, and .PDF reports, and information on how to obtain full-resolution images from the archive, and order CD-ROMs, microfilm, or oversize charts. Some larger data sets, including the IMLGS, have their own web interfaces. The IMLGS provides searches of sea floor and lakebed cores, grabs, dredges, and drill samples available from sample repositories at partner institutions, with links to browse and download related information from NCEI and other sources.

NOAA National Centers for Environmental Information, 2015, U.S. Coastal Relief Model Data Layer. Dataset accessed at 2016- 01-26 at http://www.ngdc.noaa.gov/mgg/coastal/crm.html.

NGDC's U.S. Coastal Relief Model (CRM) provides the first comprehensive view of the U.S. coastal zone integrating offshore bathymetry with land topography into a seamless representation of the coast. The CRM spans the U.S. East and West Coasts, the northern coast of the Gulf of Mexico, Puerto Rico, and Hawaii, reaching out to, and in places even beyond, the continental slope. Bathymetric and topographic data sources include: NGDC's NOS hydrographic surveys, multibeam bathymetry, and trackline bathymetry; the U.S. Geological Survey (USGS); and other federal government agencies and academic institutions. Bathymetric contours from the International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico project were also used. Digital elevation models (DEMs) of the Great Lakes, Southern Alaska, and high-resolution DEMs of U.S. coastal communities and territories are also available. To provide long-term scientific data stewardship for the Nation's geophysical data, ensuring quality, integrity, and accessibility.

NOAA National Centers for Environmental Information Bathymetric Data Viewer, 2016. Bathymetric layers coverage. Dataset accessed at 2016-07-27 at https://maps.ngdc.noaa.gov/viewers/bathymetry/

Polygons were digitized to delineate the coverage of several single-beam bathymetric datasets compiled on NOAA’s Bathymetric Data Viewer. Data was collected in 1967 and 1968 by the US Navy Naval Oceanographic Office. Additionally, large areas in Onslow and Long Bays were surveyed in 1983 by the USGS Branch of Pacific Marine Geology.

National Geophysical Data Center, 1976, The NGDC Seafloor Sediment Grain Size Database. National Geophysical Data Center, NOAA. Dataset accessed at 2016-01-26

doi:10.7289/V5G44N6W

The NGDC (now NCEI) Seafloor Sediment Grain Size Database contains particle size data for over 17,000 seafloor samples worldwide. The file was begun by NGDC in 1976 in response to a need by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) for a detailed, digital file of textural analyses. Data are from OCSEAP studies, academic institutions, environmental baseline studies conducted under contract to the Bureau of Land Management under the Outer Continental Shelf (OCS) Program, and from laboratory reports generated by the U.S. Naval Oceanographic Office. Data include collecting institution, ship, cruise, sample id, latitude/longitude, date of collection, water depth, sampling device, method of analysis, sample weight, sampled interval, raw weight percentages of sediment, within a given phi range. Some samples also have percentages of total gravel, sand, silt, clay, and statistical measurements such as mean, median, skewness, kurtosis, and standard deviation of grain size.

North Carolina Department of Environmental Quality and Moffat and Nichol, 2011, Sediment Resource Inlets, Dredging location, DCM sandbag, beach nourishment, beach bulldozing, structures, and Sediment resource data layers from N.C. Beach and Inlet Management Plan Final Report. Dataset accessed at 2016- 01-26 at http://portal.ncdenr.org/web/cm/bimp-final-report1.

North Carolina is renowned for its 326 miles of ocean shoreline, barrier islands and 19 active inlet complexes. North Carolina beaches and inlets have tremendous economic value and serve as important habitat for fish and wildlife resources. Beaches and inlets support millions of recreational visitors every year, provide billions of dollars in economic value through business and tourism, provide ocean access for commercial and recreational fishermen, and are an integral part of the state's history, culture, identity, and way of life. However, without effective planning and management, the future of the state's coastal communities and a significant part of the state's economic base could be adversely affected by storms, sea-level rise, shifting shorelines, and erosion. The North Carolina Department of Environment and Natural Resources (DENR) is committed to the longterm conservation and management of the state's beaches and inlets. As part of this commitment, the Beach and Inlet Management Plan (BIMP) was developed by the Division of Water Resources (DWR) and the Division of Coastal Management (DCM) in order to provide the necessary information to address the natural resources, funding mechanisms and strategies for the comprehensive management of the state's ocean and inlet shorelines. The BIMP is the first statewide compilation of data and issues related to managing the beaches and inlets. The framework for development of the BIMP is the culmination of past efforts, legislative actions, studies and recommendations.

A beach nourishment database has been compiled from several sources to provide a comprehensive summary of the States nourishment activities. Sources include the U.S. Army Corps of Engineers, Center for Developed Shorelines, Carteret County Beach Preservation Plan, Spencer Rogers of North Carolina Sea Grant, and Tom Jarrett with Coastal Planning & Engineering, Inc. The database extends over a time period from 1939 through 2007

A dredging database has been compiled from 1975 to 2007 for projects performed or contracted by the USACE. Projects occurring prior to these dates were obtained from the North Carolina

Historic Dredging Data book from the Wilmington district of the USACE. In a previous study by Moffatt & Nichol on shallow draft navigation (November 2005), a database was created of all shallow draft projects from 1975 through 2004. Deep draft projects and projects from 2005 to 2007 were added to this database. Dredge projects in Region 4 are limited to Region 4b (Oregon Inlet). Locations of dredge projects in Region 4b can be seen in Figure XI-36. The complete dredge database is available in Appendix E.

Ocean Dredged Material Disposal Sites (ODMDS) designated by EPA for dredged material disposal under section 102 of the Marine Protection, Research, and Sanctuaries Act (MPRSA). Dataset accessed at 2016- 01-26 at GSAA Coast & Ocean Portal http://gsaaportal.org/.

This GIS dataset was created for purpose of describing the locations of ocean disposal sites (ODMDS) for the state of North Carolina so that these data can be considered with respect to other data on coastal resources and activities. This dataset represents Ocean Dredged Material Disposal Sites (ODMDS) areas designated by EPA for dredged material disposal under section 102 of the Marine Protection, Research, and Sanctuaries Act (MPRSA). EPA designated sites are to be used for ocean disposal to the extent feasible.

Ocean Surveys, I., 2003, Final Report Topsail Beach Marine Geophysical Investigation, Offshore of Topsail Island, Onslow Bay, North Carolina: Map Appendix.

This appendix contains additional site and geologic maps, along with equipment and seismic Interpretation figures. This was part of a larger effort to assess offshore sand borrow sources for Nourishment at Topsail Beach, NC in 2003.

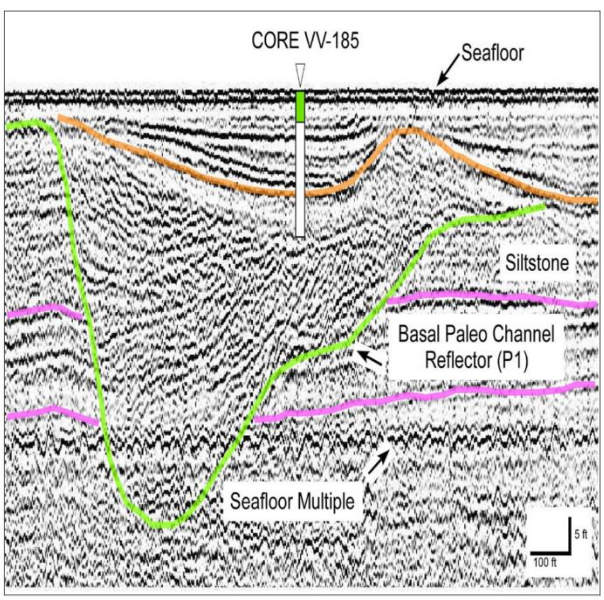


Figure 8. Seismic reflection "boomer" profile of paleochannel P1 in Zone 1, revealing the depth of this relict channel feature. Green shading in the core represents suitable sand identified by the WD (4.5 ft in core VV-185). Note younger basal channel reflector (orange) truncates the top of the older channel sequence of paleochannel P1.
[Seismic data from Line 56]

Ocean Surveys, I., 2004a, Final Report Geophysical Survey of Sediment Deposits Offshore Bogue Island Onslow Bay, North Carolina:, accessed at OSI Report #01ES094 Prepared for U.S. Department of the Army Wilmington District. Core layer.

During the period 8-29 January 2002, Ocean Surveys, Inc. (OSI) conducted a marine geophysical investigation in Onslow Bay offshore Bogue Island, North Carolina. The survey investigation focused on assessing potential sand resources and areas of hardbottom within a semi-rectangular area measuring approximately 28 by 5 statute miles located approximately ½-statute mile offshore of Bogue Island and extending between Beaufort and Bogue Inlets (Figure 1). The investigation, conducted for the Army Corps. of Engineers (ACOE) - Wilmington District, was completed in accordance with Contract No. DACW54-98-D-0017 (Task Order 0010) and is part of an on-going effort by the ACOE to replenish the oceanfront on Bogue Island with sand for shoreline stabilization and protection of property. A letter report, submitted by OSI in February 2002 (included in its entirety in Appendix 1) following completion of the survey, provides a summary of the field investigation and an overview of the equipment utilized with manufacturer equipment specifications attached. The previously submitted letter report also includes a data discussion section and recommends a vibratory coring plan to ground-truth the acquired geophysical data. Following submittal of the letter report, OSI re-examined the acquired subbottom data at the request of the ACOE to propose additional core locations for ground-truthing. This additional proposed set of cores was submitted to the ACOE on 12 April 2002 in a digital CAD drawing file entitled addcore.dgn. The following report presents an evaluation and review of the acquired geophysical data based on the results of the ground-truth vibratory coring program performed in support of the project by the ACOE (April-July 2002).

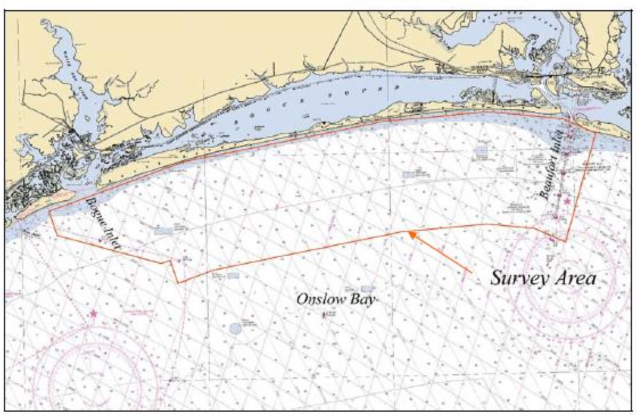


Figure 1 – Site location map (taken from NOAA Chart No11543).

Ocean Surveys, I., 2004b, Final Report Marine Geophysical Investigation for the Evaluation of Sand Resource Areas: Offshore Topsail Island, North Carolina New Topsail Inlet to New River Inlet in Onslow Bay.

During the period 27 March to 17 April 2003, Ocean Surveys, Inc. (OSI) conducted a marine geophysical investigation to search for and evaluate potential sand resource (borrow) areas offshore Topsail Island, North Carolina (Figure 1). The area designated for investigation covers the inner continental shelf from approximately Rich Inlet to just northeast of New River Inlet, and lies seaward of the 30 foot depth contour extending 5 nautical miles (nm) offshore. Topsail Island is a barrier island that forms the coastline in the central portion of Onslow Bay and contains numerous public beaches including Topsail, Onslow, Sea Haven, and North Topsail Beaches among others. Several small towns and developments dot the island which stretches from New Topsail Inlet at the southwest end to New River Inlet at the northeast tip and occupies territory in both Pender and Onslow Counties, respectively. This work is part of the continuing effort to replenish the oceanfront of Topsail Island with sand for shoreline stabilization and the protection of property and man made structures from storms. This investigation was performed under contract with Greenhorne & O'Mara, Inc. (G&O) for the Wilmington District (WD) of the U.S. Army Corps of Engineers (USACE).

Park, J., and Wells, J.T., 2005, Longshore Transport at Cape Lookout , North Carolina : Shoal Evolution and the Regional Sediment Budget: Journal of Coastal Research, v. 21, no. 1, p. 1–17.

The Cape Lookout cuspate foreland has undergone significant offshore accretion since the first rudimentary field studies were conducted in the 1800s. Despite the wave-dominated setting, however, little is known about littoral processes under the wide range of wave conditions that impact the complicated coastal geometry at the cape. In this study we examined littoral processes, driven by longshore currents, using a numerical wave refraction/diffraction model (Ref/Dif 1) and through use of aerial photographs and nautical charts. Results show that longshore current direction and speed, as expected, are highly variable and depend primarily on incoming wave direction. Southerly longshore currents on Core Banks predominate under northeast and east wave approaches, whereas weaker northerly currents are generated under southeast and south wave approaches. The result of these patterns provides a source of sediments to Cape Lookout Shoal. Results show the sediment input from Core Banks to the shoal is of the order 512,000 to 581,000 m3/yr. The western limb of the system receives a portion of these sediments, which are released from the shoal and transported north by waves that approach from the southeast, south, and southwest. Predicted longshore currents on the shoal indicate that repeated extension and retreat of Cape Lookout Point would result from the imbalance between southerly longshore currents on the east side of the shoal and northerly longshore currents on the west side. Cape Lookout Shoal may play a role in protecting sections of adjacent barrier islands by interfering with shoreward wave propagation and by allowing waves to focus energy onto their offshore subaqueous areas. It is still unclear, however, how sediments on the northern proximal regions of the shoal are transported to the distal regions farther south.

Piatkowski, D. and J.P. Walsh. 2014. BOEM's Coastal Resiliency Planning Initiatives and Ongoing Efforts in North Carolina. NC Beach and Inlet Waterways Association Annual Meeting, Wrightsville Beach, NC.

The extent and magnitude of erosion and storm damage along the U.S. coastline is increasing as a consequence of widespread development, management challenges, and sea level and storm impacts. As the nation's steward of offshore non-energy mineral resources, the Bureau of Ocean Energy Management (BOEM) in the U.S. Department of the Interior (DOI) is integrally involved in supporting short- and long-term coastal resiliency initiatives along the Atlantic and Gulf coastlines. Through negotiated lease agreements, BOEM's Marine Minerals Program (MMP) serves an important role in supporting coastal resiliency initiatives by granting access to sand and gravel resources from the Outer Continental Shelf (OCS). However, sand is a finite resource,

and state resources are being depleted. Because of this reality, coupled with a growing regional demand, BOEM is challenged with the responsibility of optimizing resource use while considering a myriad of physical, biological, economic, and social implications.
Following Hurricane Sandy in October 2012, the demand for sand to support immediate recovery and long-term sustainability of vulnerable coastal communities stimulated broader collaboration between federal, state, and private sector entities. This expanded dialog highlighted the need for a change in perspective from a project centric focus to a broader regional approach. In 2013, BOEM received $13.6 million through the Disaster Relief Appropriations Act to address critical needs for OCS sand and gravel throughout the Atlantic coastal areas undergoing recovery and rebuilding. In the spirit of long-term coastal resiliency planning, BOEM allocated approximately $5 million to conduct Geophysical and Geological (G&G) surveys to identify and delineate OCS sand resources from Maine through Florida and determine sediment suitability (e.g., grain size) for potential use for resiliency initiatives; this yielded the Broad Agency Announcement (BAA). Additionally, BOEM awarded cooperative agreements with 13 coastal states affected by Hurricane Sandy, including North Carolina, to evaluate and consolidate existing data and help prioritize future work.

BOEM and East Carolina University (ECU) recently signed a two-year cooperative agreement ($200,000) to evaluate available data offshore of the North Carolina coast. Under this agreement, ECU will find and obtain, if possible, existing G&G data offshore of North Carolina. These data will be combined into a database and ultimately will be used to characterize potential sand resource areas, specifically in northeastern NC, an area strongly impacted by Hurricane Sandy. The overall goal is to have data available and accessible for planners and managers. The database generated will web-accessible to managers and the public, allowing informed decision making and cost effective coastal resiliency project planning. The results from this effort will help guide G&G data acquisition efforts in the BAA.

The combined efforts of the 13 state Cooperative Agreements and the BAA will allow a broader regional focus on resource needs for resiliency efforts. To optimize use while minimizing environmental impacts, BOEM is moving towards use of Marine Spatial Planning exercises in conjunction with research conducted under the Environmental Studies Program. This will enable the science needed to inform long-term planning decisions that (1) avoid multi-use conflicts, (2) optimize efficient and cost effective use of sand resources while (3) minimizing environmental impacts. The goal of developing a consolidated map of state and Federal sand resources along the entire Atlantic Coast from Maine through Florida is an unprecedented endeavor that is important to BOEM's stewardship role in managing offshore sand and gravel resources.

Reid, J.M., Reid, J.A., Jenkins, C.J., Hastings, M.E., Williams, S.J., Poppe, L.J., Norton, G.A., and Survey, U.S.G., 2005, Five Sediment Property Data Layers from usSEABED : Atlantic Coast Offshore Surficial Sediment Data Release: U.S. Geological Survey Data Series 118, version 1.0. Online at http://pubs.usgs.gov/ds/2005/118/.

Over the past 50 years there has been an explosion in scientific interest, research effort and information gathered on the geologic sedimentary character of the U.S. Atlantic Coast continental margin. Data and information from thousands of publications have greatly increased our scientific understanding of the geologic origins of the shelf surface but rarely have those data been combined and integrated.

This publication is the first release of the Atlantic coast data from the usSEABED database. The report contains a compilation of published and unpublished sediment texture and other geologic data about the seafloor from diverse sources. usSEABED is an innovative database system developed to bring assorted data together in a unified database. The dbSEABED system is used to process the data. Examples of maps displaying attributes such as grain size and sediment color are included. This database contains information that is the scientific foundation for the USGS Marine Aggregate Resources and Processes Assessment and Benthic Habitats projects, and will be useful to the marine science community for other studies of the Atlantic coast continental margin.

Rice, T.M., Beavers, R.L., Snyder, S.W., Beach, R.P., Duck, S.O., Carolina, N., Beavers, L., and Stephen, W., 1998, Vibracore and trackline data layers from Preliminary Geologic Framework of the Inner Continental Shelf Offshore Duck, North Carolina, U.S.A.: Journal of Coastal Research, Special Issue, no. 26, p. 219–225. Vibracore and trackline data layers.

230 kilometers of very high-resolution (3.5 kHz) seismic reflection profiles were collected seaward of the USACE Field Research Facility located on the northern Outer Banks of North Carolina in 1997. The 62 square kilometer area extends from the lower shoreface (12 m) across the inner shelf to 24 m water depth. These data, supplemented by preliminary analyses of 20 vibracores (6 m maximum penetration), demonstrate that this section of the continental shelf is being exhumed by modern erosional processes. The subbottom stratigraphy is characterized by a stacked series of thin tabular Quaternary sequences which (1) crop out on the seafloor, and (2) are cut by multiple paleofluvial channels. The lower shoreface is underlain by an active sand sheet which thins to less than 1 meter at about 11-12 m water depth. Shoreward of 12 m the bathymetry is relatively steep and smooth; seaward of 12 m the seabed is characterized by low undulating topography. At approximately 18 m water depth, the bathymetry portrays significant (> 3 m) topographic variability. The transition from smooth to highly irregular bathymetry parallels an apparent increase in the number of paleofluvial channels that crop out on the seafloor. The tidal lithologies identified by vibracores pen etrating these sequences and channel-fill sections imply that (1) abrupt lateral and vertical facies changes are common, and (2) the fabric and geotechnical strength of the lithic material significantly influences the seafloor topography on a local scale (10’s to 100’s of meters).

Riggs, S., Snyder, S., Hine, A., Snyder, S., Ellington, D., and Mallette, P., 1985. Vibracore and seismic coverage layers.Geologic Framework of Phosphate Resources in Onslow Bay , North Carolina Continental Shelf.
Economic Geology 80, p. 716-738.

High-resolution Uniboom, sparker, and 3.5 kHz subbottom seismic profiles, in combination with 9-m vibracores from Onslow Bay, delineate a belt of Neogene sediments which crop out on the North Carolina continental shelf around the east flank of the mid-Carolina platform high. This broad, southeast-trending basement high has controlled the general distribution of Cenzoic sediment sequences within the mid-Atlantic continental margin. The Neogene section includes the Miocene Pungo River Formation, which thickens downdip to the east and southeast off the mid-Carolina platform high. The Pungo River Formation consists of three third-order and at least 21 fourth-order seismic depositional sequences, many of which are abruptly truncated by erosional surfaces and associated channels. These seismic sequences reflect third- and fourth-order eustatic sea-level cycles within the Miocene second-order transgressive sea-level cycle. The fourth-order seismic sequences appear to be equivalent to cyclic lithostratigraphic units characterized by interbedded phosphoritc sands, phosphatic foraminiferal muds, calcareous quartz sands, calcarenites, and dolosilts. Some phosphoritc sands also occur in the Holocene sand sheet which forms a thin and discontinuous cover on the Pungo River sediments in the Frying Pan phosphate district. Preliminary evaluation of phosphate resources in Ohslow Bay has delineated several potential economic prospects. The Pungo River Formation crops out in a northeastsouthwest-trending belt which is 150 km long by 25 to 50 km wide and extends into the subsurface to the east and southeast. In two different areas within Onslow Bay, vibracores have penetrated five beds which contain anomalous concentrations of phosphate. Two beds within the Frying Pan phosphate district are estimated to contain 3.75 billion metric tons of phosphate concentrate with an average content of 29.2 percent P20•. The other three beds in the northeast Onslow Bay phosphate district are extensive units with low to intermediate phosphate content within the total sediment (up to 9.8% P205). These three "lean" deposits contain at least 780 million metric tons of phosphate concentrate with average P•O5 contents which range from 29.7 to 31 percent. Phosphate resources in the Frying Pan phosphate district have a moderate to high potential for economic development, whereas those in the northeast Onslow Bay phosphate district have a low potential for economic development. This newly discovered continental shelf phosphate province could become economically feasible to mine in the near future when rapidly expanding demand for fertilizers and agricultural products, combined with ever-increasing land-use pressures, produces an unacceptable escalation in the cost of mining land-based reserves.

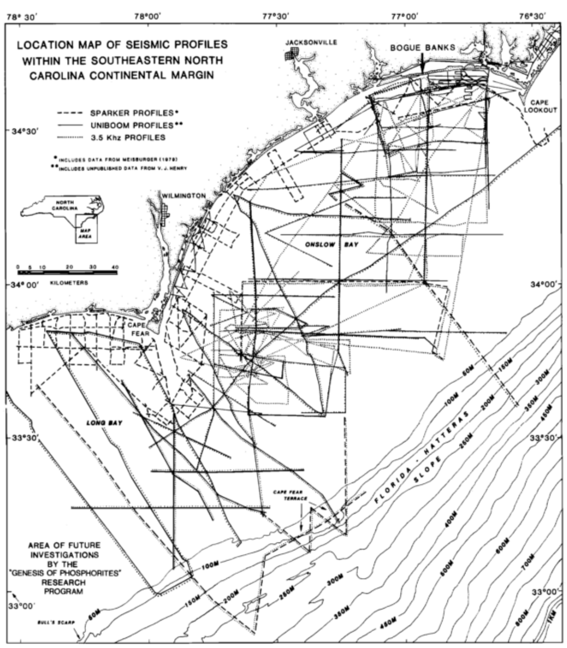


FIG. 4. Map of Onslow and Long Bays showing the interpreted high-resolution seismic subbottom profile data base.

Riggs, S.R., Cleary, W., and Snyder, S., 1995, Influence of inherited geologic framework on barrier shoreface morphology and dynamics. Marine Geology 126, p. 213-234.

Passive margin coastlines with limited sand supplies, such as much of the U.S. Atlantic margin, are significantly influenced by the geologic framework of older stratigraphic units that occur beneath and seaward of the shoreface. Many U.S. east coast barrier islands are *perched barriers* in which the underlying, pre-modern sediments determine the morphology of the shoreface and strongly influence modern beach dynamics and composition. Perched barriers consist of varible layers of beach sand on top of older, eroding stratigraphic units with highly variable compositions and geometries. Along many parts of the coastal system, stratigraphically-controlled bathymetric features on the inner shelf modify waves and currents and thereby effect patterns of sediment erosion, transport, and deposition on the adjacent shoreface. It is essential to understand this geologic framework before attempting to model the large-scale behavior of these types of coastal systems.

In North Carolina, most shoreline features are controlled by the pre-Holocene stratigraphic framework of the shoreface; the beaches are perched on top of pre-existing Pleistocene, Tertiary, and Cretaceous sediments. The surficial geology of the coastal zone is subdivided into two distinct provinces resulting in different stratigraphic controls of the shoreface. North of Cape Lookout the geological framework consists of a Quaternary sequence that fills a regional depositional basin called the Albemarle Embayment. The coastal zone south of Cape Lookout is dominated by Tertiary and Cretaceous units that crop out across the coastal plain and continental shelf, with very thin Quaternary units only locally preserved. Superimposed upon this regional stratigraphy is an ancient drainage system resulting in a series of fluvial valleys filled with younger coastal sediments separated by large interfluve areas of older stratigraphic units. This results in a coastal system in which the shoreface is either nonheadland or headland dominated, respectively. Headland dominated shorefaces are further divided into subaerial and submarine categories. Nonheadland dominated shorefaces are further divided into those influenced primarily by transgressive or regressive processes, or channel-dominated depositional processes (i.e., inlet migration or stream valley fill). Examples of each of these six types of shorefaces are presented to demonstrate the control that the geologic framework exhibits on shoreface morphologies and processes.

Riggs, S.R., Snyder, S.W., Hine, A.C., and Mearns, D.L., 1996, Hardbottom morphology and relationship to the geological framwork: Mid-Atlantic continental shelf: Journal of Sedimentary Research, v. 66, no. 4, p. 830–846.

High-energy, sediment-starved continental shelves of the mid-Atlantic region have abundant hardbottoms that extend from the shoreface to the shelf edge. Because of the thin and irregularly distributed Holocene sand sheet, shelf morphology is determined mainly by outcropping Tertiary and Pleistocene stratigraphic units. Each unit and combination of units produces different hardbottom morphologies that depend upon the geometry and spatial relationships of the units, lithology and patterns of stratification, and subsequent weathering and erosion. Hardbottoms vary in surface relief from smooth, flat surfaces to scarped surfaces with up to 10 m of relief. The morphology ranges from sloping and stepped erosional ramps to vertical and undercut scarps with associated broad rubble ramps. Hardbottoms associated with each of the different gently dipping Tertiary depositional sequences have distinctive morphologies. Hardbottoms developed on Pleistocene units unconformably overlie the Tertiary sequences as flat-lying marine carbonates, or cut into them as channel systems backfilled with fluvial and estuarine sediments. Initial dissection of hardbottoms produced highly convoluted surfaces that resulted from subaerial weathering, stream erosion, and karst formation during sea-level lowstands. During subsequent sea-level highstands, these primary morphologies were greatly modified through the interaction of bioerosion and storms. Understanding continental shelf hardbottoms is critical for interpreting the sedimentology and stratigraphy of the Atlantic Coastal Plain and for reconstructing paleoceanographic conditions, for the following reasons. (1) They are an extensive part of the stratigraphic record on shelves that are not actively subsiding and have small volumes of terrigenous input with low sediment accumulation rates. (2) They are important stages in the formation of major stratigraphic unconformities, condensed sections, and sequence boundaries. (3) They support diverse biological communities that produce primary carbonate sediments and are rapidly degraded and modified by bioerosion and physical processes supplying abundant "new sediment" to the continental shelf.

Robinson, M.M., and McBride, R. a., 2008, Vibracore data layer from Anatomy of a shoreface sand ridge revisited using foraminifera: False Cape Shoals, Virginia/North Carolina inner shelf: Continental Shelf Research, v. 28, no. 17, p. 2428–2441.

Certain details regarding the origin and evolution of shelf sand ridges remain elusive. Knowledge Of their internal stratigraphy and microfossil distribution is necessary to define the origin and to determine the processes that modify sand ridges. Fourteen vibracores from False Cape Shoal, a well-developed shoreface-attached sand ridge on the Virginia/North Carolina inner continental shelf, were examined to document the internal stratigraphy and benthic foraminiferal assemblages, as well as to reconstruct the depositional environments recorded in down-core sediments. Seven sedimentary and foraminiferal facies correspond to the following stratigraphic units: fossiliferous silt, barren sand, clay to sandy clay, laminated and bioturbated sand, poorly sorted massive sand, fine clean sand, and poorly sorted clay to gravel. The units represent a Pleistocene estuary and shoreface, a Holocene estuary, ebb tidal delta, modern shelf, modern shoreface, and swale fill, respectively. The succession of depositional environments reflects a Pleistocene sea-level highstand and subsequent regression followed by the Holocene transgression in which barrier island/spit systems formed along the Virginia/North Carolina inner shelf 5.2 ka and migrated landward and an ebb tidal delta that was deposited, reworked, and covered by shelf sand.

Savidge, D.K., and Bane, J.M., 2001, Wind and Gulf Stream influences on along-shelf transport and off-shelf export at Cape Hatteras, North Carolina: Journal of Geophysical Research, v. 106, no. C6, p. 11505.

Along-shelf transports across three cross-shelf lines on the continental shelf near Cape Hatteras have been calculated from moored current meter data over a continuous 24 month period in 1992–1994. The along-shelf convergence has been used to infer off-shelf export. Transport and transport convergence have been related to wind and Gulf Stream forcing and to variability in sea level at the coast. The along-shelf transport variability is primarily wind-driven and highly correlated with sea level fluctuations at the coast. Both winds and along-shelf transport exhibit a near-annual period variability. Along-shelf transport is not well correlated with Gulf Stream offshore position. Along-shelf transport convergence is highly correlated with Gulf Stream position offshore, with a more shoreward Gulf Stream position leading increased along-shelf convergence by hours to a few days. Long-period variability of 14–16 months and 1–3 months is apparent in both Gulf Stream position and transport convergence. Variability in along-shelf convergence is poorly correlated with wind, wind convergence, or coastal sea level. A likely hypothesis accounting for the observed relationship between Gulf Stream position and along-shelf transport convergence is that the Gulf Stream is directly influencing cross-shelf export processes along the outer boundary of the study site. Despite predominantly convergent flow on the shelf at Cape Hatteras, brief periods of along-shelf divergence and shoreward cross-shelf transport exist (∼10% of the time just north of Cape Hatteras and ∼34% of the time just south of Cape Hatteras during episodes of up to 3–8 days duration). Implied onshore flows of a few cms are tentatively identified in the moored current meter data for these periods. Satellite imagery for an extended along-shelf divergent period clearly suggests that shelf edge parcels could be advected a significant fraction of the way across the shelf.

Schnitker, D., 1967, Distribution of foraminifera on the North Carolina Continental Shelf. University of Illinois, Ph.D.

The purpose of this study is threefold: first, to inventory the foraminiferal faunas of the continental shelf of North Carolina, second, to determine quantitatively the composition of the foraminiferal populations; and third, to describe the distribution of these populations within the study area. Interpretation of the faunal data attempts to characterize distinctive habitats and to relate particular distributions to the general oceanography of the area.

Shideler, G.L., and Swift, D.J.P., 1972, Trackline layer. Seismic Reconnaissance of Post-Miocene Deposits, Middle Atlantic Continental Shelf-Cape Henry, Virginia to Cape Hatteras, North Carolina: Marine Geology, v. 12, p. 165–185.

A seismic reconnaissance survey was conducted to examine post-Miocene deposits on the Middle Atlantic Shelf between Cape Henry, Virginia and Cape Hatteras, North Carolina. Approximately 900 km of continuous seismic reflection profiles were obtained, employing a 400-joule high resolution boomer system.

The post-Miocene section unconformably overlies a furrowed and discordant Tertiary substrate. The basal unconformity appears to be of regional extent, and its configuration supports the presence of an eastward-trending ancestral Albemarle fluvial channel near the present mouth of Albemarle Sound. A basal sedimentary sequence of pre-Wisconsinan and Early Wisconsinan age is widespread, and comprises most of the post-Miocene section. It contains both transgressive fluvial deposits, and regressive coastal barrier lithosomes. An overlying sequence of Late Wisconsinan age was deposited in a regressive paralic-neritic environment. Holocene deposits, unconformably overlying the Pleistocene sequence, form a discontinuous sand sheet whose upper surface is molded into a north- or northeast-trending ridge and swale topography.

The morphology of the outer shelf and shelf break is variable throughout the region. Prominent wave-cut terraces reflecting Pleistocene glacio-eustatic movements are present, except in the southern third of the region. Most areas of the outer shelf exhibit ridge and swale systems which appear to be polygenetic. Variations in shelf break morphology suggest differential rates of Holocene sedimentation and shelf development. Shelf upbuilding and progradation are minimal near Cape Henry, and maximal near Cape Hatteras where Diamond Shoals may be actively advancing eastward across the shelf.

Swift, D.J.P., Sears, P.C., and Bohlke, B., 1978, Evolution of a shoal retreat massif, North Carolina shelf: Inferences from areal geology: Marine Geology, v. 27, p. 19–42.

The Albemarle Shelf Valley Complex on the northern North Carolina Shelf is a leveed shelf-floor channel trending seaward from the modern Alhemarle estuary. Vibracores and seismic profiles indicate that the levees have a twofold internal structure. Levee cores consist of fine sand interbedded with mud lenses. The cores are mantled with a generally coarser, cleaner sand. The levees are interpreted as shoal retreat massifs; deposits formed as the littoral-drift depositional centers on either side of the ancestral Albemarle estuary retreated landward during the Holocene transgression.

The shelf-valley complex underwent systematic changes in bottom morphology and sediment character as the reversing tidal jet of the estuary mouth was replaced by the intermittent south-trending storm flows of the open shelf. A pattern of ridges and troughs with 10 m of relief was incised into north sides of the massifs flanking the shelf valley.

The coarser surficial sand into which the bedform pattern has been impressed appear to be a lag deposit formed by the winnowing of the massifs during storm flow. On ridge crests this surficial sand sheet has been molded into sand waves up to 3 m high. The relative orientations of sand waves, ridges, and the shoreline indicate that the structure of the velocity field during peak flows must be quite complex. Ridges converge southward with the shoreline at angles of 15--20 ° , while the sand waves atop them make angles of about 75 ° with the shoreline; the sand waves are thus neither orthogonal with respect to the shoreline nor with respect to the ridges. Sand-wave orientation indicates southward bottom flow with an offshore component.

Existing hydrodynamical theory does not adequately explain this pattern. Extensive hydraulic measurements of careful design will be required so we can interpret the bedform pattern and its role in the coastal sand budget.

Thieler, E.R., Brill, A.L., Cleary, W.J., Hobbs, C.H., and Gammisch, R.A., 1995, Geology of the Wrightsville Beach , North Carolina shoreface : Implications for the concept of shoreface profile of equilibrium: Marine Geology, v. 126, p. 271–287.

Nearly 300 km of 3.5 kHz subbottom profile and 100 kHz sidescan-sonar data, a suite of over 100 short (-2 m) percussion cores and vibracores have been collected on the shoreface and inner continental shelf off Wrightsville Beach, North Carolina. Sidescan-sonar images were analyzed for acoustic backscatter to delineate the surface sediment distribution. Groundtruth data for the sidescan-sonar interpretations were provided by surface grab samples. Cross-shore sediment transport by combined waves and currents is the predominant sedimentologic signature on this shoreface. The shoreface is dominated by a shore-normal system of rippled scour depressions that begin in 3-4 m water depth and extend to the base of the shoreface about 1 km offshore, at 10 m depth. The depressions are 40-100 m wide, and up to 1 m deep. They are floored by coarse, rippled shell hash and gravel; some are separated by rock-underlain fine sand ridges. On the inner shelf, the bathymetric and sedimentary fabrics become shore-oblique, due to a series of relict ridges with l-2 m of relief. The ridges are coarse on their landward sides and covered on their seaward flanks by thin veneers of fine sand. Field evidence from the Wrightsville Beach shoreface demonstrates that a shoreface equilibrium profile as defined by Dean (1991) and others does not exist here. For example: (1) the grain size varies widely and inconsistently over the profile; (2) shoreface profile shape is controlled predominantly by underlying geology, including Tertiary limestone outcrops and Oligocene silts; and (3) sediment transport patterns cannot be explained by simple diffusion due to wave energy gradients, and that transport occurs seaward of the assumed engineering “closure depth” of 8.5 m. This has several implications for the application of equilibrium profile-based numerical models used to investigate coastal processes and design coastal engineering projects at Wrightsville Beach. The most important practical implication is that a number of assumptions required by existing analytical and numerical models (e.g., Dean, 1991; GENESIS; SBEACH) used for the design of shore protection projects and large-scale coastal modeling over decadal time scales cannot be met.

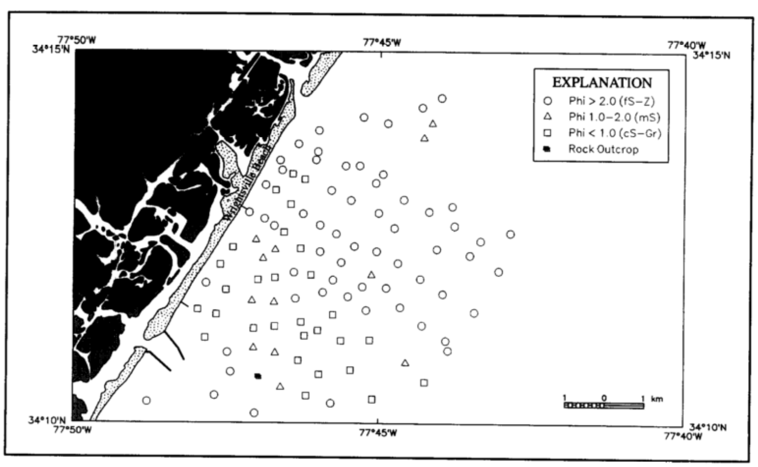


Fig. 3. Grain size classification for surface sediment samples obtained off Wrightsville Beach. There is little uniformity in grain size distribution across the shoreface.

Thieler, E.R., Gayes, P., Schwab, W.C., and Harris, M.S., 1999, Tracing sediment dispersal on nourished beaches; two case studies: Coastal Sediments ’99, v. 4, no. 3, p. 2118–2136.

The event- to decade-scale patterns of sediment dispersal on two artificially nourished beaches have been mapped using a combination of geophysical surveys, closely-spaced vibracores, and repeated beach profiles. At both Wrightsville Beach, NC and Folly Island, SC the sediment used for beach nourishment is macroscopically distinct from native sediment and can be used to identify sediment transport pathways and infer mechanisms for across-shelf transport. The data from both sites demonstrate that significant quantities of nourishment sediment are being transported seaward onto the inner continental shelf. The time and space scales of this transport are of engineering interest for the planning, design and long-term maintenance of nourished beaches.

Thieler, R., Pilkey, O., Cleary, W., and Schwab, W., 2001, Sidescan coverage and vibracore layers. Modern Sedimentation on the Shoreface and Inner Continental Shelf at Wrightsville Beach, North Carolina, U.S.A. Journal of Sedimentary Research 71 (6).

The geologic framework and surficial morphology of the shoreface and inner continental shelf off the Wrightsville Beach, North Carolina, barrier island were mapped using high-resolution sidescan-sonar, bathymetric, and seismic-reflection surveying techniques, a suite of over 200 diver vibracores, and extensive seafloor observations by divers. The inner shelf is a sediment-starved, active surface of marine erosion; modern sediments, where present, form a patchy veneer over Tertiary and Quaternary units. The lithology of the underlying units exerts a primary control on the distribution, texture, and composition of surficial sediments, as well as inner-shelf bathymetry.

The shoreface is dominated by a linear, cross-shore morphology of rippled scour depressions (RSDs) extending from just seaward of the surf zone onto the inner shelf. On the upper shoreface, the RSDs are incised up to 1 m below surrounding areas of fine sand, and have an asymmetric cross section that is steeper-sided to the north. On the inner shelf, the RSDs have a similar but more subdued cross-sectional profile. The depressions are floored primarily by shell hash and quartz gravel. Vibracore data show a thick (up to 1.5 m) sequence of RSD sediments that unconformably overlies ancient coastal lithosomes. In this sediment-starved inner shelf setting, rippled scour depressions probably form initially on preexisting coarse-sediment substrates such as modern lag deposits of paleofluvial channel lithosomes or ancient tidal inlet thalwegs. Interannual observations of seafloor morphologic change and the longer-term record contained in vibracores suggest that the present seafloor morphology is either relatively stable or represents a recurring, preferential morphologic state to which the seafloor returns after storm-induced perturbations. The apparent stability is interpreted to be the result of interactions at several scales that contribute to a repeating, self-reinforcing pattern of forcing and sedimentary response which ultimately causes the RSDs to be maintained as sediment-starved bedforms responding to both along-shore and across-shore flows.

Sediment accumulation from over 30 years of extensive beach nourishment at Wrightsville Beach appears to have exceeded the local shoreface accommodation space, resulting in the "leaking" of beach and shoreface sediment to the inner shelf. A macroscopically identifiable beach nourishment sediment on the shoreface and inner shelf was used to identify the decadal-scale pattern of sediment dispersal. The nourishment sediment is present in a seaward-thinning wedge that extends from the beach over a kilometer onto the inner shelf to waters depths of 14 m. This wedge is best developed offshore of the shoreline segment that has received the greatest volume of beach nourishment.

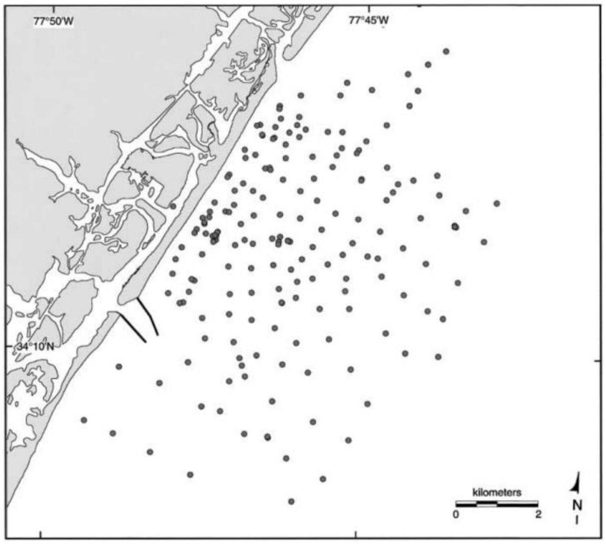


FIG. 5.—Map showing the locations of vibracores obtained on the shoreface and inner shelf off Wrightsville Beach, North Carolina.

Thieler, R.E., Foster, D.S., Mallinson, D.J., Himmelstoss, E.A., McNinch, J.E., List, J.H., and Hammar-Klose, E.S., 2013, Trackline, bathymetry and vibracore layers with associated .jpegs, Quaternary geophysical framework of the northeastern North Carolina coastal system: U.S. Geological Survey Open-File Report 2011–1015. Data accessed at 2016-01-26 http://pubs.usgs.gov/of/2011/1015/.

The northeastern North Carolina coastal system, from False Cape, Virginia, to Cape Lookout, North Carolina, has been studied by a cooperative research program that mapped the Quaternary geologic framework of the estuaries, barrier islands, and inner continental shelf. This information provides a basis to understand the linkage between geologic framework, physical processes, and coastal evolution at time scales from storm events to millennia. The study area attracts significant tourism to its parks and beaches, contains a number of coastal communities, and supports a local fishing industry, all of which are impacted by coastal change. Knowledge derived from this research program can be used to mitigate hazards and facilitate effective management of this dynamic coastal system.

Thieler, E.R., Foster, D.S., Himmelstoss, E.A., and Mallinson, D.J., 2014, Geologic framework of the northern North Carolina , USA inner continental shelf and its influence on coastal evolution: Marine Geology, v. 348, p. 113–130.

The inner continental shelf off the northern Outer Banks of North Carolina was mapped using sidescan sonar, interferometric swath bathymetry, and high-resolution chirp and boomer subbottom profiling systems. We use this information to describe the shallow stratigraphy, reinterpret formation mechanisms of some shoal features, evaluate local relative sea-levels during the Late Pleistocene, and provide new constraints, via recent bedform evolution, on regional sediment transport patterns. The study area is approximately 290 km long by 11 km wide, extending from False Cape, Virginia to Cape Lookout, North Carolina, in water depths ranging from 6 to 34 m. Late Pleistocene sedimentary units comprise the shallow geologic framework of this region and determine both the morphology of the inner shelf and the distribution of sediment sources and sinks. We identify Pleistocene sedimentary units beneath

Diamond Shoals that may have provided a geologic template for the location ofmodern Cape Hatteras and earlier paleo-capes during the Late Pleistocene. These units indicate shallow marine deposition 15–25 mbelowpresent sea-level. The uppermost Pleistocene unit may have been deposited as recently as Marine Isotope Stage 3, although some apparent ages for this timing may be suspect. Paleofluvial valleys incised during the Last Glacial Maximum traverse the inner shelf throughout the study area and dissect the Late Pleistocene units. Sediments deposited in the valleys record the Holocene transgression and provide insight into the evolutionary history of the barrier-estuary systemin this region. The relationship between these valleys and adjacent shoal complexes suggests that the paleo-Roanoke River did not form the Albemarle Shelf Valley complex as previously proposed; a major fluvial systemis absent and thus makes the formation of this feature enigmatic. Major shoal features in the study area show mobility at decadal to centennial timescales, including nearly a kilometer of shoal migration over the past 134 yr. Sorted bedforms occupy ~1000 km2 of seafloor in Raleigh Bay, and indicate regional sediment transport patterns between Capes Hatteras and Lookout that help explain long-term sediment accumulation and morphologic development. Portions of the inner continental shelf with relatively high sediment abundance are characterized by shoals and shoreface attached ridges, and where sediment is less abundant, the seafloor is dominated by sorted bedforms. These relationships are also observed in other passive margin settings, suggesting a continuum of shelf morphology that may have broad application for interpreting inner shelf sedimentation patterns.

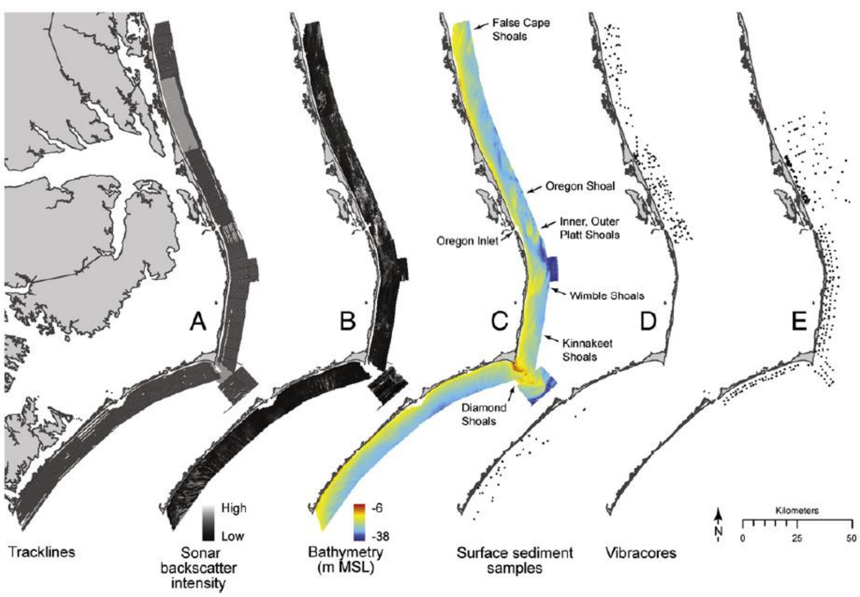


Fig. 2. Maps showing data used in this study. A) Tracklines for chirp and boomer seismic systems, sidescan sonar, and bathymetry systems. Dark gray indicates swath bathymetry, light gray indicates single-beam fathometer (off Duck and inner portion of Diamond Shoals). B) Sidescan sonar mosaic, depicting low acoustic backscatter (fine-grained sediments) as dark tones, and high acoustic backscatter (coarse-grained sediments) as light tones. C) Bathymetry compiled from swath and single-beam sources, with shoal features described in text identified. D) Locations of Van Veen surface sediment samples used to ground truth acoustic backscatter data. E) Locations of sediment cores collected by other studies, and made available by the North Carolina Geological Survey for this study.

Timmons, E.A., Rodriguez, A.B., Mattheus, C.R., and DeWitt, R., 2010, Transition of a regressive to a transgressive barrier island due to back-barrier erosion, increased storminess, and low sediment supply: Bogue Banks, North Carolina, USA: Marine Geology, v. 278, no. 1-4, p. 100–114.

Although back-barrier erosion is a prevalent process of island narrowing, it is often overlooked in conceptual models of barrier island evolution. In many wave-dominated barrier island settings, the absence of overwash precludes landward movement of the back-barrier shoreline and hence the island as a whole from sustaining its width. Typically, regressive barriers are wide and exhibit high elevations with the most seaward dune ridge possessing the highest elevation. This morphology may prevent overwash and inlets from breaching the barrier, and therefore the associated sediment from reaching the back-barrier shoreline for millennia. Backbarrier shoreline erosion from sea-level rise and storms can be permanent in the absence of sediment supply from rivers, overwash, and inlet processes. With continued narrowing and lowering of the island, regressive barriers may reach a critical state, making overwash and inlet formation imminent and transitioning the island to a transgressive barrier. The modern day morphologic variability along the 40-km long island of Bogue Banks, North Carolina includes both regressive and transgressive segments, making this setting ideal for examining whether the transition between these barrier island types is gradual or threshold-driven. Bogue Banks consists of two discrete segments characterized by high-elevation beach ridges, large island widths, and stratigraphy consistent with regressive barrier islands. These regressive-island segments are separated by a broad, narrow section of the island devoid of any washover fans, flood-tide deltas or other transgressive elements. Analyses of seismic data from the inner continental shelf reveal paleochannels intersecting the wide sections of the island, while the narrow central part of the island occupies an interfluvial area. Reworking of fluvial sediment from paleochannels was an important sediment source for the barrier during regression. Optically Stimulated Luminescence (OSL) dates from the most landward beach ridges constrained initiation of island regression at ~3000 cal yr BP, close to when there was a significant decrease in the rate of relative sea-level rise from ~5 mm/yr to ~0.8 mm/yr. Transects of cores, seismic data, ground penetrating radar data, and radiocarbon and OSL dates show that prior to ~1500 cal yr BP the central narrow section of the island was wide and progradational, similar to adjacent areas. Back-barrier erosion of the central part of the barrier primarily caused island narrowing as a result of increased storminess, which occurred around the Medieval Climate Anomaly (~1100 cal yr BP). This part of the island was more vulnerable to erosion than adjacent areas due to increased bay-ravinement (Bogue Sound is widest there) and its lower elevation (farther away from paleochannel-sediment source). Relict inlet channels exist along the central portion of the island, formed within the last 250 yr, and likely closed shortly after formation. The presence of historical inlets along the narrow central section of the island indicates Bogue Banks may be nearing a critical width threshold and will subsequently transition to a transgressive barrier. Because the change in barrier morphology associated with back-barrier erosion occurred over a period of time when the rate of sea-level rise was relatively low, low sediment supply and increased storm frequency are shown to be the main forcing mechanisms of island narrowing. These impacts, in addition to a predicted increase in sea-level rise rates and human modifications (e.g. maintenance of a high-elevation foredune, closing of inlets, prevention of island overwash and associated sediment delivery to the back-barrier shoreline) will likely promote rapid transition of regressive barrier islands to those dominated by transgressive processes.

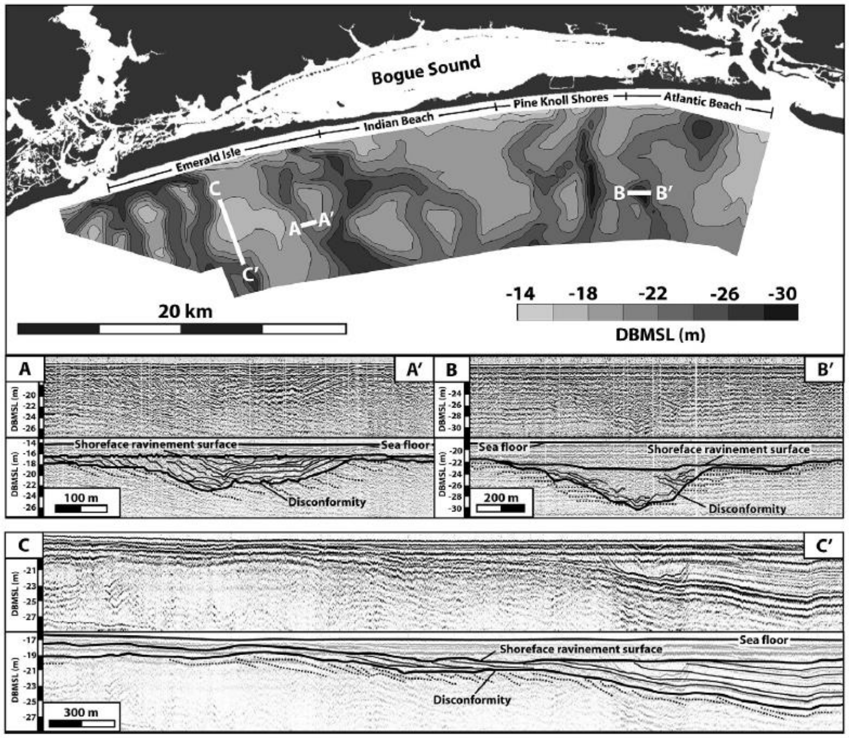


Fig. 3. Contoured structure map, in depth below mean sea-level (DBMSL), of the disconformity showing locations of the paleochannels. Examples of seismic data, from which the map is based (A–A′, B–B′ and C–C′), show the paleochannel-fill facies and the shoreface ravinement surface.

U.S. Army Corps of Engineers Wilmington District, 2010, Trackline, vibracore, grab sample, sediment contour and borrow area data layers from Final Integrated Feasibility Report and Environmental Impact Statement Coastal Storm Reduction Surf City and North Topsail Beach North Carolina. Data accessed at 2016-01-26 at http://www.saw.usace.army.mil/Portals/59/docs/coastal_storm_damage_reduction/SCNTB/Final%20Integrated%20Feasibility%20Report%20and%20EIS,%20dated%20December%202010.pdf

The purpose of this study is to evaluate coastal storm damage reduction for the towns of Surf City and North Topsail Beach, North Carolina, and develop the most suitable plan of damage reduction for the present and future conditions for a 50-year period of analysis. Topsail Island is on the southeastern North Carolina coast. From south to north, the three towns on the island are Topsail Beach, Surf City, and North Topsail Beach. The primary study area for this report includes the towns of Surf City and North Topsail Beach and associated nearby borrow sites. Two Transportation and Infrastructure Committee resolutions dated February 16, 2000, and April 11, 2000, authorized this report. A General Reevaluation Report has been completed for the town of Topsail Beach under a separate authority.

U.S. Army Corps of Engineers Wilmington District, 2014, Final Integrated Feasibility Report and Environmental Impact Statement Coastal Storm Reduction Bogue Banks, Carteret County North Carolina. Data accessed at 2016-01-26 at http://www.saw.usace.army.mil/Portals/59/docs/coastal_storm_damage_reduction/Bogue%20Banks/Bogue%20Banks%20Integrated%20Final%20Report%2006%20AUGUST%202014.pdf

The purpose of this study is to evaluate coastal storm damage reduction along Bogue Banks, a barrier island approximately 25 miles long located on North Carolina’s central coast in Carteret County. The feasibility study is a cost-shared effort with Carteret County as the non-Federal study sponsor. Project Delivery Team (PDT) representatives included participants of Federal, State, and local governments in the effort to identify cost-effective, publicly acceptable, and environmentally and technically sound alternatives to reduce storm damages along the project shoreline. This study identified coastal storm damage problems on Bogue Banks, inventoried opportunities for addressing these problems as well as any planning constraints that could impact plan formulation, and analyzed alternatives. This analysis identified the National Economic Development (NED) plan, which is the plan that maximizes net benefits to the nation through reduction of future storm damages.

U.S. Geological Survey, 2013, Data layer of grab samples from inner continental shelf of North Carolina during U.S. Geological Survey research cruises 1999-045-FA, 2001-005-FA, 2002-013-FA, 2004-003-FA. Included in USGS Quaternary Geophysical Framework of the Northeastern North Carolina Coastal System Open-File Report 2011-1015.

The northeastern North Carolina coastal system, from False Cape, Virginia, to Cape Lookout, North Carolina, has been studied by a cooperative research program that mapped the Quaternary geologic framework of the estuaries, barrier islands, and inner continental shelf. This information provides a basis to understand the linkage between geologic framework, physical processes, and coastal evolution at time scales from storm events to millennia. The study area attracts significant tourism to its parks and beaches, contains a number of coastal communities, and supports a local fishing industry, all of which are impacted by coastal change. Knowledge derived from this research program can be used to mitigate hazards and facilitate effective management of this dynamic coastal system.

This ESRI point shapefile contains the locations of marine sediment samples collected by the U.S. Geological Survey along the inner continental shelf study area. It was produced to ground-truth (verify) topography and backscatter intensity of the seafloor. Grain size analysis of these samples have been included in U.S. Geological Survey East-Coast Sediment Analysis Report published in 2005 (Open-File 2005-1001).

U.S. Geological Survey, 2013, Data layer of vibracores from offshore of Dare County, North Carolina. Included in USGS Quaternary Geophysical Framework of the Northeastern North Carolina Coastal System Open-File Report 2011-1015.

The northeastern North Carolina coastal system, from False Cape, Virginia, to Cape Lookout, North Carolina, has been studied by a cooperative research program that mapped the Quaternary geologic framework of the estuaries, barrier islands, and inner continental shelf. This information provides a basis to understand the linkage between geologic framework, physical processes, and coastal evolution at time scales from storm events to millennia. The study area attracts significant tourism to its parks and beaches, contains a number of coastal communities, and supports a local fishing industry, all of which are impacted by coastal change. Knowledge derived from this research program can be used to mitigate hazards and facilitate effective management of this dynamic coastal system.

This point shapefile indicating the location of vibracores was provided by the North Carolina Geological Survey (NCGS). The vibracores have been curated by NCGS. The 4-inch (~10 cm) cores were collected by the Debris Barge (D/B) Snell using a 20-foot (6m) Alpine vibracorer deployed with the ship's crane. The plastic core liners were cut into approximately 1- meter sections and then split, photographed, sampled, and described. Samples were taken at approximately 1-meter intervals and processed by the DOT Soils and Materials testing lab in Raleigh, NC for sediment texture. The N.C. State University contract report was included as an appendix in the COE Final Feasibility Report and Environmental Impact Statement on Hurricane Protection and Beach Erosion Control Volume I, Dare County Beaches (Bodie Island Portion) dated September 2000.

Walsh, J.P., Conery, I.W., Corbett, D.R., Mallinson, D.J., Garmire, K., Allen, T., and Freeman, C., 2015a, Sand Resource Needs, Data Availability and Beach Nourishment Projects in North Carolina, *in* GSA Southeastern Section 65th Annual Meeting.

Storms and sea-level rise continue to impact coastlines around the world. In North Carolina many communities are conducting or planning beach nourishment in an effort to minimize future storm impacts. These projects are costly and must be completed properly based on accurate geological and geophysical data to have the best chance for success. The proximity and size of a suitable sand source can impact project costs, and problems may still arise even with extensive data. Hurricane Sandy in October 2012 had dramatic impacts on coastal areas north of Cape Hatteras, and in response, the Bureau of Ocean Energy Management is supporting research along the East Coast to plan for potential use of resources in the Outer Continental Shelf (OCS). East Carolina University scientists are working the NC Division of Coastal Management, Geodynamics and others to obtain, analyze and catalog existing geological and geophysical data in the OCS (3-8 nm offshore). Information on datasets will be made available to the public via the NC Coastal Atlas and federal data engines. This presentation will review and discuss ongoing efforts at the shoreline and offshore to address coastal resiliency in NC.

Walsh, J.P., Corbett, D.R., Mallinson, D.J., Conery, I.W., Garmire, K., Cornette, C.J., and Kelly, N., 2015b, Shoreline and Sediment Dynamics Along the Central Outer Banks, *in* Atlantic Estuarine Research Society 2015 Meeting.

The Outer Banks of North Carolina is a long, narrow barrier island complex (mostly <2 km wide) that shelters the vast Pamlico and Albemarle sounds from the open Atlantic Ocean. This terrestrial feature forms the seaward boundary for the second largest estuarine system of the United States, but this slender geological structure is dynamic, morphed by powerful storm waves and persistent currents. The central Outer Banks, defined here as extending from Nags Head to Cape Hatteras includes the Bodie Island peninsula, Oregon Inlet and northern Hatteras Island. Except for a few communities spaced along it, much of the island is part of the Cape Hatteras National Seashore. Receiving over 2 million visitors annually, communities along this stretch serve as an important economic engine for the State and are a key part of the cultural fabric and history of Dare County. A critical challenge for this area is maintaining access along it and to the sea. Long-term erosion has occurred along portions of the ocean and estuarine shoreline. Locally, ocean erosion has exceeded 4 m y^{-1}, and episodically Highway 12 has been made impassable. Conversely, sedimentation has been problematic in navigational channels, especially Oregon Inlet. Nourishment and dredging efforts have occurred at various locations in the system, and future efforts and sand resources are being evaluated. In this poster, the natural processes and human efforts that influence sediment dynamics are reviewed and discussed.

Walsh, J.P., and D. Piatkowski. 2015. An Update: BOEM's Coastal Resiliency Planning Initiatives and Ongoing Efforts in North Carolina, *in* North Carolina Beach Inlet & Waterway Association Annual Conference.

The extent and magnitude of erosion and storm damage along the U.S. coastline is increasing as a consequence of widespread development, management challenges, and sea level and storm impacts. As the nation's steward of offshore non-energy mineral resources, the Bureau of Ocean Energy Management (BOEM) in the U.S. Department of the Interior is integrally involved in supporting short- and long-term coastal resiliency initiatives along the Atlantic and Gulf coastlines. Through negotiated lease agreements, BOEM's Marine Minerals Program serves an important role in supporting coastal resiliency initiatives by granting access to sand and gravel resources from the Outer Continental Shelf. However, sand is a finite resource, and state resources are being depleted. Because of this reality, coupled with a growing regional demand, BOEM is challenged with the responsibility of optimizing resource use while considering a myriad of physical, biological, economic, and social implications.

Following Hurricane Sandy in October 2012, the demand for sand to support immediate recovery and long-term sustainability of vulnerable coastal communities stimulated broader collaboration between federal, state, and private sector entities. BOEM and East Carolina University (ECU) signed a two-year cooperative agreement in 2014 to evaluate available data offshore of the North Carolina coast. ECU scientists are working the NC Division of Coastal Management, Geodynamics and others to obtain, analyze and catalog existing data. This presentation will review and discuss ongoing NC and BOEM efforts for coastal resiliency planning.

Whittaker, J., Goncharov, A., Williams, S., Müller, D., Leitchenkov, G., 2013. Global sediment thickness Data Layer updated for the Australian-Antarctic Southern Ocean, Geochemistry, Geophysics, Geosystems. Dataset accessed at 2016-01-26 at doi: 10.1002/ggge.20181

NGDC's global ocean sediment thickness grid (Divins, 2003) has been updated for the Australian-Antarctic region (60°-155°E, 30°-70°S). New seismic reflection and refraction data have been used to add detail to the conjugate Australian and Antarctic margins and intervening ocean floor where previously regional sediment thickness patterns were poorly known.

On the margins, sediment thickness estimates were computed from velocity-depth functions from sonobuoy/refraction velocity solutions ground-truthed against seismic reflection data. For the Southeast Indian Ridge abyssal plain, sediment thickness contours from Géli et al. (2007) were used.

The new regional sediment thickness grid was combined with NGDC's original ocean sediment thickness grid (Divins, 2003) to create an updated global grid of ocean sediment thickness. Even using the minimum estimates, sediment accumulations on the extended Australian and Antarctic continental margins are 2 km thicker across large regions and up to 9 km thicker in the Ceduna Basin compared to NGDC's original sediment thickness grid (Divins, 2003), which has been deprecated but is still available.

Willson, K., 2009, Shoreface mapping and sand resource inventory: North Topsail Beach and Surf City, North Carolina. University of North Carolina Wilmington Thesis.

North Topsail Beach and Surf City, located along the north and central portions of Topsail Island, North Carolina respectively, are two of the most vulnerable coastal communities in the State in regard to beach erosion and storm impacts. This is primarily due to the relatively low topography of Topsail Island and the lack of sand available on the shoreface to nourish the beaches. Over the past decade a profusion of data has been collected offshore Topsail Island in an attempt to locate beach quality sand for beach nourishment projects along the Island. This study compiled and utilized these data to map the shoreface off North Topsail Beach and Surf City with respect to surficial and subsurface geomorphology. The data utilized in this study includes vibracores, sidescan sonar data, subbottom profile data, and SCUBA diver ground truthing data and grab samples.

A number of Oligocene age units associated with the River Bend Formation were identified throughout the course of the study which crop out on the seafloor surface and compose the underlying strata of the shoreface. None of the units mapped as Oligocene age show potential for being a viable source of beach quality sand due to a combination of fine grain material, high silt content, and/or high carbonate percent. Despite the underlying units composing the shoreface exhibiting little potential for sand resources, three channel like features that were incised into the Oligocene units where identified due to the density of data throughout the survey area. These three areas suggest that isolated deposits of beach quality sand may exist on the shoreface off Topsail Island.

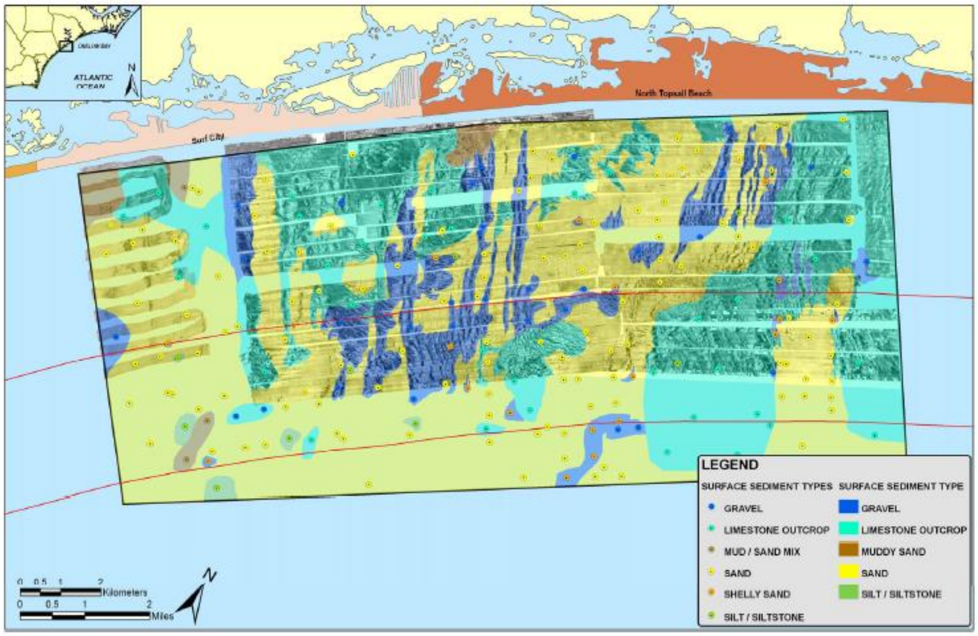


Figure 12. Map showing sidescan sonargraph overlaid with Surficial sediment types based on UNCW diver grab samples, UNCW diver retrieved vibracores, and USACE vibracores. Note the locations of ground truthing surveys and vibracores.