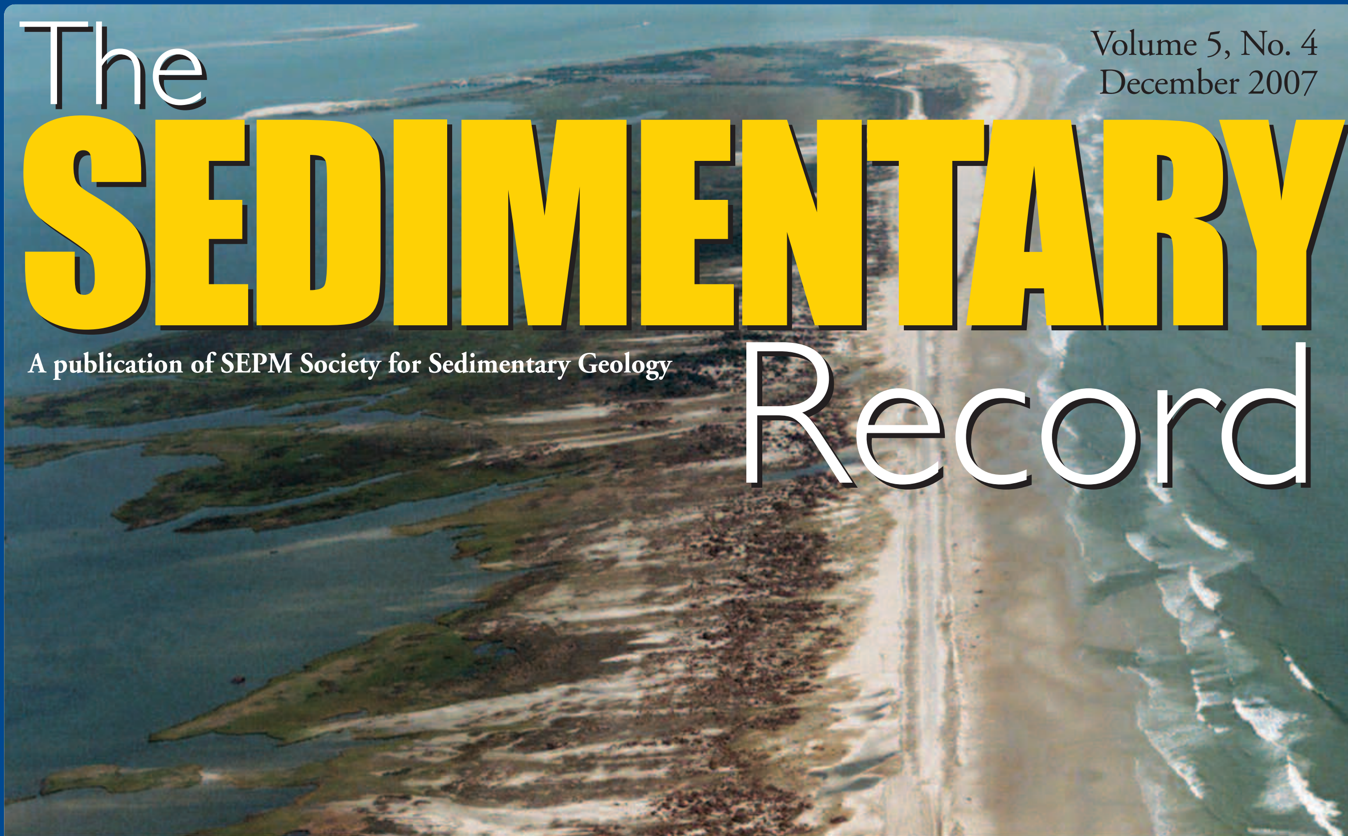
Volume 5, No. 4
December 2007

The SEDIMENTARY Record

A publication of SEPM Society for Sedimentary Geology



INSIDE: LATE HOLOCENE BARRIER ISLAND COLLAPSE: OUTER BANKS, NORTH CAROLINA, USA

PLUS: TIME SCALE CREATOR
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Late Holocene barrier island collapse: Outer Banks, North Carolina, USA

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ABSTRACT

We document here the threat of large scale destruction (collapse) of barrier islands based on the study of many cores taken along the Outer Banks and in Pamlico Sound, North Carolina. Around 1,100 cal yr BP, probably as the result of hurricane activity, portions of the southern Outer Banks must have collapsed to allow normal salinity waters to bathe southern Pamlico Sound for several hundred years. Such collapse could occur again during our current regime of global warming, rising sea level and increased tropical cyclone activity. The economic effect of barrier island break collapse on Outer Banks communities would be devastating.

INTRODUCTION

Large-scale destruction by recent hurricanes of Gulf Coast barrier islands, extending from Santa Rosa Island in the Florida Panhandle to the Chandaleur Isles in Louisiana, demonstrates their ephemeral nature. For example, sand was stripped from large sections of Dauphin Island, Alabama and deposited in Mississippi Sound during Hurricane Katrina (2005) (http://coastal.er.usgs.gov/hurricanes/katrina/lidar/dauphin-island.html). Parts of the Chandeleur Isles were destroyed (eroded to below sea level) due to the impacts of Hurricane Ivan (2004) and Hurricane Katrina (2005) (http://coastal.er.usgs.gov/hurricanes/katrina/photo-comparisons/chandaleur.html). Removal of large (several km or more) sections of the subaerial component of barrier islands resulting in a submarine shoal is herein termed "collapse." The potential for barrier islands to collapse has global significance given the continuing increase of coastal populations and the economic importance of coastal industries.

We have used foraminiferal assemblages collected from vibracores taken on and behind the barrier islands, to investigate the stability and longevity of the Outer Banks, North Carolina (Fig. 1). High resolution data from an 8.21 m vibracore (PS03) in the estuarine south-central Pamlico Sound (Fig. 1) provide the best preserved record yet recovered of change within this system and are used here to illustrate our findings. The unexpected presence of subtropical to tropical planktonic foraminifera and *in situ* normal salinity neritic benthic foraminiferal assemblages in this and at least three adjacent cores suggests that large portions of the southern Outer Banks collapsed approximately 1,100 cal yr BP, allowing normal salinity, shelf waters to enter the Pamlico basin. For several hundred years, until the barrier islands were rebuilt just prior to the arrival of English settlers in North Carolina in 1584, the southern Pamlico basin was an open bay rather than a restricted estuary.

The Outer Banks are generally low and narrow barrier islands extending for ca. 300 km along the northeast coast of North Carolina (Fig. 1A). Currently, just five inlets cut the barrier. The barrier islands are perched on the last glacial maximum Hatteras Flats Interstream Divide (HFID) (Fig. 1B) that in the late Pleistocene and early Holocene separated southwest flowing Pamlico Creek (Fig. 1B) from a similar drainage basin immediately to the east (Riggs and Ames, 2003; Mallinson et al., in review). Post-glacial sea-level rise flooded the Pamlico Creek drainage, the Tar and Neuse River valleys (Fig. 1B), and the paleo-Roanoke River valley underlying Albemarle Sound to the north (Fig. 1A). This flooding, which occurred approximately 9,000 to 7,000 cal yr BP (Sager and Riggs, 1998; Mallinson et al., 2005), formed estuaries and bays, which eventually became sounds when the Outer Banks barrier islands formed (Riggs and Ames, 2003). This paper reports on the intriguing sedimentary and micropaleontological record of several vibracores that indicates that the southern Outer Banks barrier islands underwent significant destruction, presumably as the result of a major hurricane or hurricanes, approximately 1,100 cal yr BP.

METHODS

More than 100 vibracores have been taken over the past ten years in Pamlico Sound and on the barrier islands from Pea Island to Core Banks (Fig. 1A). These cores can be placed in the geologic framework provided by extensive geophysical profiling (Fig. 1B). Vibracore PS03, taken in 6.5m of water in south-central Pamlico Sound (Fig. 1) near the thalweg of Pamlico Creek, was sampled for foraminifera

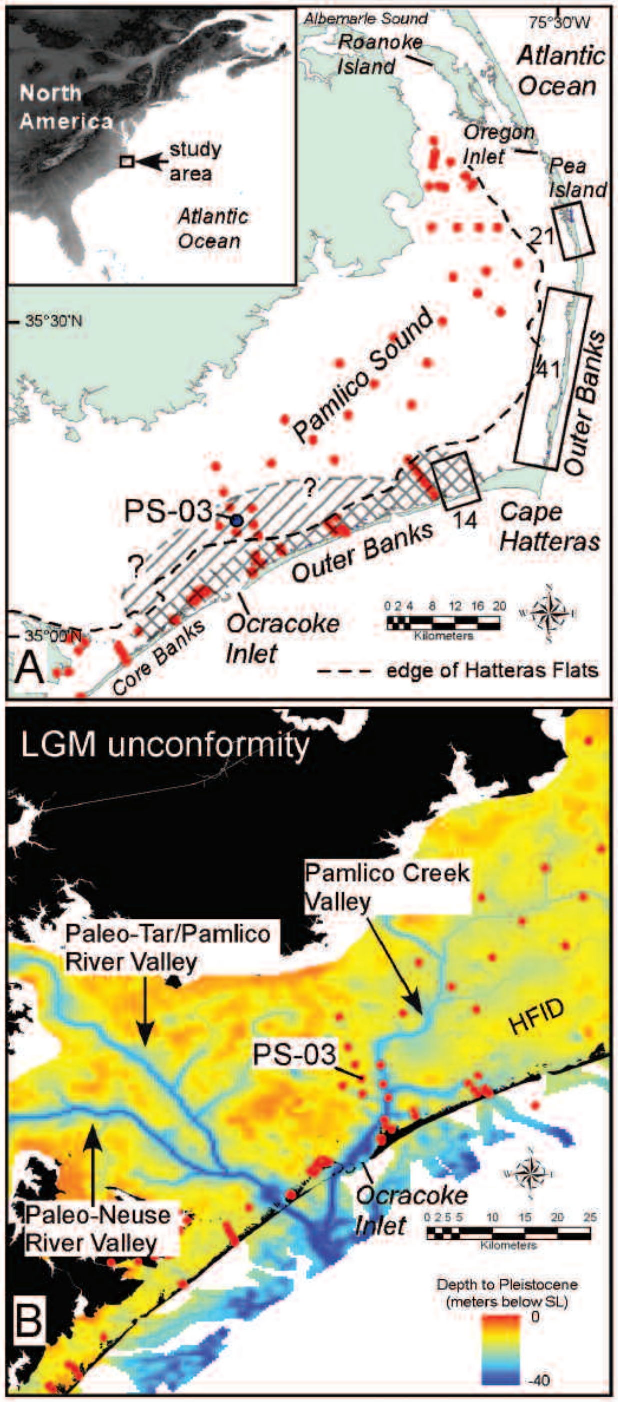

Figure 1. A, Location of vibracore PS03 and other vibracores (dots) in the Pamlico Sound region. Boxed areas along barrier islands indicate areas covered by (and the number of) closely spaced vibracores. The distribution of ca 1,200-500 yr old inner shelf foraminiferal assemblages within Pamlico Sound and beneath the barrier islands is indicated by cross-hatching. The projected extent of the ca 1,100-500 yr old shelf foraminiferal assemblage with planktonics is indicated by diagonal lines. The black dashed line is the western boundary of Hatteras Flats. B, Structure contour map (m) of the top of the Pleistocene (last glacial maximum, LGM, unconformity) based on seismic data. Location of vibracore PS03 and paleo-drainages of the Neuse and Tar rivers and of Pamlico Creek are indicated. HFID, Hatteras Flats Interstream Divide.

in 2 cm contiguous intervals. Six calibrated (Bronk Ramsey, 2005; Hughen et al., 2004; Reimer et al., 2004) 2-sigma radiocarbon ages from PS03, each on ca.1000 specimens of the benthic foraminifer *Elphidium excavatum*, and one on bulk organic matter, provide the temporal framework for the micropaleontological and lithologic data. Additional radiocarbon and optically stimulated luminescence age (OSL) estimates from other vibracores provide a regional chronostratigraphic context (Mallinson et al., 2007; Smith et al. 2007).

ENVIRONMENTAL CHANGE IN SOUTHERN PAMLICO SOUND

The lowermost 2.31 m of core PS03 (Fig. 2) are generally barren of foraminifera. Flaser-bedded upward-coarsening muddy sand containing estuarine diatoms and abundant organic matter is interpreted to represent estuarine conditions as post-glacial sea-level rise flooded the paleo-Tar River, the paleo-Neuse River, and the Pamlico Creek drainages commencing about 6,980-7,330 cal yr BP. Pamlico Creek flooded up the thalweg and was restricted from open marine conditions by the Hatteras Flats Interstream Divide (HFID) to the east (Fig. 1B).

Deposition of the overlying upward-fining muddy unit (5.88 to 5.08 m; Fig. 2) began about 4,070-4,340 cal yr BP. Based on comparison with modern foraminiferal distributions in Pamlico Sound (Abbene et al., 2006), samples in this unit that are dominated by *Elphidium excavatum* and *Ammonia parkinsoniana* indicate highly brackish estuarine conditions. These two euryhaline taxa also live today on the North Carolina inner shelf where they occur with stenohaline benthic taxa (Schnitker, 1971). Samples in this section of PS03 dominated by *E. excavatum* and *A. parkinsoniana*, but also containing varying abundances of characteristic neritic benthic species (e.g., *Bolivina striatula, Hanzawaia strattoni*; Schnitker, 1971), indicate commencement of incursion of more saline waters over the HFID (Figs. 1B, 3A).

Burrowed muddy sand from 5.08 to 4.17 m (Fig. 2) was deposited in a relatively short time, from about 3,910-4,140 to 3,740-3,990 cal yr BP. It contains a benthic foraminiferal assemblage typical of the inner shelf today (dominated by the euryhaline *Elphidium excavatum* and *Ammonia parkinsoniana*, with the stenohaline *Hanzawaia strattoni, Nonionella atlantica* and *Buccella inusitata* as subsidiary species), together with Gulf Stream planktonic foraminifera (e.g., *Globigerinoides ruber, Globorotalia menardii*) (Fig. 2). This assemblage differs from modern inlet assemblages (Abbene et al., 2006) both in its composition and in its preservation. The modern inlet assemblages typically occur in sand and are composed of large specimens that have been broken and abraded by transport, whereas the muddy sand assemblage includes well preserved specimens of all sizes, i.e., ranging from young to mature individuals. The composition and characteristics of the muddy sand assemblage indicates that normal-salinity shelf waters extended into the southern Pamlico basin as rising sea level overtopped the HFID adjacent to the paleo-drainages and formed an open southern Pamlico Bay. The benthic assemblage lived at this location whereas Gulf Stream planktonics were transported into southern Pamlico Bay perhaps within Gulf Stream frontal filaments (Fig. 3A) (see Pietrafesa et al., 1985). Normal salinity benthic foraminiferal species occur with estuarine species up-core from 4.17 to 3.42 m in a generally fining-upward section of core (Fig. 2). Planktonic foraminifera, however, are absent indicating an increasingly less open aspect to Pamlico Bay from 3,740-3,990 cal yr BP until 3,450-3,750 cal yr BP.

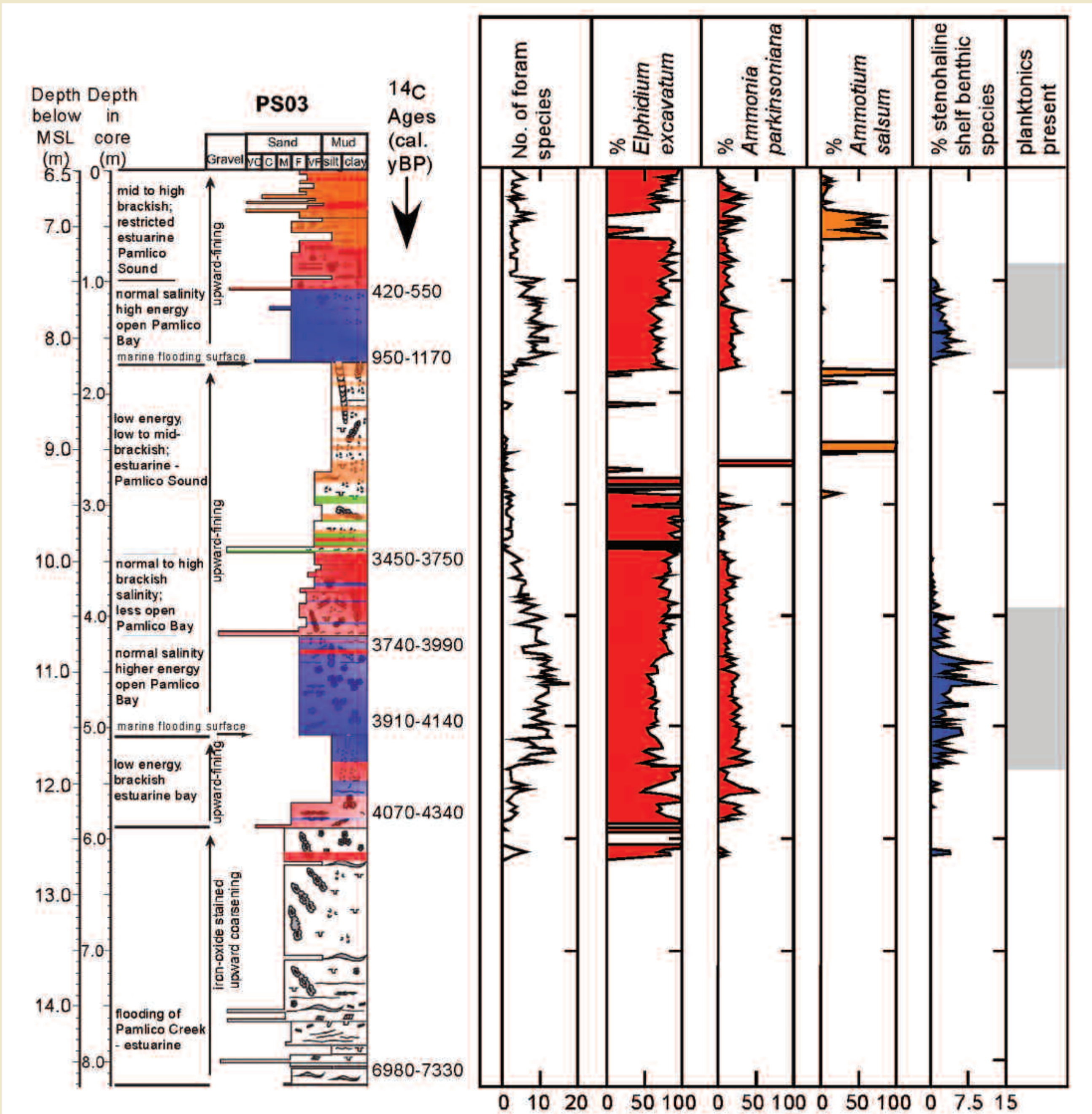

Figure 2. Lithologic log of vibracore PS03 from south-central Pamlico Sound and associated foraminiferal, chronologic and sedimentologic data. Paleoenvironmental interpretations based on these data are given to the left of the log. Colors indicate foraminiferal assemblages as defined by cluster analysis. Blue = normal salinity bay; red = high brackish estuary; orange = low to mid brackish estuary; green = undifferentiated estuary. Note that **Elphidium excavatum** *and* **Ammonia parkinsoniana** *are euryhaline species that occur today both in high brackish estuarine and normal marine salinity shelf settings.*

Fining-upward sediments continue from 3.42 to 1.72 m. This core segment (Figure 2) contains sparse specimens of the typical low to mid-brackish (Abbene et al., 2006), estuarine agglutinated benthic foraminifer *Ammotium salsum*, indicating that open Pamlico Bay had evolved into a back-barrier estuarine system (i.e., Pamlico Sound) by about 3,500 cal yr BP (Fig. 2), the approximate age of the oldest barrier island beach ridges yet dated on the Outer Banks by OSL methods (Mallinson et al., 2007).

Fine sand from 1.72 to 1.07 m overlies the estuarine mud and is characterized by a foraminiferal assemblage similar to that from 5.08 to 4.17 m (Fig. 2). The *in situ* benthic assemblage (*Elphidium excavatum, Ammonia parkinsoniana, Hanzawaia strattoni, Buccella frigida, Cibicides lobatulus, Fissurina laevigata*) indicates normal marine salinity and planktonic species (e.g., *Globigerinoides ruber, Globorotalia menardii*) a Gulf Stream influence. Accelerator mass spectrometry (AMS) C-14 ages of 950-1,170 cal yr BP near the base of this unit

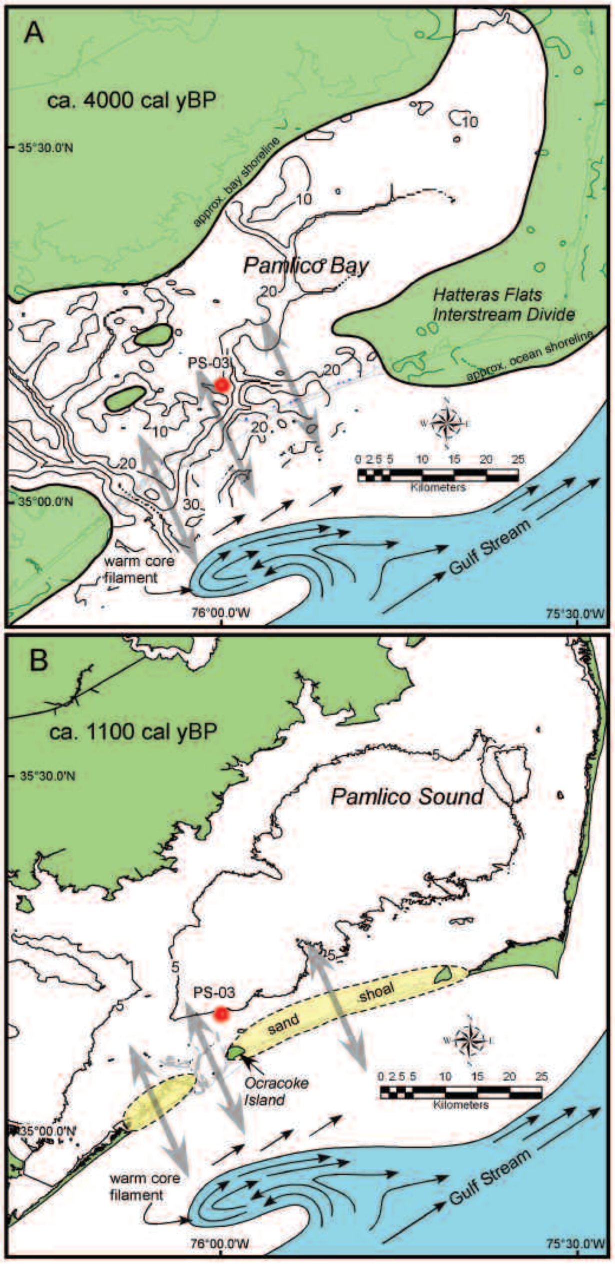

Figure 3. Diagrams to illustrate environmental conditions in the southern Pamlico basin at ca 4,000 cal yr BP and ca 1,100 cal yr BP. A, Flooding occurred across interstream divides separating paleo-valleys through which tidal exchange took place. Valleys initially flooded ca. 7,000 cal yr BP. As sea level rose, by ca. 4,000 cal yr BP flooding of sections of the Hatteras Flats Interstream Divide adjacent to the paleo-drainages allowing normal salinity waters into the southern Pamlico basin. Grey arrows indicate tidal exchange. Contours indicate the depth (meters below present mean sea level) to the Pleistocene surface and define the paleotopography that controlled the timing of flooding and morphology of Pamlico Bay. B, Barrier islands formed by ca. 3,500 cal yr BP. Barrier island collapse along the southern margin of Pamlico Sound ca. 1,100 cal yr BP resulted in a shallow, submarine sand shoal over which normal salinity waters, derived from northward migrating Gulf Stream warm-core filaments, were advected into the southern part of the Pamlico basin in response to wind-forcing. Contours indicate modern bathymetry (meters below mean sea level) within Pamlico Sound.

and 420-550 cal yr BP near the top (Fig. 2) indicate that shelf waters returned to the southern Pamlico basin for 400 to 700 years. For this to have occurred, substantial collapse of the southern Outer Banks barrier islands must have taken place about 1,100 cal yr BP. Collapse involved a total loss of supratidal habitat as the barrier island sand body was smeared out across the Hatteras Flats (Fig. 3B). We envisage gaps several km in width in the barrier islands (i.e., wider than an inlet) and water depths of a few meters above the submarine sand shoal such that water from Gulf Stream frontal filaments (Pietrafesa et al., 1985) could be advected into the southern Pamlico basin in response to wind-forcing (Fig. 3B). Because the maximum depth of modern Pamlico Sound is only 6 to 7 m, it is likely that the depth of water over the shoal was less than this.

The uppermost 1.07 m of core consist of muddy sand with foraminiferal assemblages (dominated by E. excavatum, A. parkinsoniana and A. salsum) (Fig. 2) typical of the mid-to-high brackish conditions that characterize Pamlico Sound at the site of vibracore PS03 today. Thus, restricted estuarine conditions returned to this area approximately 500 years ago and an open southern Pamlico Bay, once more had become an estuarine, back-barrier Pamlico Sound (Fig. 2).

ENVIRONMENTAL INDICATIONS FROM ADDITIONAL VIBRACORES

Sixty-two vibracores from Core Banks, Ocracoke Island, Hatteras Island (west of Cape Hatteras) and from the adjacent HFID (Fig. 1A) reveal the presence of a variably shelly medium sand unit (ca. 2 to 7 m below mean sea level), containing moderately diverse, open inner shelf benthic foraminiferal assemblages, underlying barrier island and modern estuarine shoal sand that is generally barren or that contains few foraminifera. AMS C-14 and OSL age estimates from the shelly sand unit (labeled “sand shoal” on Fig. 3B) show that normal salinity inner shelf conditions characterized this region around 1,200 to 500 cal yr BP. AMS C-14 ages on basal back-barrier salt marsh peat indicate that the modern barrier islands were present by 500 cal yr BP. These data are consistent with the timing of barrier island collapse and reformation inferred from PS03. To the north of Cape Hatteras, foraminiferal assemblages from beneath the barrier islands and Hatteras Flats indicate intervals of partial island collapse between ca 3,000 and 500 cal yr BP, in addition to a complex history of numerous inlet openings and closings. Sand units containing shelf benthic foraminiferal assemblages with Gulf Stream planktonics have been found in four southern Pamlico Sound cores but are absent in northern Sound cores (Fig. 1A), indicating that the major collapse of barrier islands that occurred a little over 1,000 years ago was restricted to the southern Outer Banks.

POSSIBLE CAUSES OF BARRIER ISLAND COLLAPSE

Tsunami and hurricanes are potential causes of barrier island collapse. Unfortunately, foraminiferal signatures of tsunami are not yet sufficiently well defined (e.g., Hawkes et al., 2006). Major hurricanes (category 3 and greater) hit coastal North Carolina several times a century, but vibracore PS03, three adjacent cores, and more than 30 cores across the Hatteras Flats and through the modern barrier islands, indicate just one substantial collapse, several centuries in duration, since the barrier islands formed around 3,500 cal yr BP. A major hurricane, or a closely spaced series of major hurricanes, such as hit the Gulf Coast in 2004 and 2005, is the most likely proximal causal agent in this North Carolina coastal region that was dubbed

"Hurricane Alley" in the 1950s. The collapse, and subsequent interval characterized by an open southern Pamlico Bay, spans the Medieval Warm Period (Cronin et al., 2003). Perhaps warmer temperatures during this interval resulted in increased hurricane intensity or activity. The combination of currently rising sea level and continuing high or increasing level of hurricane activity (e.g., Emmanuel, 2005; Trenberth, 2005; Webster et al., 2005) during a period of global warming constitutes a burgeoning threat to the future of North Carolina's Outer Banks. If barrier island collapse occurs again, the economic impact on Outer Banks communities, and on the tourist industry, in particular, would be devastating.

ACKNOWLEDGEMENTS

This research is part of the North Carolina Geology Cooperative program (NCCGC). Funding for USGS cooperative agreement award 02ERAG0044 and NSF Cooperative Agreement number OCE-9807266 and support from the Cushman Foundation for Foraminiferal Research and the East Carolina University Research Fund is gratefully acknowledged. Acknowledgement is also made to the donors of the American Chemical Society Petroleum Research Fund for partial support of this research. We thank J. Watson, J. Woods, M. Keusenkothen, S. Dillard, D. Ames, C. Hillier and D. Merritt for their assistance and Robert Weisberg (USF) for his advice on physical oceanography.

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Accepted October 2007