

Metger, M. Lauren HOLOCENE PALEOENVIRONMENTAL CHANGE IN SOUTHERN PAMLICO SOUND, NORTH CAROLINA (Under the direction of Dr. Stephen J. Culver) Department of Geological Sciences

Response of barrier islands to the current regime of global warming and sea-level rise is of great interest given the economic importance of these coastal features. To understand the range of probable responses it is necessary to investigate the Holocene record of barrier island history. Seventeen vibracores were collected from southern Pamlico Sound (PS) to investigate the distribution of lithofacies and biofacies through foraminiferal and sedimentological analysis in order to define the Holocene evolution of this coastal system. Six biofacies were recognized by cluster analysis: (A) Low Brackish Estuary: dominated by *Elphidium excavatum* and *Ammonia parkinsoniana* and with *Ammotium salsum* and *Haynesina germanica*; (B) High Brackish Estuary (Possible Inlet Influence): dominated by *Elphidium excavatum* and *Ammonia parkinsoniana* with miliolids; (C) Inlet: dominated by *Elphidium excavatum* and containing robust taxa similar to modern assemblages found near and within inlets of the Outer Banks; (D) Normal Marine Salinity Bay: dominated by *Elphidium excavatum*; but including delicate stenohaline benthic taxa indicative of modern normal marine salinity conditions; (E) High Brackish Estuary: strongly dominated by *Elphidium excavatum* and (F) Estuary (Low Specimen Count): dominated by *Elphidium excavatum* (the only taxa found in this biofacies).

Foraminiferal data, together with sedimentological and C-14 age data were used to reconstruct the geological evolution of southern Pamlico Sound. Flooding of the

Pamlico Creek and the paleo-Tar and paleo-Neuse Rivers occurred ca. 7000 cal yr B.P. with rising sea level, creating the Pamlico Creek estuary and the Tar and Neuse River estuaries. Approximately 5500 cal yr B.P., normal marine salinity waters were influencing the outer Tar and Neuse River estuaries. As sea level continued to rise, the Hatteras Flats Interstream Divide was overtopped and by ca. 4000 cal yr B.P. the estuarine southern PS was influenced by Gulf Stream waters, as indicated by the presence of the tropical to subtropical foraminifera *Globigerinoides ruber* and *Globorotalia menardii*, but the outer Tar and Neuse River estuaries were restricted from such exchange by the formation of a proto-Portsmouth Island. Barrier islands had formed along the Hatteras Flats Interstream Divide by ~2000-2500 cal yr B.P., but Portsmouth Island was reduced to a sand shoal, perhaps due to a hurricane, allowing normal marine salinity waters to once again influence the outer Tar and Neuse River estuaries. The presence of shelf species (juveniles to adults) and their good preservation together with planktonic foraminifera in southern PS during a more recent and longer interval (ca. 1100 to 500 cal yr BP) is considered to be due to a collapse into submarine shoals of the barrier islands south of Cape Hatteras rather than to inlet processes. The cause of such barrier island collapse would most likely be a major hurricane or a series of hurricanes.

HOLOCENE PALEOENVIRONMENTAL CHANGE IN
SOUTHERN PAMLICO SOUND, NORTH CAROLINA

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M. Lauren Metger

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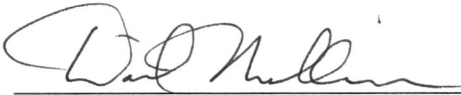
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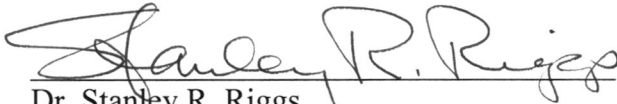
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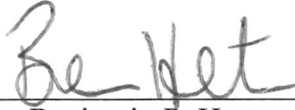
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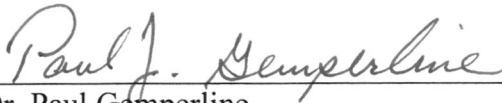
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DEDICATION

For Ransom

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islands present in Pamlico Bay. (D) ca. 2500 cal yr B.P. Outer Banks barrier islands established and Pamlico Sound experienced estuarine conditions. Gulf Stream influence behind Portsmouth Island as it was reduced to a sand shoal. Beach ridges formed Cape Hatteras. (E) ca. 1100 cal yr B.P. Collapse of the southern Outer Banks resulting in Gulf Stream influence in southern Pamlico Sound (modified from Culver et al., 2007; Culver et al., unpublished). Pink dots represent vibracores collected in the current study, blue dots represent vibracores from Foley (2007), green dot represents PS03 (Grand Pre, 2006), gray arrows represent tidal exchange, and contours are in meters. Bolded circles indicate presence of foraminiferal assemblages indicating Gulf Stream influence. 101

INTRODUCTION

The Outer Banks of North Carolina are a thin strip of barrier islands extending the entire length of North Carolina from Virginia to South Carolina (Figure 1). These islands are dynamic in that their presence and behavior change in response to sea level (Riggs and Ames, 2003). Pamlico Sound lies behind the Outer Banks and has connections to the Atlantic Ocean primarily through three inlets (Oregon, Hatteras, and Ocracoke) (Figure 1). Fresh water discharge into the sound occurs via the Tar and Neuse Rivers. To the north, the Roanoke and Chowan Rivers flow into the Albemarle Sound, a low brackish estuary, which in turn drains into the Pamlico Sound, affecting salinity in the north (Wells and Kim, 1989).

Research conducted along the Outer Banks suggests that formation of the barrier islands occurred in stages. Dating of sediment cores collected from Kitty Hawk Woods indicates formation of that portion of the Outer Banks at ~3000 cal yr B.P. (Mallinson et al., 2008). The Albemarle-Pamlico basin has experienced back-barrier estuarine conditions for at least 3000 years. From ca. 7000 to 3000 years BP the Pamlico estuary was separated from the Atlantic Ocean by the peninsula that was to become the Hatteras Flats (Culver et al., 2007). A high resolution foraminiferal analysis of a vibracore, PS03, collected from southern Pamlico yielded data indicative of normal marine salinity conditions in southern Pamlico Sound from 1100 to 500 cal yr B.P. (Grand Pre, 2006; Culver et al., 2007). The influx of normal marine salinity waters into the Sound is inferred to have occurred due to a significant collapse of the barrier islands south of Cape Hatteras (Culver et al., 2007).

Other studies along the barrier islands confirm the suggestion that portions of the island chain (Portsmouth Island, Ocracoke Island, and parts of Hatteras Island) were not present during the last few thousand years (Mallinson et al., 2005; Ricardo, 2005; Rosenberger, 2006; Smith, 2006; Twamley, 2006).

This study expands the work of Grand Pre (2006) and Foley (2007) by mapping the spatial extent of normal marine salinity units initially observed in Pamlico Sound vibracore PS03 (Figure 1). Seventeen additional vibracores were collected in southern Pamlico Sound for the current study and were subjected to lithologic and biostratigraphic analysis and AMS C-14 dating.

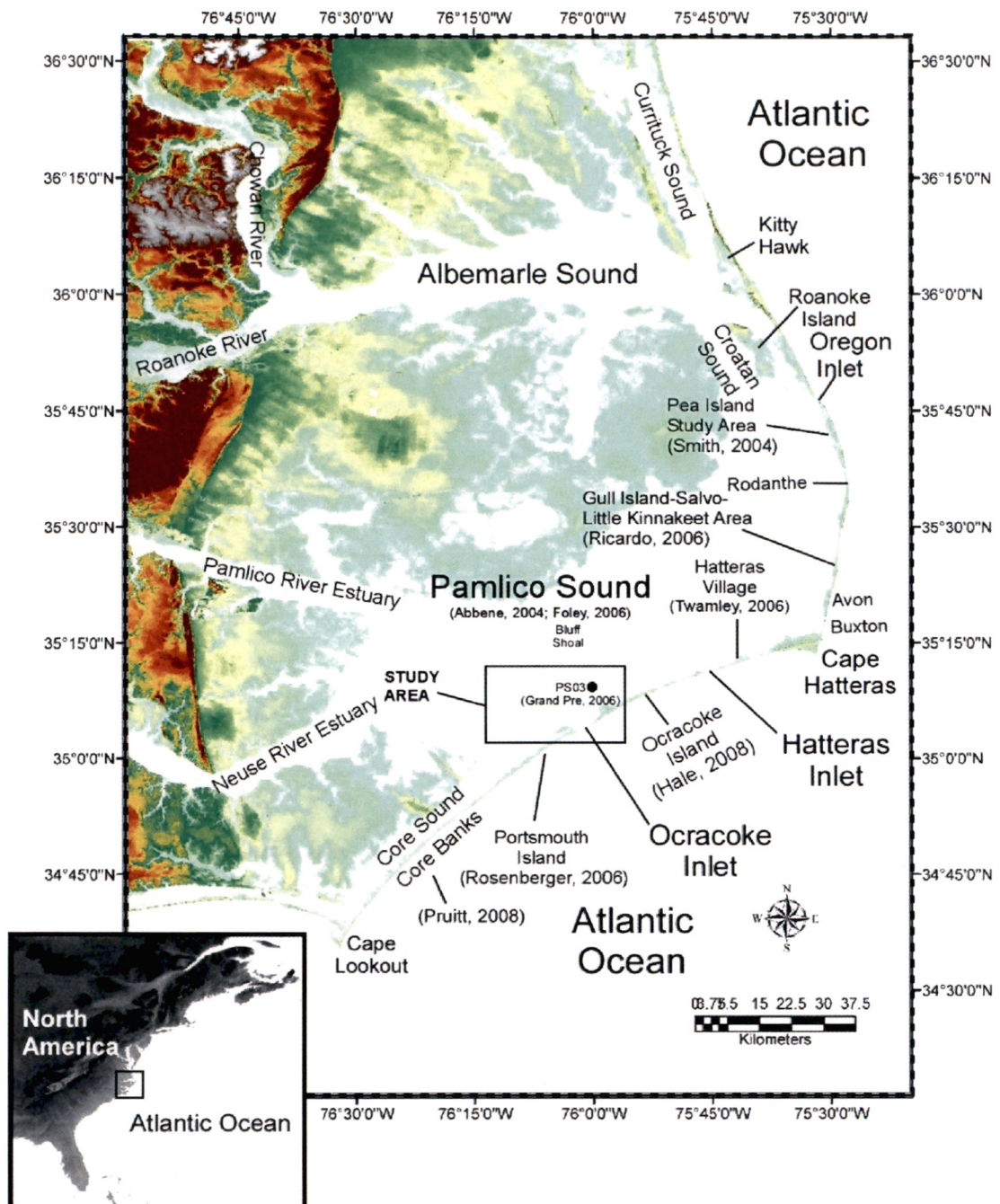


Figure 1: Location map of study area in eastern North Carolina. Elevations based on LIDAR data (NCfloodmaps.com). Various study areas mentioned within the text are marked.

Objectives

The purpose of this project is to investigate Holocene environmental change in southern Pamlico Sound, North Carolina (Figure 1). Foraminiferal biofacies and lithofacies have been defined and placed in a chronostratigraphic framework to help determine the presence and absence of barrier island segments and their influence upon the interaction between estuarine and open shelf waters. Foraminiferal and sedimentologic data collected from 17 vibracores taken in southern Pamlico Sound (Figure 1) have been compared to the results and associated interpretations derived from vibracore PS03 and other Holocene paleoenvironmental studies in and around Pamlico Sound (Smith, 2004; Grand Pre, 2006; Smith, 2006; Foley, 2007; Ricardo, 2005; Twamley, 2006; Rosenberger, 2006; Hale, 2008).

The following specific objectives have been achieved:

1. Describe the sedimentary features and define the downcore lithofacies in vibracores collected from Pamlico Sound and illustrate them using sedimentary logs.
2. Define foraminiferal biofacies within the cores via cluster analysis and compare foraminiferal assemblages downcore to modern assemblages.
3. Obtain AMS radiocarbon age estimates of foraminifera near lithologic changes within cores to provide a chronology of environmental change.
4. Reconstruct Holocene paleoenvironmental change and place those changes in a temporal context.

Physical and Geologic Setting

Pamlico Sound (PS), North Carolina is a drowned river estuary located behind the Outer Banks barrier islands on the passive margin coast of North America (Dame et al., 2000; Inman, 2003). PS is part of the larger Albemarle-Pamlico estuarine system (Figure 1). Exchange of water between the PS and the Atlantic Ocean occurs primarily through three inlets (Oregon, Hatteras, and Ocracoke Inlets) located along the barrier island chain (Wells and Kim, 1989). Fresh water influx comes from the Tar, Neuse, Roanoke and Chowan Rivers and surface water drainage by many coastal plain blackwater streams, and groundwater aquifers such as the Castle Hayne (Dame et al., 2000) (Figure 2). Pamlico Sound is the second largest estuary found on the east coast of North America, having an area of 5340 km² and an estimated volume of 16.9 x 10.9 m³ (Burkholder et al., 2004).

Pleistocene-aged paleochannels, which drained the basin during the last glacial maximum sea-level lowstand approximately 20,000 years ago, control the bathymetry (Riggs et al., 1995; Riggs and Ames, 2003). These channels filled with fluvial and estuarine sediments by flooding of the fluvial valley during latest Pleistocene post-glacial sea-level rise (Figures 3, 4). PS is relatively shallow, with a maximum depth of 8 m and an average depth of 3.6 m (Wells and Kim, 1989; Burkholder et al., 2004) (Figure 5). The sound is divided into three sub-basins (northern, middle, and southern), the southern and middle basins are separated by Bluff Shoal (Riggs and Ames, 2003). There is little astronomical tidal influence, and mixing is achieved by wind tides (Riggs and Ames, 2003).

Sediments within the estuary vary depending on source, shoreline protection, and energy level (Tully, 2004) (Figure 6). In general, three basic sediment types are found: sand, peat, and organic-rich mud (Riggs and Ames, 2003). Silt and clay-sized particles are found in the basin region; sand is found in and around the inlets and in scattered shoals within the sound (Wells and Kim, 1989).

Salinity varies through the estuary and is dependent on exchange between the brackish Albemarle Sound to the north and Core Sound to the south, normal salinity waters from the inlets to the Atlantic from the east, and fresh water discharge from the west. Generally salinity decreases to the west with increased distance from the inlets and towards Albemarle Sound. Vertical stratification is seasonal and ephemeral and dependant upon storm frequency and intensity (Pietrafesa et al., 1986; Wells and Kim, 1989). Fresh water influence varies annually, influencing salinity in the sound on a seasonal basis; generally lower in the winter (December) and generally higher in the spring (April) (Pietrafesa et al., 1985; Wells and Kim, 1989). In the southern Pamlico Sound field area of this study, salinity values average from 15-20 psu (Abbene, 2006).

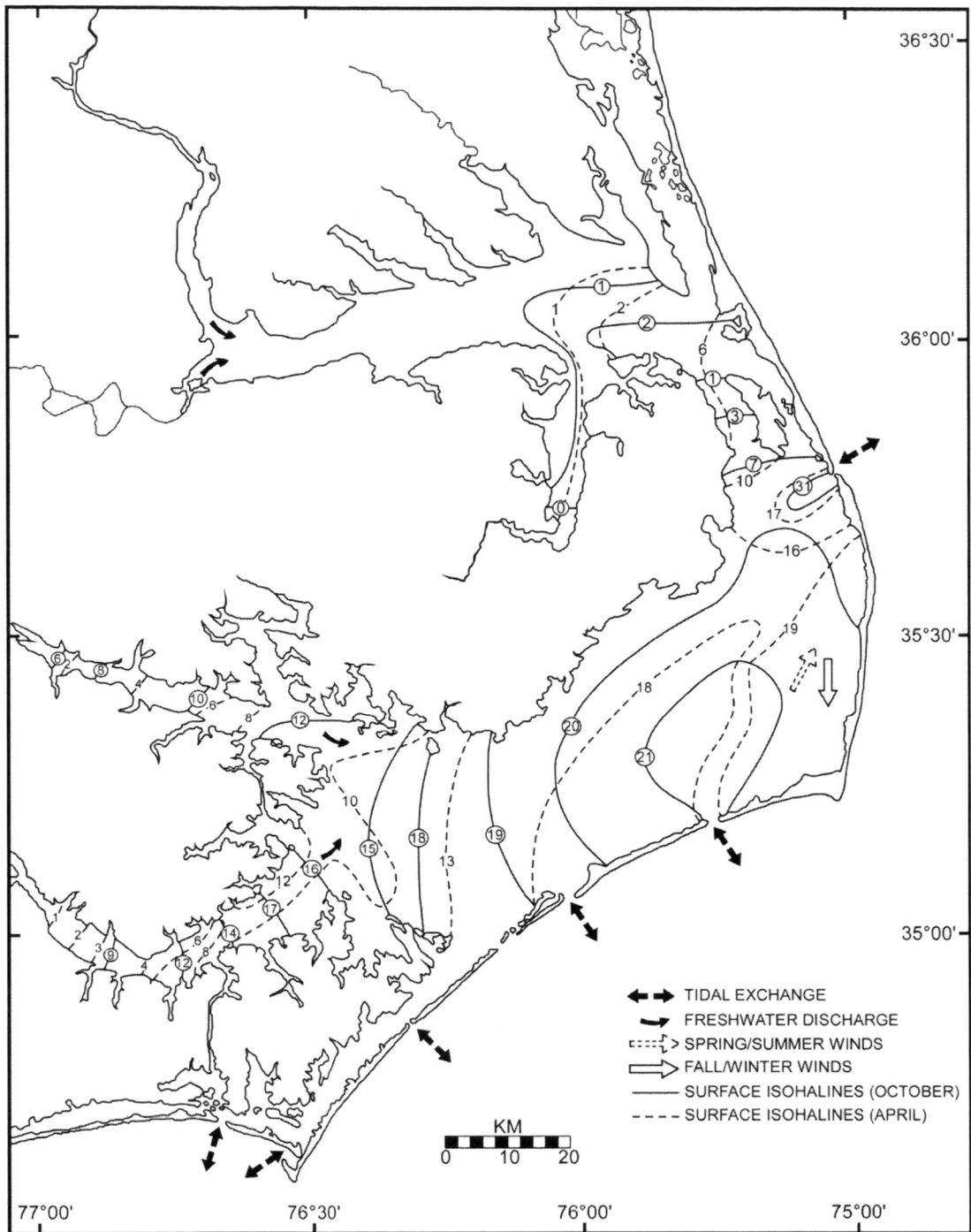


Figure 2: Map showing tidal exchange at inlets, freshwater discharge, seasonal winds, and seasonal isohalines for Pamlico Sound (modified from Wells and Kim, 1989).

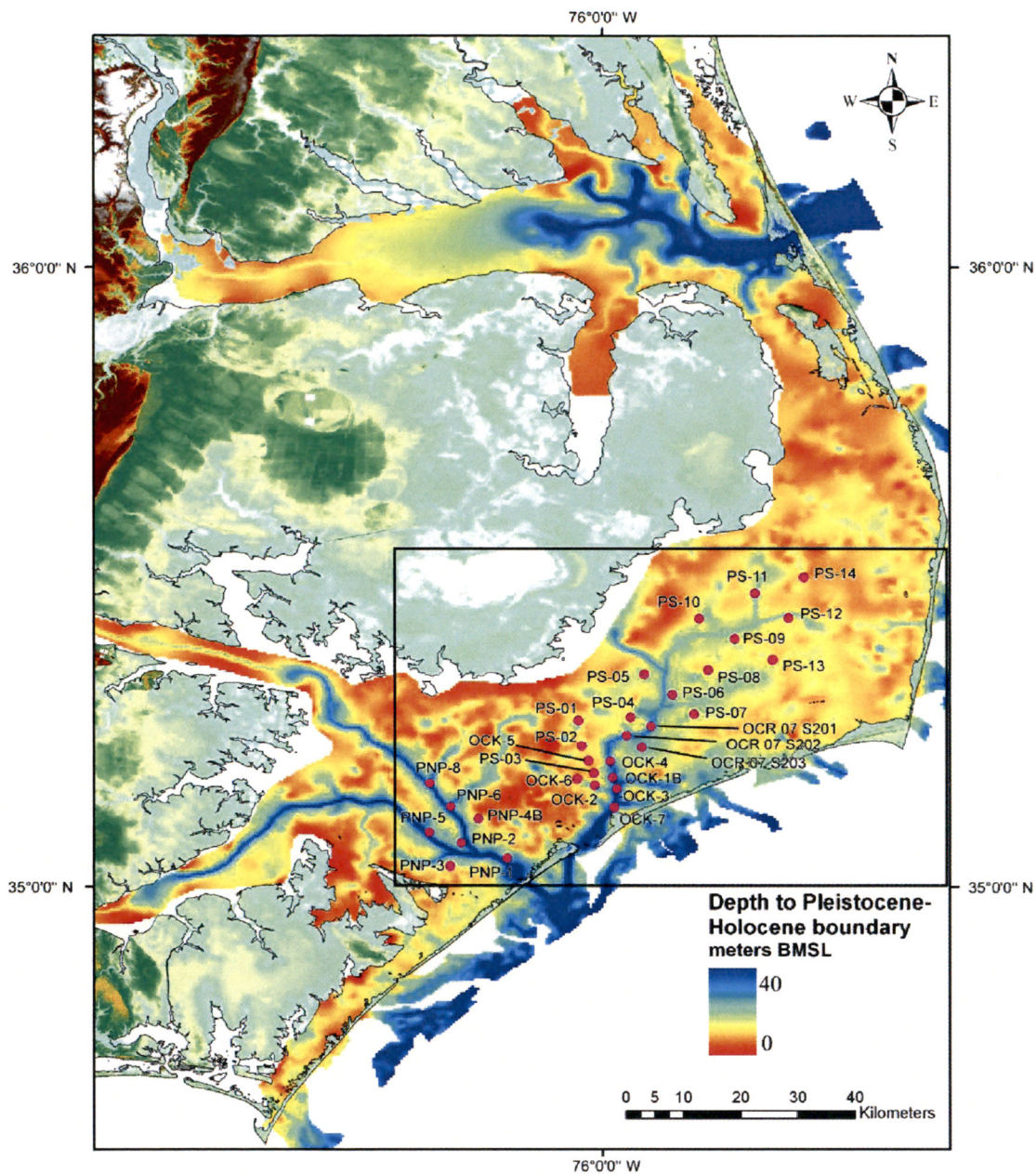


Figure 3: Map showing the paleo-topography of the late Pleistocene drainage systems underlying the coastal system of eastern North Carolina (D. Mallinson). Box indicates the study area, pink dots represent vibracore locations.

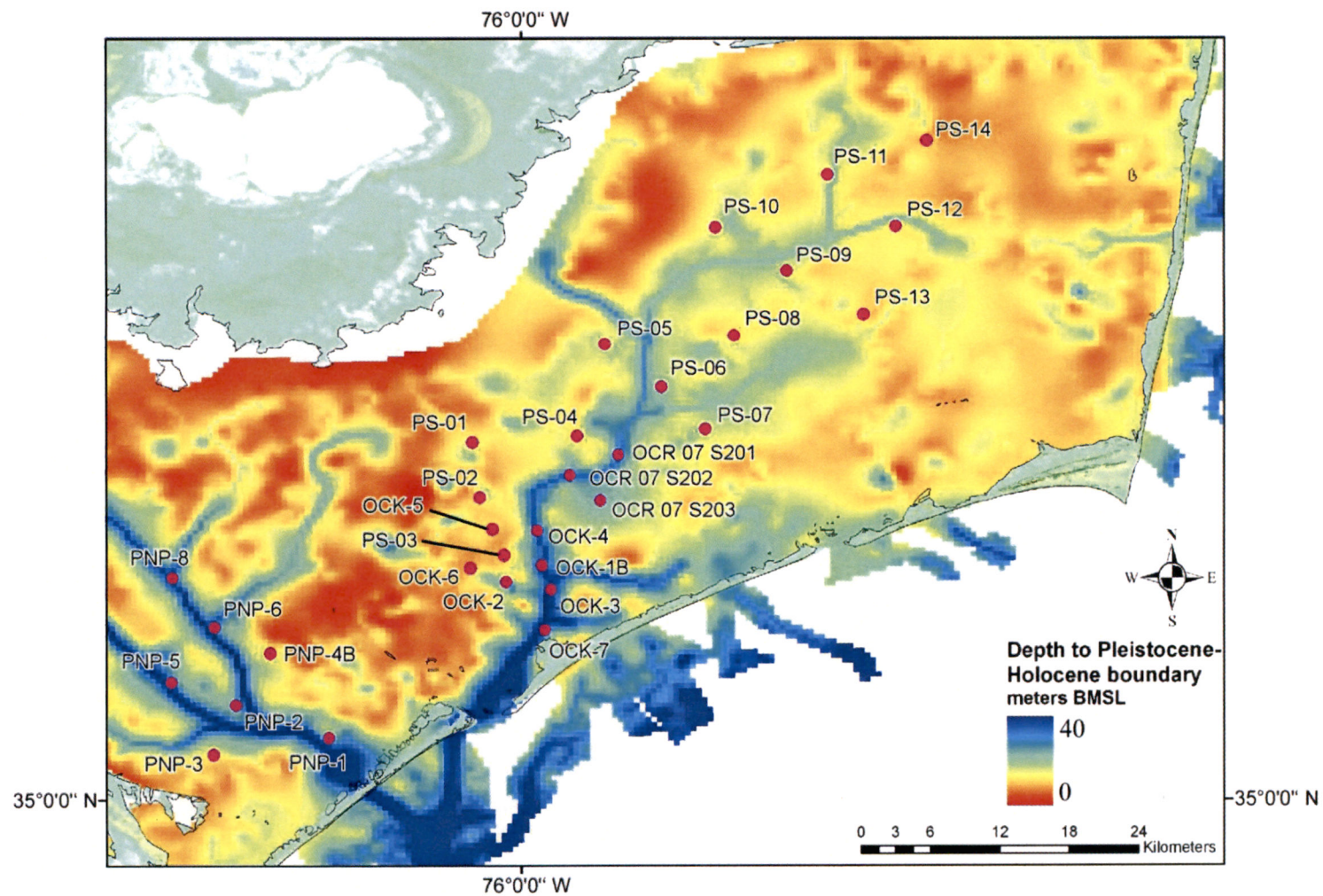


Figure 4: Map of boxed area from Figure 3 showing location of Pamlico Sound vibracores from this study, Grand Pre (2006), and Foley (2007).

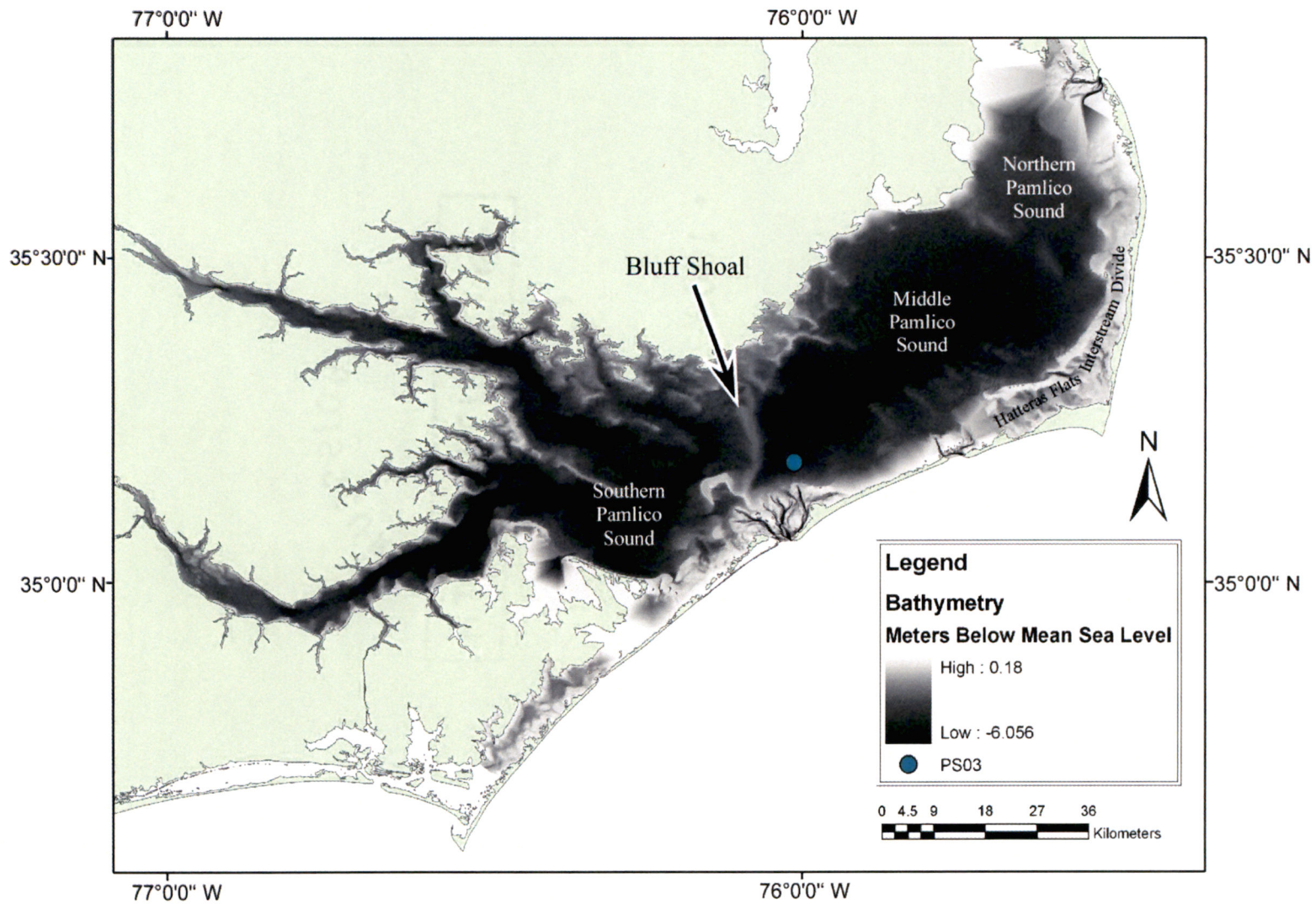


Figure 5: Bathymetry (m) of Pamlico Sound showing location of PS03 and Bluff Shoal (bathymetry data from Reid et al., 2005).

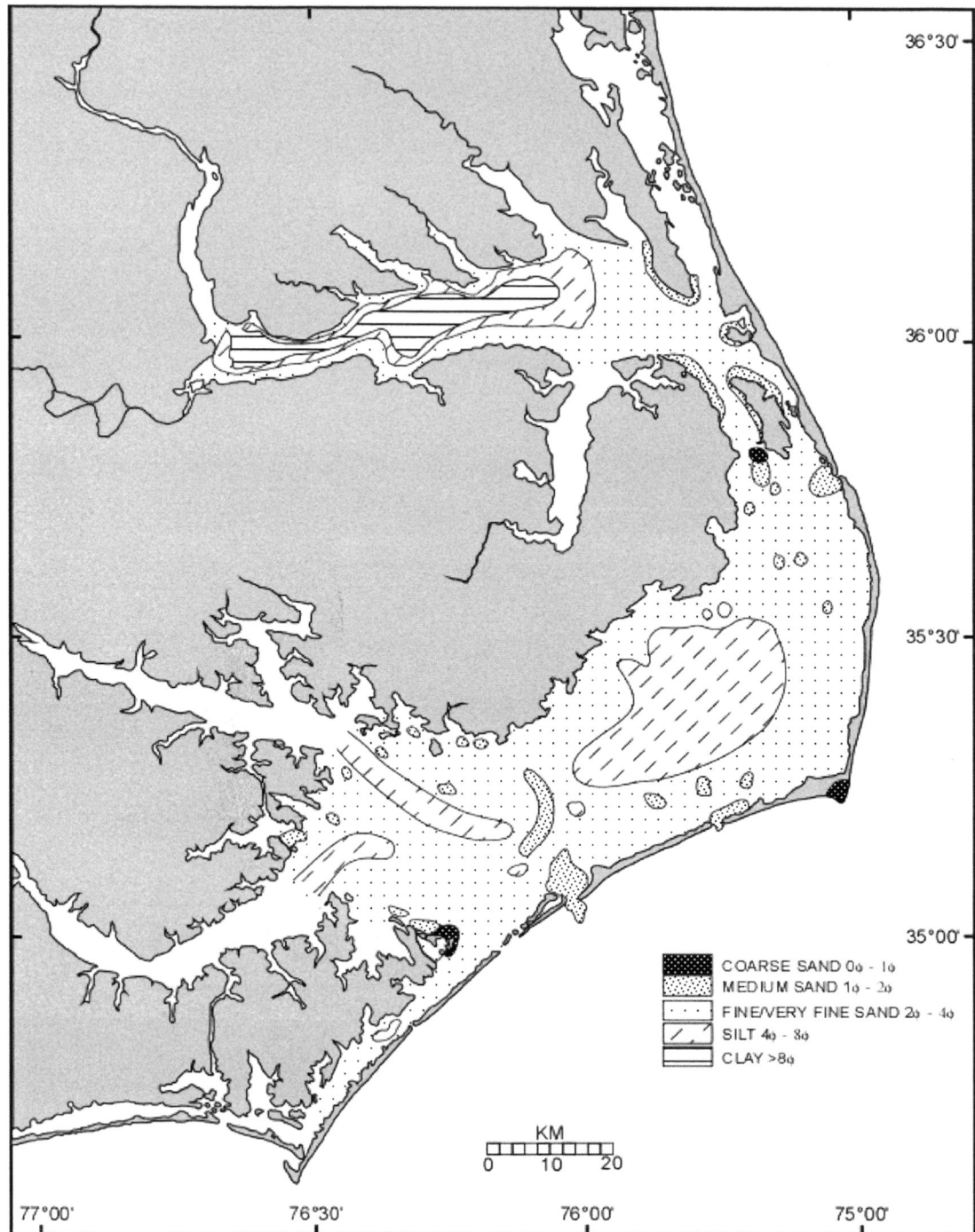


Figure 6: Map showing surface sediment texture in Pamlico and Albemarle Sounds (modified from Wells and Kim, 1989).

PREVIOUS WORK

Foraminifera

Foraminifera are useful for reconstructing both modern and paleoenvironmental changes due to their sensitivity to variables such as food availability, salinity, competition, predation, temperature, dissolved oxygen, etc.; and therefore their distributions are environment specific (Figure 7) (Boltovoskoy and Wright, 1976; Scott et al., 2001). Studies of modern foraminiferal assemblages give an insight into what dictates their distributions and allows for downcore interpretations of past environments.

Numerous studies documenting the distribution of modern foraminifera have been conducted in North Carolina and the surrounding region; including the sounds and estuaries (Buzas, 1965; Grossman and Benson, 1967; Ellison and Nichols, 1970; Akers, 1971; LeFurgey, 1976; Abbene, 2004; Vance, 2004; Vance et al., 2006; Abbene et al., 2006; Pruitt, 2008), marshes (Spencer, 2000; Culver and Horton, 2005; Horton and Culver, 2008), barrier lagoonal systems (Culver et al., 1996; Woo et al., 1997), and the continental shelf (Wilcoxon, 1964; Murray, 1969; Schnitker, 1971; Workman, 1981). Downcore studies of foraminiferal assemblages resulting in paleoenvironmental interpretations include Karlsen et al. (2000), Smith (2004), Mallinson et al. (2005), Ricardo (2005), Culver et al. (2006), Rosenberger (2006), Smith (2006), Twamley (2006), Grand Pre (2006), Culver et al. (2007), Foley (2007), Hale (2008), and Stanton (2008).

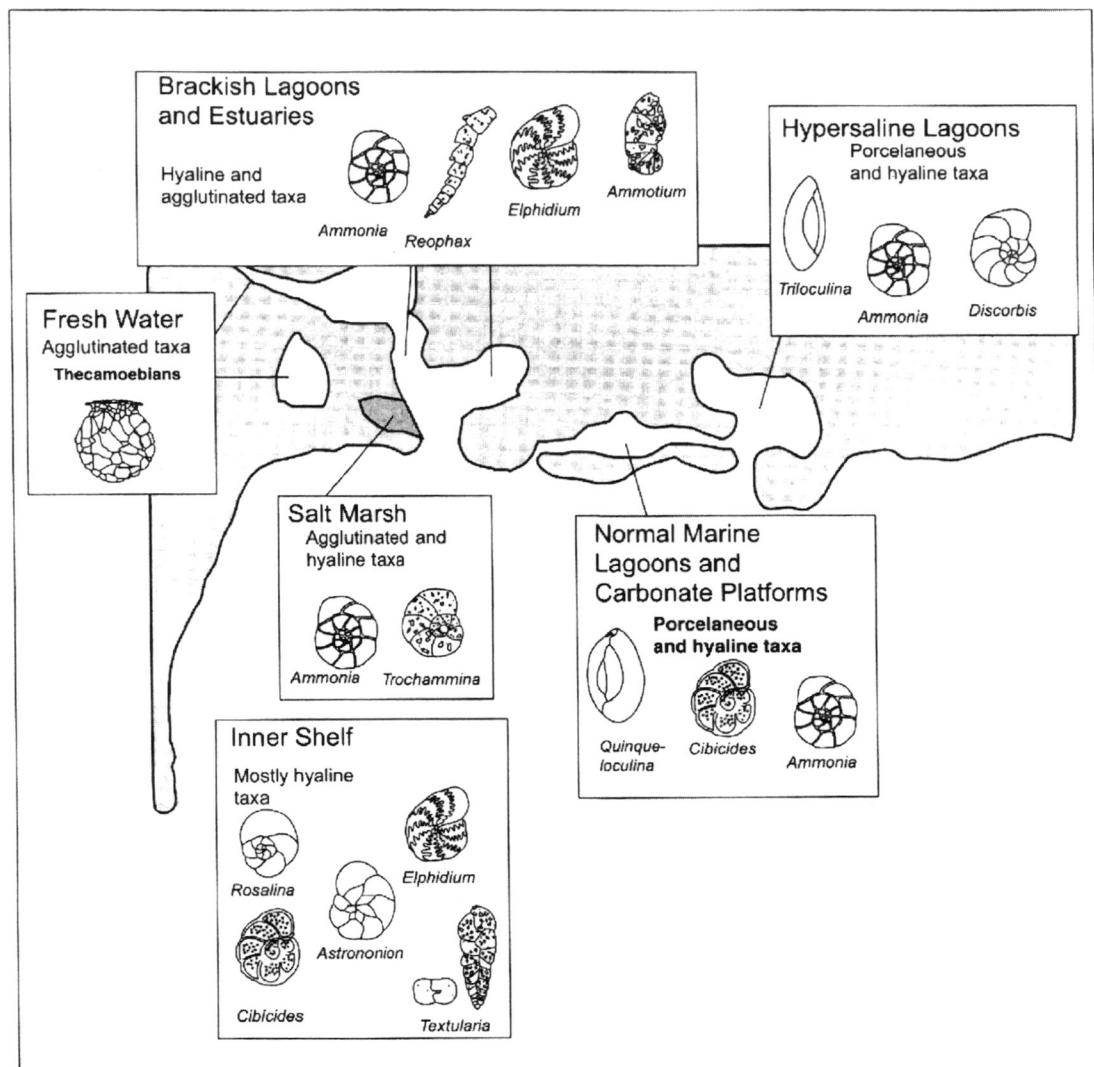


Figure 7: Typical foraminiferal assemblages that characterize marginal marine environments (Scott et al., 2001).

In the following section, the major findings of these studies are summarized. This information provides the basis for interpretations of foraminiferal assemblages recovered from the vibracores analyzed in this study.

Modern Day Foraminiferal Distributions

Marginal Marine (Sounds, Estuaries, Inlets, Salt Marshes, Lagoons)

Spencer (2000) studied foraminiferal assemblages from the Phillips Creek salt marsh in Virginia. Three biofacies were defined: low marsh, middle/transitional marsh, and high marsh. The low marsh biofacies did not contain any calcareous species and was characterized by *Miliammina fusca* and *Trochammina inflata*. The middle/transitional biofacies was dominated by *Tiphotrocha comprimata* and *T. inflata*. The high marsh biofacies was subdivided into a lower high marsh and an upper high marsh. *T. inflata*, *T. comprimata* and *Jadammina macrescens* dominated the lower part of the high marsh biofacies; while *J. macrescens* and *Trochammina salsa* dominated the upper part of the high marsh biofacies.

Marshes (low and high) of the Outer Banks were studied by Culver and Horton (2005) at three sites: Currituck Sound (low-salinity), Pea Island (intermediate salinity), and Oregon Inlet (high-salinity). Both live and dead foraminifera were observed, but certain species had greater preservation potential (*Arenoparrella mexicana*, *Haplophragmoides wilberti*, *Jadammina macrescens* and *Trochammina inflata*) than others (*Miliammina fusca*) due to post-mortem degradation (Culver and Horton, 2005).

Horton and Culver (2008) studied foraminifera from three back-barrier intertidal sites along the Outer Banks, North Carolina (Currituck Barrier Island, Oregon Inlet, and Pea Island). Two distinct assemblages were observed: agglutinated and calcareous. The agglutinated assemblage was found in the vegetated portion of the marshes and was dominated by *Ammobaculites crassus*, *A. subcatenulatus*, *Arenoparrella mexicana*, *Jadammina macrescens*, *Miliammina fusca*, and *Trochammina inflata*. The mud and sandflats contained the calcareous assemblage and was dominated by *Ammonia parkinsoniana*, *Elphidium excavatum*, and *Haynesina germanica*.

Nichols and Norton (1969) used foraminifera to divide the James River Estuary, Virginia into upper and lower segments. The upper estuary (< 14 psu) was dominated by the agglutinated taxon, *Ammobaculites*. The lower estuary (> 14 psu) was characterized by the calcareous taxon, *Elphidium* with less than 18% *Ammobaculites*.

In the adjacent Rappahannock River Estuary, Virginia, Ellison and Nichols (1970) also found that salinity was the main factor determining the distribution of biofacies: shoal, basin, and marsh. The basin biofacies was characterized by species tolerant of high salinity and was dominated by *Elphidium clavatum* (= *E. excavatum* in this study). The shoal biofacies was characterized by low salinity foraminifera and was dominated by *Ammobaculites crassus* (Ellison and Nichols, 1970). The marsh biofacies were divided into two salinity related groups: upper and lower marsh biofacies. The higher salinity outer marsh biofacies was dominated by *Miliammina fusca* and the lower salinity inner marsh biofacies was dominated by *Ammoastuta salsa*.

The distribution of modern foraminifera in the Albemarle Sound (Figure 8) was studied by Vance et al. (2006). By performing a cluster analysis of dead assemblages found on the surface, five environments were distinguished: nearshore marine and inlet (Biofacies A), estuarine shoal (Biofacies B), estuarine (Biofacies C), inner estuarine (Biofacies D), and marsh (Biofacies E). The nearshore marine and inlet Biofacies A had low species richness and was dominated by *Elphidium excavatum*. The estuarine shoal Biofacies B had marsh species transported in and therefore higher species richness. The most abundant species in this group were *Ammobaculites crassus* and *Ammotium salsum*. In Biofacies C represents an estuarine environment where the dominant species was *Ammotium salsum* with *Ammobaculites crassus*, *Miliammina fusca*, and *Ammobaculites subcatenulatus* comprising an important fraction of this biofacies. Inner estuarine Biofacies D was dominated by *Ammobaculites subcatenulatus* with *Ammotium salsum*, *Miliammina fusca*, and *Ammobaculites crassus* as the characteristic species. Species richness was high for the marsh Biofacies E and characteristic foraminifera included: *Miliammina fusca*, *Ammobaculites crassus*, *Miliammina petila*, *Ammonia inaequalis*, *Jadammina macrescens*, *Ammotium salsum*, and *Reophax* sp.

Abbene et al. (2006) conducted a distributional study encompassing the estuarine Pamlico Sound (Figure 9). In this study, cluster analysis of modern surficial dead foraminiferal assemblages yielded four groups: Low Salinity Estuarine Biofacies A, High Salinity Estuarine Biofacies B, Marsh Biofacies, and Marine Biofacies. Low Salinity Estuarine Biofacies A is mostly composed (83%) by *Ammotium salsum*. High Salinity Estuarine Biofacies B is dominated by the calcareous foraminifera *Elphidium excavatum*

and *Ammonia parkinsoniana*; with the agglutinated taxa *Ammotium salsum*. The Marsh Biofacies contains *Ammonia parkinsoniana*, *Ammotium salsum*, and *Trochammina inflata*; a finely agglutinated foraminifera. The Marine Biofacies did not contain any agglutinated taxa and was dominated by *Elphidium excavatum*. Although one species dominated this group, it was the most diverse of all groups and contained several inner shelf taxa: *Cibicides lobatulus*, *Cibicides refulgens*, *Elphidium subarcticum*, *Quinqueloculina lamarckiana*, and *Quinqueloculina seminula*.

Foraminiferal distribution in Roanoke, Croatan, and northern Pamlico Sound was studied by LeFurgey (1976). Agglutinated foraminifera, such as *Miliammina fusca* and *Ammobaculites crassus* were prominent in the upper reaches of the study area; while the lower reaches were dominated by species like *Miliammina fusca* and *Elphidium selseyense* (= *E. excavatum* of this study). The difference in distribution is due to variations in salinity, temperature, and calcium carbonate between the upper and lower regions. The upper Roanoke and Croatan Sounds have lower salinities, temperatures, and calcium carbonate availabilities than in the lower Roanoke Sound. The lower Roanoke Sound receives more oceanic influence, allowing more calcium carbonate and intermediate temperatures and salinities.

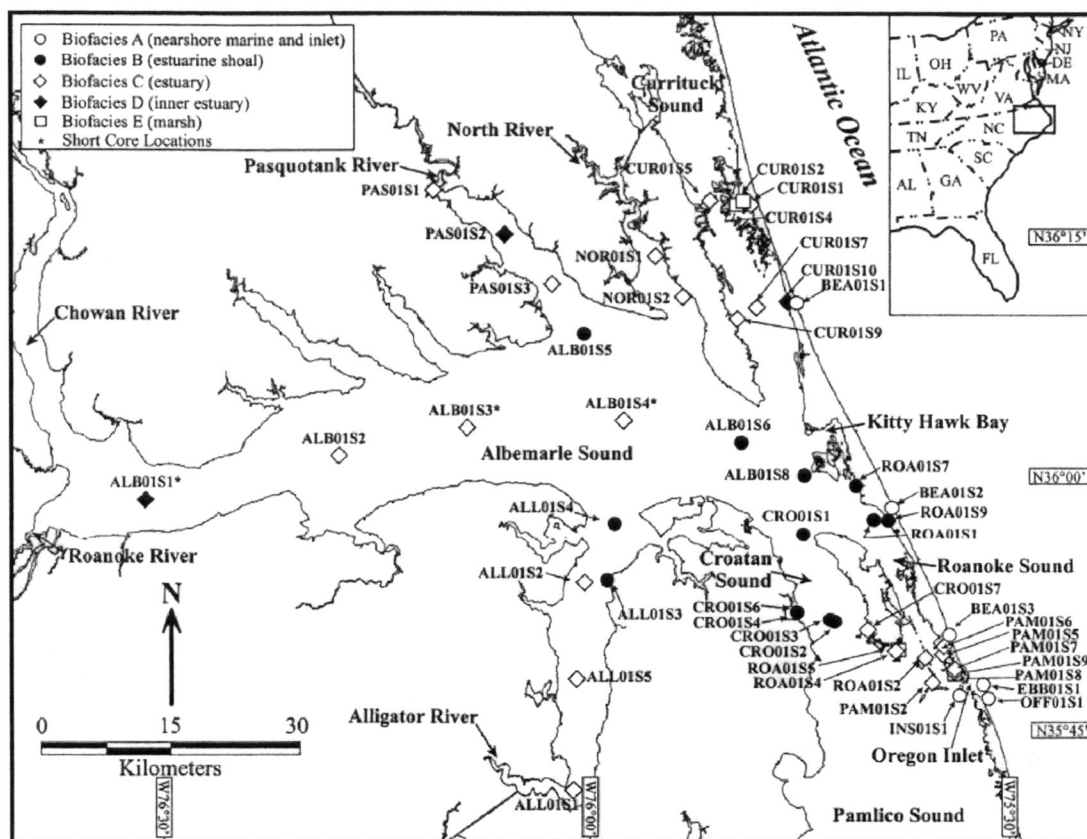


Figure 8: Modern day distributions of foraminiferal assemblages in Albemarle Sound, North Carolina (Vance et al., 2006).

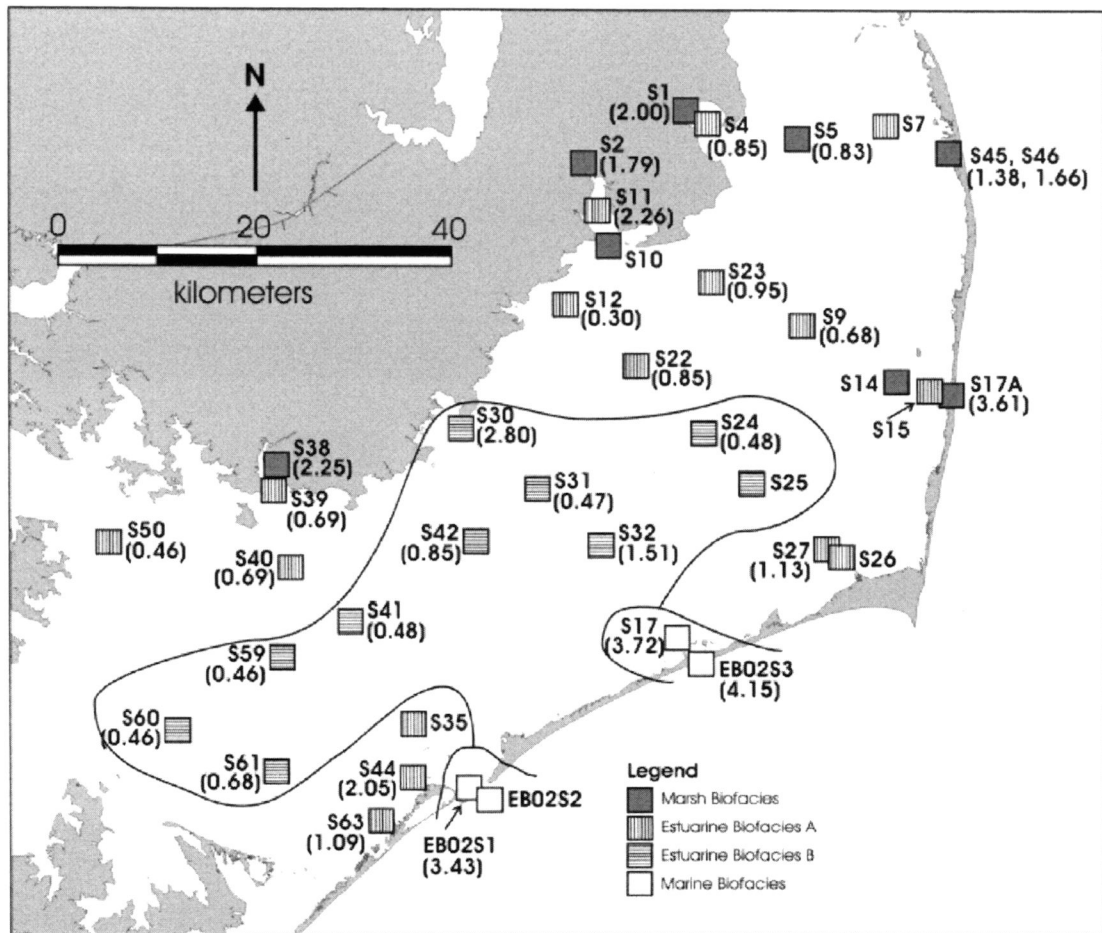


Figure 9: Modern day distributions of foraminiferal assemblages in Pamlico Sound, North Carolina (Abbene et al., 2006).

The distribution of barrier island-lagoon foraminifera was documented by Culver et al. (1996) in the southern Delmarva Peninsula, Virginia. The objective of this study was to determine if analysis of living and dead assemblages could be used to discriminate 20 sub-environments within the study area. Of the 20 sub-environments, canonical variate analysis discriminated only four (Culver et al., 1996). Woo et al. (1997) used live foraminifera to determine sub-environments in the same study area as Culver et al. (1996). Seven sub-environments were discriminated on the basis of living communities (Woo et al., 1997).

Akers (1971) studied foraminifera of the Beaufort area, NC including the continental shelf, Beaufort Inlet, lagoon, and marsh. Four assemblages were recognized: open ocean, lagoonal, fluvial-marine, and marsh. The open ocean assemblages had abundant species and included *Ammonia beccarii*, *Elphidium gunteri*, *Hanzawaia concentrica* (= *H. strattoni* in this study), and *Quinqueloculina seminula*. The lagoonal assemblage had lower diversity, fewer calcareous foraminifera (*Elphidium* and *Ammonia*), and a few arenaceous (*Trochammina* and *Ammobaculites*) species present. The marsh assemblage also had low species diversity and contained *Arenoparrella mexicana*, *Miliammina fusca*, and *Tiphotrecha comprimata*. *Elphidium gunteri* dominated the Beaufort Inlet (fluvial-marine).

Two studies have concentrated on the distribution of benthic foraminifera in southern Pamlico Sound and the adjacent Core Sound (Figure 1) and are potentially important for interpreting the cores of this study.

Grossman and Benson (1967) documented the distribution of ostracoda and foraminifera in southern Pamlico Sound. Five foraminiferal assemblages were identified: open sound (*Ammobaculites* and *Ammotium* to the west and *Elphidium* species gradually replaced the agglutinated taxa to the east), saltwater lagoon (*Elphidium gunteri* and *E. tumidum*), estuarine (*Ammobaculites*, *Miliammina*, and *Ammotium*), marsh (*Haplophragmoides*, *Trochammina*, and *Miliammina*), and tidal-delta biofacies; which was separated into a sound-delta subfacies (*Elphidium galvestonense*) and a marine-delta subfacies (*Quinqueloculina* and *Triloculina*). The distribution of foraminifera was controlled by salinity, currents, and vegetation patterns (Grossman and Benson, 1967).

Pruitt (2008) documented foraminiferal and geochemical changes in Core Sound using 79 surface samples and five short cores collected in 2004 and comparing them to biofacies documented for the area in 1959. The 1959 study (Grossman and Benson, 1967) defined five biofacies: Estuarine, Open-Sound, Salt-Water Lagoon, Tidal-Delta, and Salt Mash. The 2004 data produced four biofacies: Marsh, Estuarine High Salinity A, Estuarine High Salinity B, and Estuarine Low Salinity. Four correlations were recognized (Table 1) and it was determined that two noteworthy changes occurred over 45 years in the foraminiferal assemblages. First, the Salt-Water Lagoon *Elphidium* species dominated biofacies (Grossman and Benson, 1967) changed to the modern Estuary High Salinity B biofacies, dominated by *Ammonia parkinsoniana* (Pruitt, 2008). This change may be due to an increase in eutrophication, but there were no clear data to confirm this (Pruitt, 2008). Second, miliolid species have become more widespread in

the immediate proximity of the Core Banks barrier islands, possibly due to an increase in sea-grass (Pruitt, 2008).

Table 1: Correlation table between Grossman and Benson (1967) 1959 samples and Pruitt (2008) 2004 samples.

1959	2004
Open Sound	Estuary Low Salinity
Salt Marsh	Salt Marsh
Salt-Water Lagoon	Estuary High Salinity B
Tidal-Delta	Estuary High Salinity A

North American Atlantic Continental Shelf

Wilcoxon (1964) studied foraminifera distribution from Cape Hatteras to the Florida Straits. The North and South Carolina coasts had the highest number of species per gram of sediment; and four zones were distinguished: Beach, Inner Shelf, Middle Shelf, and Outer Shelf-Upper Continental Slope. The Beach zone had abundant *Elphidium rugulosum* and *Ammonia tepida*. The Inner Shelf zone had various species of *Quinqueloculina* and *Elphidium* as characteristic species. A great abundance and variety of foraminifera were found in the Middle Shelf zone and included *Globigerinoides ruber* and *Textularia secasensis*. The Outer Shelf-Upper Continental Slope contained an

assemblage of deep water foraminifera and included *Bolivina paula* and *Cassidulina subglobosa*.

A comparison of benthic foraminiferal assemblages from Vineyard Sound, Massachusetts, and regions of the continental shelf off Long Island, New York, Cape Hatteras and Cape Lookout, North Carolina was performed by Murray (1969). A temperature gradient was observed on the shelf off Cape Hatteras between cooler waters from Virginia in the north and warmer waters from the Carolinas to the south. Assemblages to the north of Cape Hatteras were dominated by *Cibicides concentricus*, *Eggerella advena*, *Rosalina* sp., and *Stetsonia minuta*. Assemblages to the south were more diverse and included *Cibicides pseudoungerianus*, *Miliolinella circularis*, *Quinqueloculina* sp. and *Trifarina angulosa* (Murray, 1969).

Foraminiferal distribution off the coast of North Carolina on the continental shelf (Figure 10) was studied by Schnitker (1971). Schnitker made three important observations: 1) there is a boundary at the latitude (35°N) of Cape Hatteras that separates faunas; 2) due to Gulf Stream waters, there is a higher faunal diversity south of Cape Hatteras and 3) benthic and planktonics increase in number with depth. The pattern of increase with depth is true both nearshore and offshore. For example, Schnitker (1971) noticed that low abundances occurred to ca. 20 to 30 m depth. However, the number of foraminifera increases significantly to 100 specimens per cm³ of sediment at 70 m depth, and 1834 specimens per cm³ at 140 m depth.

The near-shore and central shelf environments are characterized by *Elphidium clavatum* (Schnitker, 1971). *Islandiella subglobosa* and *Bulimina marginata* dominate

the shelf edge (also north of Cape Hatteras). South of Cape Hatteras, the faunal distribution diversifies and becomes more complex from region to region, with dominant taxa percentages fluctuating. From Cape Hatteras to Cape Lookout, the central shelf is dominated by *Hanzawaia concentrica*; the central shelf of Raleigh Bay is dominated by *Paneroplis proteus*; and the central shelf of Onslow Bay is dominated by *Placopsilina confusa* and *Quinqueloculina seminula* (Schnitker, 1971). On the shelf edge south of Cape Hatteras, low percentages of various species are found: *Lenticulina orbicularis*, *Cibicides pseudoungerianus*, *Amphistegina lessonii*, *Islandiella subglobosa*, and *Trifarina angulosa* (Schnitker, 1971). Figure 11 illustrates the distribution of planktonic foraminifera on the North Carolina continental shelf. Overall, the most abundant planktonic foraminifera species found off the North Carolina coast were *Globigerinoides ruber* and *Globorotalia menardii* (Figures 12 and 13) (Schnitker, 1971).

Workman (1981) looked at foraminiferal assemblages on the inner shelf off Nags Head and Wilmington, North Carolina. A faunal boundary exists between the two areas due to two different water masses: cool Virginian waters to the north and warm Carolinian waters to the south. To the north there was low diversity and assemblages were dominated by several species of *Elphidium*. Southern fauna had greater diversity and assemblages were dominated by species of *Quinqueloculina*.

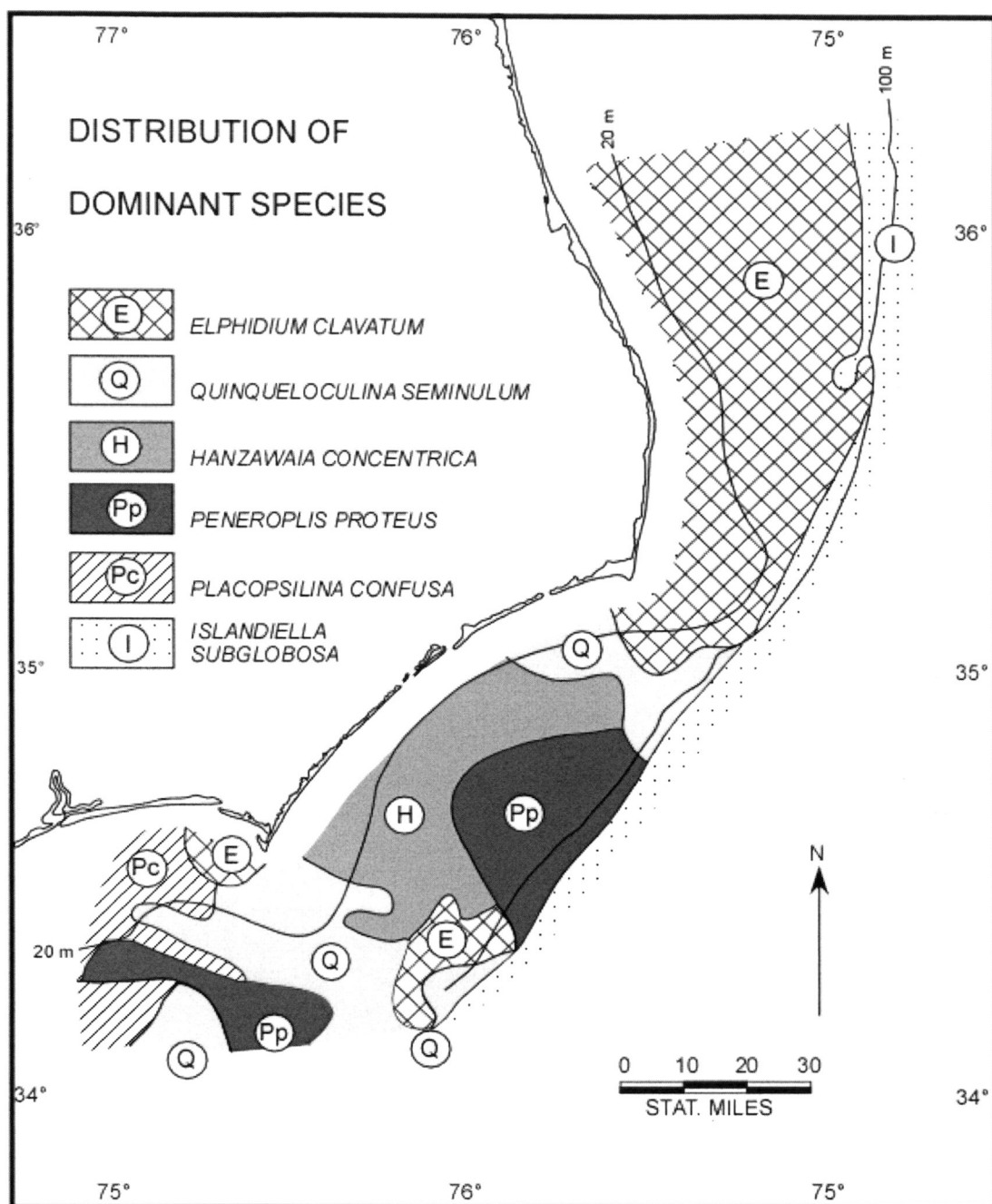


Figure 10: Dominant foraminifera found on the North Carolina shelf (modified from Schnitker, 1971).

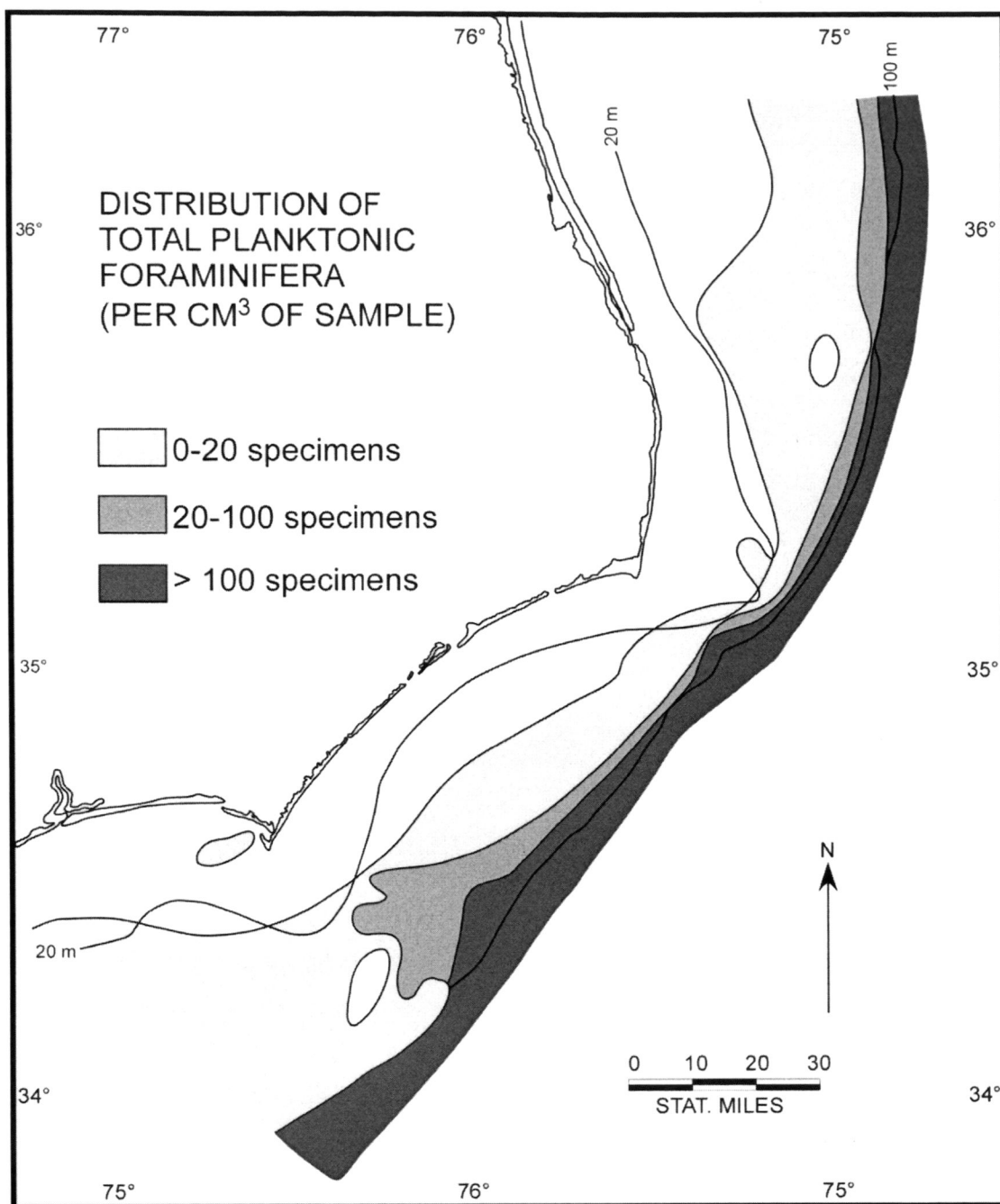


Figure 11: Distribution of total planktonic foraminifera (specimens per cubic centimeter of sample) on North Carolina continental shelf (modified from Schnitker, 1971).

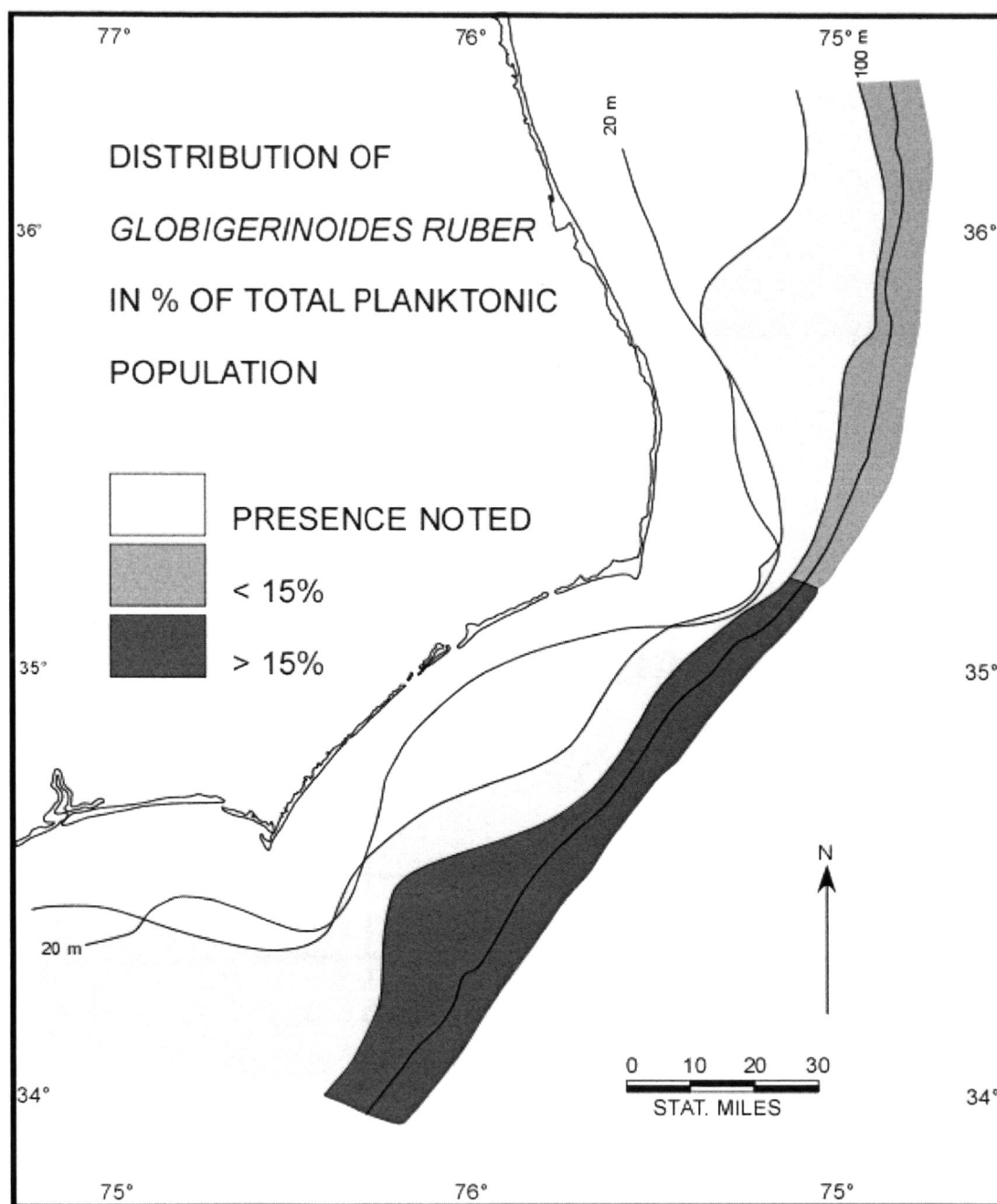


Figure 12: Distribution of *Globigerinoides ruber* on the North Carolina continental shelf (modified from Schnitker, 1971).

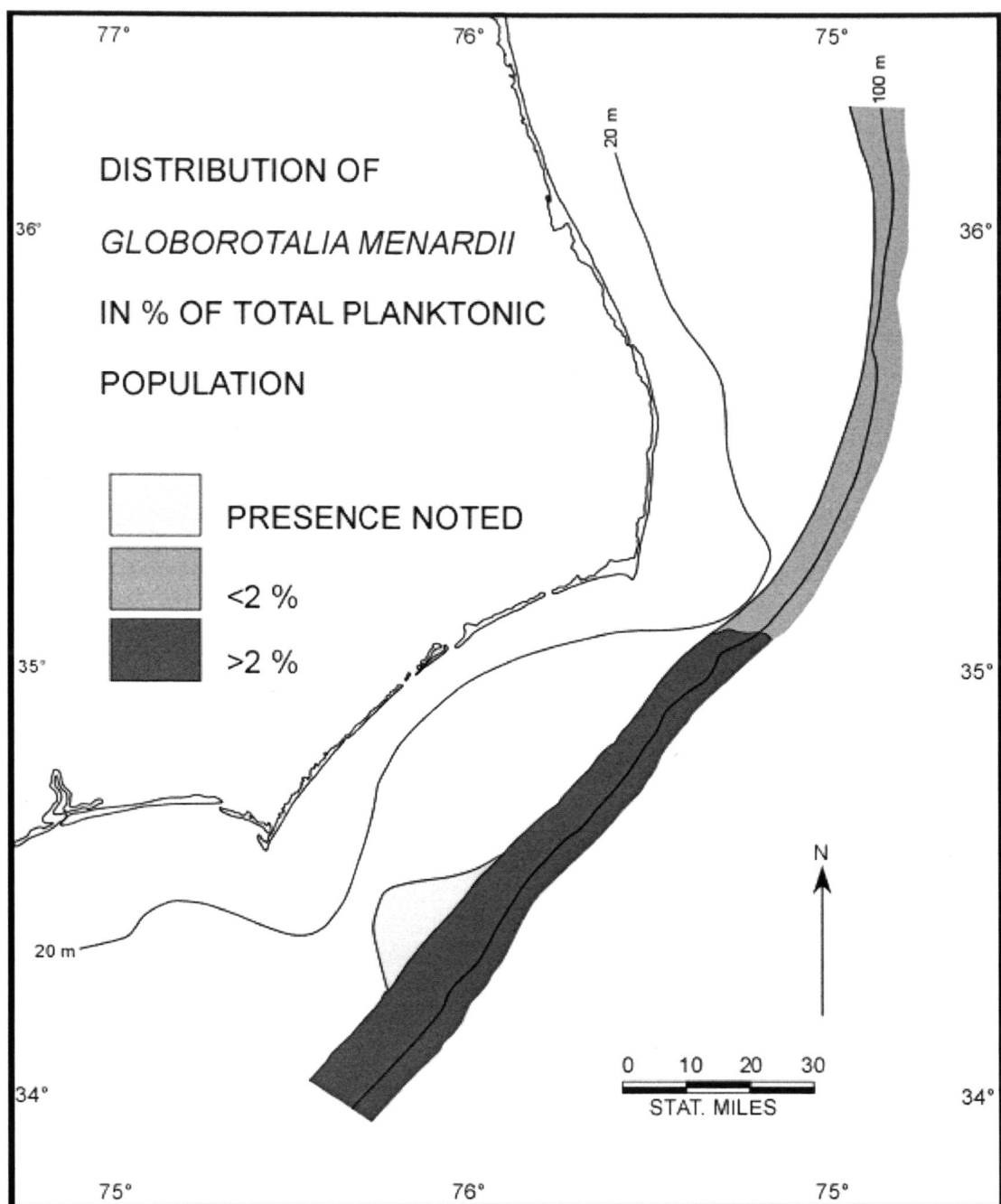


Figure 13: Distribution of *Globorotalia menardii* on the North Carolina continental shelf (modified from Schnitker, 1971).

Foraminifera-based Holocene Paleoenvironmental Interpretations

Downcore environmental changes can be reconstructed once the distribution of modern benthic foraminifera is known. Interpretations using foraminifera can include, for example, storm frequency, sea-level change, and climate change. The published literature is vast and so the following section is restricted to examples from North Carolina and Virginia. Many of these studies are unpublished Master's Theses but they provide essential background information for the current study.,

In Chesapeake Bay, Virginia the benthic foraminifer *Elphidium* exhibits a direct correlation between percent abundance and salinity (Cronin et al., 2000). For salinities of 20-30 psu, *Elphidium* is more abundant overall in the assemblage (~50%-85%); and in lower salinities (below ~10 psu) *Elphidium* is absent altogether. The study determined that salinity within the bay has oscillated over the last 1000 years and the area experienced 14 wet-dry cycles, occurring approximately every 60-70 years (Cronin et al., 2000).

Karlsen et al. (2000) used *Ammonia parkinsoniana*, an opportunistic species that is tolerant of periodic anoxic and dysoxic conditions, to document historical trends in dissolved oxygen (DO) in the Chesapeake Bay. *Ammonia parkinsoniana* (both normal and deformed tests) was recorded and plotted as a percent of the total assemblage down core (Karlsen et al., 2000). Higher percents of *Ammonia parkinsoniana* indicated increased anoxic conditions. Karlsen et al. (2000) suggested that DO content in the bay is controlled by river discharge; higher discharge rates result in decreased frequency of anoxic conditions and lower abundances of *Ammonia parkinsoniana*.

Culver et al. (2006) studied foraminiferal, sedimentary, geochemical, and ground-penetrating radar (GPR) transects to reconstruct the late Holocene geology of Pea Island, North Carolina. Inlet and overwash processes have dominated the area for at least 1000 years. Four fining-upward sequences were identified as overwash events that are topped by estuarine, inlet, and marsh sediments.

Ricardo (2005) studied foraminifera, lithologic, geophysical, and geospatial data from Salvo-Little Kinnekeet and Gull Island areas to reconstruct the paleoenvironment from this area. He defined three biofacies in the shallow subsurface using 18 vibracores collected from the back-barrier estuary: back-barrier estuarine shoal; open marine/inner shelf; and mixed back-barrier marsh/estuarine shoal. Estuarine shoal foraminifera (*Elphidium excavatum* and *Ammonia parkinsoniana*) were found in the upper sediment (~1.5-2m). Open shelf/open embayment foraminifera (*Elphidium excavatum*, *E. mexicanum*, and *E. subarcticum*) were found at 2 to 5 m below MSL. Radiocarbon dating of these intervals yielded age estimates indicating that from 3000 to 1250 cal. yrs. B.P. the region experienced open marine conditions. Following 1250 cal yr B.P. the Gull Island region was a semi-enclosed embayment; Hatteras Island began to form, and by ~500 cal yr B.P. had stabilized (Ricardo, 2005).

Twamley (2006) defined six litho/biofacies (inner shelf, inlet, low energy estuarine, high energy estuarine, marsh, and barrier island) from 27 vibracores collected from Hatteras Village Area, North Carolina. The inner shelf marine unit included normal salinity foraminifera *Elphidium excavatum*, *Elphidium subarcticum*, *Nonionella atlantica*, and *Hanzawaia strattoni*. The inlet litho/biofacies contained more shell material than the

inner shelf marine unit, as well as abundant *Quinqueloculina seminula*, *Quinqueloculina lamarckiana*, and *Quinqueloculina jugosa*. Low energy estuarine litho/biofacies were dominated by *Elphidium excavatum* and *Ammonia parkinsoniana* and the agglutinated species *Ammotium salsum*. High energy estuarine litho/biofacies were either barren of foraminifera or contained only *Ammotium salsum*. Typical marsh assemblages dominated the marsh litho/biofacies and included *Arenoparrella mexicana*, *Haplophragmoides wilberti*, and *Trochammina inflata*. The barrier island litho/biofacies unit is characterized by beach ridge sand and was barren of foraminifera. By dating basal peat from the Hatteras Village area using ^{14}C , Twamley (2006) determined that the back-barrier marsh formed 500 cal yr BP.

Hale (2007) used 19 vibracores from three shore-perpendicular transects to collect lithostratigraphic, chronostratigraphic, geophysical, and foraminiferal data on Ocracoke Island. Seven Holocene litho/biofacies were defined; barrier island sand/overwash sand, marsh, estuarine flats, shallow submarine sand flats, flood tide delta, normal salinity low energy/low energy inner shelf, and normal salinity high energy/inlet. The barrier island sand/ overwash sand was barren of foraminifera and was characterized by massive to laminated, fine to medium-grained sand. The marsh environment contained typical finely agglutinated marsh foraminiferal assemblages found in organic-rich sandy mud. The biofacies was characterized by *Trochammina inflata*, *Arenoparrella mexicana*, and *Haplophragmoides wilberti*. The estuarine flats were characterized by *Ammonia parkinsoniana*, *Elphidium excavatum*, and *Haynesina germanica*. Characteristic lithologies for the biofacies were fine to medium-grained sands and muddy sand. The

shallow submarine sand flats were typically barren of foraminifera and characterized by gravel, sand, mud, and shell hash. The flood tide delta was characterized by *Glabratellina lauriei*, *Elphidium mexicanum*, and *Hanzawaia strattoni*. The normal salinity low energy/low energy inner shelf biofacies was characterized by *Elphidium poeyanum*, *Haynesina germanica*, *Elphidium excavatum*, and *Elphidium galvestonense* with *Bolivina lowmani*, *Rectobolivina advena*, *Trifarina angulosa*, and Gulf Stream planktonics. The normal salinity, high energy/inlet was characterized by robust taxa *Quinqueloculina jugosa*, *Quinqueloculina seminula*, and *Quinqueloculina lamarckiana* with *Elphidium* species. The findings of Hale (2007) confirm that from approximately 1200 cal yr BP until 500 cal yr BP, the southern Outer Banks experienced a collapse allowing full marine conditions to dominate southern Pamlico Sound.

Rosenberger (2006) reconstructed the late Holocene geologic history of the back-barrier environment of Portsmouth Island, North Carolina using lithologic, foraminiferal, geochemical, and chronostratigraphic data. Six paleoenvironments were defined: marsh, barrier island/sand flat, inner shelf (Inner Shelf A, Inner Shelf B, Low Energy Shelf), and Normal Salinity (inlet?). The marsh paleoenvironment is characterized by *Trochammina inflata* and *Haplophragmoides willberti*. The barrier island/sand flat paleoenvironment is barren of foraminifera. The inner shelf paleoenvironments had assemblages typical of the inner shelf off the coast of North Carolina and were dominated by *Elphidium excavatum* and other subsidiary species (Rosenberger, 2006). The findings of Rosenberger (2006) provide further evidence that between 1200 to 500 cal yr the

southern Outer Banks experienced partial collapse allowing marine influence in southern Pamlico Sound.

Grand Pre (2006) and Culver et al. (2007) used high-resolution foraminiferal, sedimentologic, and stable isotopic data to reconstruct the Holocene paleoenvironment in Pamlico Sound, North Carolina from an 8.2 m long vibracore (Figure 14). Four biofacies were defined by comparing foraminiferal assemblages to the modern distribution of foraminifera: Normal Marine Salinity Bay, High Brackish Estuary, Low to Mid-Brackish Estuary, and Intermediate-probably estuary. Foraminiferal and stable isotopic data indicate exposure of Pamlico Sound to normal marine salinity conditions occurred twice during the Holocene. The first exposure occurred between 4340-4070 to 3750-3450 cal yr BP and correlates with the Mid-Holocene Hypsithermal. The second exposure occurred between 1170-950 to 550-440 cal yr BP and may have occurred because of sea-level rise and/or increased storm activity during the Medieval Warm Period. The younger event was explained by partial barrier island collapse of the southern Outer Banks (Grand Pre, 2006; Culver et al., 2007).

The study by Foley (2006) is particularly relevant to the current study in that it similarly is based on the foraminifera and sediments from several vibracores in Pamlico Sound. Foley's 13 vibracores were arranged along shore perpendicular and shore parallel transects from central Pamlico Sound (Figure 15). In the early Holocene (~7000 cal yr B.P.) there was a change from terrestrial to estuarine conditions. No planktonics were present to indicate open marine conditions at any time during the Holocene.

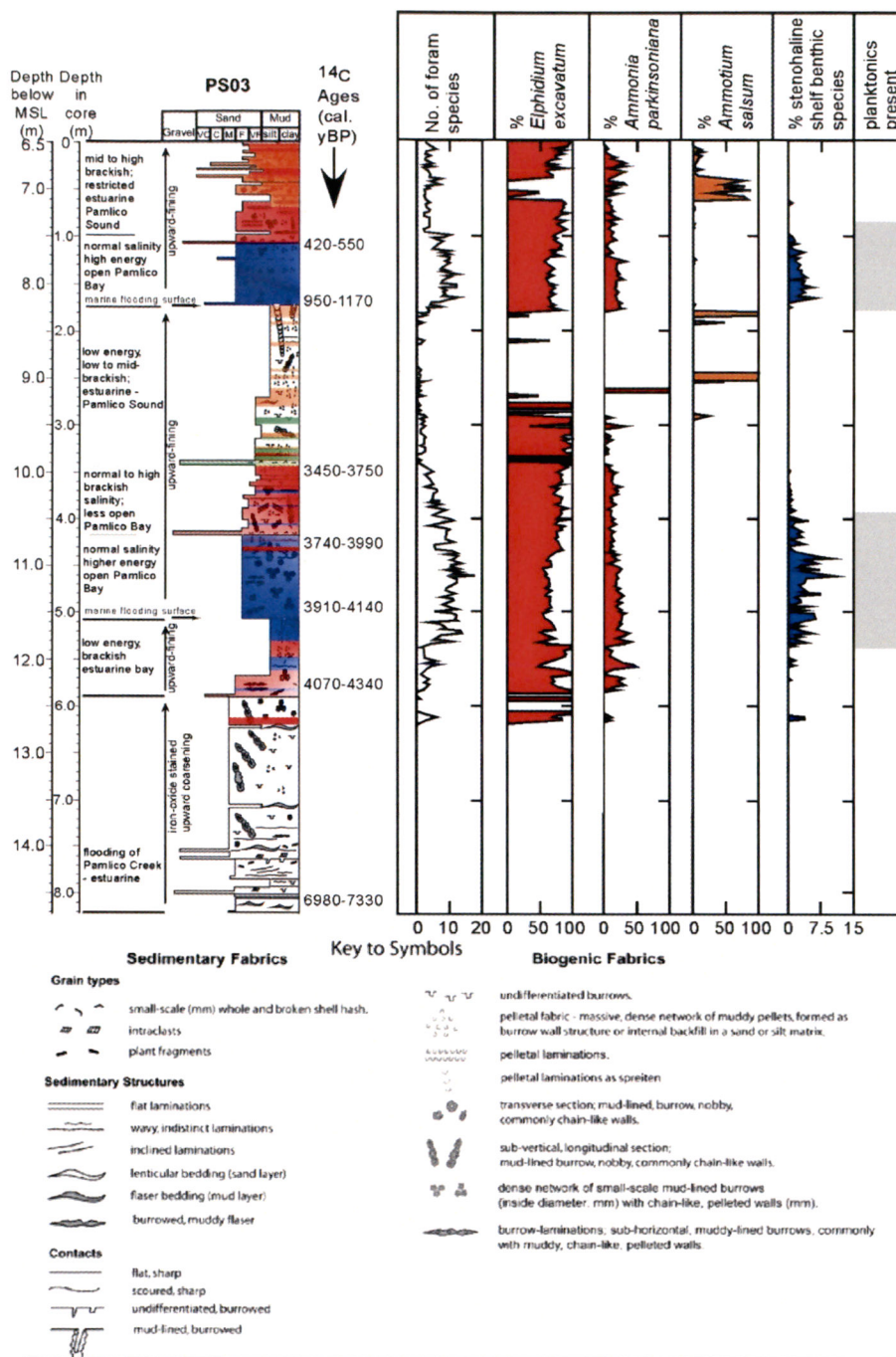


Figure 14: Detailed sedimentary log, foraminiferal data, and AMS ages for vibracore PS-03 (Culver et al., 2007).

Four assemblages were defined: low salinity estuary, a monospecific biofacies consisting of *Ammotium salsum*; low intermediate salinity estuary, dominated by *Ammotium salsum*, but also containing *Ammonia parkinsoniana* and *Trochammina inflata*; high intermediate salinity estuary, which had a greater ratio of *Ammonia parkinsoniana* to *Ammotium salsum* with a few taxa indicative of salt marshes; and high salinity estuary, dominated by *Elphidium excavatum* and *Ammonia parkinsoniana* with the occasional *Ammotium salsum* (Foley, 2007). Estuarine foraminiferal assemblages characterize the Holocene section with agglutinated or mixed calcareous and agglutinated foraminiferal assemblages (Foley, 2006). Figure 15 is a map of Foley's study area, vibracores, and transects. Transects B-B' (Figures 15; 16) and D-D' (Figures 15; 17) were chosen for detailed summaries due to their proximity to the vibracores of this study and PS03 (Grand Pre, 2006).

Transect B-B' (Figures 15, 16) traversed central Pamlico Sound and included cores PS-02, PS-04, PS-06, PS-08, PS-09, and PS-12 (Foley, 2007). The Pleistocene-Holocene boundary was observed in cores PS-04, PS-08, and PS-12. In PS-04 the boundary was marked by a transition from grayish olive muddy sand into orange-stained burrowed sand. In PS-08 the boundary was marked by a transition from medium bluish gray muddy sand to an olive gray sandy mud. In PS-12 the boundary was marked by a transition from a greenish-blue gray mud to an olive gray sandy mud. Foley (2007) observed three paleovalley lows within the B-B' transect. PS-02 was collected from the thalweg of a tributary of Pamlico Creek whereas PS-06 and PS-09 were collected from the paleochannel of Pamlico Creek. Generally the Holocene sediments within these cores

were muddy with small percentages of sand. However, the southern most portion of B-B' displayed a slight sand increase in sand content (PS-02 and PS-04).

Foraminiferal data indicated a general increase in salinity estuarine environments up core along transect B-B' (Figures 15, 16). The southern portion of B-B' contained an abrupt transition from a low to high salinity estuary, with the high salinity conditions pinching out to the north between cores PS-04 and PS-06. A more gradual transition from low to higher salinity estuary was observed in the northern and central cores from the study area (PS-06, PS-08, PS-09, and PS-12). However, low-salinity estuarine foraminiferal assemblages were observed at the top of PS-09.

Transect D-D' (Figures 15, 17) included two cores, PS-01 and PS-02, and was located in the westernmost portion of the study area. The Pleistocene-Holocene boundary was not observed in this transect, and cores were generally more sandy than those from B-B'. Like transect B-B' a general increase in salinity was observed upcore. The normal salinity open Pamlico Bay sediments recorded in vibracore PS03 (Grand Pre, 2006) were not found in any of the Foley (2007) cores. Therefore, normal salinity waters did not extend into the Foley (2007) study area during either the Mid-Holocene Hypsithermal flooding event or the Medieval Warm Period flooding event.

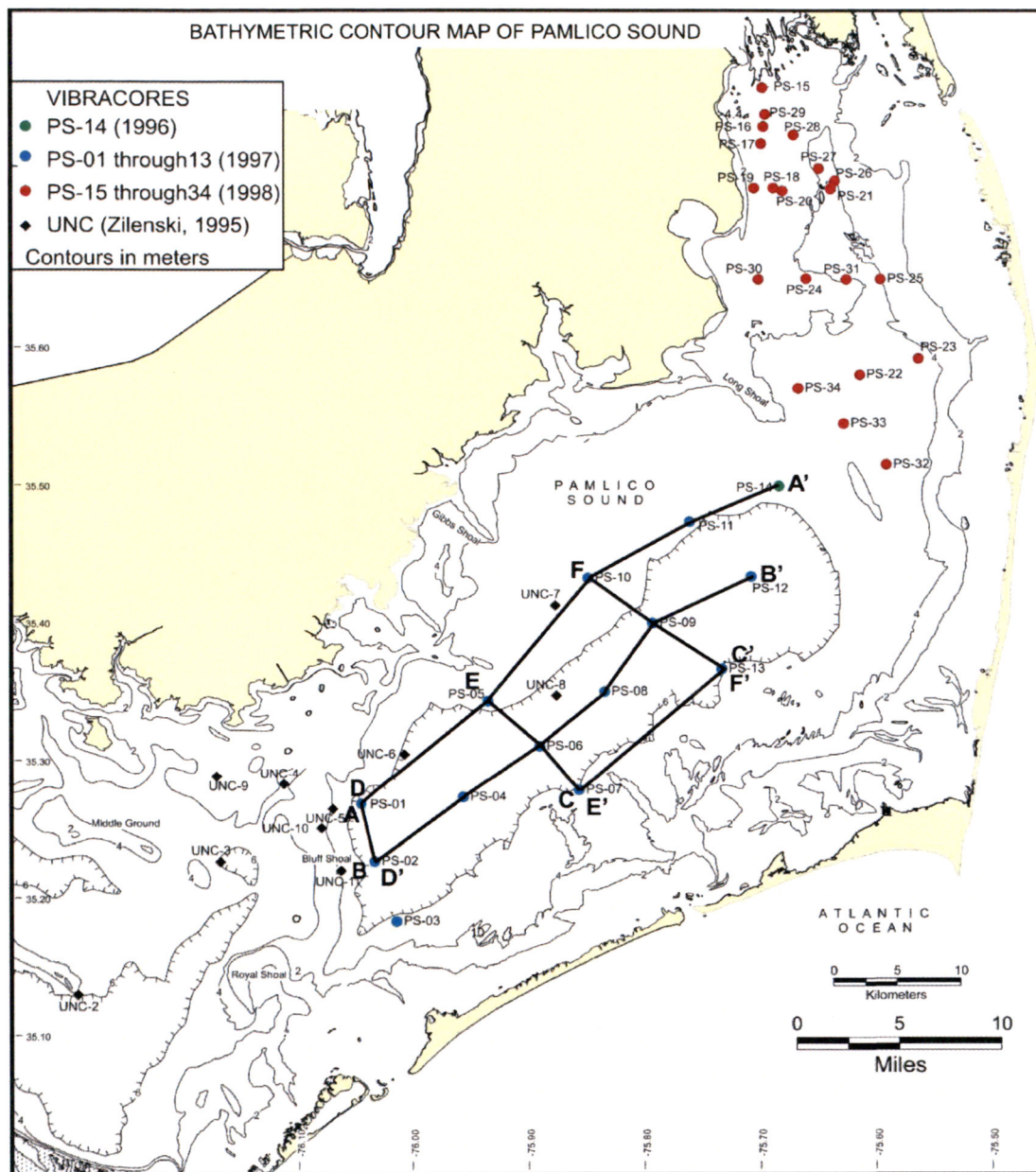


Figure 15: Location map of Foley vibracore transects in middle Pamlico Sound (Foley, 2007).

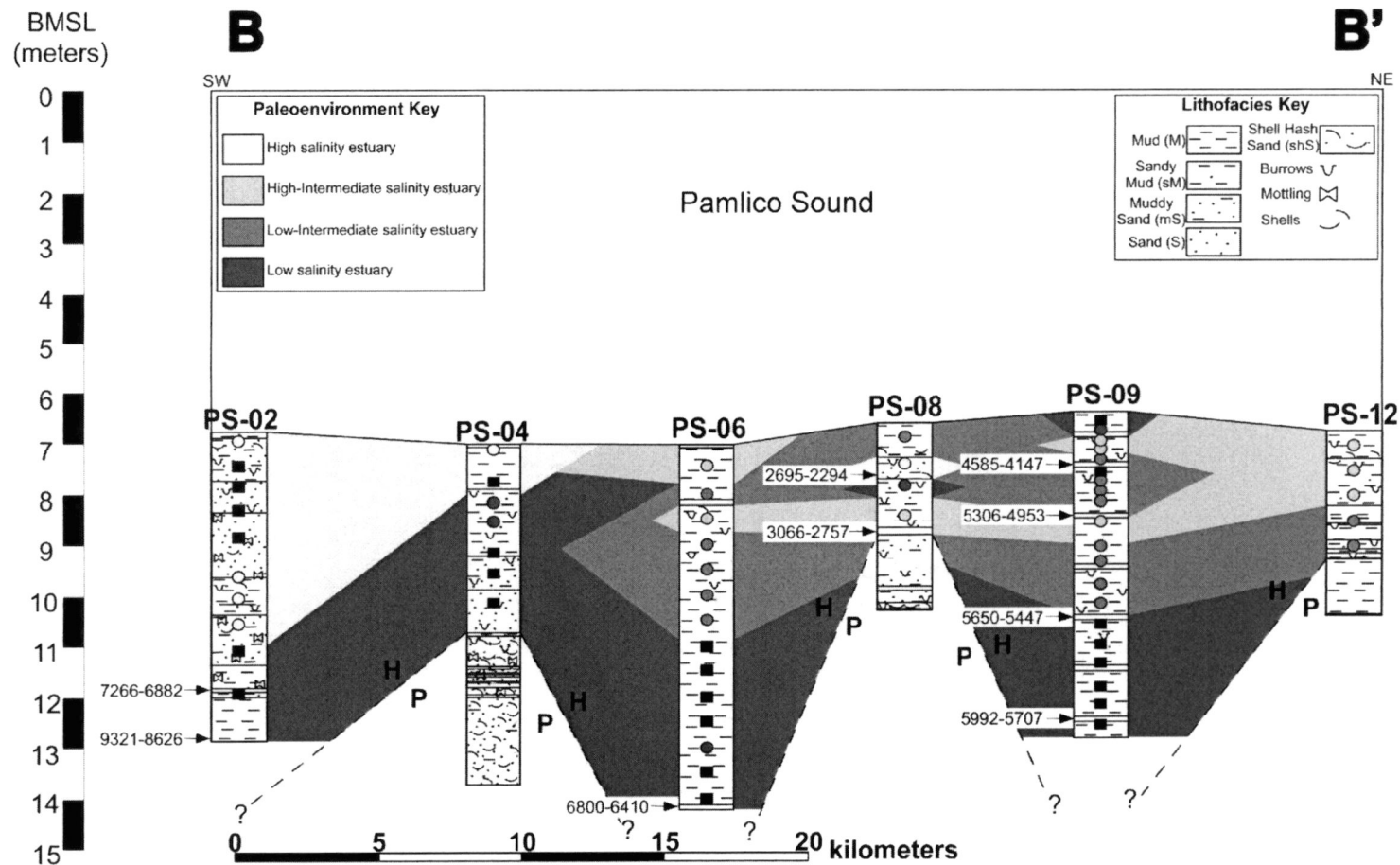


Figure 16: Paleoenvironmental transect B-B' (see Figure 15 for location). Squares represent a sample barren of foraminifera and circles indicate the paleoenvironment. Calibrated radiocarbon ages are indicated along the left margin of the cores (Foley, 2007).

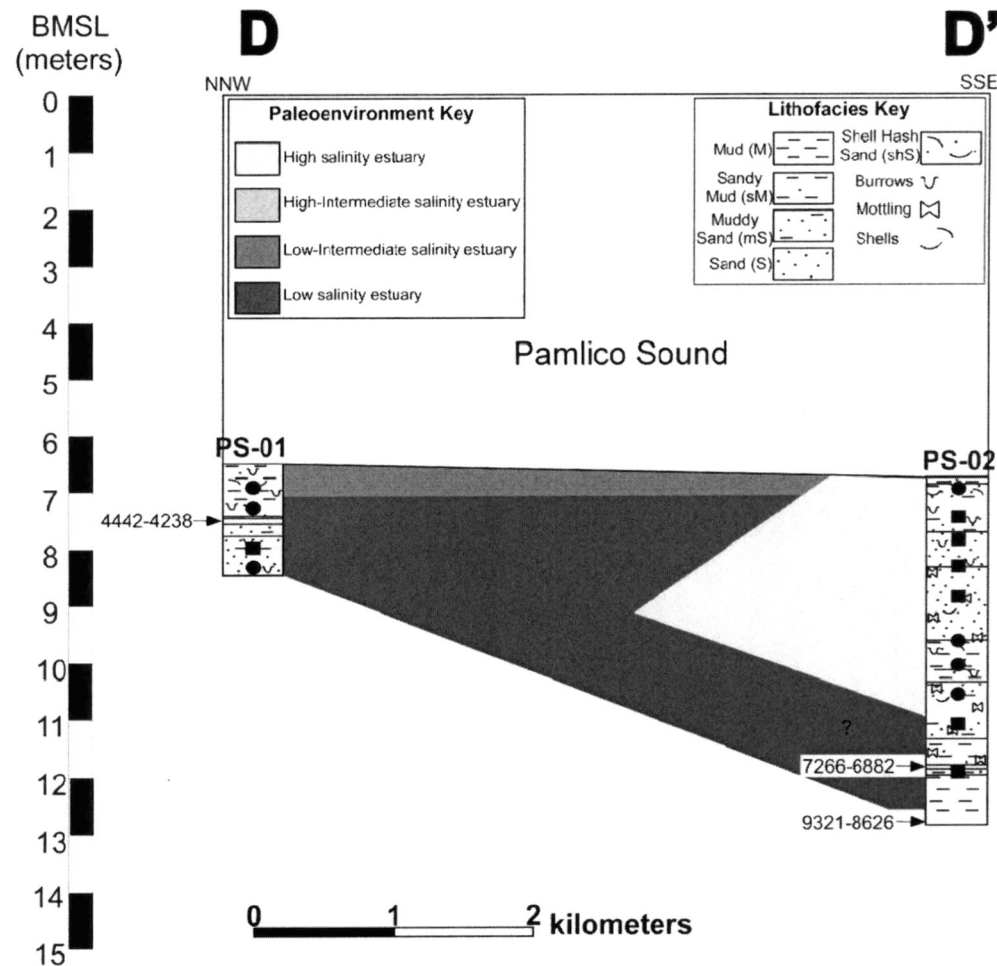


Figure 17: Paleoenvironmental transect D-D' (see Figure 15 for location). Squares represent a sample barren of foraminifera and circles indicate the paleoenvironment. Calibrated radiocarbon ages are indicated along the left margin of the cores (Foley, 2007).

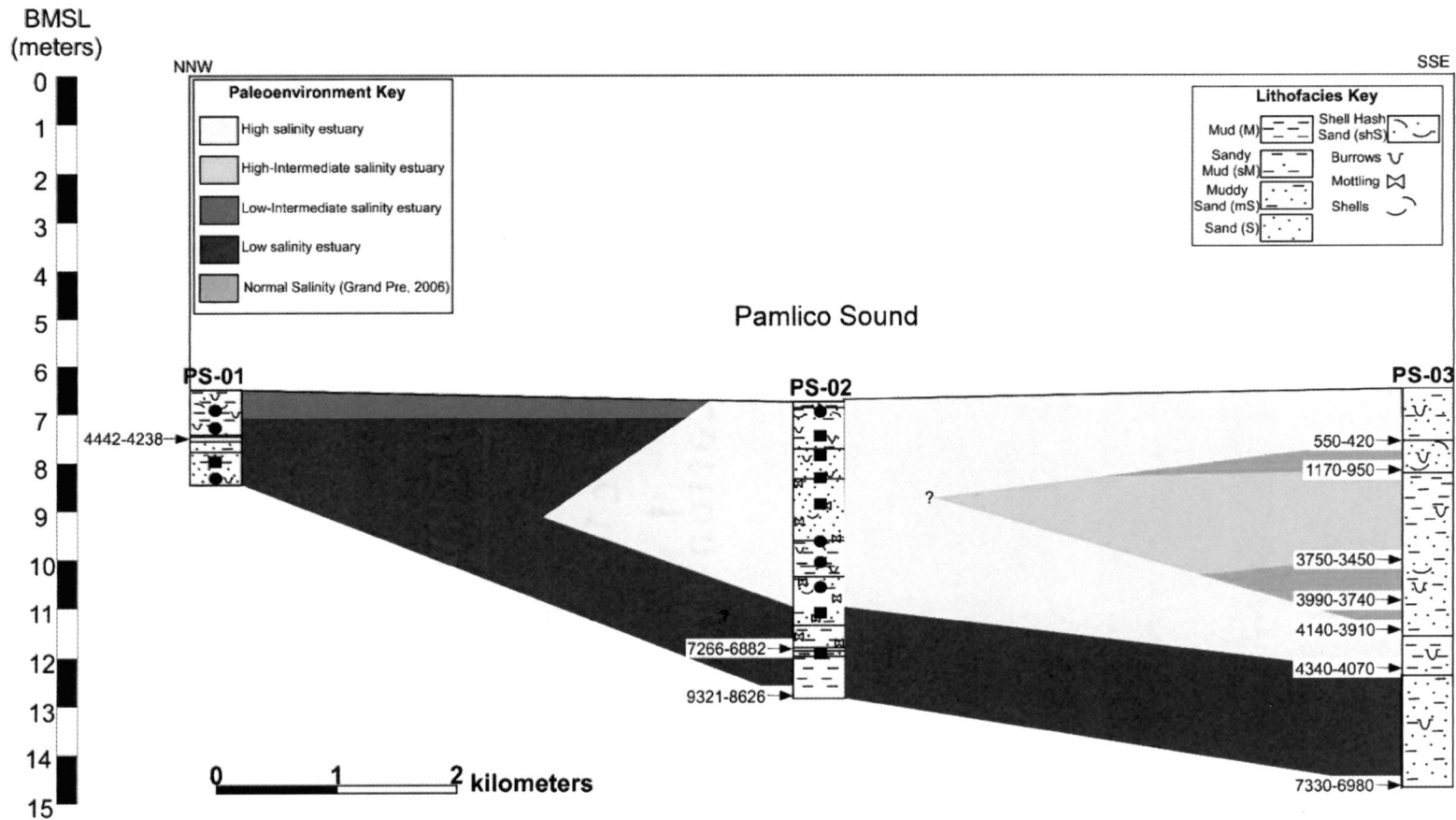


Figure 18: Paleoenvironmental transect including PS-01, 02, and 03 (see Figure 15 for location). PS-03 information is from Grand Pre (2006). Squares represent a sample barren of foraminifera and circles indicate the paleoenvironment for PS-01 and 02. Calibrated radiocarbon ages are indicated along the left margin of the cores (Foley, 2007).

Sedimentology

Numerous studies of the Albemarle Estuarine System, the Croatan Sound, and the Pamlico Sound have identified several depositional sequences (Sager, 1996; Sager and Riggs, 1998; Corbett et al., 2007; Rudolph, 1999; Riggs et al., 2000; Mallinson et al., 2005; Smith et al., 2008; Tully, 2004; Culver et al., 2007). Sager (1996) and Sager and Riggs (1998) used lithology, seismic data, and radiocarbon dates to determine the in-fill history of the Albemarle Estuarine system. They defined six lithofacies and two subgroups (A and B): quartz sand (LF-1A and LF-1B); peat (LF-2); laminated mud (LF-3); fossiliferous muddy sand (LF-4); interlaminated mud and sand (LF-5); and organic-rich mud (LF-6A and LF-6B). LF-1A is associated with tidal channels and contained brackish-water microfossils and is slightly finer grained and muddier than LF-1B. LF-1B is associated with fluvial environments and has heavy mineral laminations and convoluted bedding. LF-6 is divided based upon the age of the sediment; LF-6B is regarded as modern sediment and LF-6A is the older sediment upon which LF-6B was deposited (Sager, 1996; Sager and Riggs, 1998).

Sager and Riggs (1998) used seismic data, lithologic data, and calibrated (Pretoria Calibration Procedure) AMS C-14 radiocarbon dates (shell, peat, and organic-rich sediment samples) to define three distinctive depositional sequences caused by sea-level fluctuations during the Holocene. Between 7.5-7.6 ka and 6.2-6.4 ka the oldest sequence was deposited. From 7.5-7.6 ka and 6.5-6.7 ka LF-1A was deposited in an open-estuarine environment. From 6.5-6.7 ka LF-3 was deposited during a restricted-estuarine environment. Between 6.2-6.4 ka and 5.5-5.6 ka a decline in sea level exposed sections of

the estuary; and an erosional surface is found in the middle and outer estuarine zones. Between 5.5-5.6 ka and 1.4-1.6 ka the second sequence was deposited. From 5.5-5.6 ka to 2.8-3.0 ka the area experienced open-estuarine conditions, and LF-1A, LF-4, and LF-5 were deposited. LF-6A was deposited in a closed-estuarine system between 2.8-3.0 ka and 1.4-1.6 ka. Another drop in sea level from 1.4-1.6 ka and 0.4 allowed for erosion and truncation of the previous depositional sequences. The last depositional sequence, represented by LF-6B, began at 0.4 ka and represents closed-estuarine conditions.

Letrick et al. (2002) characterized the sedimentology and geochemistry of sediments from several short cores collected from the Albemarle, Currituck, Croatan, and Roanoke Sounds. Terrigenous sand and mud along with organic matter (OM) comprised core sediments. Comparison of the short cores indicated that inflections in the OM content of sediment may have correlation potential.

Short cores and radionuclides were studied by Corbett et al. (2007) to determine the sediment deposition rates of organic matter in the Albemarle Estuarine System (AES). Low accumulation rates indicated the occurrence of resuspension and flushing of sediments by waves and currents. Corbett et al. (2007) also determined that the current sediment accumulation rate is less than the current rate of sea-level rise. Therefore, short term control on sediment accumulation in the AES comes from storm wave-base and long term control comes from generation of accommodation space via sea-level rise and subsidence of the basin.

Sedimentology, seismic data, age dates, and historical data were used by Rudolph (1999) and Riggs et al. (2000) to determine the Holocene evolution of Croatan Sound,

North Carolina. They defined eight lithofacies and two subgroups (A and B): gray mud (LF-1), medium dark gray uniform muddy sand (LF-2), in-situ peat (LF-3A), detrital peat (LF-3B), quartz sand (LF-4), interlaminated mud and sand (IMS, LF-5A), oxidized muddy sand and sandy mud (LF-5B), and a highly variable sandy mud to muddy sand (LF-6).

Using the lithology and age dates from Croatan Sound, Rudolph (1999) and Riggs et al. (2000) identified five parasequences (PS-1 to PS-05). The oldest parasequence (PS-1) formed >9.7 to 5.5 ka B.P, and consisted of a fluvial gravel, overlain by peats, then estuarine mud (LF-1). Between 5.5 - 5.2 ka B.P. there was a decrease in sea-level, allowing erosion of PS-1 to occur. From ~5.2 - 3.2 ka B.P. PS-2 formed. From ~5.2 -4.0 ka B.P. a more open system was present, as indicated by deposition of LF-2 and LF-6. LF-1 was deposited at ~4.0 ka B.P. when the system became restricted. The next parasequence, PS-3, formed from ~2.1-1.1 ka B.P. after another episode of erosion. Open estuarine conditions are indicated by tidal bedforms and interlaminated mud and sand during PS-3. Later in the sequence deposition of LF-1 represents a semi-restricted estuary. Between 1.1 and 0.13 ka B.P. there were two erosive episodes. PS-4 consists of a thin surficial sand sheet, LF-4. The other parasequences are overlapped by PS-5 (~3.0 ka B.P. to present), which is associated with the Roanoke Marshes.

Organic-rich mud has been the focus of numerous studies in the Pamlico River Estuarine System, Neuse River Estuarine System, and Albemarle Sound Estuarine System (Riggs et al., 1989; Riggs et al., 1991; Riggs et al., 1993; Wyrick, 1993; Yeates, 1993; Riggs, 1996; Riggs and Ames, 2003). The flushing of swamp forests and the

erosion of swamp forest and marsh shorelines introduces organic matter into estuarine systems (Riggs et al., 1993; Wyrick, 1993; Riggs, 1996; Riggs and Ames, 2003). The Pamlico and Neuse River Estuarine Systems have similar morphology and sediment distribution to the Albemarle Sound (Riggs et al., 1993). Sand is found on the perimeter platforms with the amount of sand decreasing into the central basin. The bottom of the Albemarle Sound Estuarine System is 75% Organic-rich mud (Riggs et al., 1993; Riggs, 1996; Riggs and Ames, 2003). Eastward towards the barrier islands, the organic-rich mud transitions into a fine sand (Riggs et al., 1993; Riggs, 1996). Sediments within the system were classified as: sand, peat, organic-rich mud, and inorganic mud. The aerial extent of the sediment types, as a percentage of total bottom area is: 53.8% inorganic mud, 7.4% organic mud, 35.9% inorganic sand, and 2.9% organic sand (Riggs et al., 1993).

Within the Neuse River Estuarine System sediments, the weight percents of organic matter and mud display a direct correlation (Riggs et al., 1991). Downstream there is an increase in the inorganic sand fraction and a decrease in the inorganic mud fraction. Riggs et al. (1991) attributes the increase of inorganic sand downstream to erosion of the nearby shoreline or from the Pamlico Sound. Upstream the amount of organic sand and mud increases. The bottom of the Neuse River Estuarine System is 80% organic-rich mud and 20% sand (Riggs et al., 1991; Yeates, 1993).

Mallinson et al. (2005) reconstructed the Late Neogene and Quaternary evolution of the northern Albemarle Embayment by studying seismic surveys from the eastern Albemarle Sound, adjacent tributaries and the inner continental shelf. Eight drill sites on

the Outer Banks and the Mobil #1 well in eastern Albemarle Sound provided lithologic and chronostratigraphic data used to recreate the sedimentary evolution of the northern North Carolina coastal system. Pleistocene sequences are incised by the paleo-Roanoke River valley complex. The Pleistocene shelf sands and muds dip gently to the southeast and the valleys are filled with a transgressive fluvial gravel and sand unit. The fluvial unit is cut by a bay ravinement surface and overlain by interlaminated mud and sand representing a transition from low brackish to marine conditions. A tidal ravinement surface truncates the transition sediments and is overlain by bay-mouth sands deposited during open-embayment episodes. A wave ravinement surface truncates the bay-mouth sands and indicates the lack of a continuous barrier island system during much of the Holocene. Deposition of estuarine organic-rich mud occurred when a continuous barrier island system was established across the bay-mouth bar.

Culver et al. (2008) used micropaleontologic data from nine cores to reconstruct the depositional history in the northern Albemarle Embayment, North Carolina. During the early to late Pleistocene subhorizontal open-marine units were deposited atop late Pliocene fine-grained shelf-basin deposits. The northern portion of the study area was cut by a channel during the last glacial sea-level lowstand by the paleo-Roanoke River. During the latest Pleistocene, under cooler than modern climates, basal fluvial valley-fill accumulated followed by estuarine silt and mud. Transgressive Holocene open-marine sands were deposited ~8.5-9.0 kyr BP over the estuarine channel-fill deposits: cores collected from the barrier islands indicate that, since that time, fully marine sedimentation occurred. However, mid- to late Holocene estuarine deposits were found in Albemarle

Sound cores collected to the immediate west of the barrier island cores. Barrier island sand overlies fluvial and marine sand filling paleo-Roanoke tributary valleys to the south and they overlie open-marine sand to the north. Open inner to mid-shelf Pleistocene sediments underlie the modern northern Outer Banks. The depositional history of the study area indicates that the Holocene barrier islands had a complex history of construction and destruction.

Smith et al. (2008) compared the Pea Island and Avon-Buxton areas to determine the relationship between long-term changes in barrier island width with oceanic and estuarine shoreline dynamics. From 1852 to 1998 northern Pea Island increased in width while southern Pea Island and the Avon-Buxton area decreased in width. Width increase and decrease are dictated by the rate of oceanic shoreline erosion and back-barrier land accretion. Human modifications to the landscape (dune ridge construction, planted vegetation, and urban development) can restrict the natural barrier island processes of overwash and inlets (Smith et al., 2008).

Tully (2004) evaluated sediment dynamics in the Pamlico Sound using geochemical tracers (^{210}Pb , ^{137}Cs , and ^7Be , $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, stable isotopes, C:N ratios and abundances of Al, Fe, Zn, and Cu) from several sediment cores and marsh grabs. Cores from the estuary were characterized by organic-rich mud (ORM). Marsh grabs were characterized by surface or subsurface peat. Using the geochemical tracers found in the cores a sedimentation rate for the Pamlico Sound was calculated. Accumulation of ORM varies throughout the Pamlico Sound (0.1-0.5 cm y^{-1}). Deeper areas of the central and southern sub-basins, along with protected coves and embayments with shallower water

experienced higher rates of sediment accumulation. Study of the accumulation rates downcore revealed that in the 1960's there was a shift in sediment source or sediment dynamics. Tully (2004) suggests this shift could have been caused by a change in sediment source (i.e., shoreline erosion) over time and/or natural (i.e., hurricanes) and anthropogenic (i.e., trawling) resuspension events.

A highly detailed sedimentary record of vibracore PS03 along with numerous other vibracores from the Outer Banks, North Carolina were studied by Culver et al. (2007) to determine the infill history of Pamlico Sound and the effects of storms on barrier island dynamics. From 6,980-7,330 cal yr BP upward-coarsening muddy sand with flaser bedding was deposited in the Pamlico Sound as post-glacial sea-level rose and flooded the paleo-Pamlico Creek and the paleo-Tar and paleo-Neuse Rivers. The Hatteras Flats Interstream Divide (HFID) prevented the infiltration of open marine conditions into the paleo-Pamlico Creek to the east. An upward-fining muddy unit was deposited from 4070-4340 cal yr BP. From 3910-4140 to 3740-3990 cal yr BP muddy sand was deposited and subsequently burrowed. Topping this was a fining upwards sequence, deposited from 3,740-3,990 cal yr BP until 3,450-3,750 cal yr BP; indicating Pamlico Bay was less open to marine influence. OSL dates from the oldest known beach ridges on the Outer Banks indicate that by around 3,500 cal yr BP Pamlico Bay was a back-barrier estuarine system. Sediments from this age segment are fining-upwards sand and silt typical of low energy estuarine conditions. Overtopping the estuarine mud was another sand unit deposited from 950-1170 cal yr BP to 420-550 cal yr BP. Comparison of this sandy unit to the older sandy unit confirms that shelf waters returned to the

Pamlico Sound. Culver et al. (2007) cited a large scale collapse of the southern barrier islands (Ocracoke and Portsmouth Islands) as the method by which shelf waters were allowed to enter the Pamlico Sound. By ~500 cal yr BP muddy sand was once again being deposited in Pamlico Sound; indicating that estuarine conditions prevailed again.

METHODS

Seventeen vibracores, varying in length from 2.05m to 8.22 m (Table 2; Figure 19), were collected in Pamlico Sound in the fall of 2006 and spring of 2007. These cores represent the new data that, together with earlier cores taken in the late 1990s by S.R. Riggs, and subject to later study by Grand Pre (2006) and Foley (2007), from the database interpreted herein. Latitude and longitude, water depth, and core length were recorded. After collection, the cores were halved (lengthwise) and one half was used to construct lithologic logs and for sampling purposes; the other half was taped, bagged, and archived for future reference.

Sedimentological Analysis

Vibracores were logged according to methods outlined by Dr. K. Farrell (personal communication, January 12, 2007). Folk's methodology (1980) was employed to determine visual estimates of grain size. Some other features noted include: color; mineralogy; shell content; bioturbation; relative percent abundances of mud, sand, and gravel; and any additional sedimentological features observed downcore (see appendix A).

Foraminiferal Analysis

Samples were processed following the methods of Culver et al. (1996) and Woo et al. (1997). Ten plastic weigh boats were dried in an oven overnight, weighed, and averaged to use when calculating dry sample weights. Samples were dried in an oven overnight at 60°C, weighed; gently pulverized using a mortar and pestle; and placed in a 500 ml beaker with tap water, < 1g sodium metaphosphate, and two tablets of sodium hydroxide. After remaining in this solution overnight, samples were washed through 710 μm and 63 μm nested sieves. The 710 μm and 63 μm fractions were transferred to labeled weigh boats and dried overnight at 60°C. Specimens were then concentrated using sodium polytungstate flotation (Munsterman and Kerstholt, 1996). The set up for separation is as follows: a ring stand holds a plastic funnel with a filter; the funnel is attached to plastic tubing that leads to another funnel with filter paper. The plastic tubing is clamped shut in two places to allow controlled release of liquid from the funnel. A 400 ml beaker is placed beneath the lower funnel to receive liquid. Sodium polytungstate is poured into the funnel until it is two-thirds full. The 63 μm -710 μm fraction of a sample is slowly added to the liquid surface. Foraminifera remain on the surface, while sediment sinks to the bottom. The top clamp is then slowly released to allow sediment to be removed. When the sectioned tube is full, the top clamp is reinitiated and the bottom clamp is removed to allow sediment to fall into the funnel below. Liquid is then collected in the 400 ml beaker. The float and sink are thoroughly washed with deionized water, placed in weigh boats and dried in an oven at 60°C.

Once samples were dry, the sink was observed and notes were made of the sediment content. If the floats contained a great deal of sediment, they were split into equal parts using a microsplitter and then sprinkled onto a 45-square picking tray once a manageable amount was achieved. A random numbers table was used to choose squares to be picked. Additional fractions were picked if a count of 200 specimens was not achieved. Foraminifera were picked using a paintbrush and placed on a 60-square cardboard slide treated with gum tragacanth. Foraminifera were then sorted and identified to the species level and counted for each sample. Identifications were confirmed by comparison with type and figured specimens lodged in the Smithsonian Institution collections.

Cluster Analysis

Q-mode cluster analysis (Mello and Buzas, 1968) on 92 samples containing foraminifera was used to identify biofacies. Raw species counts were put into an Excel spreadsheet and then converted to percentages of the total count per sample. Previous studies have removed rare species and only included those comprising 2% or greater in the cluster analyses; all species were included in this analysis to include shelf foraminifera that occurred in small percentages. Percent abundance values were transformed as follows: $2\arcsin\sqrt{p}$ (p = abundance). Using the transformed abundances, Ward's linkage, and Euclidian distances, a hierarchal cluster dendrogram was generated in SYSTAT 12. Groups of samples were distinguished and biofacies interpretations of

those groups were then made based on known environmental distributions of modern foraminifera.

Radiocarbon Age Estimates

Radiocarbon dating was used to estimate ages of six samples from various cores (Table 4). This dating method is commonly used on organic material to place an age on such material to provide chronostratigraphic control of the sediment units. Assuming that the amount of ^{14}C found in living organic matter is in equilibrium with the atmosphere (Bradley, 1999). When properly calibrated to account for natural variations in ^{14}C , the technique can date organic materials back to ~40,000 yrs. B.P. (Bradley, 1999).

^{14}C was used to date 1000 specimens of *Elphidium excavatum* in six samples from various cores. The samples were collected from the cores, processed by the methods of Culver et al. (1996) and Woo et al. (1997) and then specimens were concentrated using sodium polytungstate flotation (Munsterman and Kerstholt, 1996). One thousand well preserved *Elphidium excavatum* with glassy tests were then picked, placed on a watch glass, and put in the oven to dry. Once dry, samples were stored in labeled glass vials before shipment. Dating was performed by the National Ocean Sciences AMS Facility at the Woods Hole Oceanographic Institution. The ages were then calibrated using CALIB (ver. 5.1.0.0) (Stuiver and Reimer, 1993) and the marine04.14c data set (which accounts for reservoir effect) (Hughen et al., 2004). Ages are reported as calendar ages (2 sigma range BP) (Table 4).

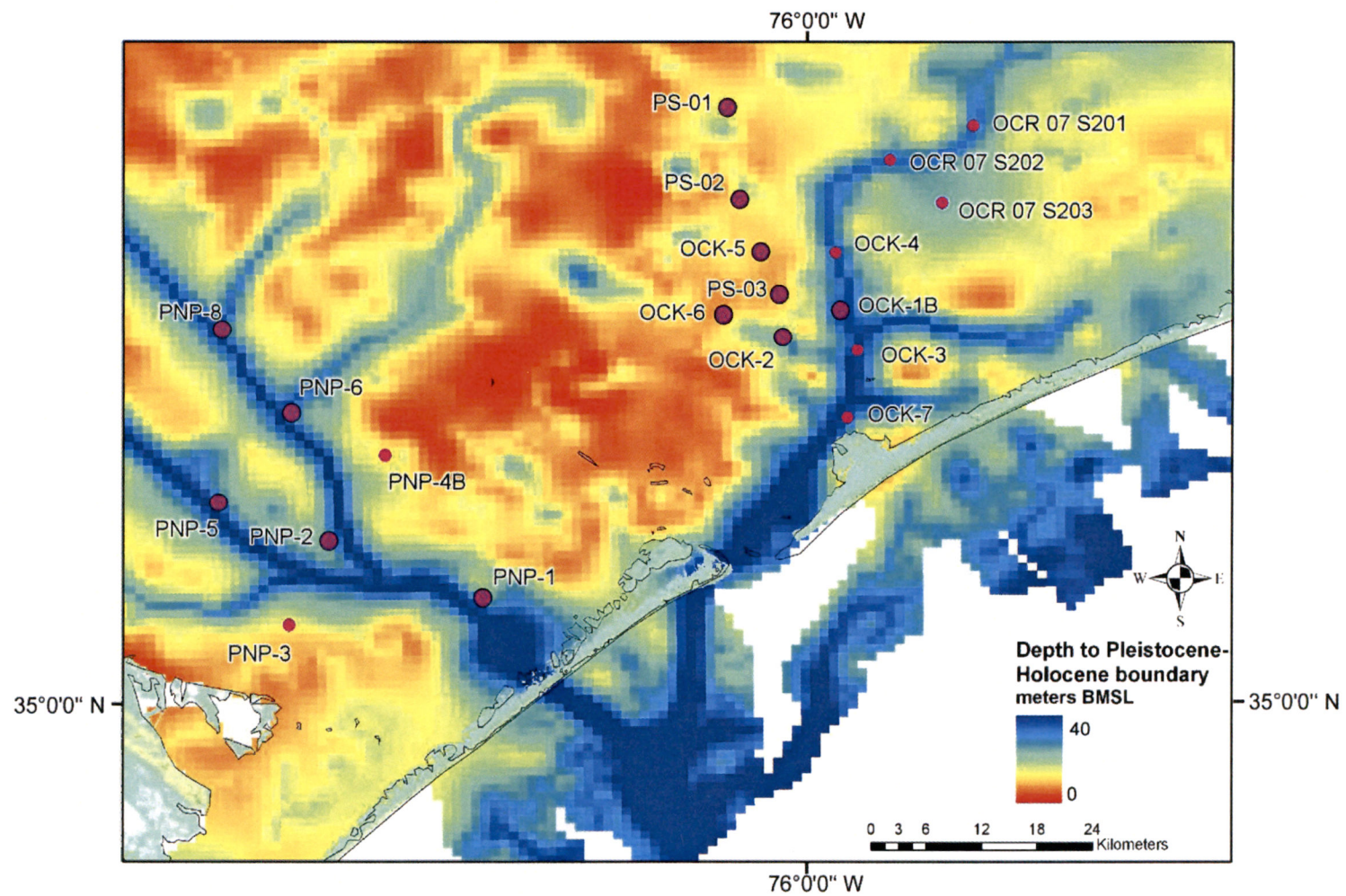


Figure 19: Location of vibracores, PNP (= paleo Neuse-Pamlico), OCK (= Ocracoke 1), OCR (= Ocracoke 2), PS (= Pamlico Sound, collected by S.R. Riggs), in Pamlico Sound, North Carolina. Depth to Pleistocene based on high resolution seismic data (D. Mallinson).

Table 2: Coordinates, lengths, and water depths for 17 vibracores collected for the current study and for three PS (Pamlico Sound cores collected by S.R. Riggs). Latitude and Longitude given in decimal degrees.

CORE #	LATITUDE	LONGITUDE	CORE LENGTH (m)	WATER DEPTH BELOW MSL (m)
PNP - 1	35.04628333	-76.14956667	4.08	4.3
PNP - 2	35.07121667	-76.22195	8.2163	6.2
PNP - 3	35.03403333	-76.23961667	8.221	6.2
PNP-4B	35.11028333	-76.19518333	7.13	6.4
PNP - 5	35.0885	-76.27231667	7.94	6.9
PNP - 6	35.12938333	-76.2387	8.5	6.7
PNP - 8	35.16705	-76.27133333	8.19	6.2
OCK - 1B	35.17633333	-75.98398333	4.08	5.5
OCK - 2	35.16353333	-76.01165	2.1	4.33
OCK - 3	35.1579	-75.97698333	2.05	3.9
OCK - 4	35.20268333	-75.98721667	4.85	6.85
OCK - 5	35.20356667	-76.02236667	2.261	7.54
OCK - 6	35.17431667	-76.03938333	3.8	6.48
OCK - 7	35.12746667	-75.98165	2.48	4
OCR 07 S201	35.2598	-75.92366	7.59	7.3
OCR 07 S202	35.24449	-75.96202	7.15	7.3
OCR 07 S203	35.22527	-75.9379	8.06	6.8
PS01	35.26922	-76.0322	1.93	6.50
PS02	35.22762	-76.0322	6.09	6.75
PS03	35.18397	-76.013	8.2	6.5

RESULTS AND INTERPRETATIONS

Lithofacies Descriptions

The sedimentology of seventeen vibracores were logged in detail with respect to grain size and sorting; percentage gravel, sand, mud, and shell debris; color, bioturbation, and sedimentological features. After a detailed analysis of each vibracore, four lithofacies were recognized: muddy sandy shell hash; sandy mud; sand; and muddy sand.

Muddy Sandy Shell Hash Lithofacies (msSH)

The muddy sandy shell hash lithofacies is dark grey to grey, with moderately poor to poor sorting. It is composed of mud (5-10%), sand (10-20%), and shell hash (70-85%). Shell material included gastropods, clams, and oysters (Figure 20).



TOP

Figure 20: Image of a typical Muddy Sandy Shell Hash (msSH) found in Pamlico Sound vibracores (OCK-6 150-180 cm). Scale bar equals 5 cm.

Sandy Mud Lithofacies (sM)

The sandy mud lithofacies is gray in color and moderately well to well sorted with sub-angular to rounded grains. It is composed of mud (60-90%) and fine sand (10-40%). Sand lenses, shell material, chain-like burrows, and articulated angel wing bivalves (*Cyrtopleura costata*) are common in this lithology and are found only in the PNP cores (Figure 21). This lithofacies correlates with mud lithofacies seen in previous studies (example Foley, 2007).



TOP

Figure 21: Image of a typical Sandy Mud (sM) found in Pamlico Sound vibracores (OCR07S201 0-32 cm). Scale bar equals 5 cm.

Sand Lithofacies (S)

The sand lithofacies is light gray to gray in color, moderately well to well sorted, with sub-angular to rounded grains (Figure 22). It is composed of sand (90-100%), mud (0-5%), and shell hash (10-15%). Mud lenses, shell material, undifferentiated burrows, and mud-lined chain-like burrows are common (Figure 23). In OCR 07 S202 alternating layers of fine to medium sand were observed. These layers had various colors: light gray, gray, rusty tannish brown, blue gray, blue green, and orange (Figure 24).



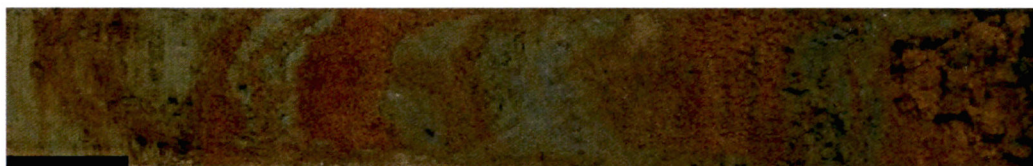
TOP

Figure 22: Image of a typical Sand (S) found in Pamlico Sound vibracores (OCK-1B 280-310 cm). Scale bar equals 5 cm.



TOP

Figure 23: Image of Sand with mud lined chain-like burrows (PNP-3 450-485 cm). Scale bar equals 5 cm.



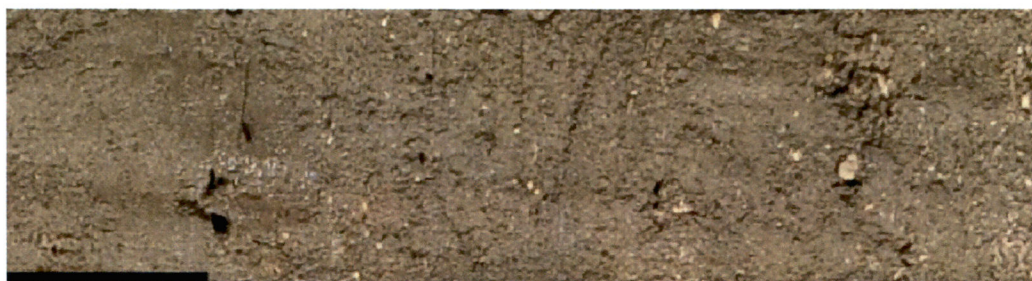
TOP

Figure 24: Image of vibracore OCR 07 S202, section 680-717 cm. Scale bar equals 5 cm.

Muddy Sand Lithofacies (mS)

The muddy sand lithofacies is light gray to dark gray in color, moderately well to well sorted with sub-angular to rounded grains (Figure 25). It is composed of sand (70-

90%) and mud (10-30%). Sand and mud lenses, along with shell material, mud-lined chain-like burrows, and undifferentiated burrows were observed.



TOP

Figure 25: Image of typical Muddy Sand (mS) found in Pamlico Sound vibracores (OCK-4 446-472 cm). Scale bar equals 5 cm.

Biofacies Descriptions

One hundred-thirty-four samples were processed for foraminiferal analysis. Of these samples, 93 contained foraminifera and 41 were barren. Fifty-one taxa were identified to the species level (Appendix D). Cluster analysis was used to determine biofacies. All taxa were included in the analysis. Six biofacies (A to F) were determined (Figure 26). Average relative percentages of the species were also determined for each biofacies (Table 3).

Biofacies A

Biofacies A consisted of 12 samples and 20 species. Average relative abundances (Table 3) indicated *Elphidium excavatum* (54.1%) and *Ammonia parkinsoniana* (34.4%) were the dominant species. Secondary species (>1% in abundance) were *Haynesina*

germanica (2.9%), *Elphidium galvestonense* (2.2%), *Ammonia tepida* (2.1%), *Ammotium salsum* (1.7 %), and *Elphidium gunteri* (0.9%).

Biofacies B

Biofacies B consisted of five samples and 29 species. The most abundant species for this biofacies was *Elphidium excavatum* (48.1%) and *Ammonia parkinsoniana* (22.2%) (Table 3). Secondary taxa (>1% in abundance) (Table 3) included, *Hanzawaia strattoni* (1.7%), *Quinqueloculina* cf. *Q. bosciana* (1.4%), *Q. jugosa* (5.7%), and *Q. seminula* (14.2%).

Biofacies C

Biofacies C consisted of five samples and 29 species. The most abundant species for this biofacies was *Elphidium excavatum* (65.5%) (Table 3). Secondary taxa (>1% in abundance) (Table 3) included *Ammonia parkinsoniana* (5.5%), *Elphidium galvestonense* (3.5%), *Elphidium mexicanum* (1.5%), *Hanzawaia strattoni* (8.3%), *Nonionella atlantica* (1.6%), planktonics (1.2%), and *Quinqueloculina seminula* (5.1%).

Biofacies D

Biofacies D consisted of nine samples and 33 species. The most abundant species for this biofacies were *Elphidium excavatum* (71.1%) and *Ammonia parkinsoniana* (12.2%) (Table 3). Secondary taxa (>1% in abundance) (Table 3) included *Ammonia tepida* (3.4%), *Elphidium gunteri* (1.3%), *E. mexicanum* (2.8%), *Hanzawaia strattoni* (1.4%), *Nonionella atlantica* (1.0%), and planktonics (1.4%). In addition to secondary

taxa, small delicate benthics were also observed in this biofacies and included:

Asterigerina carinata, *Bolivina lowmani*, *Buccella inusitata*, *Buliminella elegantissima*, *Cassidulina* sp. A, *Gavelinopsis praeegeri*, *Glabratellina* sp. A, *Guttulina* sp. A, *Sagrina pulchella*, *Trifarina angulosa*, and *Valvulineria* sp. A.

Biofacies E

Biofacies E consisted of 51 samples and 30 species. The most abundant species for this biofacies were *Elphidium excavatum* (88.3%) and *Ammonia parkinsoniana* (9.4%) (Table 3).

Biofacies F

Biofacies F consisted of eight samples. Only one taxon, *Elphidium excavatum*, which occurs in every sample in this study, is present in this biofacies (Table 3).

Chronostratigraphy

Radiocarbon ages were acquired from monospecific samples of ca. 1000 specimens of *Elphidium excavatum* (Table 4). All samples returned Holocene ages ranging from 474-594 cal yr B.P. to 5332-5572 cal yr B.P.

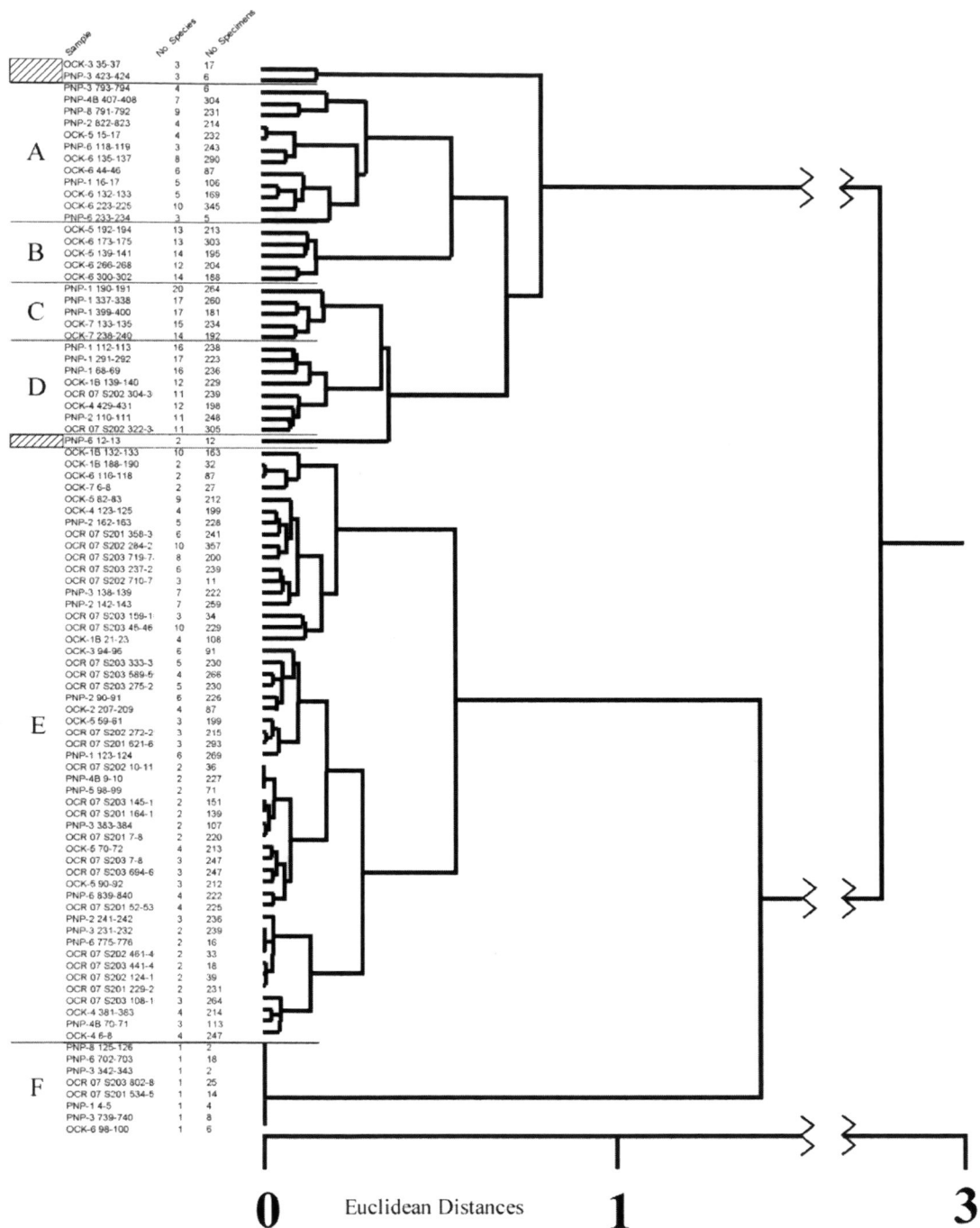


Figure 26: Dendrogram created by cluster analysis of foraminiferal abundance data. Six biofacies were identified. Sample depths and numbers of species and specimens are given for each sample. Three samples (indicated by cross-hatching) containing few specimens and species were not included in cluster groups A to F.

Table 3: Average relative abundances in a biofacies for a species. Values of 1% or more are bolded.

Taxa	Biofacies					
	A	B	C	D	E	F
<i>Ammonia parkinsoniana</i>	34.4	22.2	5.5	12.2	9.4	0.0
<i>Ammonia tepida</i>	2.1	0.2	0.9	3.4	0.8	0.0
<i>Ammotium salsum</i>	1.7	0.0	0.0	0.0	0.0	0.0
<i>Asterigerina carinata</i>	0.0	0.0	0.3	0.1	0.0	0.0
<i>Bolivina lowmani</i>	0.0	0.0	0.0	0.1	0.0	0.0
<i>Bolivina pseudoplicata</i>	0.0	0.1	0.0	0.0	0.0	0.0
<i>Buccella inusitata</i>	0.0	0.1	0.4	0.3	0.1	0.0
<i>Buliminella elegantissima</i>	0.0	0.0	0.0	0.1	0.0	0.0
<i>Cassidulina</i> sp. A	0.0	0.0	0.0	0.1	0.0	0.0
<i>Cassidulina minuta</i>	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cibicides fletcheri</i>	0.0	0.0	0.0	0.1	0.0	0.0
<i>Cibicides lobatulus</i>	0.0	0.0	0.6	0.2	0.0	0.0
<i>Cibicides</i> sp.	0.0	0.4	0.3	0.6	0.0	0.0
<i>Elphidium advenum</i>	0.0	0.0	0.1	0.1	0.0	0.0
<i>Elphidium excavatum</i>	54.1	48.1	65.5	71.1	88.3	100.0
<i>Elphidium galvestonense</i>	2.2	0.1	3.5	0.4	0.2	0.0
<i>Elphidium gunteri</i>	0.9	0.3	0.9	1.3	0.2	0.0
<i>Elphidium mexicanum</i>	0.4	1.0	1.5	2.8	0.2	0.0
<i>Elphidium poeyanum</i>	0.2	0.1	0.1	0.4	0.0	0.0
<i>Elphidium subarcticum</i>	0.0	0.1	0.2	0.1	0.0	0.0
<i>Elphidium translucens</i>	0.3	0.0	0.4	0.6	0.2	0.0
<i>Epistominella</i> sp. A	0.0	0.1	0.0	0.0	0.0	0.0
<i>Eponides repandus</i>	0.0	0.5	0.6	0.0	0.0	0.0
<i>Fissurina laevigata</i>	0.0	0.1	0.0	0.0	0.0	0.0
<i>Gavelinopsis praegeri</i>	0.0	0.3	0.0	0.1	0.0	0.0
<i>Glabratellina</i> sp. A	0.0	0.0	0.0	0.1	0.0	0.0
<i>Guttulina</i> sp. A	0.0	0.0	0.0	0.1	0.0	0.0
<i>Hanzawaia strattoni</i>	0.0	1.7	8.3	1.4	0.1	0.0
<i>Haynesina germanica</i>	2.9	0.2	0.3	0.1	0.0	0.0
Indeterminate rotaliid	0.0	0.1	0.0	0.0	0.0	0.0
<i>Neoconorbina terquemi</i>	0.0	0.0	0.1	0.0	0.0	0.0
<i>Nodosaria</i> sp. A	0.0	0.0	0.0	0.0	0.0	0.0
<i>Nonionella atlantica</i>	0.2	0.5	1.6	1.0	0.0	0.0
<i>Nonionella auricula</i>	0.0	0.0	0.0	0.1	0.0	0.0
Planktonics	0.0	0.3	1.2	1.4	0.1	0.0
<i>Planulina</i> sp. A	0.0	0.0	0.1	0.0	0.0	0.0
polymorphinid	0.0	0.0	0.0	0.0	0.0	0.0
<i>Quinqueloculina</i> sp. A	0.0	0.4	0.0	0.0	0.0	0.0
<i>Quinqueloculina</i> cf. <i>Q. bosciana</i>	0.0	1.4	0.0	0.0	0.0	0.0
<i>Quinqueloculina</i> cf. <i>Q. frigida</i>	0.0	0.0	0.2	0.0	0.0	0.0
<i>Quinqueloculina dimidiata</i>	0.0	0.5	0.1	0.0	0.0	0.0
<i>Quinqueloculina jugosa</i>	0.1	5.7	0.6	0.0	0.0	0.0
<i>Quinqueloculina lamarckiana</i>	0.0	0.3	0.5	0.0	0.0	0.0
<i>Quinqueloculina seminula</i>	0.2	14.2	5.1	0.0	0.0	0.0
<i>Reussella atlantica</i>	0.0	0.0	0.0	0.1	0.0	0.0
<i>Rosalina floridana</i>	0.0	0.1	0.3	0.1	0.0	0.0
<i>Rosalina</i> sp. A	0.0	0.7	0.0	0.2	0.0	0.0
<i>Sagrina pulchella</i>	0.0	0.0	0.0	0.1	0.0	0.0
<i>Textularia</i> cf. <i>T. gramen</i>	0.0	0.2	0.6	0.1	0.0	0.0
<i>Trifarina angulosa</i>	0.0	0.0	0.0	0.4	0.0	0.0
<i>Valvulineria</i> sp. A	0.0	0.0	0.2	0.9	0.0	0.0

Table 4: Radiocarbon ages obtained from three vibracores (OCR 07 S202, PNP-1, and OCK-5). Ages were calibrated using CALIB (ver. 5.1.0.0) (Stuiver and Reimer, 1993) and the marine04.14c data set (Hughen et al., 2004). Ages are reported as calendar ages (2 sigma range BP).

Sample Number	Sample Depth in Core (m)	Water Depth (m)	Depth Below MSL (m)	Laboratory Number	Sample Material	Conventional C14 Age		Calibrated BP 2 Sigma Ranges
						BP	1 sigma +/-	
OCR 07 S202 284-285	2.84-2.85	7.3	10.14	OS-67305	<i>Elphidium excavatum</i>	4270	35	4265-4499
OCR 07 S202 304-305	3.04-3.05	7.3	10.34	OS-67295	<i>Elphidium excavatum</i>	4380	35	4408-4647
OCR 07 S202 321-322	3.21-3.22	7.3	10.51	OS-67362	<i>Elphidium excavatum</i>	4680	40	4819-5020
OCK-5 82-83	0.82-0.83	7.54	8.36	OS-67372	<i>Elphidium excavatum</i>	915	25	474-594
PNP-1 68-69	0.68-0.69	4.3	4.97	OS-67293	<i>Elphidium excavatum</i>	2850	35	2481-2717
PNP-1 290-291	2.9-2.91	4.3	7.2	OS-67363	<i>Elphidium excavatum</i>	5110	40	5332-5572

Paleoenvironmental Interpretations

The distributions of foraminifera within estuaries are often related to salinity (Ellison, 1972; Nichols and Norton, 1969; Ellison and Nichols, 1970; Schafer and Cole, 1978; Vance et al., 2006; Abbene et al., 2006; Foley, 2007). Therefore, the discussion below is in the context of salinity. Five paleoenvironments were recognized in the vibracores based primarily on biofacies with additional information from lithofacies.

Biofacies A: Low Brackish Estuary

Biofacies A contains taxa (*Ammonia parkinsoniana*, *Elphidium excavatum*) typical of estuarine conditions (Abbene, 2006). However *Elphidium galvestonense*, is tolerant of higher energies and salinities, but is found throughout southern Pamlico Sound, at Ocracoke inlet, and in Core Sound (Grossman and Benson, 1967; Abbene, 2004; Pruitt, 2008). *Elphidium gunteri* is another taxon found within southern Pamlico Sound and at Ocracoke inlet (Grossman and Benson, 1967). *Haynesina germanica* prefers silty sediments and is tolerant of low salinities; this species is often found within the transition zone between brackish and increasingly open marine conditions (Scott et al., 1977; Banner and Culver, 1978; Murray, 1991). *Ammotium salsum* is an agglutinated taxon indicative of lower salinities when found with calcareous taxa (Ellison and Nichols, 1970; Abbene et al., 2006). In modern assemblages it is found throughout Pamlico Sound (Abbene et al., 2006). Abbene et al. (2006) Biofacies B, Foley (2007) Biofacies B, and Biofacies A of this study all contain relatively similar percentages of *Ammotium salsum* and calcareous taxa. Biofacies B of Abbene et al. (2006) does contain some

marsh foraminifera, but this is attributed to transportation from fringing marshes along the edges of Pamlico Sound. Also, the geographic location of Abbene et al. (2006) Biofacies B (Figure 9) corresponds well to the locations of vibracores and occurrence of Biofacies A within this study (Figures 27-31). Biofacies B of Foley (2006) also contains marsh taxa and the absence of such taxa from cores of this study could be due to taphonomic loss or location of this study's cores distance to fringing marshes. The presence of *Ammonium salsum* suggests this biofacies was deposited under salinity conditions of ~20 psu based on data from Abbene et al. (2006) and Foley (2007). *Ammonia tepida* is found scattered throughout Pamlico Sound in low numbers, and is most common in areas of low salinity (~ 20 psu) (Grossman and Benson, 1967).

Biofacies B: High Brackish Estuary (possible inlet influence)

Biofacies B is composed of five samples containing robust miliolids that may represent a sand shoal or inlet environment (Abbene, 2004; Rosenberger, 2006). In addition to robust species, variable lithologies and grain sizes (shelly sand and shell hash) also indicate a higher energy environment (Grossman and Benson, 1967). Grossman and Benson (1967) noted high species diversity in southern Pamlico Sound where brackish and normal-marine forms mix (brackish taxa dominate) and there were high numbers of Elphidiidae and Miliolidae. Additionally, there are no agglutinated taxa found within this biofacies, thus indicating higher salinities (~20-25 psu) (Abbene et al., 2006; Foley, 2007).

Biofacies C: Inlet

Biofacies C contains five samples and is interpreted as an inlet assemblage much like modern assemblages found near and within inlets of the Outer Banks (Workman, 1981; Abbene et al., 2006; Vance et al., 2006; and Rosenberger, 2006). *Cibicides* sp. and *Textularia* cf. *T. gramen* are typically found in open shelf waters (Schnitker, 1971; Culver and Buzas, 1980; Workman, 1981) as are planktonics (1.2%) (Murray, 1976; Schnitker, 1971). The Marine biofacies of Abbene et al. (2006) contained *Cibicides* and *Quinqueloculina seminula*, taxa not observed in any other modern assemblage within Pamlico Sound. The Marine-Delta subfacies of Grossman and Benson (1967) included *Quinqueloculina* species, planktonics, and *Hanzawaia*, taxa found at Ocracoke and Drum inlets and not within Pamlico Sound. A few specimens of the planktonic foraminifer *Globigerina* were found in the vicinity of Ocracoke inlet and within Core Sound (Grossman and Benson, 1967); the record in Core Sound was attributed to transportation from offshore.

Biofacies D: Normal Marine Salinity Bay

Biofacies D contains small, delicate benthics (eg., *Bolivina lowmani*, *Buliminella elegantissima*, *Sagrina pulchella*, *Trifarina angulosa*, and *Valvulineria* sp.) and rare planktonics (*Globigerinoides ruber* and *Globorotalia menardii*) commonly found on the mid-continental shelf and typical of normal marine salinity conditions (Schnitker, 1971). Grossman and Benson (1967) did not find planktonic species within Pamlico Sound save for an occasional specimen in the vicinity of Ocracoke inlet and within Core Sound.

Additionally, *Glabratellina* sp. is exclusive to normal marine salinity environments (Erskian and Lipps, 1987; Culver et al., 2008). The Low Energy marine biofacies of Rosenberger (2006), located just behind Portsmouth Island, also contained small, delicate species (e.g., *Bolivina lowmani*, *Stetsonia minuta*, and *Asterigerina carinata*) found within burrowed sand and muddy sand. The Normal Marine Salinity Bay biofacies of Grand Pre (2006) also contained stenohaline benthic taxa (*Bolivina lowmani*, *Cibicides* sp., *Hanzawaia strattoni*, *Trifarina angulosa*, and *Valvulineria* sp.) downcore. Like the inner shelf assemblage of Culver et al. (2007) and Grand Pre (2006), Biofacies D is dominated by *Elphidium excavatum* and *Ammonia parkinsoniana* and also contains well preserved young to mature stenohaline taxa (*Hanzawaia strattoni*, *Buccella inusitata*, *Cibicides lobatulus*, *Globigerinoides ruber*, and *Globorotalia menardii*). Culver et al. (2007) and Grand Pre (2006) interpreted this biofacies to represent a deposition in normal salinity waters within the southern Pamlico basin following a collapse of the southern Outer Banks. The collapse, perhaps storm-driven, allowed Gulf Stream waters to influence assemblages found in southern Pamlico Sound.

Biofacies E: High Brackish Estuary

Biofacies E is interpreted as representing high brackish estuarine conditions. The assemblage is dominated by the calcareous taxa *Elphidium excavatum* (88.3%) and *Ammonia parkinsoniana* (9.4%), typical estuarine foraminifers found in modern assemblages throughout southern Pamlico Sound (Abbene et al., 2006). Seven samples from this biofacies contain stenohaline benthics and planktonics in very low abundance.

Due to the proximity of these seven samples within the cores to Biofacies D, the presence of these normal marine salinity foraminifera is attributed to reworking of sediments from that biofacies, perhaps through bioturbation. The lack of lower salinity taxa (*Ammotium salsum* and *Haynesina germanica*) and higher percentages of calcareous taxa distinguish this biofacies from biofacies A.

Biofacies F: Estuary (Low Specimen Count)

Biofacies F is interpreted as representing estuarine conditions. It contained only one taxon, *Elphidium excavatum*, in low counts. Grand Pre (2006) also encountered a biofacies containing only *Elphidium excavatum* and attributed its exclusive presence to taphonomic loss of other, probably agglutinated taxa. Alternatively, this biofacies may have been originally monospecific (Goldstein et al., 1995; Grand Pre, 2006).

Paleoenvironmental Interpretation of Cross Sections

Vibracores were not taken on predetermined linear transects but rather they were located in an attempt to core the Holocene sediment infilling latest Pleistocene drainages. The cross sections presented below were drawn to illustrate lithologies and reconstruct the paleoenvironments with respect to the paleo-channels (Figure 27). The five transects do not include all vibracores described in the study. Two of the transects include vibracores from previous studies (Grand Pre, 2006; Foley, 2007). Six radiocarbon ages were acquired from monospecific samples of ca. 1000 specimens of *Elphidium excavatum*; all dates were Holocene in age. The depth to the top of Pleistocene, as

defined by geophysical data (Figure 27), indicate that Pleistocene sediments were not present in any cores (Table 5).

Many of the micropaleontological samples in this study were barren of foraminifera. Where foraminifera were present, low brackish estuarine assemblages tended to occur in slightly muddier sediments than high brackish assemblages. This pattern was also evident in Foley (2007). Therefore, paleoenvironments shown on the following cross-sections are based on a combination of lithologic and micropaleontologic data placed in the context of previous coring studies in Pamlico Sound (Abbene, 2004; Vance, 2004; Grand Pre, 2006; Foley, 2007). Where extensive core sections are barren of foraminifera, environmental interpretations are not as certain as they are in core sections containing abundant foraminifera.

Transect A-A'

Transect A-A' strikes north-west to south-east and includes cores taken from the thalweg of the paleo-Pamlico-Neuse River and is composed of vibracores PNP-8, PNP-6, PNP-2, and PNP-1 (Figure 27). A muddy sandy shell hash is present at the base of cores PNP-8, PNP-6, and PNP-2. Above the shell hash, sandy mud with minor fractions of shell material and some bioturbation comprises the rest of the cores. Interbedded sand is present in PNP-2 from 1.0-1.64 m (Figure 28). PNP-1 is composed completely of sand with three prominent layers of interbedded mud (0.75 m, 2.25 m, and 4.0 m depth) (Figure 28).

Table 5: Depth to Pleistocene beneath each vibracore of this study. Depths are based on geophysical data (D. Mallinson).

Core	Base of core (meters below MSL)	Depth to Pleistocene (meters below MSL)
OCK-1B	9.58	31.66
OCK-2	6.43	20.70
OCK-3	5.95	33.40
OCK-4	11.7	30.50
OCK-5	9.801	12.43
OCK-6	10.28	11.97
OCK-7	6.48	30.91
OCR 07 S201	14.89	28.80
OCR 07 S202	14.45	29.30
OCR 07 S203	14.86	21.80
PNP-1	8.38	21.86
PNP-2	14.4163	23.00
PNP-3	14.421	16.10
PNP-4B	13.53	13.20
PNP-5	14.84	31.35
PNP-6	15.2	29.92
PNP-8	14.39	28.80

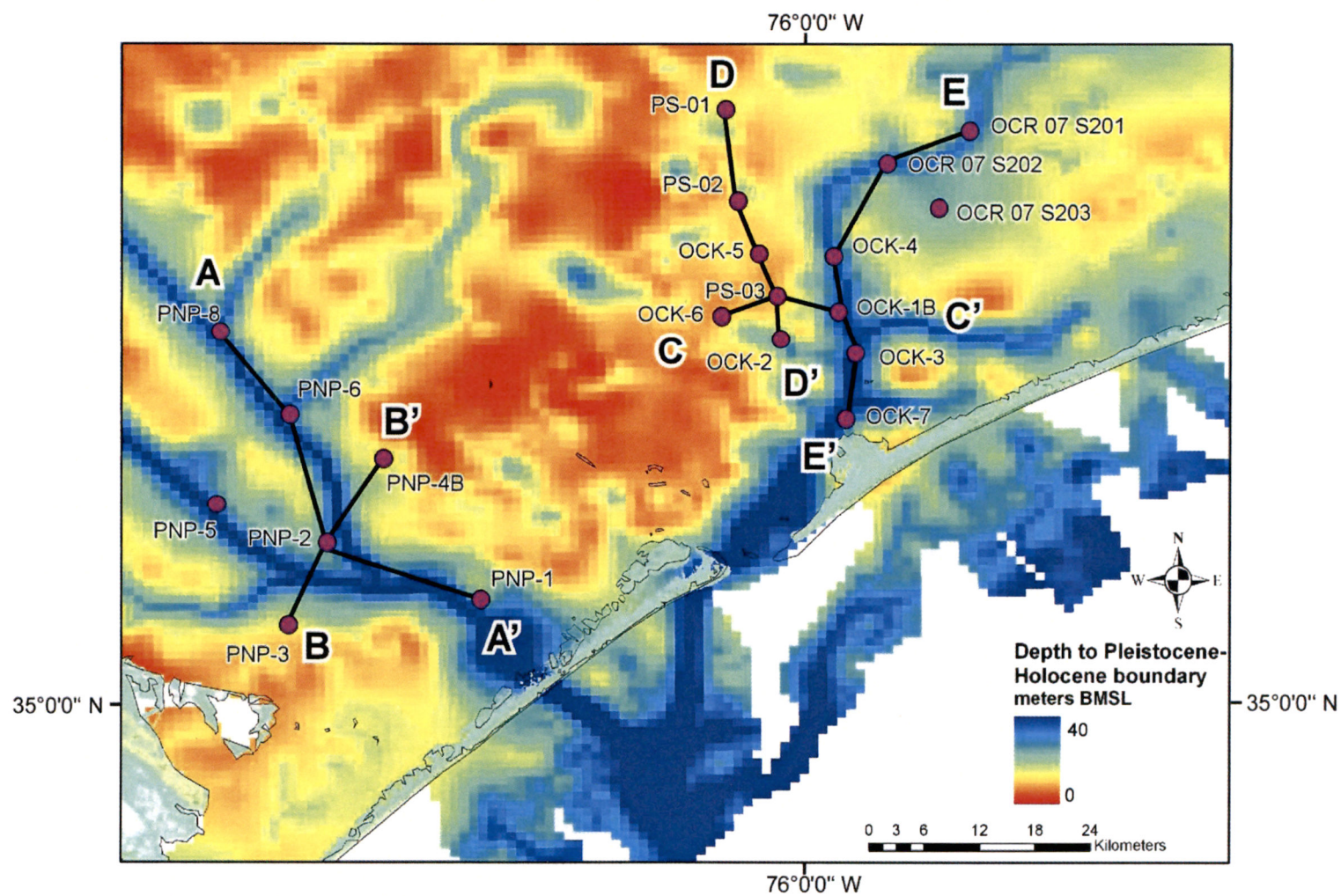


Figure 27: Map showing location of vibracore transects A to E and depth to Pleistocene in southern Pamlico Sound (D. Mallinson, unpublished).

Based on a combination of sedimentological and foraminiferal data, Holocene paleoenvironmental change along transect A-A' can be reconstructed as follows. In the north-west, the basal shell hash in PNP-8 was deposited under low brackish estuarine conditions. The sandy mud comprising the remainder of the core was deposited in a high brackish estuarine environment (Figure 29). The mostly sandy mud sediments in PNP-6 were also deposited under high brackish estuarine conditions, except for an interval from 1.5 to 2.8 m depth where a low brackish assemblage occurs (Figure 29). PNP-2 has a similar environmental record as PNP-8, a basal low brackish shell hash unit overlain by high brackish estuarine sandy mud. At 110 cm downcore, a sample plots within Biofacies D: Normal Marine Salinity Bay. This sample is correlated with a section of core in PNP-1 that contains the same biofacies. PNP-1 is located behind Portsmouth Island and is characterized by alternating high salinity biofacies (Inlet and Normal Marine Salinity Bay). The highest samples are classified as low brackish estuary. Two age estimates acquired from two samples that plotted within Biofacies D (Figures 28, 29; Table 4) indicate that these two Normal Marine Salinity Bay intervals were deposited approximately 3000 years apart (Figure 29).

Transect B-B'

Transect B-B' strikes south-west to north-east across the thalweg of the paleo-Pamlico-Neuse River and is composed of vibracores PNP-3, PNP-2, and PNP-4B (Figure 27). A shell hash is present at the base of core PNP-2; above the shell hash is sandy mud with minor fractions of shell material (Figure 30).

Sandy mud dominates this transect, but two packages of sand are present at the lower half of PNP-3 from 3.75-8.22 m and near the top of PNP-4B from 0.75-4.0 m. In PNP-3, the sand is heavily bioturbated throughout and contains mud-lined chain-like burrows. In PNP-4B the sand unit has burrows from 0.75-1.5 m and is mottled from 1.5-4.0 m.

In all three vibracores comprising this transect, low brackish estuary conditions are present at the bases of cores, followed by high brackish estuarine conditions (Figure 31). PNP-2 is dominated by high brackish estuary conditions except for one sample (110-111 cm) that plots within the Normal Marine Salinity Bay biofacies. Correlative samples do not occur in PNP-3 and PNP-4B (Figure 31). Thus, the general up-section Holocene paleoenvironmental trend for transect B-B' is one of increasing salinity (Figure 31).

Transect C-C'

Transect C-C' strikes west to east and is composed of vibracores OCK-6, PS03, and OCK-1B (Figure 27). Sediments within this transect vary (Figure 32), but in general OCK-6 and OCK-1B contain coarser sediments than the much longer PS03. In OCK-6 shell hash appears twice within the core. Above this unit is a muddy sand unit followed by another shell hash unit. An age of 7330-6980 cal yr B.P. was acquired at the base of PS03 and so this core did not penetrate the Holocene-Pleistocene boundary. PS03 has three fining-upwards sequences (Grand Pre, 2006). OCK-1B is sandy throughout, with minor fractions of mud, shell material and some bioturbation. This short core was taken

in the thalweg of a drainage (Figure 27) and so did not penetrate the Pleistocene-Holocene boundary (Figure 32; Table 5).

To the west, OCK-6 alternates between periods of high and low brackish estuarine conditions. At the base of the core, two samples plotted in Biofacies B: High Brackish Estuary (possible inlet influence) followed by a brief interval of low brackish estuarine conditions and subsequently returning to Biofacies B (Figure 33). Low brackish estuarine conditions dominate the rest of the core, except for one sample (1.16 m downcore) that indicates high brackish estuarine conditions (Figure 33). To the east, OCK-1B is barren from 4.08-2.32 m. Above that, brackish estuarine conditions characterize the rest of the core. A sample from a muddy sand at 139-141 cm is characterized by a Normal Marine Salinity Bay assemblage. Biofacies found in PS03 were summarized by Grand Pre (2006) and Culver et al. (2007) (Figure 14). Two intervals of normal marine salinity conditions were observed within PS03. The first occurred from 4.0 to 5.1 m downcore and yielded radiocarbon age estimates of 4340-4070 to 3750-3450 cal yr B.P. The second occurred from 1.0 to 1.75 m downcore and yielded radiocarbon ages of 1170-950 and 550-440 cal yr B.P. This second marine flooding unit is correlated with the sample from similar depth (1.39 m) in OCK-1B that plots within Biofacies D: Normal Marine Salinity Bay (Figure 33).

The general Holocene paleoenvironmental trends for C-C' are high brackish conditions to the east and low brackish conditions to the west. The open marine assemblages found in PS03 do not extend to OCK-6, but the upper occurrence correlates with a similar assemblage in OCK-1B (Figure 33).

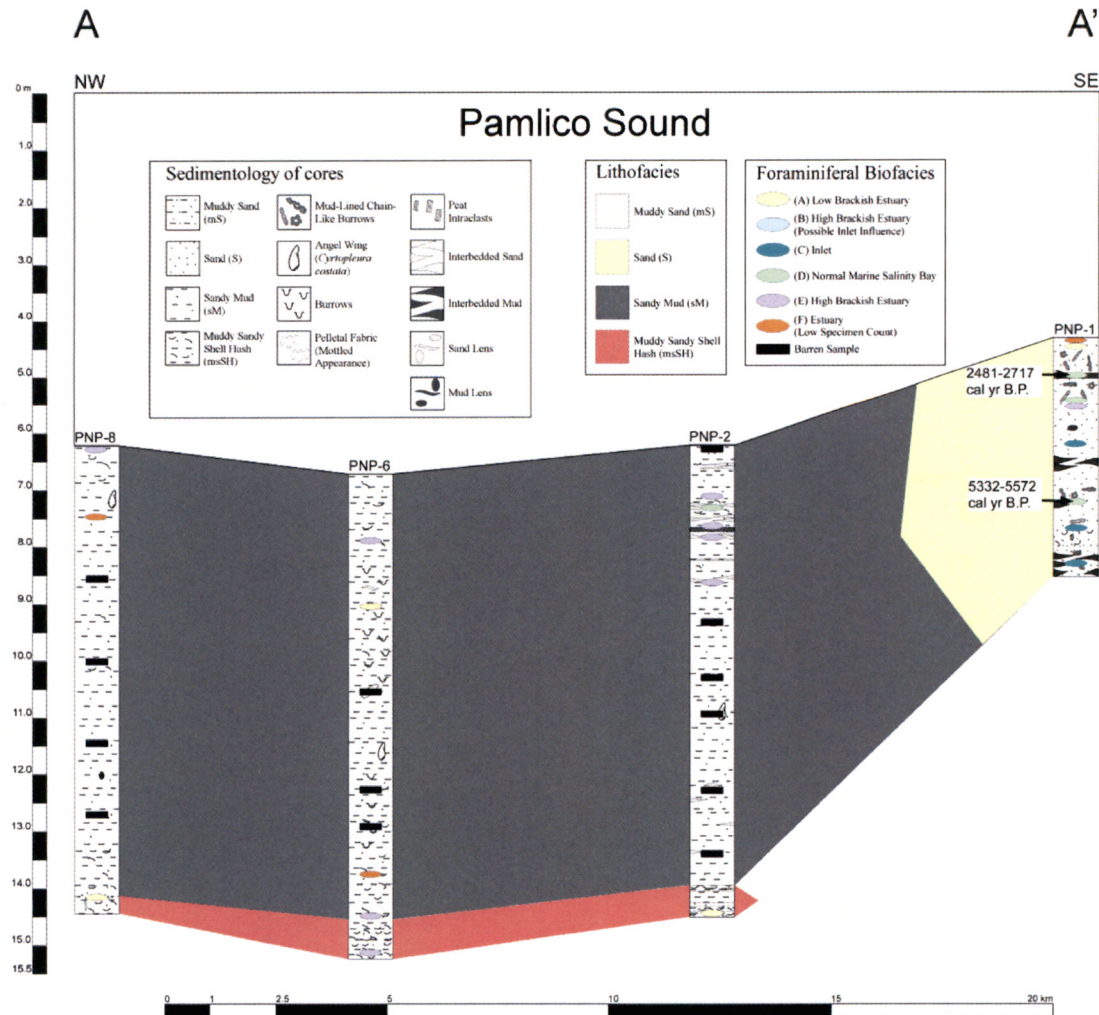


Figure 28: Transect A-A' showing distribution of lithofacies. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles. Calibrated radiocarbon ages are indicated along the left margin of the cores.

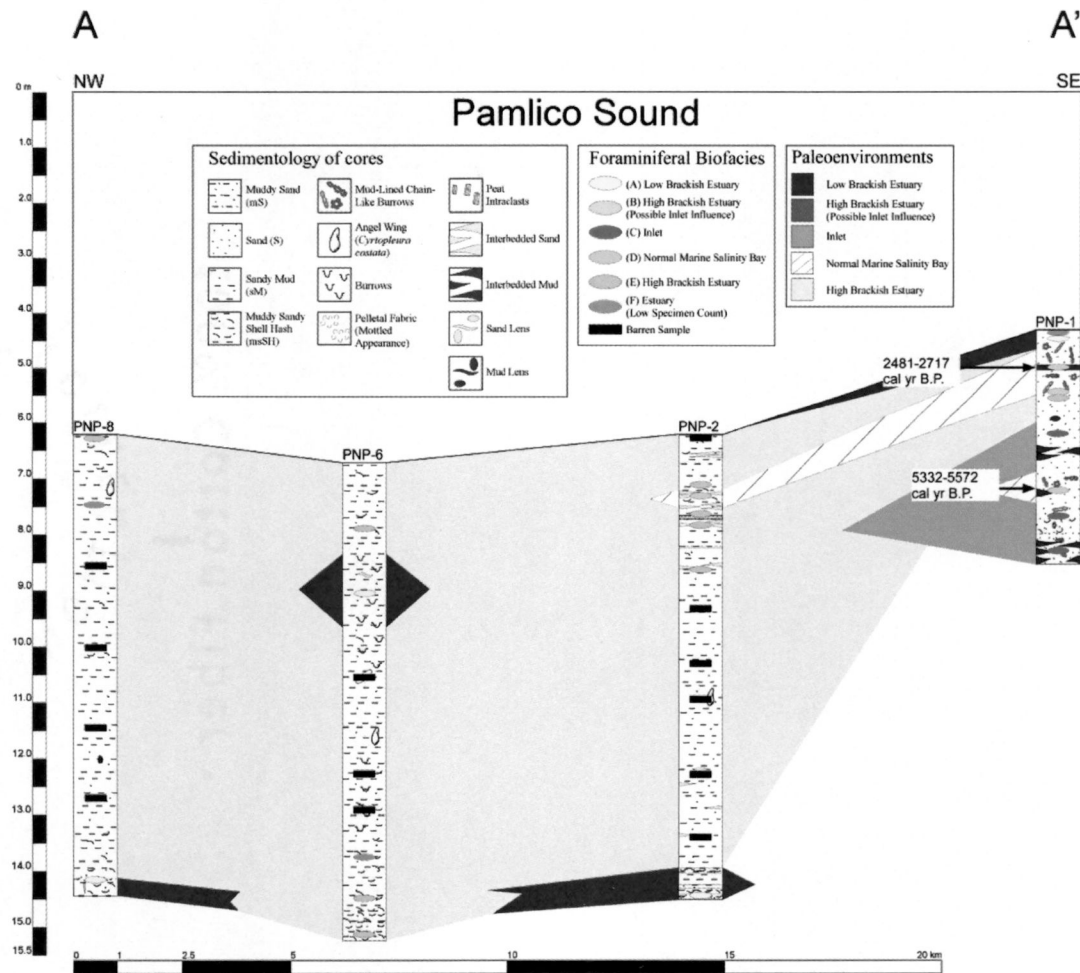


Figure 29: Transect A-A' showing distribution of biofacies and interpreted paleoenvironments. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles. Calibrated radiocarbon ages are indicated along the left margin of the cores.

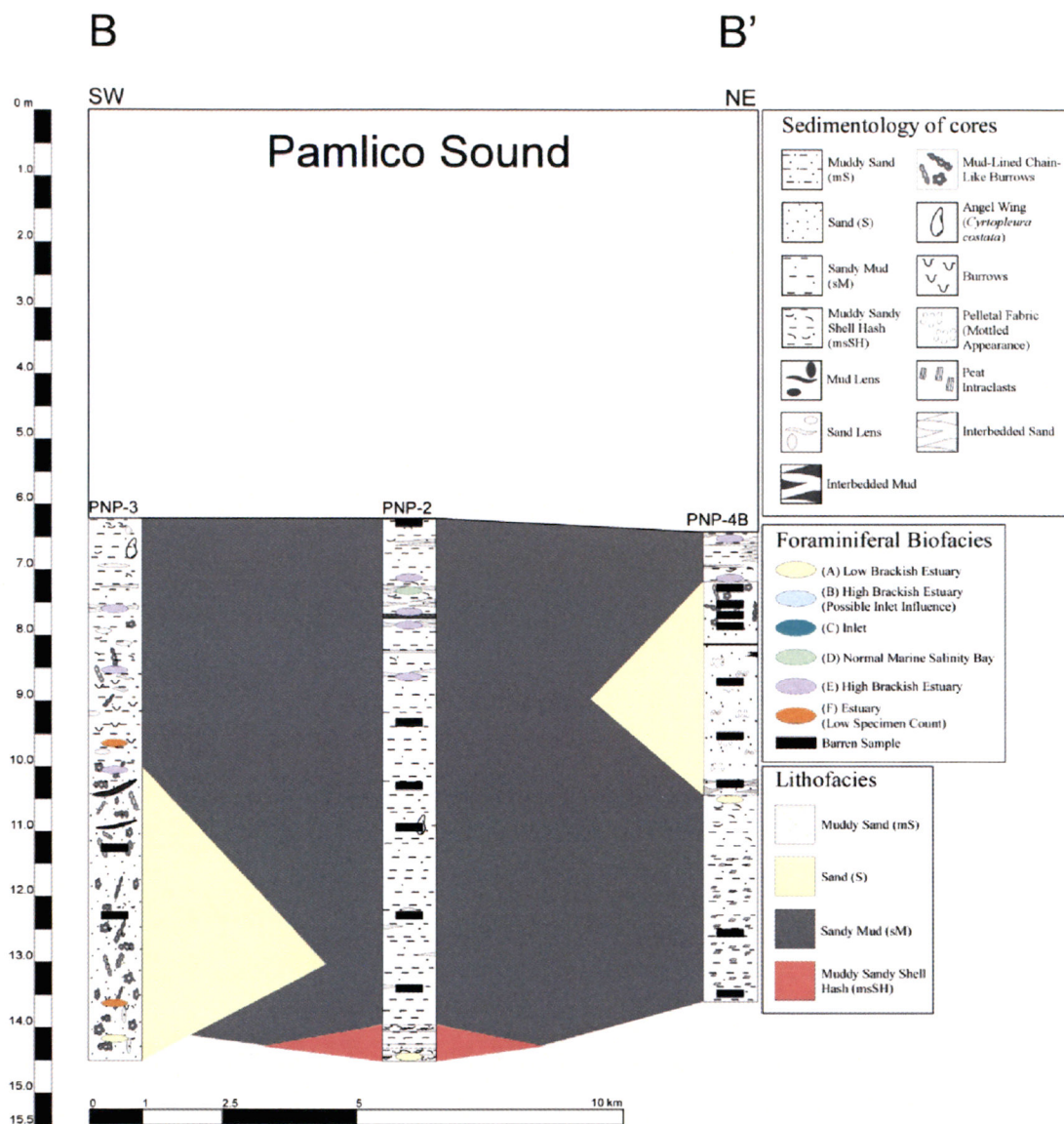


Figure 30: Transect B-B' showing distribution of lithofacies. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles.

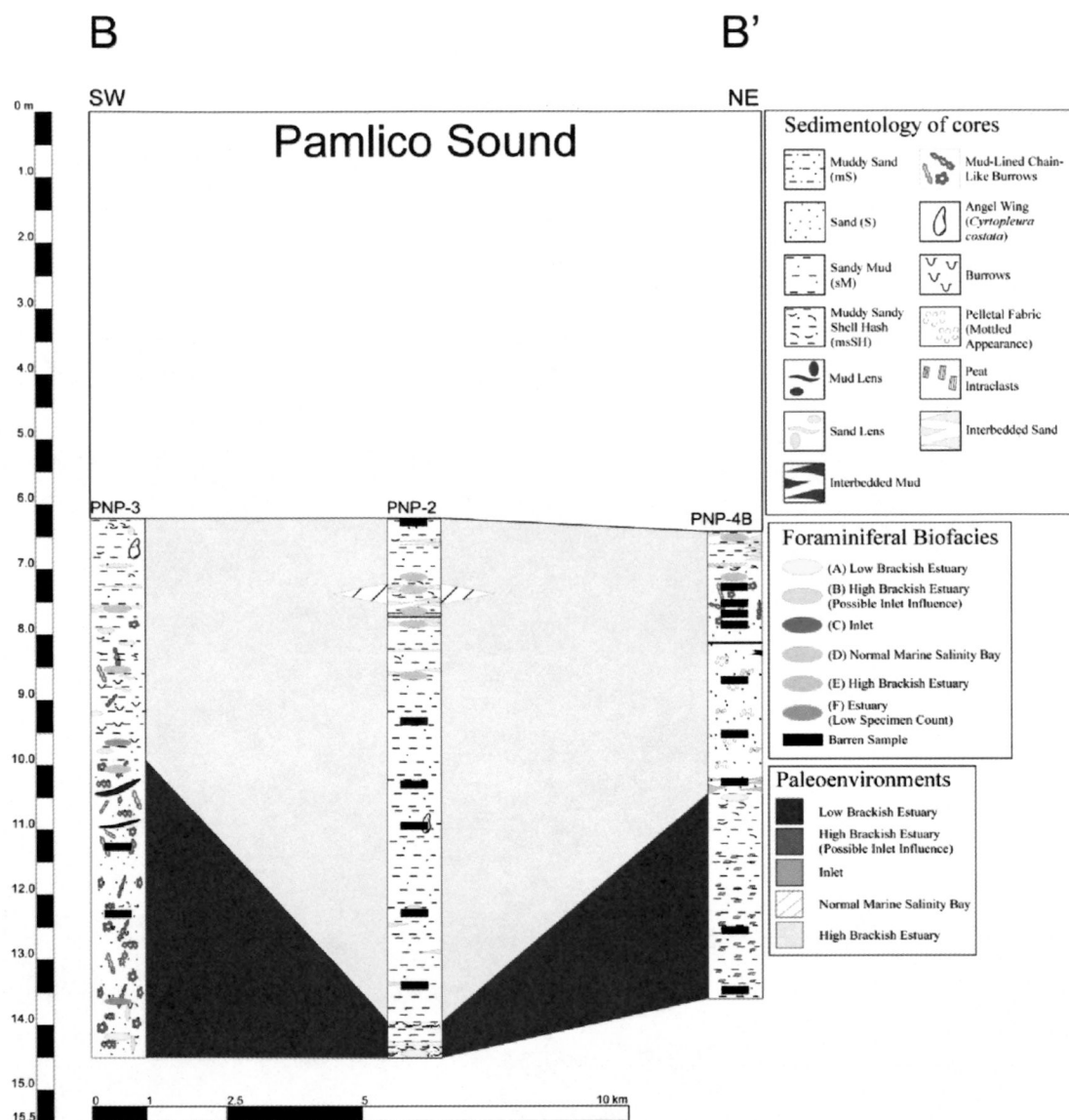


Figure 31: Transect B-B' showing distribution of biofacies and interpreted paleoenvironments. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles.

Transect D-D'

Transect D-D' strikes north to south and is composed of vibracores PS01, PS02, OCK-5, PS03, and OCK-2 (Figure 27). To the north, PS01 generally fines upwards from sand to muddy sand and finally sandy mud. The basal mud in PS02 coarsens up-core into a sand followed by muddy sand, a sand and, finally, a muddy sand (Foley, 2007). OCK-5 contains a large (>2 m) package of shell hash, possibly a paleo-oyster reef (Figure 35). Sandy mud caps this core and a sample from the base of this unit gave a radiocarbon age estimate of 474-594 cal yr B.P. PS03 has three fining-upwards sequences (Grand Pre, 2006). OCK-2 is comprised of bioturbated sand with minor fractions of shell material and mud.

PS01 is characterized by low brackish estuarine sediments and foraminiferal assemblages throughout the entire core (Foley, 2007). The base of PS02 contains two barren samples but is interpreted as low brackish estuary (Foley, 2007). The remainder of the core was interpreted by Foley (2007) to represent high brackish estuarine conditions. OCK-5 is also characterized by high brackish estuarine conditions except for the uppermost sample that contains a low brackish estuarine foraminiferal assemblage (Figure 35). The two periods of normal marine salinity conditions recognized by Grand Pre (2006) and Culver et al. (2007) in PS03 could not be correlated to any other core on this transect (Figure 35). OCK-2 contains one sample indicative of high brackish estuary conditions. From north to south there is a general increase in salinity from low brackish to high brackish conditions.

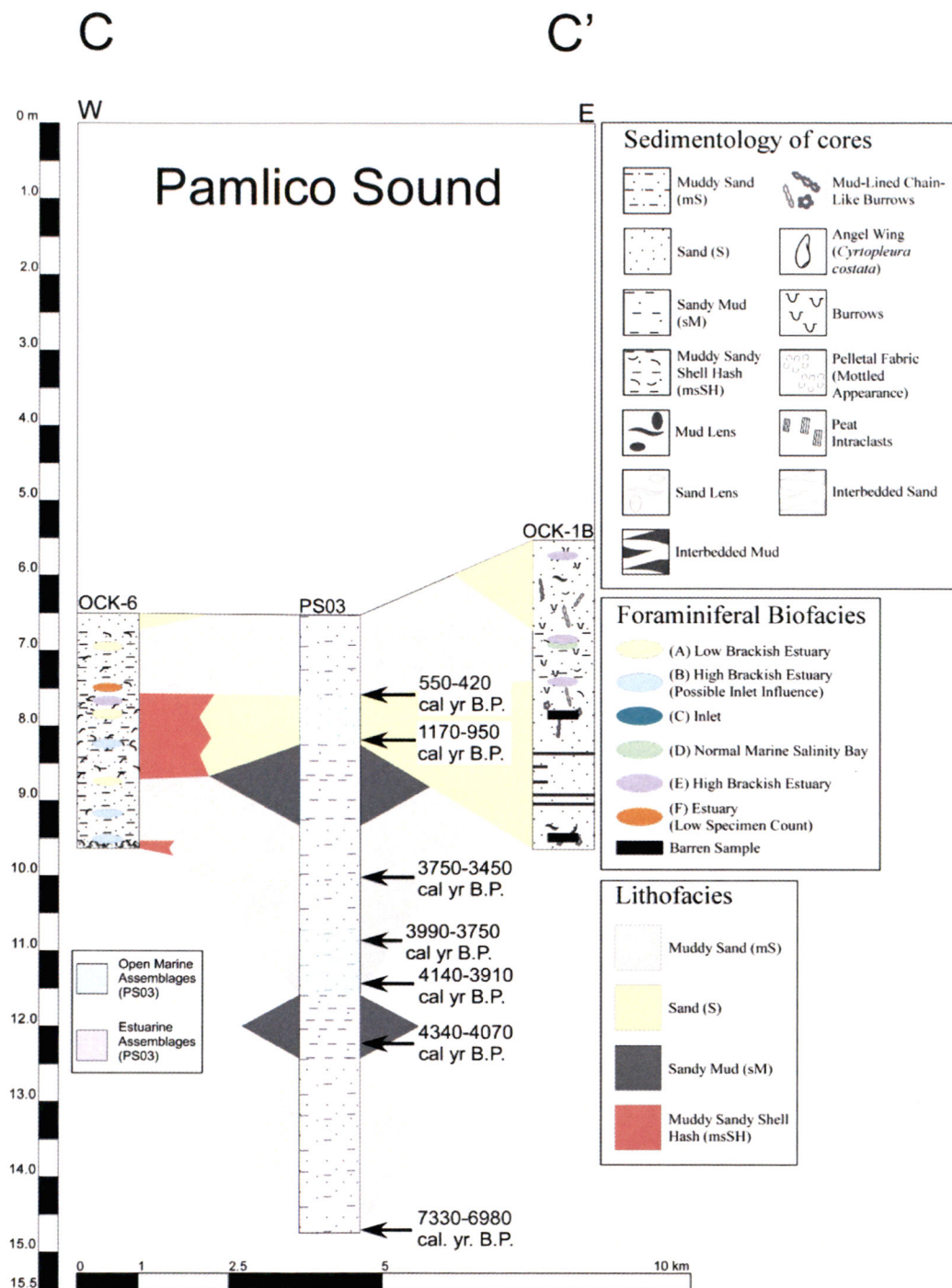


Figure 32: Transect C-C' showing distribution of lithofacies. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles. Calibrated radiocarbon ages are indicated along the right margin of the cores. Key for PS03 is from Grand Pre (2006).

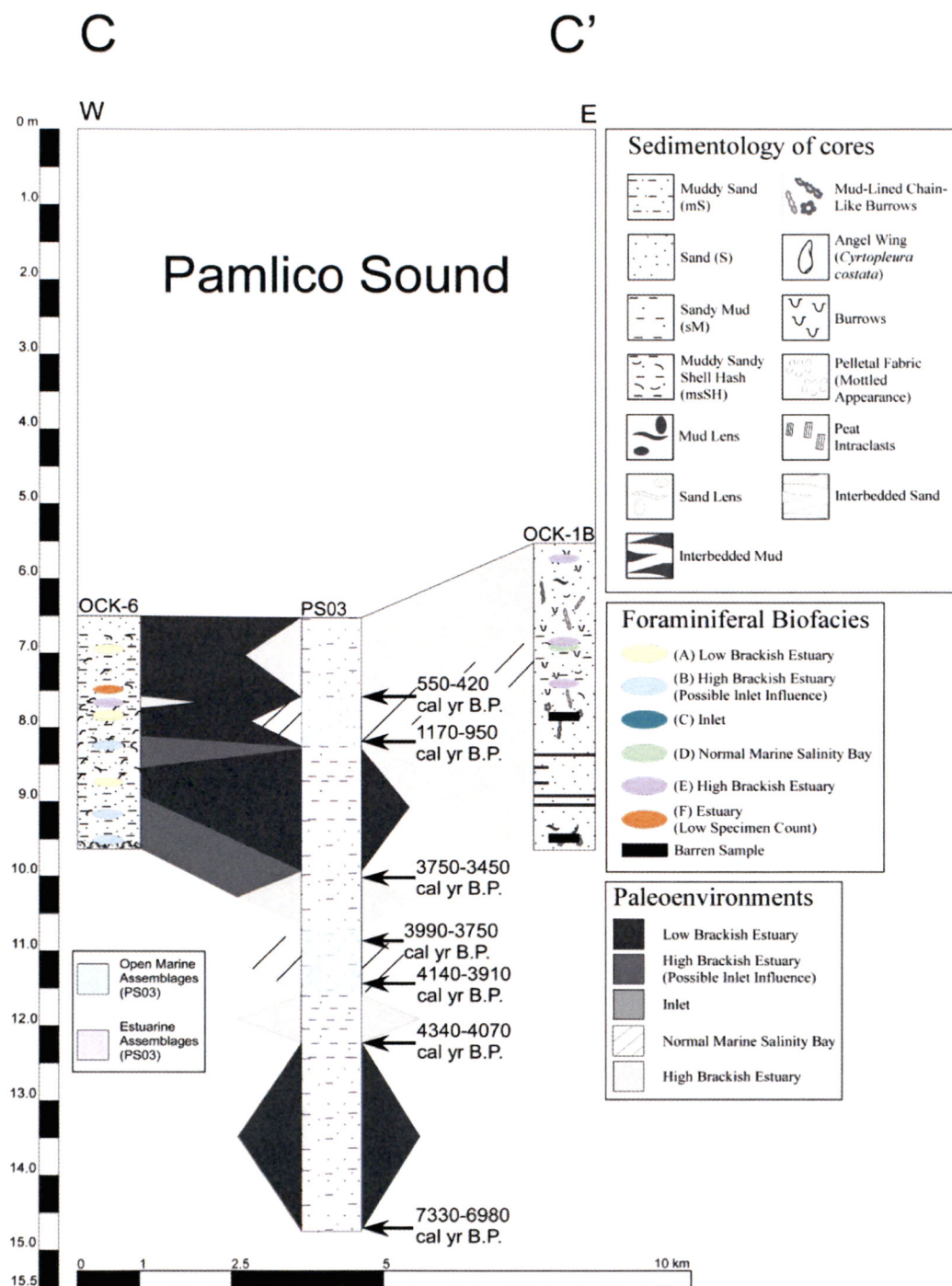


Figure 33: Transect C-C' showing distribution of biofacies and interpreted paleoenvironments. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles. Calibrated radiocarbon ages are indicated along the right margin of the cores. Key for PS03 is from Grand Pre (2006).

Transect E-E'

Transect E-E' strikes north-east to south-west generally along the thalweg of the paleo-Pamlico Creek and is composed of vibracores OCR 07 S201, OCR 07 S202, OCK-4, OCK-1B, OCK-3, and OCK-7 (Figure 27). In OCR 07 S202 alternating layers of orange sand and a green bluish gray sandy mud occur from 4.75-7.18m (Figure 24) and are overlain by a layer of shell hash at 4.7 m core depth. There is a general fining of sediments to the northeast where OCR 07 S201 is composed entirely of sandy mud. Three radiocarbon age estimates were acquired from above the shell hash in sandy mud sediments from core OCR 07 S202 (4265-4499, 4408-4647, 4819-5020 cal yr B.P.) (Figure 36).

High brackish estuarine conditions (Biofacies E) dominate this transect. Normal Marine Salinity Bay conditions (Biofacies D) occur in three cores: OCR 07 S202, OCK-4, and OCK-1B. Two samples from OCR 07 S202 gave radiocarbon ages of 4408-4647 and 4819-5020 cal yr B.P. This section of core containing Normal Marine Salinity Bay assemblages in OCR 07 S202 can be correlated with a sample containing a similar assemblage in OCK-4, although several hundred years younger (Figure 37), and may be the same unit found by Grand Pre (2006) and Culver et al. (2007) in PS03 and dated at 3990-3750 cal yr B.P. to 4140-3910 cal yr B.P. (Figure 35). This unit in OCK-4, which occurs at approximately 11 m below MSL, should probably not be correlated with the normal marine salinity bay unit found in OCK-1B at considerably shallower depths (ca. 7 m below MSL). The latter bay unit may represent the 1000 year flooding unit documented by Grand Pre (2006) and Culver et al. (2007) (Figure 33). Towards the

southeastern end of the transect, the entire length of the generally sandy core OCK-3 is interpreted as indicative of high salinity estuarine conditions. OCK-7 is similarly sandy but Biofacies C, representative of an inlet environment, occurs at the base whereas the top of OCK-7 is representative of high brackish estuarine conditions (Figure 37). The short sandy cores (OCK-3 and OCK-7) are located in the thalweg of the late Pleistocene drainage (Pamlico Creek) but their sandy composition, foraminiferal assemblages, shallow depth below MSL all indicate modern inlet shoal conditions of the nearby Ocracoke Inlet. Neither of these cores was long enough to penetrate through these modern inlet sands into the earlier Holocene fill of Pamlico Creek.

DISCUSSION

Holocene Paleoenvironmental Evolution of Southern Pamlico Sound

To better understand spatial and temporal distributions of paleoenvironments in the study area, the vibracores are split into two suites: East and West. The eastern suite of cores includes vibracores OCK-1B, OCK-2, OCK-3, OCK-4, OCK-5, OCK-6, OCK-7, OCR 07 S201, OCR 07 S202, OCR 07 S203, PS01, PS02, and PS03; and transects C-C', D-D', and E-E' (Figure 27). The western suite of cores includes vibracores PNP-1, PNP-2, PNP-3, PNP-4B, PNP-5, PNP-6, and PNP-8; and transects A-A' and B-B' (Figure 27).

In the current study, six paleoenvironments were recognized based on the combination of sedimentological and paleontological data: Low Brackish Estuary, High Brackish Estuary (with possible inlet influence), Inlet, Normal Marine Salinity Bay, High Brackish Estuary, and High Brackish Estuary (low specimen count).

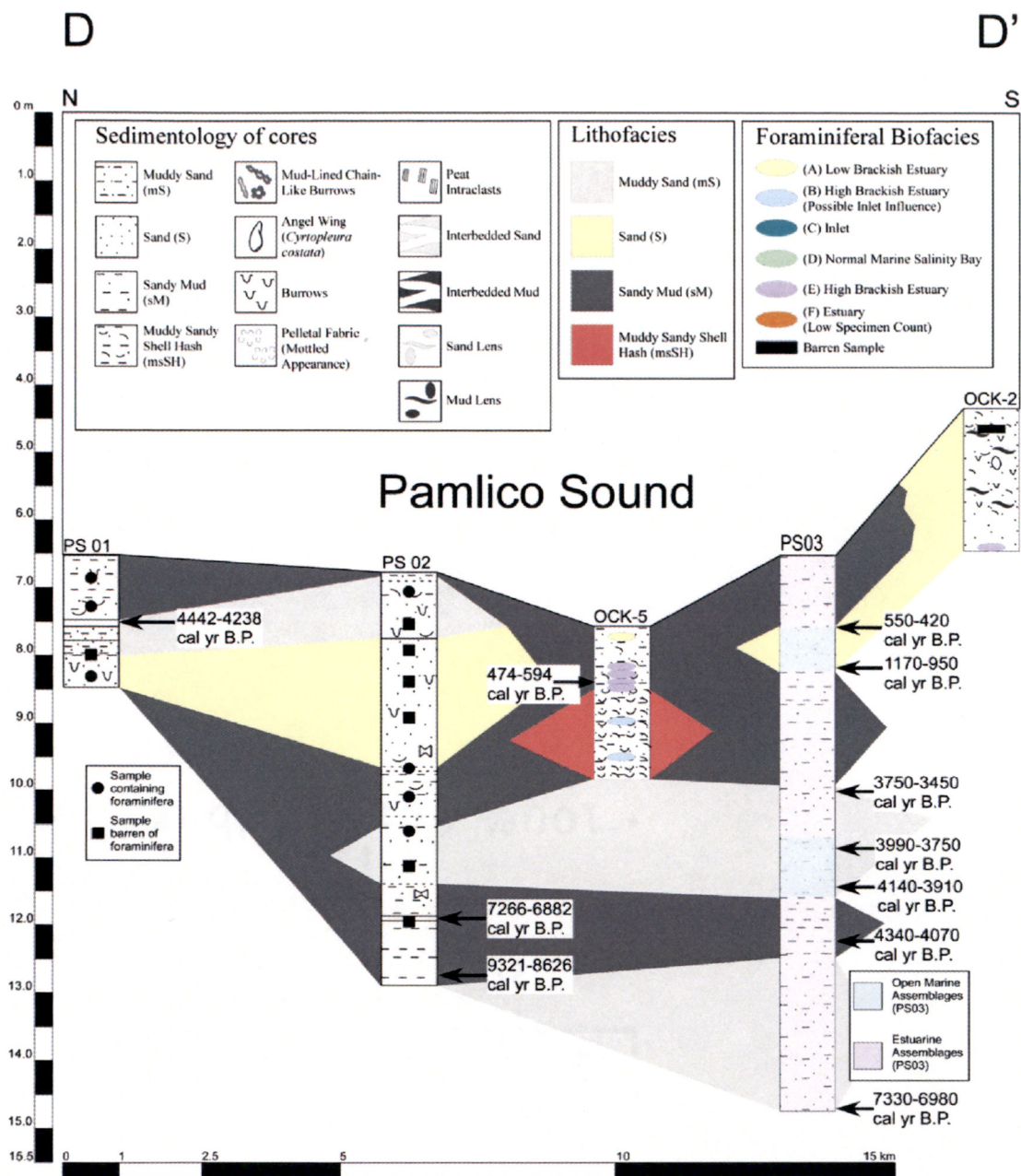


Figure 34: Transect D-D' showing distribution of lithofacies. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles. Calibrated radiocarbon ages are indicated along the margins of the cores. Key for PS01 and PS02 is from Foley (2007) and key for PS03 is from Grand Pre (2006).

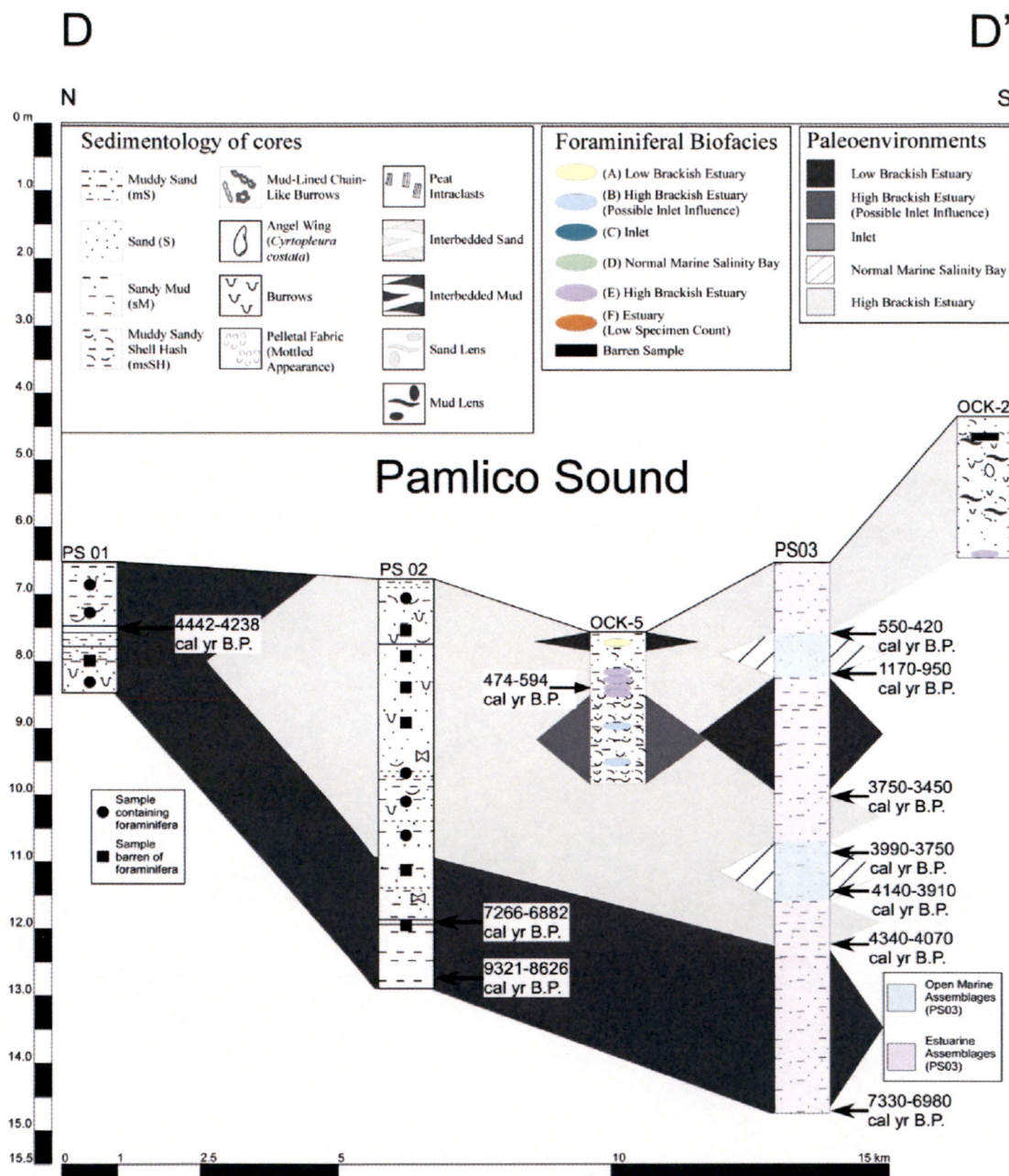


Figure 35: Transect D-D' showing distribution of biofacies and interpreted paleoenvironments. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles. Calibrated radiocarbon ages are indicated along the margins of the cores. Key for PS01 and PS02 is from Foley (2007) and key for PS03 is from Grand Pre (2006).

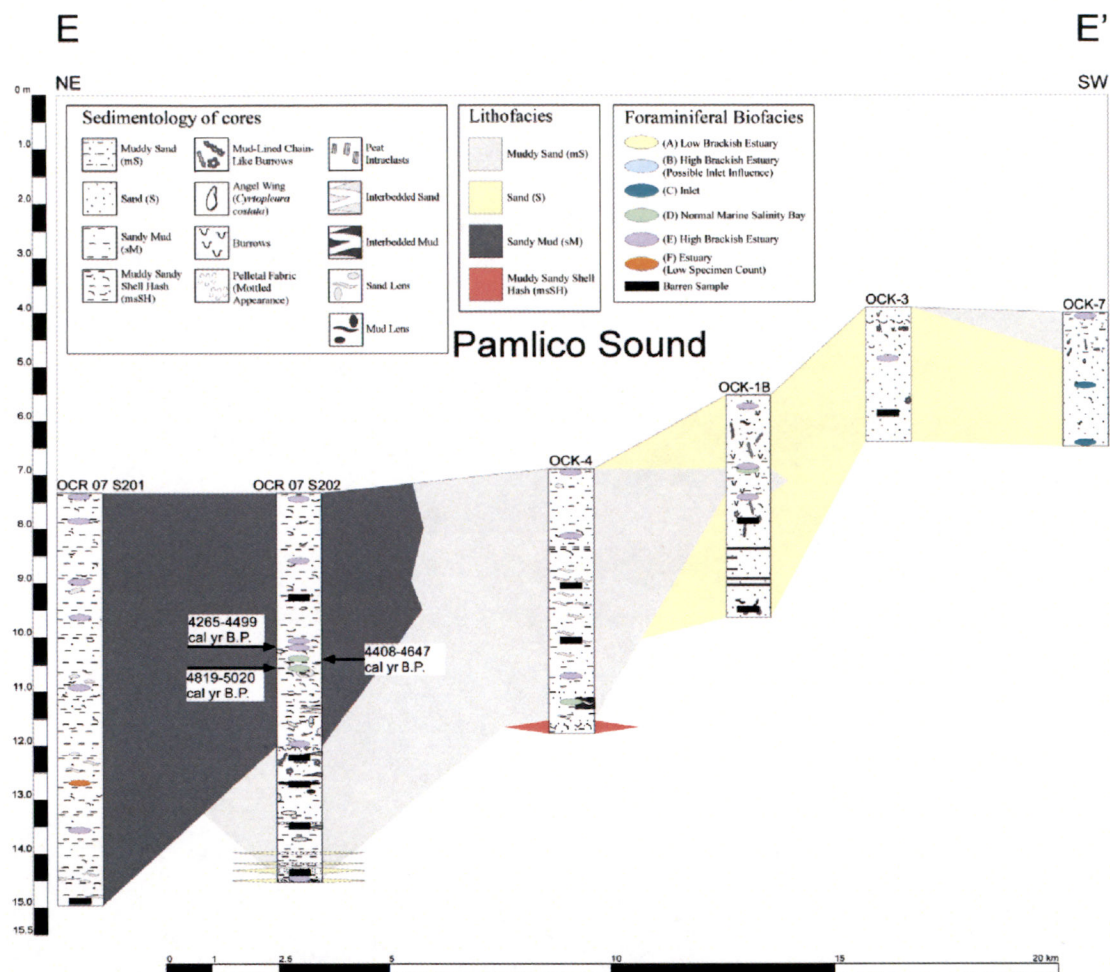


Figure 36: Transect E-E' showing distribution of lithofacies. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles. Calibrated radiocarbon ages are indicated along the margins of the cores.

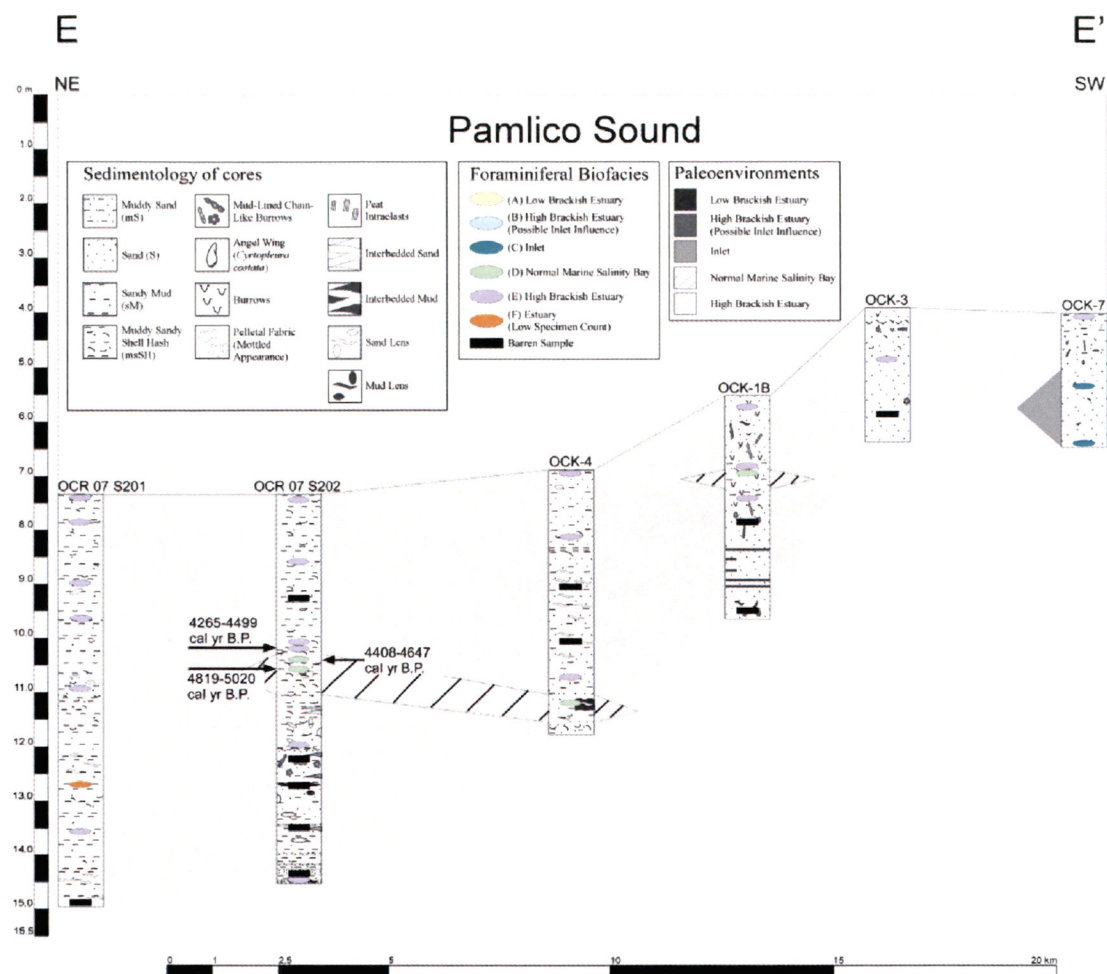


Figure 37: Transect E-E' showing distribution of biofacies and interpreted paleoenvironments. Colored ovals indicate samples containing foraminifera and their corresponding biofacies. Barren samples are indicated by black rectangles. Calibrated radiocarbon ages are indicated along the margins of the cores.

The term “flooding unit” is defined here as a depositional package containing normal marine salinity shelf planktonic foraminifera and small, stenohaline benthic foraminifera. The term “collapse” is defined here as a large scale removal of subaerial portions of the barrier islands allowing Atlantic waters to infiltrate Pamlico Sound.

Spatial Distribution of Paleoenvironments

Eastern Vibracore Suite

In the eastern suite of vibracores (OCK, OCR, and PS), higher brackish estuarine environments are seen in the northeast and southern cores (OCK-1B, 2, 3, 4, 5, 7; OCR S201, S202; and PS02 and 03); lower salinity estuarine environments are seen in the north-west and west (OCK-6 and PS01) (Figures 27, 32, 33, 34, 35, 36, and 37).

Comparison of assemblages found in the eastern suite was made to the cores of Grand Pre (2006), Culver et al. (2007), and Foley (2007) to map the extent of the flooding unit containing planktonics and delicate shelf benthics observed in PS03 and absent in the Foley (2007) vibracores. In addition to the vibracores comprising the eastern vibracore suite, data from Hale (2008) are also used for comparative purposes.

Comparison to Grand Pre (2006) and Culver et al. (2007)

Grand Pre (2006) and Culver et al. (2007) identified four biofacies in vibracore PS03 (Figures 14, 27): Normal Marine Salinity Bay, High Brackish Estuary, Low-Mid Brackish Estuary, and Indeterminate (probably estuary). Low brackish assemblages from 8.21-5.88 m (core depth) reflect the initial flooding of Pamlico Creek during the early

Holocene. Two intervals of normal marine salinity conditions have been correlated with similar intervals in cores of this study (Figures 27, 32, 33, 34, 35, 36, and 37). The first in PS03 occurred from 4140-3910 cal yr B.P. to 3990-3750 cal yr B.P. (Figure 14). This unit was not seen in any cores in transects C and D. However, this unit is likely present in OCR 07 S202 and OCK-4 along transect E-E'. Three samples from OCR 07 S202 yielded age estimates of 4499-4265 cal yr B.P. (2.84-2.85 m), 4647-4408 cal yr B.P. (3.04-3.05 m), and 5020-4819 cal yr B.P. (3.21-3.22 m) (Figure 37), similar ages as those of the initial normal marine salinity unit in PS03. The occurrence of this unit in OCR 07 S202 indicates that normal marine salinity waters penetrated well into the flooded, estuarine paleo-Pamlico Creek drainage. If later erosion has not removed this unit from other cores, normal marine salinity conditions did not influence environments to the west of the thalweg of the drainage (PS01 and PS02; Figure 27) or further north (OCR 07 S201; Figure 37). This interval of normal marine salinity conditions is attributed to rising sea level overtopping the Hatteras Flats Interstream Divide (HFID) (Figure 5) (Culver et al., 2007). The second normal marine salinity unit in PS03 occurred from 1170-950 cal yr B.P. to 550-420 cal yr B.P. and is correlated here to a Normal Marine Salinity Bay biofacies found in OCK-1B (Figure 33). This period of normal marine salinity conditions in southern Pamlico Sound is attributed to a collapse of the southern Outer Banks possibly caused by a large scale hurricane, of series of smaller storms back-to-back (Culver et al., 2007) (Figure 40).

Comparison to Foley (2007)

Foley (2007) identified four estuarine assemblages: High Salinity Estuary, High-Intermediate Salinity Estuary, Low-Intermediate Salinity Estuary, and Low Salinity Estuary. She documented the initial flooding of Pamlico Creek during the Holocene in four cores (PS02, PS06, PS09, and PS10) (Figures 15, 16); these low salinity estuarine conditions occurred from 9000 to 6000 cal yr B.P. (Figure 35). A depth slice taken at 12-54 cm (from the top of each core) was used to reconstruct near modern environments (Figure 38). A general decrease in salinity was observed from the Outer Banks to the mainland. A study of modern foraminiferal assemblages by Abbene et al. (2006) also observed a trend of decreasing salinity towards the mainland (Figure 39).

Very few Low Brackish Estuarine environments were recognized in cores of the current study; they occurred in only two cores (OCK-5 and OCK-6). High brackish assemblages dominate the current study area, but along transects C-C' and D-D' (Figures 33 and 35) interpreted environments become less saline towards the mainland. The Normal Marine Salinity Bay biofacies appears several times within the eastern suite of cores of the current study, but does not appear within the cores of Foley (2007) (Figure 40).

Comparison to Hale (2008)

Hale (2008) identified six litho/biofacies in the Ocracoke Island and Howard's reef vicinity: LBI: Barrier Island Sand/Overwash Sand and Back-barrier Sand flats, LBII: Marsh, LBIII: Estuarine Flat, LBIV: Flood tide delta/Inlet, LBV: Low Energy Normal

Salinity/Flood Tide Delta, and LBVI: High Energy Normal Salinity/ Inlet. He documented open marine conditions in the vicinity of Ocracoke Island and Howard's Reef from ~ 1200-700 cal yr B.P. (Figure 41). These findings correspond well with similar assemblages observed in PS03 and OCK-1B (Figure 33). After 700 cal yr B.P., the island began to develop as a sub-aqueous sand bar on topographic highs and numerous inlet-fill sequences were observed within topographic lows (Figure 41). Inlet assemblages were also observed in the current study in OCK-7 (1.33-2.48 m core depth) (Figure 37). Approximately 500 cal yr B.P. a sand shoal existed under the modern Howard's Reef, estuarine tidal flat/flood tide delta deposits were observed behind inlet deposits (east of Ocracoke Village) and Ocracoke Island was nearly complete in its development as evidenced by back barrier salt marsh deposits which along the length of the Outer Banks have been dated as generally younger than 500 cal yr B.P. (Smith et al., 2004; Culver et al., 2006; Smith, 2006; Hale, 2008) (Figure 41).

Western Vibracore Suite

In the western suite of vibracores (PNP), lower salinity estuarine environments are observed in the lower portion of cores PNP-8, 2, 3, and 4B (Figures 29, 31). High brackish conditions dominate the upper sections of all cores except for PNP-1; the upper two samples from this vibracore are lower salinity (Figure 29). The trend of higher brackish conditions upcore agrees with the findings of Abbene et al. (Figure 39; 2006). Below these low salinity samples in PNP-1, paleoenvironments vary from normal marine salinity, to high brackish estuary, to two periods of inlet assemblages separated by

another period of normal marine salinity (Figure 29). Comparison of assemblages found in the western suite was made to the cores of Rosenberger (2006) to map the extent of the upper flooding unit containing planktonics and delicate stenohaline shelf benthics observed in PS03.

Comparison to Rosenberger (2006)

In PNP-1, from 7.46-8.43 m below MSL an inlet environment is represented (Figure 29). From 7.07-7.46 m below MSL normal marine salinity conditions occurred from 5572-5332 cal yr. B.P. This is followed by another period of inlet conditions from 6.14-7.07 m below MSL. Normal marine salinity conditions returned to the area after a brief period of estuarine conditions from 2717-2481 cal yr. B.P. at a depth of 4.98-5.42 m below MSL (Figure 29). Rosenberger (2006) also observed inner shelf conditions at this approximate depth (3-5 m) below sea level behind Portsmouth Island. Additional studies have also observed open marine sediments at ~5 m below MSL (Salvo-Gull Island and near Hatteras Village) dated at 1200-500 cal yr B.P. and 3000 cal yr B.P. (Ricardo, 2005; Twamley et al., 2006).

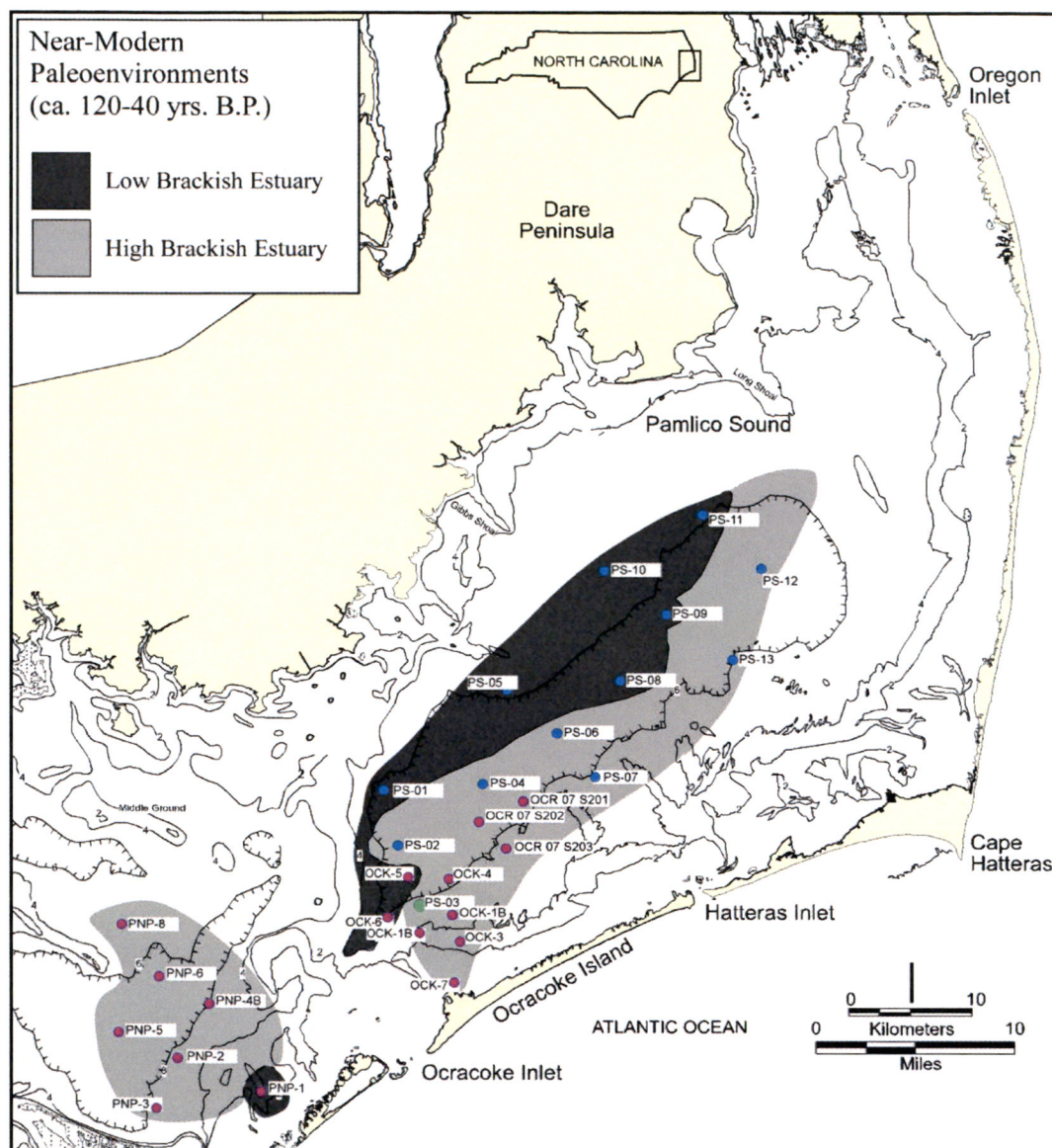


Figure 38: Near-modern paleoenvironments in Pamlico Sound (modified from Foley, 2007). Surface samples were not collected in this study or that of Foley (2007); therefore subsurface samples (12-54 cm core depth) were extrapolated upcore. According to ^{137}Cs peak and ^{210}Pb data from Tully (2004), ages range between 120 yrs to 40 yrs. B.P at these depths (in Abbene, 2004). Pink dots represent vibracores collected in this study, blue dots represent Foley (2007) vibracores, green dot represents PS03 (Grand Pre, 2007), and contours are in meters.

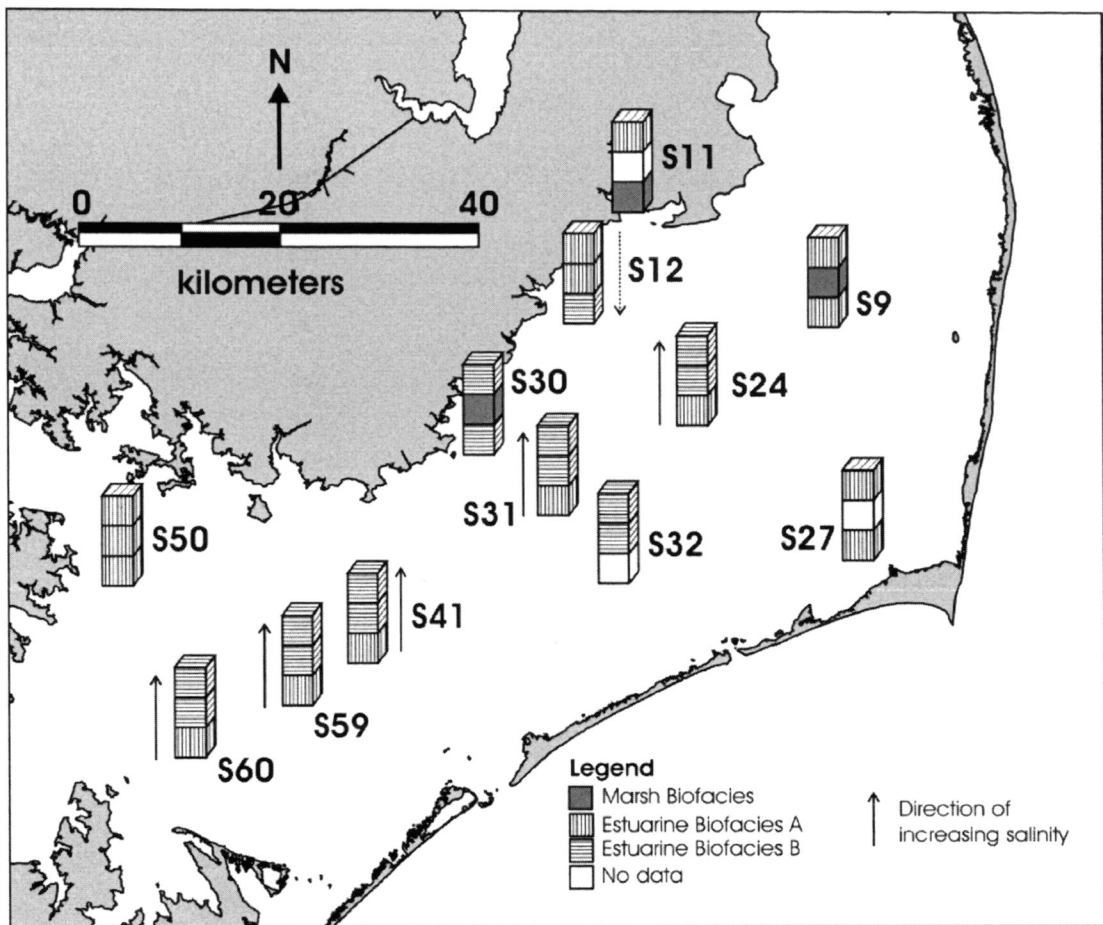


Figure 39: Change in foraminiferal assemblages over time. Lowest box represents ~120 yrs. B.P., the middle box represents ~40 yrs. BP., and the top box represents present day. Arrows represent direction of increasing salinity (Abbene et al., 2006).

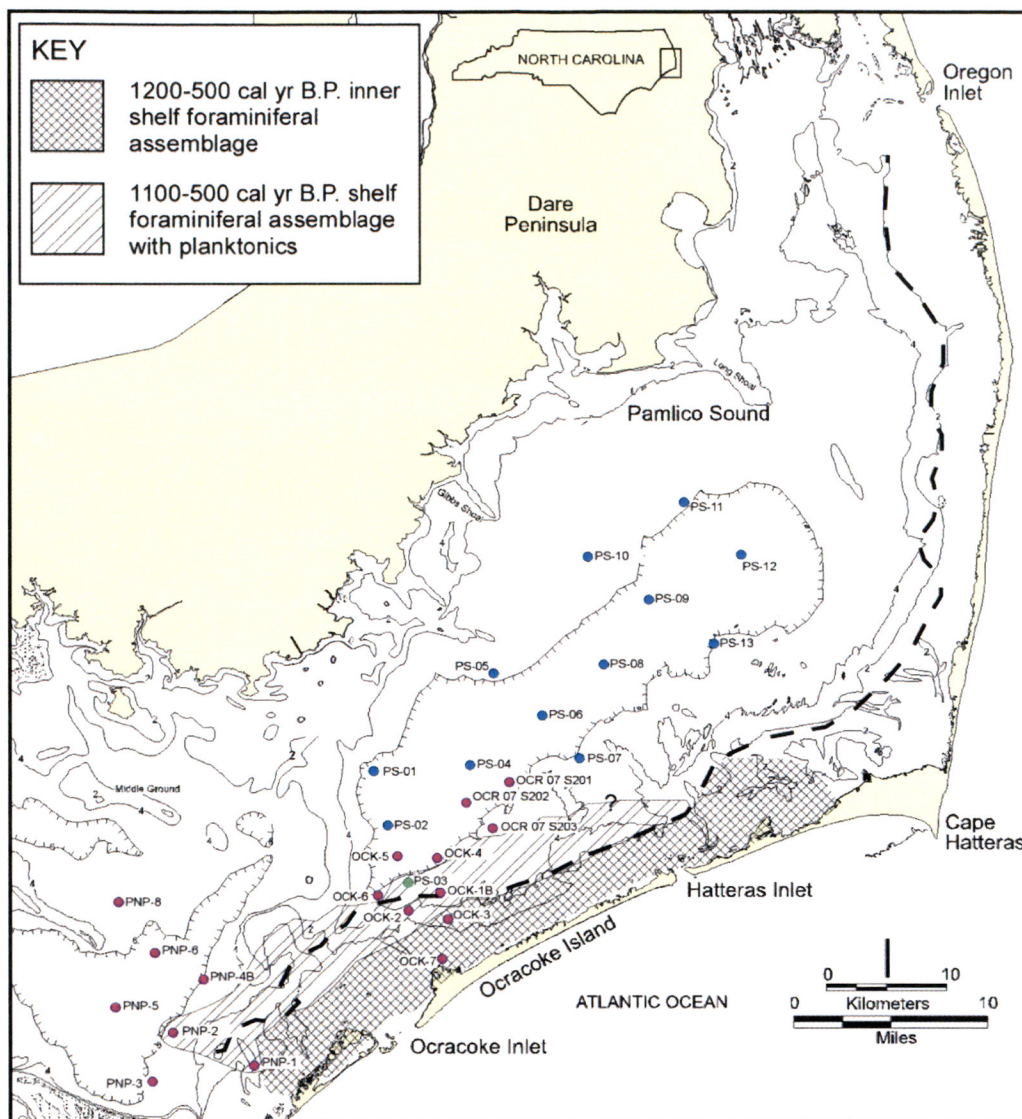


Figure 40: Location of vibracore PS03 (green dot), Foley (2007) vibracores (blue dots), and vibracores from the current study (pink dots). Cross-hatching indicates the distribution of the ca 1200-500 yr old inner inner shelf foraminiferal assemblage. Diagonal lines indicate the ca 1100-500 yr old shelf foraminiferal assemblage with planktonics. The western boundary of the Hatteras Flats is indicated by the black dashed line.

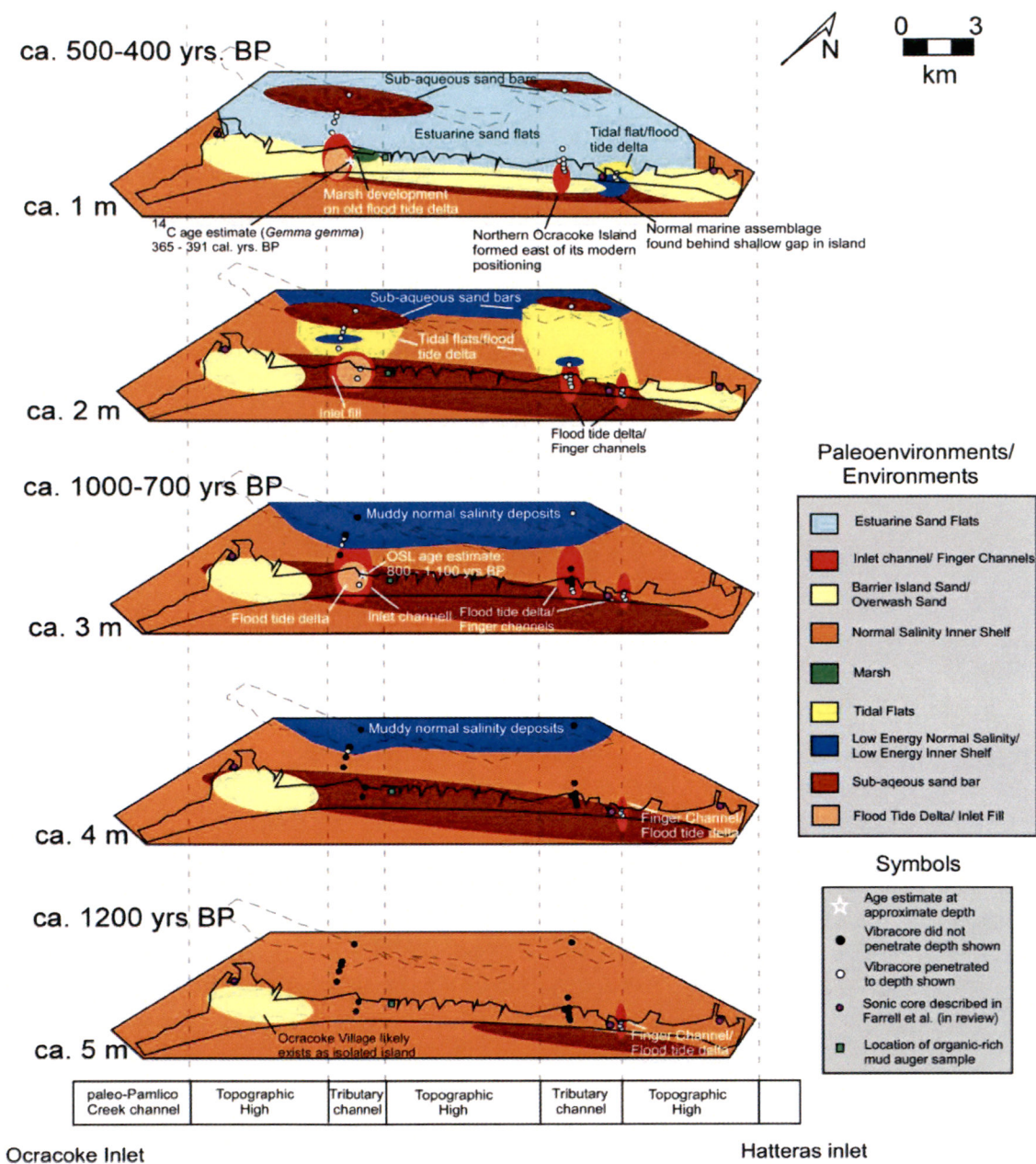


Figure 41: Paleoenviromental depth slices from 5 to 1 m below MSL in the Ocracoke Island and Howard's Reef vicinity (Hale, 2008). Paleo-topographic highs and lows indicated at bottom of figure.

Temporal Distributions of Paleoenvironments

7000-4000 cal yr B.P.

Initial flooding of Pamlico Creek and the paleo-Tar and paleo-Neuse Rivers occurred 7000 years ago with rising sea level, creating the Pamlico Creek estuary and the Tar and Neuse River estuaries (OCK-1B, 2, 3, 4, 7; PS02, 03; OCR 07 S201, 202; PNP-1, 2, 5, 6, 8) (Figure 42 A and Table 6) (Grand Pre, 2006; Culver et al., 2007; Foley, 2007). As sea level continued to rise, salinity within these estuaries increased and by ~ 5500 cal yr B.P. normal marine salinity waters were influencing the outer Tar and Neuse River estuaries (PNP-1) (Figure 42 B and Table 6) and Pamlico Bay was beginning to form. Estuarine conditions were present in the upper Tar and Neuse River estuaries and the Pamlico River estuary.

4000-1100 cal yr B.P.

By ~ 4000 cal yr B.P. normal marine salinity waters overtopped the southern part of the HFID and tidal exchange occurred between the Atlantic Ocean and Pamlico Bay (Figure 42 C and Table 6). A few islands, located upon latest Pleistocene topographic highs, were present in Pamlico Bay (PS08) (Culver et al., 2007; Mallinson et al., 2008). A proto-Portsmouth Island probably existed (Figure 42 C and Table 6) as indicated by the presence of inlet assemblages behind it (PNP-1) and estuarine assemblages further up-estuary (PNP-2, 3, 4B, 5, 6, and 8) (Figure 29). Northern Pamlico Sound became isolated from marine influence ~3000 cal yr B.P. with the construction of the northern barrier island complex (Mallinson et al., 2005; Culver et al., 2008). Ocracoke Village likely

formed around 3500 cal yr B.P. and existed as an isolated island in the vicinity of Ocracoke Village (Table 6) (Culver et al., 2007; Hale, 2008).

By ~ 2000-2500 cal yr B.P., barrier islands had formed along the HFID and beach ridges had formed Cape Hatteras (Figure 42 D). Portsmouth Island likely became a sand shoal that was overtopped allowing normal marine salinity waters to again influence the area (PNP-1) (Figure 42 D and Table 6). Open marine conditions were present in the Hatteras Village area from 4100-3000 cal yr B.P. (Twamley, 2006). Ricardo (2005) found that the Gull Island area experienced inner-shelf marine conditions from before 3000 cal yr B.P. (earlier information is precluded by limited vibracore penetration) until 1250 cal yr B.P.

1100-500 cal yr B.P.

Around 1250 cal yr B.P. Gull Island began to develop as sand shoals on the Hatteras Flats (Ricardo, 2005). Modern Portsmouth Island began to form as a shore-parallel subaqueous bar on the Pleistocene interstream divide approximately 1200-500 cal yr B.P. (Rosenberger, 2006). During the Medieval Warm Period (~1100 cal yr B.P.) sea-level rise and/or increased storminess and frequent hurricanes caused a large scale collapse of the southern Outer Banks transforming the southern Outer Banks barrier islands into submarine sand shoals and small isolated islands (Figure 42 E and Table 6) and allowing normal marine salinity waters with Gulf Stream influence to extend over a broad expanse of southern Pamlico Sound (Figures 41, 42 E) (Culver et al., 2007). The normal marine salinity conditions did not extend into central Pamlico Sound (Foley,

2007); however, the central sound did experience higher salinity estuarine conditions than northern Pamlico Sound during this time. Hale (2008) found that from 1200-500 cal yr B.P., perhaps due to increased storm frequency, Ocracoke Island was reduced to a submarine sand shoal, allowing normal salinity conditions to influence southern Pamlico Sound (Table 6).

Growth and development of the Outer Banks continued throughout the late Holocene with the modern configuration forming by approximately 500 cal yr B.P. (Table 6) (Culver et al., 2007). Three fining-upwards transgressive overwash deposits were observed in vibracores collected from Pea Island (Smith, 2004; Culver et al., 2005). AMS ^{14}C age estimates of back-barrier basal peat indicate formation of modern Pea Island occurred between ~800-500 cal yr. B.P. (Smith, 2004; Culver et al., 2005). Marsh formation puts stabilization of Gull Island around 540-460 cal yr B.P. (Table 6) (Ricardo, 2005). Smith (2006) used GPR, lithologic, and micropaleontologic data to date relict inlets and define inlet facies along Hatteras and Ocracoke Islands (from Oregon Inlet to Ocracoke Inlet). Multiple inlets were active from Cape Hatteras to Ocracoke Island; but by 500 cal yr B.P. they had closed, leaving Ocracoke and Oregon Inlets active (Table 6) (Smith, 2006).

Estuarine conditions were present behind the Hatteras Village area from 3000-500 cal yr B.P. (Twamley, 2006). AMS ^{14}C age estimates of basal peat indicate that by 500 cal yr B.P. a barrier island complex was present (Table 6) (Twamley, 2006). Back-barrier marshes formed on southwestern Ocracoke Island ~500 cal yr B.P., indicating the formation of a generally complete barrier island. However, OSL and AMS ^{14}C age

estimates indicate that until ~400 cal yr B.P. Ocracoke Island was a semi-continuous barrier island with active inlets (Hale, 2008). Barrier island formation commenced around 500 cal yr B.P. for Portsmouth Island; but increased storm activity overwashed and produced the modern back-barrier morphology of the island (Rosenberger, 2006).

500 cal yr B.P. to Present

When the first European settlers came to North Carolina in the 1580s, their maps indicated that the configuration of the Outer Banks barrier islands was very similar to that of today but several more inlets were open (Smith, 2006). During the past 500 years the estuarine sediments accumulating in southern Pamlico Sound are generally coarser than estuarine deposits that accumulated earlier in the mid-Holocene, possibly as a result of clearance of vegetation (Grand Pre, 2006; Culver et al., 2007). Foley (2007) documented distributions of foraminifera in central Pamlico Sound for approximately 120 years ago that were very similar to modern distributions (Abbene et al., 2006). Low brackish foraminiferal assemblages characterized the west-central sound (Figure 38) and high brackish foraminifera characterized the east-central (Foley, 2006) and southern (this study) Pamlico Sound (Figure 38). Abbene et al. (2006) found a trend of increasing salinity in Pamlico Sound over the past approximately 120 years. She attributed that pattern to the influx of freshwater during the late 1870s to 1900 as a result of 12 hurricanes that affected North Carolina.

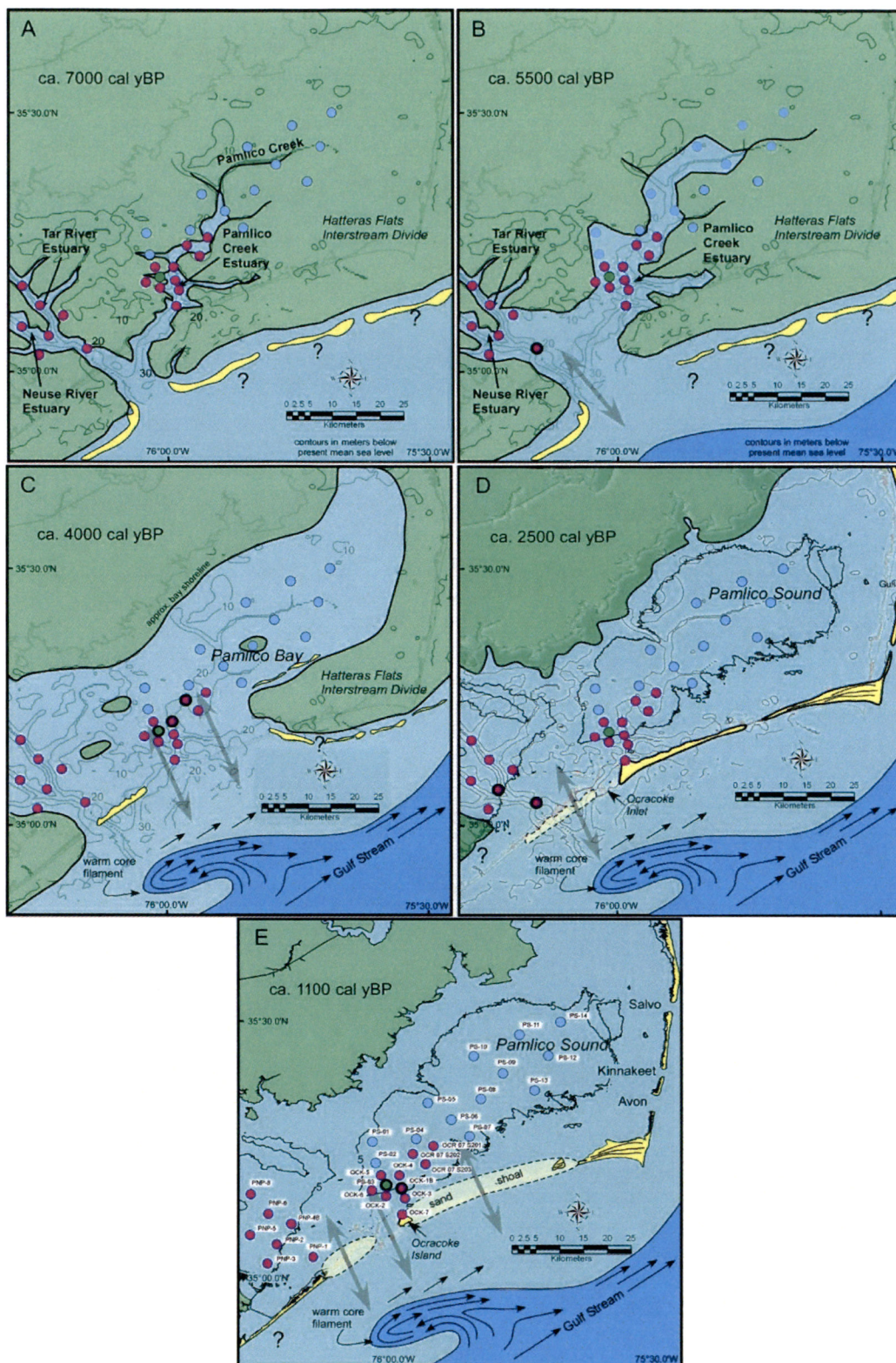


Figure 42: Five panel figure illustrating the Holocene evolution of Pamlico Sound. (A) ca. 7000 cal yr B.P. Initial flooding of drainages in the southern Pamlico Basin forming estuaries. (B) ca. 5500 cal yr B.P. Outer portions of Tar and Neuse River estuaries influenced by Gulf Stream waters. Estuarine conditions characterized the Pamlico Creek estuary and upper Tar and Neuse River estuaries. (C) ca. 4000 cal yr B.P. Gulf Stream influence in southern Pamlico Bay; Portsmouth Island begins to develop. Several islands present in Pamlico Bay. (D) ca. 2500 cal yr B.P. Outer Banks barrier islands established and Pamlico Sound experienced estuarine conditions. Gulf Stream influence behind Portsmouth Island as it was reduced to a sand shoal. Beach ridges formed Cape Hatteras. (E) ca. 1100 cal yr B.P. Collapse of the southern Outer Banks resulting in Gulf Stream influence in southern Pamlico Sound (modified from Culver et al., 2007; Culver et al., unpublished). Pink dots represent vibracores collected in the current study, blue dots represent vibracores from Foley (2007), green dot represents PS03 (Grand Pre, 2006), gray arrows represent tidal exchange, and contours are in meters. Bolded circles indicate presence of foraminiferal assemblages indicating Gulf Stream influence.

Table 6: Summary of Holocene geologic evolution of the northern and southern Outer Banks over the last 7000 years. Summary based on data from this study, Smith (2004), Ricardo (2005), Grand Pre (2006), Smith (2006), Twamley (2006), Culver et al. (2007), Foley (2007), and Hale (2008).

Northern Outer Banks and Northern Pamlico Sound	Age yrs BP	Southern Pamlico Sound
Oregon Inlet to Cape Hatteras		Cape Hatteras to Ocracoke Inlet
Modern barrier island configuration, mostly ephemeral inlet activity		Modern barrier island configuration. Brackish conditions in southeastern Pamlico Sound
Semi-continuous barrier island chain (active inlets: Salvo, Kinnekeet, and Avon)	500	Semi-continuous barrier island chain with active inlets at Ocracoke Island
Semi-continuous barrier island chain (active inlets: Kinnekeet and Rodanthe)		Marsh development in south central Ocracoke Island marks subaerial barrier island
	1000	Open Bay conditions in southeastern Pamlico Sound. Subaqueous sand bar in Ocracoke Island area
Gaps between islands continue to narrow. Restricted embayment conditions exist in central and northern Pamlico Sound	1500	Continued growth of barrier island chain narrows gaps between islands and establishes a relatively continuous barrier island chain. Brackish conditions in southeastern Pamlico Sound
	2000	Portsmouth Island partially reduced to sand shoal
Barrier island growth narrows gaps between islands	2500	Gradual barrier island growth. Increased brackish conditions in southeastern Pamlico Sound. Open marine conditions behind Portsmouth Island as it is reduced to a sand shoal.
Open embayment conditions in Gull Island and Salvo Day Use areas	3000	
Discontinuous barrier island chain with relatively isolated individual islands	3500	Discontinuous barrier island chain. Individual islands at Cape Hatteras, Hatteras Village and Ocracoke Village. Open embayment conditions in southeastern Pamlico Sound
Rising sea-level overtops Hatteras Flats Interstream Divide. Early formation of beach ridges	4000	Rising sea-level overtops Hatteras Flats Interstream Divide. Early formation of beach ridges. Inlet assemblages found behind Portsmouth Island (Whalebone Inlet?) estuarine conditions in Tar/Neuse River estuaries.
	5500	Normal marine salinity conditions in outer Tar and Neuse River estuaries. Pamlico Bay begins to form.
	7000	Initial flooding of Pamlico Creek and paleo-Tar and Neuse Rivers.

SUMMARY

1. Seventeen vibracores were collected (2006-2007) from southern Pamlico Sound, North Carolina and, together with data from 14 vibracores collected in the Sound during the late 1990s, and data from many vibracores through the Outer Banks, were used to interpret paleoenvironmental change throughout the Holocene.
2. Four lithofacies were recognized: muddy sandy shell hash; sandy mud; sand; and muddy sand, all representing a variety of estuarine and inlet environments.
3. Six biofacies (A to F) representing five paleoenvironments were determined using cluster analysis of foraminiferal assemblages from the 17 2006-2007 vibracores: (A) Low Brackish Estuary, (B) High Brackish Estuary (Possible Inlet Influence), (C) Inlet, (D) Normal Marine Salinity Bay, (E) High Brackish Estuary, and (F) Estuary (Low Specimen Count). The Low Brackish Estuary paleoenvironment was the only biofacies to contain *Ammotium salsum*, a species typically found in low brackish environments. The High Brackish Estuary (Possible Inlet Influence) contained robust miliolids that may represent a sand shoal or inlet environment. The Inlet environment contained assemblages similar to those found near and within modern inlets of the Outer Banks (*Cibicides* sp., *Textularia* cf. *T. gramen*, and *Quinqueloculina seminula*). The Normal Marine Salinity Biofacies contained small, delicate stenohaline benthics (e.g., *Bolivina lowmani*, *Buliminella elegantissima*, *Sagrina pulchella*, *Trifarina angulosa*, and *Valvulineria* sp.) and rare planktonics (*Globigerinoides ruber* and *Globorotalia menardii*) commonly found on the mid-continental shelf and typical of

normal marine salinity conditions. The High Brackish Estuary environment was dominated by typical estuarine foraminifera (*Elphidium excavatum* (88.3%) and *Ammonia parkinsoniana* (9.4%)). Biofacies F represented estuarine conditions and was grouped with either low brackish or high brackish assemblages based on the lithologic and foraminiferal characteristics of adjacent samples in cores.

4. Six radiocarbon ages (monospecific samples of ca. 1000 specimens of *Elphidium excavatum*) were acquired from the Normal Marine Salinity biofacies in three vibracores (OCR 07 S202, PNP-1, and OCK-5) and ranged from 5532 to 474 cal yr BP.
5. Five cross sections (A to E) were constructed to illustrate lithologies and reconstruct the paleoenvironments with respect to the last glacial maximum fluvial channels that underlie southern Pamlico Sound.
6. A depth slice at ~12-54 cm (core depth) was drawn to map the distribution of modern estuarine environments and expand on earlier findings. Low brackish environments were present towards the mainland and directly behind Portsmouth Island. High brackish estuarine environments were found towards the Outer Banks (with the exception of PNP-1 directly behind Portsmouth Island).
7. Normal marine salinity conditions, with Gulf Stream influence, were present in southern Pamlico Sound several times during the Holocene.
 - a. The first interval (5572-5332 cal yr B.P.) was recorded in the outer Neuse-Tar estuary (PNP-1) and is bounded by inlet assemblages.

- b. The second (~4900-4000 cal yr B.P.) influenced waters in a broader area of southern Pamlico Sound and is recorded in several cores (PS03, OCR 07 S202, and OCK-4). Both of these intervals of marine influence are attributed to rising sea level and possible hurricane activity.
- c. Radiocarbon age estimates of foraminifera from a Normal Marine Salinity biofacies in PNP-1 indicate that Portsmouth Island had been reduced to a submarine sand shoal from 2717-2481 cal yr. B.P., perhaps by a major hurricane or series of hurricanes. During this interval normal marine salinity waters extended ~ 10 km into southern Pamlico Sound.
- d. The most recent and most widespread episode of normal marine conditions with Gulf Stream influence occurred ~ 1100 cal yr B.P., again most likely as the result of hurricane activity. The southern Outer Banks had reformed by ca. 500 cal yr B.P. and estuarine conditions had returned to southern Pamlico Sound

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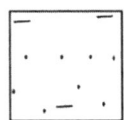
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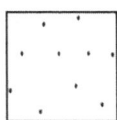
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APPENDIX A: SEDIMENTOLOGICAL LOGS OF VIBRACORES

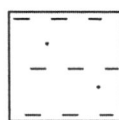
KEY

Lithofacies

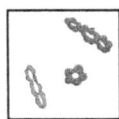
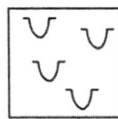
Muddy Sand (mS)



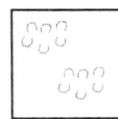
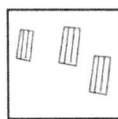
Sand (S)



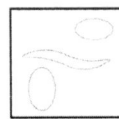
Sandy Mud (sM)

Muddy Sandy Shell
Hash (msSH)FeaturesMud-Lined
Chain-Like
BurrowsAngel Wing
(*Cyrtopleura costata*)

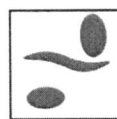
Burrows

Pelletal Fabric
(Mottled
Appearance)

Peat Intraclasts

Interbedded
SandInterbedded
Mud

Sand Lens



Mud Lens

Biofacies

Biofacies A — A —

Biofacies B — B —

Biofacies C — C —

Biofacies D — D —

Biofacies E — E —

Biofacies F — F —

Barren — ■ —

Micropaleontological
sample included in
cluster analysis but not
grouped within a
biofacies



Foraminifera Sample



OCK-2 (Water Depth 4.33 m)

Core Length (m)	Depth Below MSL (m)	GRAVEL			SAND					MUD			Lithofacies	Biofacies	Environmental Interpretations	Additional Comments	Foram Sample (cm)		
		C	P	G	VC	C	M	F	VF	Silt	Clay	Peat							
0	4.5												S	■	High Brackish Estuary	Shelly layer Articulated Great Atlantic Cockle Shell 100% Sand with mud lenses, undifferentiated burrows and shell material	★ 30-32		
	5.0																		
1.0																			
	6.0																		
2.0														E			★ 207-209		
	7.0																		
3.0																			
	8.0																		
4.0																			
	9.0																		
5.0																			
	10.0																		
6.0																			
	11.0																		
7.0																			
	12.0																		
8.0																			
	13.0																		
9.0																			

OCK-5 (Water Depth 7.54 m)

[illegible]

OCK-6 (Water Depth 6.48 m)

[illegible]

[illegible]

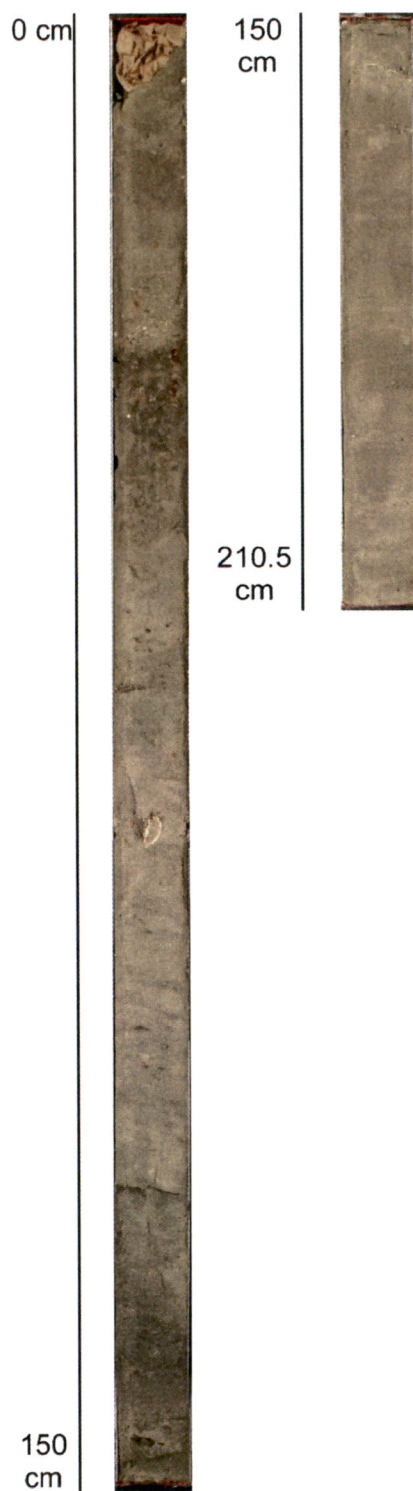
PNP-6 (Water Depth 6.7 m)

Core Length (m)	Depth Below MSL (m)	GRAVEL			SAND					MUD		Lithofacies	Biofacies	Environmental Interpretations	Additional Comments	Foram Sample (cm)
		C	P	G	VC	C	M	F	VF	Silt	Clay					
0	7.0															★ 12-13
1.0	8.0												E	High Brackish Estuary		★ 118-119
2.0	9.0												A	Low Brackish Estuary	Undifferentiated burrows	★ 233-234
3.0	10.0											sM				
4.0	11.0														Void space, may be dissolved angel wing	★ 382-383
5.0	12.0															
6.0	13.0															★ 554-555
7.0	14.0												F			★ 702-703
8.0	15.0											msSH	E			★ 775-776
9.0	16.0												E	Shell hash		★ 839-840

APPENDIX B: DIGITAL IMAGES OF VIBRACORES

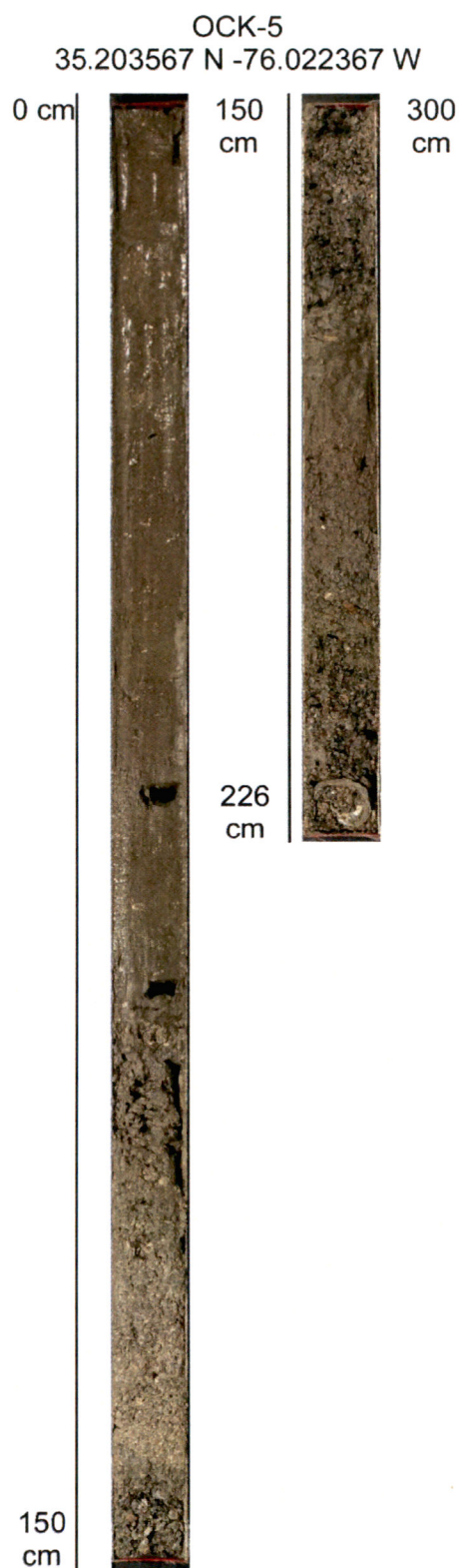


OCK-2
35.163533 N -76.011650 W







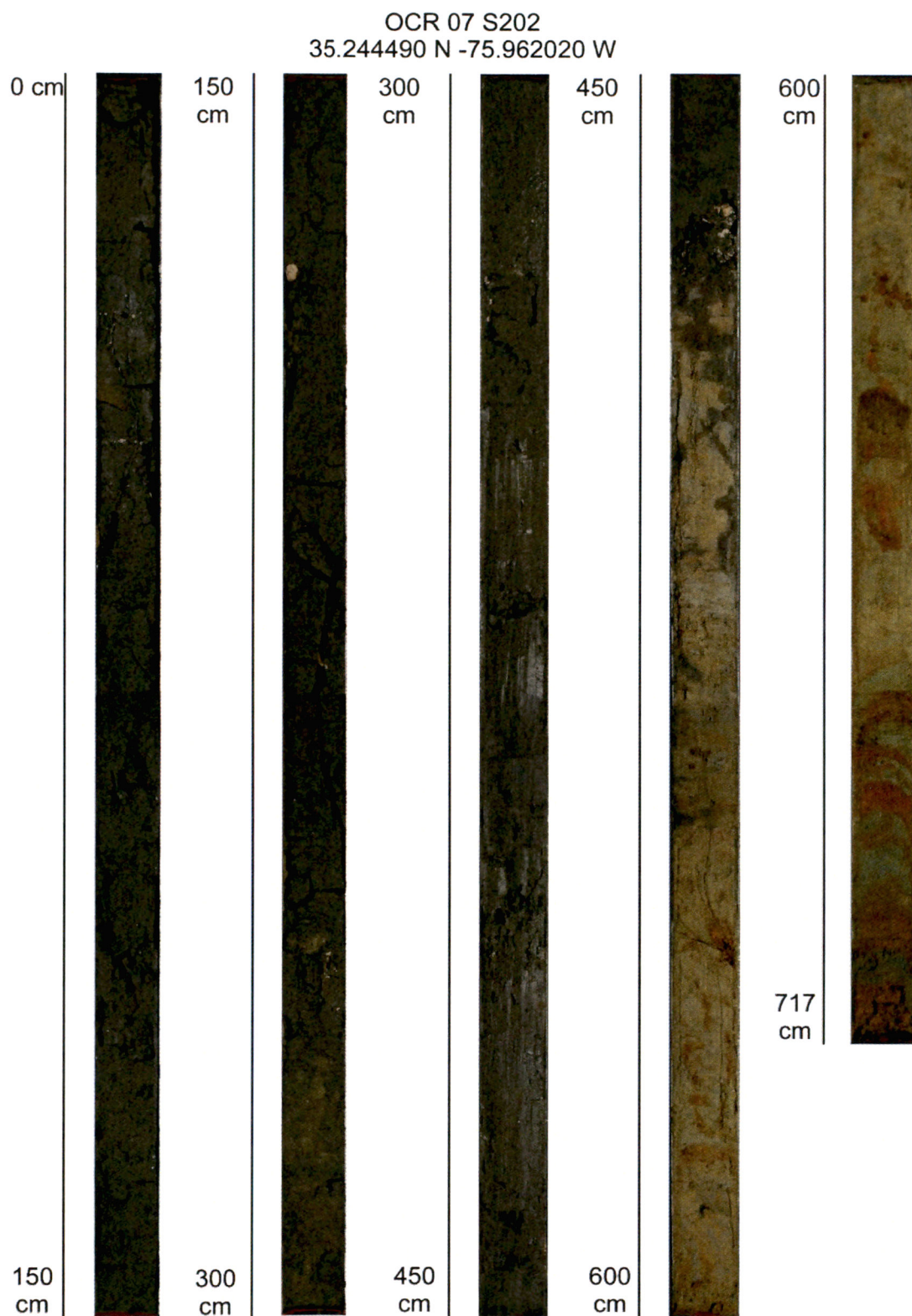


OCK-6
35.174317 N -76.039383 W









OCR 07 S203
35.225270 N -75.937900 W





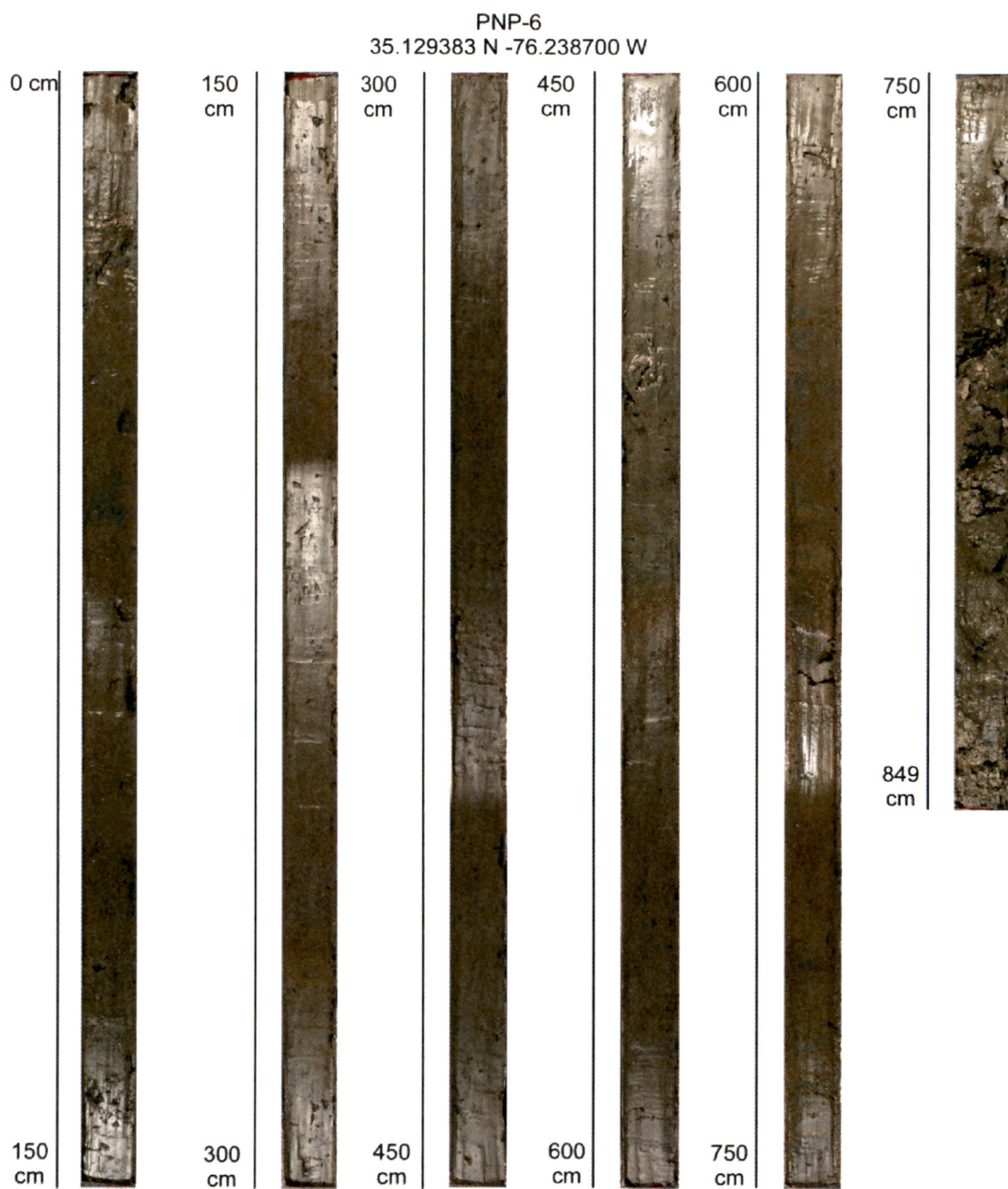
PNP-2
35.071217 N -76.221950 W













APPENDIX C: CODE NUMBERS OF FORAMINIFERAL SAMPLES

core	water depth of core (m)	core depth (cm)	depth below MSL (cm)	code #	core	water depth of core (m)	core depth (cm)	depth below MSL (cm)	code #
OCR 07 S201	7.3	7-8	737-738	1	PNP-3	6.2	383-384	1003-1004	47
OCR 07 S201		52-53	782-783	2	PNP-3		423-424	1043-1044	48
OCR 07 S201		164-165	894-895	3	PNP-3		739-740	1359-1360	49
OCR 07 S201		229-230	959-960	4	PNP-3		793-794	1413-1414	50
OCR 07 S201		358-359	1088-1089	5	PNP-4B	6.4	9-10	649-650	51
OCR 07 S201		534-535	1264-1265	6	PNP-4B		70-71	710-711	52
OCR 07 S201		621-622	1351-1352	7	PNP-4B		407-408	1047-1048	53
OCR 07 S202	7.3	10-11	740-741	8	PNP-5	6.9	98-99	788-789	54
OCR 07 S202		124-125	854-855	9	PNP-6	6.7	12-13	682-683	55
OCR 07 S202		272-273	1002-1003	10	PNP-6		118-119	788-789	56
OCR 07 S202		284-285	1014-1015	11	PNP-6		233-234	903-904	57
OCR 07 S202		304-305	1034-1035	12	PNP-6		702-703	1372-1373	58
OCR 07 S202		322-323	1052-1053	13	PNP-6		775-776	1445-1446	59
OCR 07 S202		461-462	1191-1192	14	PNP-6		839-840	1509-1510	60
OCR 07 S202		710-711	1440-1441	15	PNP-8	6.2	7-8	627-628	61
OCR 07 S203	6.8	7-8	687-688	16	PNP-8		125-126	745-746	62
OCR 07 S203		45-46	725-726	17	PNP-8		791-792	1411-1412	63
OCR 07 S203		108-109	788-789	18	OCK-1B	5.5	21-23	571-573	64
OCR 07 S203		145-146	825-826	19	OCK-1B		132-133	682-683	65
OCR 07 S203		159-160	839-840	20	OCK-1B		139-140	689-690	66
OCR 07 S203		237-238	917-918	21	OCK-1B		188-190	738-740	67
OCR 07 S203		275-276	955-956	22	OCK-2	4.33	207-209	640-642	68
OCR 07 S203		333-334	1013-1014	23	OCK-3		35-37	425-427	69
OCR 07 S203		441-442	1121-1122	24	OCK-3		94-96	484-486	70
OCR 07 S203		589-590	1269-1270	25	OCK-4	6.85	6-8	691-693	71
OCR 07 S203		694-695	1374-1375	26	OCK-4		123-125	808-810	72
OCR 07 S203		719-720	1399-1400	27	OCK-4		381-383	1066-1068	73
OCR 07 S203		802-803	1482-1483	28	OCK-4		429-431	1114-1116	74
PNP-1	4.3	4-5	434-435	29	OCK-5	7.54	15-17	769-771	75
PNP-1		16-17	446-447	30	OCK-5		59-61	813-815	76
PNP-1		68-69	498-499	31	OCK-5		70-72	824-826	77
PNP-1		112-113	542-543	32	OCK-5		82-83	836-837	78
PNP-1		123-124	553-554	33	OCK-5		90-92	844-846	79
PNP-1		190-191	620-621	34	OCK-5		139-141	893-895	80
PNP-1		291-292	721-722	35	OCK-5		192-194	946-948	81
PNP-1		337-338	767-768	36	OCK-6	6.48	44-46	692-694	82
PNP-1		399-400	829-830	37	OCK-6		98-100	746-748	83
PNP-2	6.2	90-91	710-711	38	OCK-6		116-118	764-766	84
PNP-2		110-111	730-731	39	OCK-6		132-133	780-781	85
PNP-2		142-143	762-763	40	OCK-6		135-137	783-785	86
PNP-2		162-163	782-783	41	OCK-6		173-175	821-823	87
PNP-2		241-242	861-862	42	OCK-6		223-225	871-873	88
PNP-2		822-823	1442-1443	43	OCK-6		266-268	914-916	89
PNP-3	6.2	138-139	758-759	44	OCK-6		300-302	948-950	90
PNP-3		231-232	851-852	45	OCK-7	4.0	6-8	406-408	91
PNP-3		342-343	962-963	46	OCK-7		133-135	533-535	92
					OCK-7		238-240	638-640	93

APPENDIX D: RAW CENSUS DATA OF FORAMINIFERAL ASSEMBLAGES

Raw census data includes counts of all taxa identified in the ninety-three samples containing foraminifera. In order to present this data in as few pages as possible, the cores and intervals are coded 1-93. These codes correspond to Appendix C.

Name	code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
<i>Ammonia parkinsoniana</i>		24	22	13	11	27		19	3	2	15	37	26	21	2	1	25	19	4	14	2
<i>Ammonia tepida</i>						5		4			2	5	10	5		1					
<i>Ammotium salsum</i>			1																		
<i>Asterigerina carinata</i>																					
<i>Bolivina lowmani</i>																					
<i>Bolivina pseudoplicata</i>																					
<i>Buccella inusitata</i>																		1			
<i>Buliminella elegantissima</i>																					
<i>Cassidulina</i> sp. A																					
<i>Cassidulina minuta</i>																		1			
<i>Cibicides fletcheri</i>																					
<i>Cibicides lobatulus</i>																		2			
<i>Cibicides</i> sp.						1						3		1							
<i>Elphidium advenum</i>														1				1			
<i>Elphidium excavatum</i>		196	200	126	220	206	14	270	33	37	198	306	170	241	31	9	221	190	257	137	30
<i>Elphidium galvestonense</i>														2							
<i>Elphidium gunteri</i>												1					1	8	3		
<i>Elphidium mexicanum</i>												1	5	11							
<i>Elphidium poeyanum</i>						1															
<i>Elphidium subarcticum</i>												1									
<i>Elphidium translucens</i>						1							8								2
<i>Epistominella</i> sp. A																					
<i>Eponides repandus</i>																					
<i>Fissurina laevigata</i>																					
<i>Gavelinopsis praegeri</i>																					
<i>Glabratellina</i> sp. A																					
<i>Guttulina</i> sp. A														1							
<i>Hanzawaia strattoni</i>																		4			
<i>Haynesina germanica</i>			2									1		1							
indeterminate rotaliid																					
<i>Neokonorbina terquemi</i>																					
<i>Nodosaria</i> sp. A																					
<i>Nonionella atlantica</i>													4	5				1			
<i>Nonionella auricula</i>																					
Planktonics												1	3	12							
<i>Planulina</i> sp. A																					
polymorphid																					
<i>Quinqueloculina</i> sp. A																					
<i>Quinqueloculina</i> cf. <i>Q. bosciana</i>																					
<i>Quinqueloculina dimidiata</i>																					
<i>Quinqueloculina</i> cf. <i>Q. frigida</i>																					
<i>Quinqueloculina jugosa</i>																					
<i>Quinqueloculina lamarckiana</i>																					
<i>Quinqueloculina seminula</i>																					
<i>Reussella atlantica</i>													2								
<i>Rosalina floridana</i>																					
<i>Rosalina</i> sp. A																					
<i>Sagrina pulchella</i>																					
<i>Textularia</i> cf. <i>T. gramen</i>																					
<i>Trifarina angulosa</i>													7								
<i>Valvulineria</i> sp. A												1	3	5				2			
No. Specimens		220	225	139	231	241	14	293	36	39	215	357	239	305	33	11	247	229	264	151	34
No. Species		2	4	2	2	6	1	3	2	2	3	10	11	11	2	3	3	10	3	2	3

Name	code	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
<i>Ammonia parkinsoniana</i>		25	21	10	1	20	28	26			49	24	29	17	6	28	34	9	25	36	29
<i>Ammonia tepida</i>		8	3	1		2		2				4		4		3	8	3	2	15	11
<i>Ammotium salsum</i>																					
<i>Asterigerina carinata</i>															2	1		1			
<i>Bolivina lowmani</i>																				1	
<i>Bolivina pseudoplicata</i>																					
<i>Buccella inusitata</i>		2		2				1				1	2			2	1		1		
<i>Buliminella elegantissima</i>																					
<i>Cassidulina</i> sp. A																1					
<i>Cassidulina minuta</i>																1					
<i>Cibicides fletcheri</i>																					
<i>Cibicides lobatulus</i>														1							
<i>Cibicides</i> sp.								1				3	5		3	2	1			1	
<i>Elphidium advenum</i>															1						
<i>Elphidium excavatum</i>		202	204	221	17	241	218	167	25	4	53	171	162	245	129	153	169	120	196	182	206
<i>Elphidium galvestonense</i>											2	3	3		25	5	7				
<i>Elphidium gunteri</i>								1				8	7		6	3		1	1	1	2
<i>Elphidium mexicanum</i>			1	5		3					1	5	7		4	7	4	6	1	6	2
<i>Elphidium poeyanum</i>												4	1				1				
<i>Elphidium subarcticum</i>													1		2						
<i>Elphidium translucens</i>													1		4	2		1			8
<i>Epistominella</i> sp. A																					
<i>Eponides repandus</i>															1		1	2			
<i>Fissurina laevigata</i>		1																			
<i>Gavelinopsis praegeri</i>													1			1					
<i>Glabratellina</i> sp. A												1									
<i>Guttulina</i> sp. A																					
<i>Hanzawaia strattoni</i>												1	14	1	29	6	13	18			
<i>Haynesina germanica</i>											1		1					2		1	
indeterminate rotaliid																					
<i>Neoconorbina terquemii</i>																					
<i>Nodosaria</i> sp. A																					
<i>Nonionella atlantica</i>												1	2		2	3	3	1		2	
<i>Nonionella auricula</i>																					
Planktonics		1										5	1	1	1	6	3	4		1	1
<i>Planulina</i> sp. A																					
polymorphid																					
<i>Quinqueloculina</i> sp. A																					
<i>Quinqueloculina</i> cf. <i>Q. bosciana</i>																					
<i>Quinqueloculina dimidiata</i>																	1				
<i>Quinqueloculina</i> cf. <i>Q. frigida</i>																2					
<i>Quinqueloculina jugosa</i>																2		2			
<i>Quinqueloculina lamarckiana</i>																4	3				
<i>Quinqueloculina seminula</i>																37	10	2			
<i>Reussella atlantica</i>																					
<i>Rosalina floridana</i>												2			1		2	1			
<i>Rosalina</i> sp. A							1									2					
<i>Sagrina pulchella</i>								1				1									
<i>Textularia</i> cf. <i>T. gramen</i>													1		3						
<i>Trifarina angulosa</i>																					
<i>Valvulineria</i> sp. A			1					1				2				2	1	1		2	
No. Specimens		239	230	239	18	266	247	200	25	4	106	236	238	269	264	223	260	181	226	248	259
No. Species		6	5	5	2	4	3	8	1	1	5	16	16	6	20	17	17	17	6	11	7

Name	code	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
<i>Ammonia parkinsoniana</i>		27	14	54	18	15		11	1		2	19	3	48	6		92	2		1	25
<i>Ammonia tepida</i>		4		10	11								1				9				
<i>Annotium salsum</i>																5		1			
<i>Asterigerina carinata</i>																					
<i>Bolivina lowmani</i>					3																
<i>Bolivina pseudoplicata</i>																					
<i>Buccella inusitata</i>																					
<i>Buliminella elegantissima</i>																					
<i>Cassidulina sp. A</i>																					
<i>Cassidulina minuta</i>																					
<i>Cibicides fletcheri</i>																					
<i>Cibicides lobatulus</i>																					
<i>Cibicides sp.</i>																					
<i>Elphidium advenum</i>																					
<i>Elphidium excavatum</i>		193	221	146	187	224	2	96	1	8	2	208	109	183	65	7	142	2	18	15	194
<i>Elphidium galvestonense</i>									4		1			13							
<i>Elphidium gunteri</i>														14							
<i>Elphidium mexicanum</i>		2												6							
<i>Elphidium poeyanum</i>																					
<i>Elphidium subarcticum</i>																					
<i>Elphidium translucens</i>		2		4	1									1							
<i>Epistominella sp. A</i>																					
<i>Eponides repandus</i>																					
<i>Fissurina laevigata</i>																					
<i>Gavelinopsis praegeri</i>																					
<i>Glabratellina sp. A</i>																					
<i>Guttulina sp. A</i>																					
<i>Hanzawaia strattoni</i>																				1	
<i>Haynesina germanica</i>											1			39							2
indeterminate rotaliid																					
<i>Neoconorbina terquemi</i>																					
<i>Nodosaria sp. A</i>																					
<i>Nonionella atlantica</i>																					
<i>Nonionella auricula</i>																					
Planktonics					1																
<i>Planulina sp. A</i>																					
polymorphid																					
<i>Quinqueloculina sp. A</i>																					
<i>Quinqueloculina cf. Q. bosciana</i>																					
<i>Quinqueloculina dimidiata</i>			1																		
<i>Quinqueloculina cf. Q. frigida</i>																					
<i>Quinqueloculina jugosa</i>																					
<i>Quinqueloculina lamarckiana</i>																					
<i>Quinqueloculina seminula</i>																					
<i>Reussella atlantica</i>																					
<i>Rosalina floridana</i>																					
<i>Rosalina sp. A</i>																					
<i>Sagrina pulchella</i>																					
<i>Textularia cf. T. gramen</i>																					
<i>Trifarina angulosa</i>					1																
<i>Valvulineria sp. A</i>																					
No. Specimens		228	236	214	222	239	2	107	6	8	6	227	113	304	71	12	243	5	18	16	222
No. Species		5	3	4	7	2	1	2	3	1	4	2	3	7	2	2	3	3	1	2	4

Name	code	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
<i>Ammonia parkinsoniana</i>				48	9	32	46	6	8		4	4	34	7	20	63	19	25	30	25	59
<i>Ammonia tepida</i>							21					1	3	2	6	9	2	1	1		2
<i>Ammotium salsum</i>												3									
<i>Asterigerina carinata</i>						1															
<i>Bolivina lowmani</i>																					
<i>Bolivina pseudoplicata</i>									1												
<i>Buccella inusitata</i>															1						
<i>Buliminella elegantissima</i>																					
<i>Cassidulina sp. A</i>																					
<i>Cassidulina minuta</i>																					
<i>Cibicides fletcheri</i>																					
<i>Cibicides lobatulus</i>						1	2								2						
<i>Cibicides sp.</i>						1															
<i>Elphidium advenum</i>							1												1		
<i>Elphidium excavatum</i>	1	2	161	87	120	134	26	77	3	83	239	161	204	154	157	178	186	173	186	92	
<i>Elphidium galvestonense</i>				11	1				12	1								1	1		
<i>Elphidium gunteri</i>			4	1		6			2				1								
<i>Elphidium mexicanum</i>			1		4	10		1		1		1			4					1	
<i>Elphidium poeyanum</i>			6			1									2						
<i>Elphidium subarcticum</i>											1				1						
<i>Elphidium translucens</i>			1			1										3					
<i>Epistominella sp. A</i>																					2
<i>Eponides repandus</i>																					1
<i>Fissurina laevigata</i>			1																1		3
<i>Gavelinopsis praegeri</i>																			1		
<i>Glabratellina sp. A</i>																					
<i>Guttulina sp. A</i>																					
<i>Hanzawaia strattoni</i>							5														1
<i>Haynesina germanica</i>			8																		
indeterminate rotaliid																					
<i>Neoconorbina terquemii</i>																					
<i>Nodosaria sp. A</i>						1															
<i>Nonionella atlantica</i>						1					1				2						
<i>Nonionella auricula</i>															1						
<i>Planktonics</i>							1												3		1
<i>Planulina sp. A</i>																					
polymorphid																					
<i>Quinqueloculina sp. A</i>																					
<i>Quinqueloculina cf. Q. bosciana</i>																					4
<i>Quinqueloculina dimidiata</i>																					
<i>Quinqueloculina cf. Q. frigida</i>																					6
<i>Quinqueloculina jugosa</i>																					2
<i>Quinqueloculina lamarckiana</i>																				1	20
<i>Quinqueloculina seminula</i>																					
<i>Reussella atlantica</i>																					
<i>Rosalina floridana</i>				1																	1
<i>Rosalina sp. A</i>							1														
<i>Sagrina pulchella</i>																					
<i>Textularia cf. T. gramen</i>																					
<i>Trifarina angulosa</i>						1										1					
<i>Valvulineria sp. A</i>															4						
No. Specimens		1	2	231	108	163	229	32	87	17	91	247	199	214	198	232	199	213	212	212	195
No. Species		1	1	9	4	10	12	2	4	3	6	4	4	4	12	4	3	4	9	3	14

	code	81	82	83	84	85	86	87	88	89	90	91	92	93
Name														
<i>Ammonia parkinsoniana</i>		57	44		17	82	82	73	156	39	20	8	7	8
<i>Ammonia tepida</i>			1				34							
<i>Ammotium salsum</i>														
<i>Asterigerina carinata</i>														
<i>Bolivina lowmani</i>														
<i>Bolivina pseudoplicata</i>		1												
<i>Buccella inusitata</i>								2					2	1
<i>Buliminella elegantissima</i>														
<i>Cassidulina</i> sp. A														
<i>Cassidulina minuta</i>														
<i>Cibicides fletcheri</i>									2					
<i>Cibicides lobatulus</i>														6
<i>Cibicides</i> sp.								1	1	1	2			
<i>Elphidium advenum</i>														
<i>Elphidium excavatum</i>		76	34	6	70	110	168	111	166	110	126	19	162	150
<i>Elphidium galvestonense</i>			3			1				1			4	1
<i>Elphidium gunteri</i>			4					2	1	1	1		3	1
<i>Elphidium mexicanum</i>		2				2	1	10	2				2	1
<i>Elphidium poeyanum</i>							1	1						
<i>Elphidium subarcticum</i>		1					1							
<i>Elphidium transluscens</i>														
<i>Epistominella</i> sp. A											1			
<i>Eponides repandus</i>		1						2			1		1	1
<i>Fissurina laevigata</i>														
<i>Gavelinopsis praegeri</i>														
<i>Glabratellina</i> sp. A														
<i>Guttulina</i> sp. A														
<i>Hanzawaia strattoni</i>		1						11		3	5		25	9
<i>Haynesina germanica</i>		2					2							1
indeterminate rotaliid											1			
<i>Neoconorbina terquemii</i>													1	
<i>Nodosaria</i> sp. A														
<i>Nonionella atlantica</i>			1					3	3	2	1		5	7
<i>Nonionella auricula</i>														
Planktonics											2		3	2
<i>Planulina</i> sp. A													1	
polymorphid						1								
<i>Quinqueloculina</i> sp. A		4												
<i>Quinqueloculina</i> cf. <i>Q. bosciana</i>		13								1	1			
<i>Quinqueloculina dimidiata</i>										1				
<i>Quinqueloculina</i> cf. <i>Q. frigida</i>														
<i>Quinqueloculina jugosa</i>		15						16	4	22	4		3	
<i>Quinqueloculina lamarckiana</i>										1				
<i>Quinqueloculina seminula</i>		34					1	68	9	22	22		13	2
<i>Reussella atlantica</i>														
<i>Rosalina floridana</i>											1			
<i>Rosalina</i> sp. A		6												
<i>Sagrina pulchella</i>														
<i>Textularia</i> cf. <i>T. gramen</i>								3	1				2	2
<i>Trifarina angulosa</i>														
<i>Valvulineria</i> sp. A														
No. Specimens		213	87	6	87	196	290	303	345	204	188	27	234	192
No. Species		13	6	1	2	5	8	13	10	12	14	2	15	14

**APPENDIX E: RELATIVE ABUNDANCE DATA FOR FORAMINIFERAL TAXA
INCORPORATED IN THE CLUSTER ANALYSIS**

Code numbers correspond to Appendix C.

Name	code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
<i>Ammonia parkinsoniana</i>		10.91	9.78	9.35	4.76	11.20		6.48	8.33	5.13	6.98	10.36	10.88	6.89	6.06	9.09	10.12	8.30	1.52	9.27	5.88
<i>Ammonia tepida</i>						2.07		1.37			0.93	1.40	4.18	1.64		9.09					
<i>Ammotium salsum</i>			0.44																		
<i>Asterigerina carinata</i>																					
<i>Bolivina lowmani</i>																					
<i>Bolivina pseudoplicata</i>																					
<i>Buccella inusitata</i>																		0.44			
<i>Buliminella elegantissima</i>																					
<i>Cassidulina</i> sp. <i>A</i>																					
<i>Cassidulina minuta</i>																		0.44			
<i>Cibicides fletcheri</i>																					
<i>Cibicides lobatulus</i>																		0.87			
<i>Cibicides</i> sp.						0.41						0.84		0.33							
<i>Elphidium advenum</i>														0.33				0.44			
<i>Elphidium excavatum</i>		89.09	88.89	90.65	95.24	85.48	100.00	92.15	91.67	94.87	92.09	85.71	71.13	79.02	93.94	81.82	89.47	82.97	97.35	90.73	88.24
<i>Elphidium galvestonense</i>														0.66							
<i>Elphidium gunteri</i>												0.28					0.40	3.49	1.14		
<i>Elphidium mexicanum</i>												0.28	2.09	3.61							
<i>Elphidium poeyanum</i>						0.41															
<i>Elphidium subarcticum</i>												0.28									
<i>Elphidium translucens</i>						0.41							3.35								5.88
<i>Epistominella</i> sp. <i>A</i>																					
<i>Eponides repandus</i>																					
<i>Fissurina laevigata</i>																					
<i>Gavelinopsis praegeri</i>																					
<i>Glabratellina</i> sp. <i>A</i>																					
<i>Guttulina</i> sp. <i>A</i>													0.42								
<i>Hanzawaia strattoni</i>																		1.75			
<i>Haynesina germanica</i>			0.89									0.28		0.33							
indeterminate rotaliid																					
<i>Neoconorbina terquemii</i>																					
<i>Nodosaria</i> sp. <i>A</i>																					
<i>Nonionella atlantica</i>													1.67	1.64				0.44			
<i>Nonionella auricula</i>																					
Planktonics												0.28	1.26	3.93							
<i>Planulina</i> sp. <i>A</i>																					
polymorphid																					
<i>Quinqueloculina</i> sp. <i>A</i>																					
<i>Quinqueloculina</i> cf. <i>Q. bosciana</i>																					
<i>Quinqueloculina dimidiata</i>																					
<i>Quinqueloculina</i> cf. <i>Q. frigida</i>																					
<i>Quinqueloculina jugosa</i>																					
<i>Quinqueloculina lamarckiana</i>																					
<i>Quinqueloculina seminula</i>																					
<i>Reussella atlantica</i>													0.84								
<i>Rosalina floridana</i>																					
<i>Rosalina</i> sp. <i>A</i>																					
<i>Sagrina pulchella</i>																					
<i>Textularia</i> cf. <i>T. gramen</i>																					
<i>Trifarina angulosa</i>													2.93								
<i>Valvulineria</i> sp. <i>A</i>												0.28	1.26	1.64				0.87			
Total percentage		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Name	code	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
<i>Ammonia parkinsoniana</i>		10.46	9.13	4.18	5.56	7.52	11.34	13.00			46.23	10.17	12.18	6.32	2.27	12.56	13.08	4.97	11.06	14.52	11.20
<i>Ammonia tepida</i>		3.35	1.30	0.42		0.75		1.00				1.69		1.49		1.35	3.08	1.66	0.88	6.05	4.25
<i>Ammotium salsum</i>																					
<i>Asterigerina carinata</i>															0.76	0.45		0.55			
<i>Bolivina lowmani</i>																				0.40	
<i>Bolivina pseudoplicata</i>																					
<i>Buccella inusitata</i>		0.84		0.84				0.50				0.42	0.84			0.90	0.38		0.44		
<i>Buliminella elegantissima</i>																					
<i>Cassidulina</i> sp. A																0.45					
<i>Cassidulina minuta</i>																					
<i>Cibicides fletcheri</i>																0.45					
<i>Cibicides lobatulus</i>														0.37							
<i>Cibicides</i> sp.								0.50				1.27	2.10		1.14	0.90	0.38			0.40	
<i>Elphidium advenum</i>															0.38						
<i>Elphidium excavatum</i>		84.52	88.70	92.47	94.44	90.60	88.26	83.50	100.00	100.00	50.00	72.46	68.07	91.08	48.86	68.61	65.00	66.30	86.73	73.39	79.54
<i>Elphidium galvestonense</i>											1.89	1.27	1.26		9.47		1.92	3.87			
<i>Elphidium gunteri</i>								0.50				3.39	2.94		2.27	1.35		0.55	0.44	0.40	0.77
<i>Elphidium mexicanum</i>			0.43	2.09	0.00	1.13	0.00				0.94	2.12	2.94		1.52	3.14	1.54	3.31	0.44	2.42	0.77
<i>Elphidium poeyanum</i>												1.69	0.42				0.38				
<i>Elphidium subarcticum</i>													0.42		0.76						
<i>Elphidium translucens</i>													0.42		1.52	0.90		0.55		3.09	
<i>Epistominella</i> sp. A																					
<i>Eponides repandus</i>																0.38	0.38	1.10			
<i>Fissurina laevigata</i>		0.42																			
<i>Gavelinopsis praegeri</i>													0.42			0.45					
<i>Glabratellina</i> sp. A												0.42									
<i>Guttulina</i> sp. A																					
<i>Hanzawaia strattoni</i>												0.42	5.88	0.37	10.98	2.69	5.00	9.94			
<i>Haynesina germanica</i>											0.94		0.42					1.10		0.40	
indeterminate rotallid																					
<i>Neokonorbina terquemi</i>																					
<i>Nodosaria</i> sp. A																					
<i>Nonionella atlantica</i>												0.42	0.84		0.76	1.35	1.15	0.55		0.81	
<i>Nonionella auricula</i>																					
Planktonics		0.42										2.12	0.42	0.37	0.38	2.69	1.15	2.21		0.40	0.39
<i>Planulina</i> sp. A																					
polymorphid																					
<i>Quinqueloculina</i> sp. A																					
<i>Quinqueloculina</i> cf. <i>Q. bosciana</i>																	0.38				
<i>Quinqueloculina dimidiata</i>																					
<i>Quinqueloculina</i> cf. <i>Q. frigida</i>																0.76					
<i>Quinqueloculina jugosa</i>																0.76		1.10			
<i>Quinqueloculina lamarckiana</i>																1.52	1.15				
<i>Quinqueloculina seminula</i>																14.02	3.85	1.10			
<i>Reussella atlantica</i>																					
<i>Rosalina floridana</i>												0.85			0.38		0.77	0.55			
<i>Rosalina</i> sp. A							0.40									0.90					
<i>Sagrina pulchella</i>								0.50				0.42									
<i>Textularia</i> cf. <i>T. gramen</i>													0.42			1.14					
<i>Trifarina angulosa</i>																					
<i>Valvulineria</i> sp. A			0.43					0.50					0.85			0.90	0.38	0.55		0.81	
Total percentage		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Name	code	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
<i>Ammonia parkinsoniana</i>		11.84	5.93	25.23	8.11	6.28		10.28	16.67		33.33	8.37	2.65	15.79	8.45		37.86	40.00		6.25	11.26
<i>Ammonia tepida</i>		1.75		4.67	4.95								0.88				3.70				
<i>Ammotium salsum</i>																41.67		20.00			
<i>Asterigerina carinata</i>																					
<i>Bolivina lowmani</i>					1.35																
<i>Bolivina pseudoplicata</i>																					
<i>Buccella inusitata</i>																					
<i>Buliminella elegantissima</i>																					
<i>Cassidulina sp. A</i>																					
<i>Cassidulina minuta</i>																					
<i>Cibicides fletcheri</i>																					
<i>Cibicides lobatulus</i>																					
<i>Cibicides sp.</i>																					
<i>Elphidium advenum</i>																					
<i>Elphidium excavatum</i>		84.65	93.64	68.22	84.23	93.72	100.00	89.72	16.67	100.00	33.33	91.63	96.46	60.20	91.55	58.33	58.44	40.00	100.00	93.75	87.39
<i>Elphidium galvestonense</i>									66.67		16.67			4.28							
<i>Elphidium gunteri</i>														4.61							
<i>Elphidium mexicanum</i>		0.88												1.97							
<i>Elphidium poeyanum</i>																					
<i>Elphidium subarcticum</i>																					
<i>Elphidium translucens</i>		0.88		1.87	0.45									0.33							
<i>Epistominella sp. A</i>																					
<i>Eponides repandus</i>																					
<i>Fixurina laevigata</i>																					
<i>Gavelinopsis praegeri</i>																					
<i>Glabratellina sp. A</i>																					
<i>Guttulina sp. A</i>																					
<i>Hanzawaia strattoni</i>																				0.45	
<i>Haynesina germanica</i>											16.67			12.83						0.90	
indeterminate rotaliid																					
<i>Neconorbina terquemii</i>																					
<i>Nodosaria sp. A</i>																					
<i>Nonionella atlantica</i>																					
<i>Nonionella auricula</i>																					
Planktonics					0.45																
<i>Planulina sp. A</i>																					
polymorphid																					
<i>Quinqueloculina sp. A</i>																					
<i>Quinqueloculina cf. Q. bosciana</i>																					
<i>Quinqueloculina dimidiata</i>			0.42																		
<i>Quinqueloculina cf. Q. frigida</i>																					
<i>Quinqueloculina jugosa</i>																					
<i>Quinqueloculina lamarckiana</i>																					
<i>Quinqueloculina seminula</i>																					
<i>Reussella atlantica</i>																					
<i>Rosalina floridana</i>																					
<i>Rosalina sp. A</i>																					
<i>Sagrina pulchella</i>																					
<i>Textularia cf. T. gramen</i>																					
<i>Trifarina angulosa</i>					0.45																
<i>Valvulineria sp. A</i>																					
Total percentage		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	code	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
<i>Ammonia parkinsoniana</i>				20.78	8.33	19.63	20.09	18.75	9.20		4.40	1.62	17.09	3.27	10.10	27.16	9.55	11.74	14.15	11.79	30.26
<i>Ammonia tepida</i>							9.17					0.40	1.51	0.93	3.03	3.88	1.01	0.47	0.47		1.03
<i>Ammonoium salsum</i>												1.21									
<i>Asterigerina carinata</i>						0.61															
<i>Bolivina lowmani</i>																					
<i>Bolivina pseudoplicata</i>																					
<i>Buccella inusitata</i>									1.15												
<i>Buliminella elegantissima</i>															0.51						
<i>Cassidulina sp. A</i>																					
<i>Cassidulina minuta</i>																					
<i>Cibicides fletcheri</i>																					
<i>Cibicides lobatulus</i>						0.61	0.87								1.01						
<i>Cibicides sp.</i>						0.61															
<i>Elphidium advenum</i>							0.44												0.47		
<i>Elphidium excavatum</i>	100.00	100.00	69.70	80.56	73.62	58.52	81.25	88.51	17.65	91.21	96.76	80.90	95.33	77.78	67.67	89.45	87.32	81.60	87.74	47.18	
<i>Elphidium galvestonense</i>					10.19	0.61			70.59	1.10								0.47			
<i>Elphidium gunteri</i>			1.73	0.93		2.62			11.76					0.47				0.47	0.47		
<i>Elphidium mexicanum</i>			0.43		2.45	4.37		1.15		1.10		0.50	0.00		2.02					0.51	
<i>Elphidium poeyanum</i>			2.60			0.44									1.01						
<i>Elphidium subarcticum</i>										1.10					0.51						
<i>Elphidium translucens</i>			0.43			0.44										1.29					
<i>Epistominella sp. A</i>																					
<i>Eponides repandus</i>																					1.03
<i>Fissurina laevigata</i>			0.43																0.47	0.51	
<i>Gavelinopsis praegeri</i>																				1.54	
<i>Glabratellina sp. A</i>																			0.47		
<i>Guttulina sp. A</i>																					
<i>Hanzawaia strattoni</i>							2.18													0.51	
<i>Haynesia germanica</i>			3.46																		
indeterminate rotaliid																					
<i>Neoconorbina terquemi</i>																					
<i>Nodosaria sp. A</i>						0.61															
<i>Nonionella atlantica</i>						0.61				1.10					1.01						
<i>Nonionella auricula</i>															0.51						
Planktonics							0.44												1.42	0.51	
<i>Planulina sp. A</i>																					
polymorphid																					
<i>Quinqueloculina sp. A</i>																					
<i>Quinqueloculina cf. Q. bosciana</i>																					
<i>Quinqueloculina dimidiata</i>																				2.05	
<i>Quinqueloculina cf. Q. frigida</i>																					
<i>Quinqueloculina jugosa</i>																				3.08	
<i>Quinqueloculina lamarckiana</i>																				1.03	
<i>Quinqueloculina seminula</i>																			0.47	10.26	
<i>Reussella atlantica</i>																					
<i>Rosalina floridana</i>			0.43																		
<i>Rosalina sp. A</i>							0.44													0.51	
<i>Sagrina pulchella</i>																					
<i>Textularia cf. T. gramen</i>																					
<i>Trifarina angulosa</i>						0.61									0.51						
<i>Valvulinera sp. A</i>															2.02						
Total percentage		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Name	code	81	82	83	84	85	86	87	88	89	90	91	92	93
<i>Ammonia parkinsoniana</i>		26.76	50.57		19.54	41.84	28.28	24.09	45.22	19.12	10.64	29.63	2.99	4.17
<i>Ammonia tepida</i>			1.15				11.72							
<i>Ammotium salsum</i>														
<i>Asterigerina carinata</i>														
<i>Bolivina lowmani</i>														
<i>Bolivina pseudoplicata</i>		0.47												
<i>Buccella inusitata</i>								0.66					0.85	0.52
<i>Bulinella elegantissima</i>														
<i>Cassidulina sp. A</i>														
<i>Cassidulina minuta</i>														
<i>Cibicides fletcheri</i>									0.58					
<i>Cibicides lobatulus</i>														3.13
<i>Cibicides sp.</i>								0.33	0.29	0.49	1.06			
<i>Elphidium advenum</i>														
<i>Elphidium excavatum</i>	35.68	39.08	100.00	80.46	56.12	57.93	36.63	48.12	53.92	67.02	70.37	69.23	78.13	
<i>Elphidium galvestonense</i>		3.45			0.51				0.49			1.71	0.52	
<i>Elphidium gunteri</i>		4.60						0.66	0.29	0.49	0.53	1.28	0.52	
<i>Elphidium mexicanum</i>	0.94				1.02	0.34	3.30	0.58				0.85	0.52	
<i>Elphidium poeyanum</i>						0.34	0.33							
<i>Elphidium subarcticum</i>	0.47					0.34								
<i>Elphidium translucens</i>														
<i>Epistominella sp. A</i>											0.53			
<i>Eponides repandus</i>	0.47							0.66			0.53		0.43	0.52
<i>Fissurina laevigata</i>														
<i>Gavelinopsis praegeri</i>														
<i>Glabratellina sp. A</i>														
<i>Guttulina sp. A</i>														
<i>Hanzawaia strattoni</i>	0.47							3.63	0.00	1.47	2.66	10.68	4.69	
<i>Haynesina germanica</i>	0.94						0.69						0.52	
indeterminate rotaliid											0.53			
<i>Neoconorbina terquemii</i>													0.43	
<i>Nodosaria sp. A</i>														
<i>Nonionella atlantica</i>			1.15					0.99	0.87	0.98	0.53	2.14	3.65	
<i>Nonionella auricula</i>														
Planktonics											1.06	1.28	1.04	
<i>Planulina sp. A</i>													0.43	
polymorphid						0.51								
<i>Quinqueloculina sp. A</i>	1.88													
<i>Quinqueloculina cf. Q. bosciana</i>	6.10									0.49	0.53			
<i>Quinqueloculina dimidiata</i>										0.49				
<i>Quinqueloculina cf. Q. frigida</i>														
<i>Quinqueloculina jugosa</i>	7.04							5.28	1.16	10.78	2.13	1.28		
<i>Quinqueloculina lamarckiana</i>										0.49				
<i>Quinqueloculina seminula</i>	15.96						0.34	22.44	2.61	10.78	11.70	5.56	1.04	
<i>Reussella atlantica</i>														
<i>Rosalina floridana</i>											0.53			
<i>Rosalina sp. A</i>	2.82													
<i>Sagrina pulchella</i>														
<i>Textularia cf. T. gramen</i>								0.99	0.29			0.85	1.04	
<i>Trifarina angulosa</i>														
<i>Valvulinaria sp. A</i>														
Total percentage		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

**APPENDIX F: LIST OF FORAMINIFERAL TAXA WITH ORIGINAL
REFERENCES**

Ammonia parkinsoniana (d'Orbigny): *Rosalina parkinsoniana* d'Orbigny, 1839b, p. 99, pl. 4, figs. 25-27

Ammonia tepida (Cushman): *Rotalia beccarii* (Linnaeus) var. *tepida*. Cushman, 1926, p. 79, pl. 1, figs. 8a, b, c.

Ammotium salsum (Cushman and Brönnimann): *Ammobaculites salsus* Cushman and Brönnimann, 1948, p. 16, pl. 3, figs. 7-9.

Asterigerina carinata d'Orbigny: *Asterigerina carinata* d'Orbigny, 1839b, p. 118, pl. 5, fig. 25, pl. 6, figs. 20a, b, 21.

Bolivina lowmani Phleger and Parker: *Bolivina lowmani* Phleger and Parker, 1951, pt. 2, p. 13, pl. 6, figs. 20a, b, 21.

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Cassidulina sp.

Cassidulina minuta Cushman: *Cassidulina minuta* Cushman, 1933, p. 91, pl. 10, figs. 3a-c.

Cibicides fletcheri Galloway and Wissler: *Cibicides fletcheri* Galloway and Wissler, 1927, p. 64, pl. 10, figs. 8-9.

Cibicides lobatulus (Walker and Jacob): *Nautilus lobatulus* Walker and Jacob, 1798, p. 642, pl. 14, fig. 36.

Cibicides sp.

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Elphidium excavatum (Terquem): *Polystomella excavata* Terquem, 1875, p. 25, pl. 2, figs. 2 a-f.

Elphidium galvestonense (Kornfeld): *Elphidium gunteri* (Cole) var. *galvestonensis*, Kornfeld, 1931, p. 87, pl. 15, figs. 1a, b, 2a, b, 3a, b.

Elphidium gunteri Cole: *Elphidium gunteri*, Cole, 1931, p. 34, pl. 4, figs. 9, 10.

Elphidium mexicanum (Kornfeld): *Elphidium incertum* (Williamson) var. *mexicanum*. Kornfeld, 1931, p. 89, pl. 16, figs. 1a, b, 2a, b.

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Elphidium translucens Natland: *Elphidium translucens* Natland, 1938, p. 144, pl. 5, figs. 3, 4.

Epistominella sp.

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Fissurina laevigata Reuss: *Fissurina laevigata* Reuss, 1850, p. 366, pl. 46, fig. 1.

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Glabratellina sp.

Globigerinoides ruber (d'Orbigny): *Globigerina rubra* d'Orbigny, 1839b, p. 82, pl. 4, figs. 12-14.

Globorotalia menardii (d'Orbigny): *Rotalia menardii* d'Orbigny, 1826, p. 273.

Guttulina sp.

Hanzawaia strattoni (Applin): *Truncatulina americana* (Cushman) var. *strattoni*. Applin et al., 1925, p. 99, pl. 3, fig. 3.

Haynesina germanica (Ehrenberg): *Nonionina germanica* (Ehrenberg), 1841, p. 23, pl. 2, figs. 1 a-g.

Indeterminate rotaliid

Neoconorbina terquemi (Rzehak): *Discorbina terquemi* Rzehak, 1888, p. 228.

Nodosaria sp.

Nonionella atlantica Cushman: *Nonionella atlantica* Cushman, 1947, p. 90, pl. 20, figs. 4, 5.

Nonionella auricula Heron-Allen and Earland: *Nonionella auriculus* Heron-Allen and Earland, 1930, p. 41, pl. 10, figs. 10, 11.

Planulina sp.

Polymorphiniid sp.

Quinqueloculina sp.

Quinqueloculina cf. *Q. bosciana* d'Orbigny: *Quinqueloculina bosciana* d'Orbigny, 1839b, p. 191, pl. 11, figs. 22-24.

Quinqueloculina cf. *Q. frigida* Parker: *Quinqueloculina frigida* Parker, 1952, p. 406, pl. 3, figs. 20a, b.

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Quinqueloculina jugosa Cushman: *Quinqueloculina seminulum* (Linnaeus) var. *jugosa* Cushman, 1944, p. 13, pl. 2, fig. 15.

Quinqueloculina lamarckiana d'Orbigny: *Quinqueloculina lamarckiana* d'Orbigny, 1839b, p. 189, pl. 11, figs. 14-15.

Quinqueloculina seminula (Linnaeus): *Serpula seminulum* Linnaeus, 1758, p. 786.

Reussella atlantica Cushman: *Reussella atlantica* Cushman, 1947, p. 91, pl. 20, figs. 6, 7.

Rosalina floridana (Cushman): *Discorbis floridanus* Cushman, 1922, p. 39, pl. 5, figs. 11, 12.

Rosalina sp.

Sagrina pulchella d'Orbigny: *Sagrina pulchella* d'Orbigny, 1839b, p. 150, pl. 1, figs. 23, 24.

Textularia cf. *T. gramen* d'Orbigny: *Textularia gramen* d'Orbigny, 1846, p. 248, pl. 15, figs. 4-6.

Trifarina angulosa (Williamson): *Uvigerina angulosa* Williamson, 1858, p. 67, pl. 5, fig. 140.

Valvulineria sp.

APPENDIX G: FORAMINIFERAL PLATES

Plate 1
(Scales = 100 μ m)

Figures

- 1 *Ammotium salsum* (Cushman and Brönnimann); side view
- 2 *Textularia* cf. *T. gramen* (d'Orbigny); side view
- 3 *Quinqueloculina bosciana* (d'Orbigny); side view
- 4 *Quinqueloculina dimidiata* (Terquem); side view
- 5 *Quinqueloculina* cf. *Q. frigida* (Parker); side view
- 6 *Quinqueloculina jugosa* (Cushman); side view
- 7 *Quinqueloculina lamarckiana* (d'Orbigny); side view
- 8 *Quinqueloculina seminula* (Linnaeus); side view
- 9 *Nodosaria* sp.; side view
- 10 *polymorphinid*; side view
- 11 *Fissurina laevigata* (Reuss); side view
- 12 *Bulliminella elegantissima* (d'Orbigny); side view
- 13 *Bolivina lowmanii* (Phleger and Parker); side view
- 14 *Bolivina pseudoplicata* (Heron-Allen and Earland); side view
- 15 *Reussella atlantica* (Cushman); side view
- 16 *Sagrina pulchella* (d'Orbigny); side view
- 17 *Trifarina angulosa* (Williamson); side view
- 18, 19 *Buccella inusitata* (Andersen); dorsal view and ventral view
- 20, 21 *Epistominella* sp.; dorsal view and ventral view
- 22, 23 *Gavelinopsis prageri* (Heron-Allen and Earland); dorsal view and ventral view

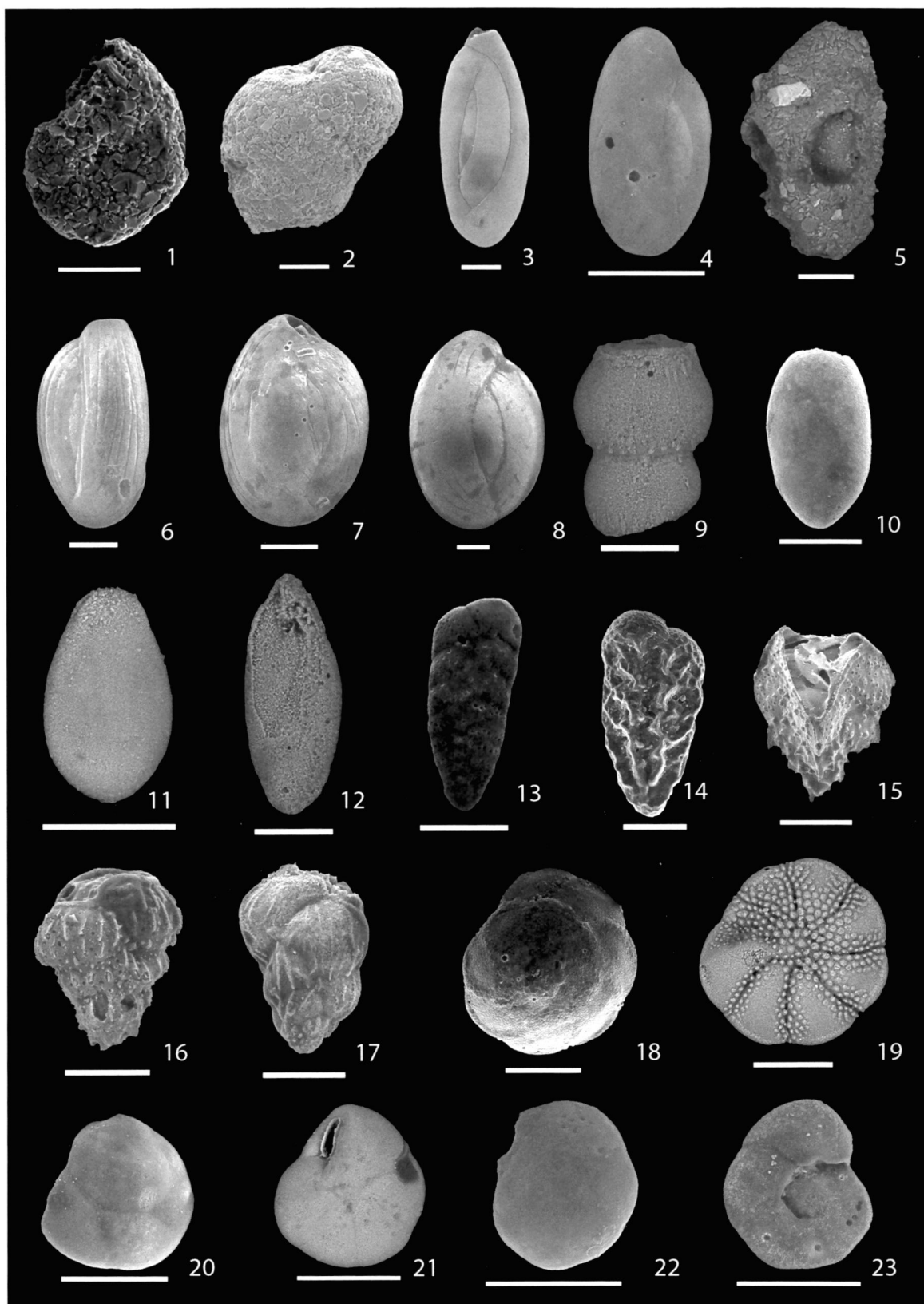


Plate 2(Scales = 100 μ m)**Figures**

- | | |
|---------------|--|
| 1, 2 | <i>Neoconorbina terquemi</i> (Rzehak); dorsal view and ventral view |
| 3, 4 | <i>Rosalina floridana</i> (Cushman); dorsal view and ventral view |
| 5, 6 | <i>Rosalina</i> sp.; dorsal view and ventral view |
| 7, 8 | <i>Valvulineria</i> sp.; dorsal view and ventral view |
| 9, 10 | <i>Glabratellina</i> sp.; dorsal view and ventral view |
| 11, 12 | <i>Asterigerina carinata</i> (d'Orbigny); dorsal view and ventral view |
| 13, 14 | <i>Ammonia parkinsoniana</i> (d'Orbigny); dorsal view and ventral view |
| 15, 16 | <i>Ammonia tepida</i> (Cushman); dorsal view and ventral view |
| 17 | <i>Elphidium advenum</i> (Cushman); side view |
| 18 | <i>Elphidium excavatum</i> (Terquem); side view |
| 19 | <i>Elphidium galvestonense</i> (Kornfeld); side view |
| 20 | <i>Elphidium gunteri</i> (Cole); side view |
| 21 | <i>Elphidium mexicanum</i> (Kornfeld); side view |
| 22 | <i>Elphidium poeyanum</i> (d'Orbigny); side view |
| 23 | <i>Elphidium subarcticum</i> (Cushman); side view |
| 24 | <i>Elphidium translucens</i> (Natland); side view |

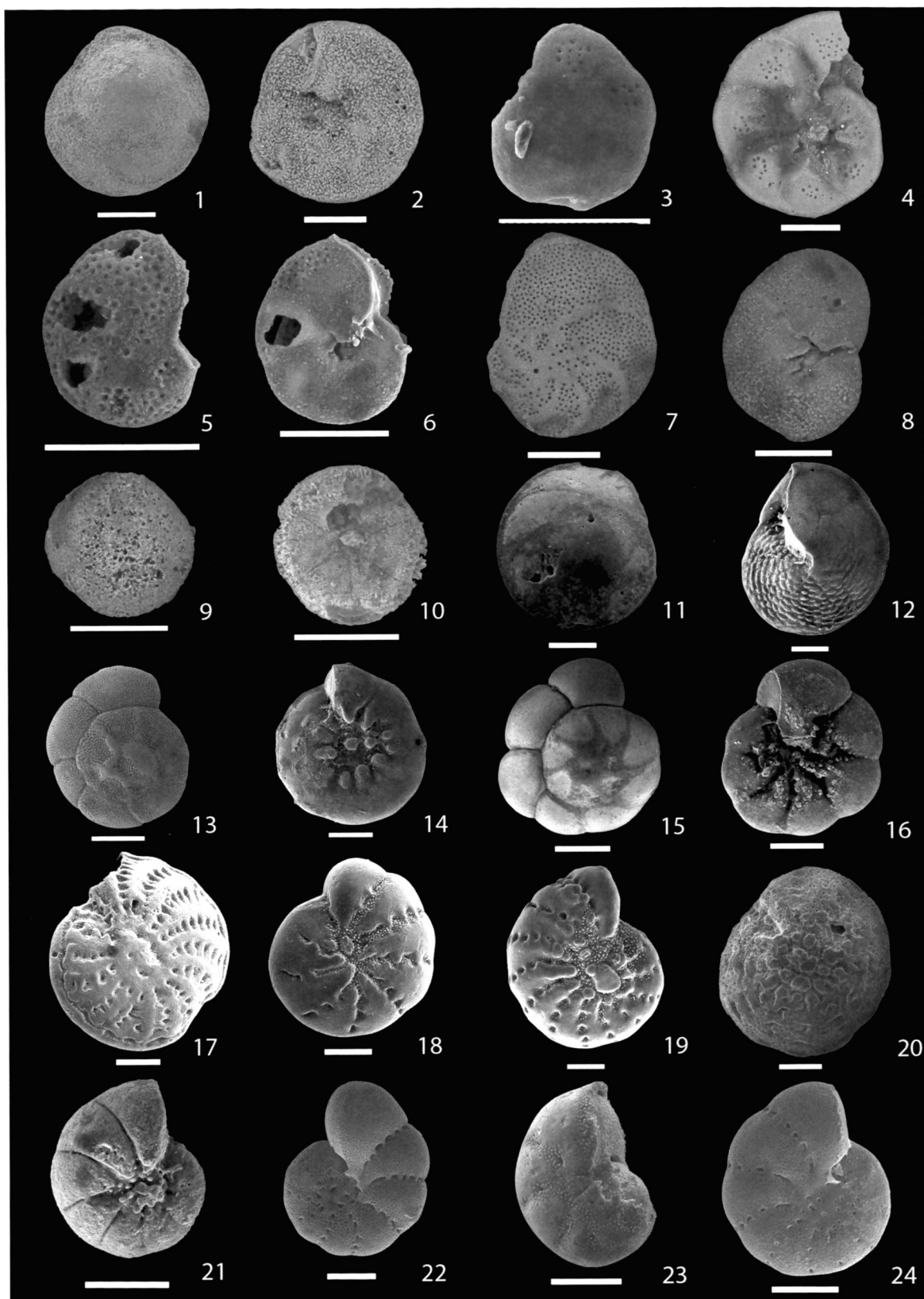


Plate 3(Scales = 100 μm)**Figures**

- | | |
|---------------|--|
| 1 | <i>Haynesina germanica</i> (Ehrenberg); side view |
| 2, 3 | <i>Eponides repandus</i> (Fichtel and Moll); dorsal view and ventral view |
| 4, 5 | <i>Planulina</i> sp.; dorsal view and ventral view |
| 6, 7 | <i>Cibicides fletcheri</i> (Galloway and Wissler); dorsal view and ventral view |
| 8, 9 | <i>Cibicides lobatulus</i> (Walker and Jacob); dorsal view and ventral view |
| 10, 11 | <i>Cibicides</i> sp.; dorsal view and ventral view |
| 12, 13 | <i>Cassidulina minuta</i> (Cushman); side/apertural view and side view |
| 14, 15 | <i>Nonionella atlantica</i> (Cushman); dorsal view and ventral view |
| 16, 17 | <i>Nonionella auricula</i> (Heron-Allen and Earland); dorsal view and ventral view |
| 18, 19 | <i>Hanzawaia strattoni</i> (Applin); dorsal view and ventral view |
| 20, 21 | <i>Globorotalia menardii</i> (d'Orbigny); dorsal view and ventral view |
| 22 | <i>Globigerinoides ruber</i> (d'Orbigny); dorsal view and ventral view |

