

PALEOECOLOGY AND PREHISTORY: FOSSIL POLLEN AT GRAY'S REEF
NATIONAL MARINE SANCTUARY, GEORGIA

By

WENDY WEAVER
(Under the direction of Ervan G. Garrison)

ABSTRACT

Two sediment cores from Gray's Reef National Marine Sanctuary, Georgia, were examined for pollen in order to obtain a chronostratigraphic pollen record. This record assists in paleoenvironmental reconstruction of the Georgia Bight when it was sub-aerially exposed sometime between 18,000 BP and 8,000 BP and contributes additional lines of evidence for the prediction of submerged, prehistoric, human occupation sites on the continental shelf. Although no material capable of producing a radiometric date was found, a possible, relative biostratigraphic pollen assemblage was discovered that may indicate a Younger Dryas (12,500-11,400 BP) sea level still stand. Both cores produced biostratigraphic pollen zones with similar taxa, representing a cooler, and perhaps wetter, time period inferred to be the Younger Dryas. These zones have no modern analog.

INDEX WORDS: Fossil pollen, sea level, paleoenvironment, Pleistocene, Holocene, Younger Dryas, paleoshoreline, outer continental shelf, paleoindian

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DEDICATION

To my sisters...

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CHAPTER 1

INTRODUCTION

Recent archaeological discoveries (*U.S. News and World Report*, Oct. 5-12, 1998 and *Discover*, Feb., 1999) have re-ignited the controversy surrounding early entry into the New World by humans. These earliest Americans were once thought to have arrived in North America from Siberia via the exposed Bering Strait and ice-free corridor during the terminal Pleistocene. Intriguing new evidence, however, may indicate a coastal migration to North America and an even earlier pre-Clovis occupation (before 12,000 BP).

While many archaeologists have claimed pre-Clovis dates for their sites, most of these claims have not survived scientific scrutiny. The majority of pre-Clovis radiocarbon dates were found to be either contaminated or the result of natural activity (Frison and Walker, 1990). Notable exceptions that have withstood rigorous inquiry are the Meadowcroft rock shelter in Pennsylvania and Monte Verde in Chile. Radiocarbon dates from these sites indicate human presence in the New World as early as 16,000 BP and 12,000 BP, respectively. These results suggest that current theories of migration into the New World need re-evaluation.

Despite these intriguing pre-Clovis (pre- 12,000 BP) anomalies, additional archaeological evidence for an earlier human occupation has not been forthcoming. Site prediction based on an entrance across the Bering Strait and

through the “ice-free corridor” has yielded little, if any, clues, and perhaps confounded the issue even more.

A study of Clovis and Clovis-type fluted projectile points, diagnostic of early Paleo-indian hunters during the Late Pleistocene and Early Holocene, indicates that the greatest density and distribution of these projectile points is in eastern North America, and not in the interior, as would be the case if migration had occurred from the Bering Strait (Faught, 1995). Recent, developing theories have postulated a possible coastal migration route of humans into North America. The search for support of the coastal migration theory has shifted towards looking for these early sites on the continental shelf that are now submerged by transgression that began as ice sheets melted during the Late Pleistocene and Early Holocene (18,000 - 10,000 BP).

The archaeological potential of the continental shelves has been anticipated for at least half a century (Emery and Edwards, Fladmark, 1979). Finds of fresh and salt water peats, oolites, late Pleistocene megafauna fossils, and tree stumps on the continental shelf have stimulated speculation that early archaeological sites may also be preserved on the continental shelf of North America.

With the use of seismic technologies such as side-scan sonar and sub-bottom profiling, and the development of predictive models based on terrestrial analogs and geomorphic features (Dunbar et al., 1989), inundated prehistoric sites on the continental shelf have been discovered along the Gulf (Florida, Louisiana and Texas), Northeastern Atlantic, and California coasts (Stright, 1989;

Faught, 1995; Kraft, 1983). None of these sites, however, has yielded a Clovis or pre-Clovis age. Most are of Archaic age (8,000 – 3,000 BP) and are in the shallower, inner, continental shelf. Presumably, the Clovis and possible pre-Clovis (12,000-10,000 BP) shorelines lie farther seaward (Dunbar, et al., 1992; Garrison, 1992). A possible candidate for the Clovis shoreline was mapped by Garrison (*supra*) at the 73-meter bathymetric contour in the northern Gulf of Mexico continental shelf.

With a vast expanse of ever-deepening, submerged continental shelf, how is it possible to locate potential areas of early human occupation? Archaeologists are now using paleoecological data - microfossils such as pollen - to assist in the formulation of possible subsistence and adaptation strategies of the first Americans. The identification of ecozones, such as estuaries, uplands, and riverine bottomlands from *in situ* deposits in conjunction with geomorphological data assists in the location of submerged prehistoric archaeological sites.

Because the earliest evidence of human occupation in Georgia dates to 11,500 BP (Anderson, et al., 1990), which was a time of lower sea level, Gray's Reef National Marine Sanctuary, Georgia, has the potential to manifest such data and answer questions concerning ecological niches exploited by early humans (terrestrial, marine, estuarine), location of glacial refugia of mesic arboreal species, and clues to past climate and sea level fluctuations. These data from Gray's Reef can assist in the formulation of predictive models that can be employed to locate prehistoric archaeological sites on the submerged Atlantic continental shelf.

Previous Research

Previous investigations at Gray's Reef National Marine Sanctuary (GRNMS) by the University of Georgia (UGA), Georgia Department of Natural Resources (GDNR), and the National Oceanic and Atmospheric Administration (NOAA) have yielded Pleistocene megafauna fossils of bison, horse, and mastodon, as well as fossil bivalves and gastropods. Trace fossils such as *Ophomorpha* sp. have been found as well. A fluted projectile point, diagnostic of the Paleo-indian toolkit, was also dredged from the shelf off Wassaw Island by a shrimper (Anderson, et al., 1990).

A nearby paleochannel of the Medway River has also been located 12 miles (18km) due north at J Reef via sub-bottom profiler (Littman, 2000). Sediment cores taken from J Reef contained silts and clays with oyster fragments (*Crassostrea virginica*), wood fragments of spruce, and abundant arboreal pollen (Littman, 2000).

Limited preliminary palynological investigations have yielded pollen in the sediment at Gray's Reef National Marine Sanctuary (Weaver, 1999). Spruce (*Picea*) that is indicative of a cooler climate, has been positively identified from previous cores taken at the reef. (F. Rich, personal communication). None of these sediment cores has been dated in association with pollen and as of yet, there is no chronostratigraphic pollen record for this region of the South Atlantic Bight, a once terrestrial region over 100 km from existing terrestrial pollen sites.

Hypothesis 1: The sediment at Gray's Reef National Marine Sanctuary contains countable and identifiable pollen and pollen assemblages.

Hypothesis 2: The pollen assemblages identified in the sediment at Gray's Reef National Marine Sanctuary can be used for paleoclimatic reconstruction of the Late Pleistocene and Early Holocene when sea level was lower than present.

CHAPTER 2

MARINE PALYNOLOGY AND VEGETATION HISTORY OF THE GEORGIA COASTAL PLAIN

Marine Palynology

With the advent of the Deep Sea Drilling Program, aspects of terrestrial palynology began to be increasingly applied to marine sediment. Initial studies (Stanley, 1966) determined that the sediments of the continental shelf contained the highest amount and variety of pollen. Recent marine palynologists have found the sediments of the shelf to contain varying concentrations of pollen (Heusser, 1985). Marine clays contain the highest amount of pollen and carbonate sediment the least (supra).

Dispersal of marine pollen is due to wind and water transport. Ninety (90%) percent of marine pollen is transported to the continental shelf by rivers (Heusser, 1998; Groot and Groot, 1966; Stanley, 1969) and represents a catchment area between 30 and 100 km of the shoreline (Faegri and Iverson, 1964). Final deposition is affected by the selective effects of fluvio-marine sedimentation.

Since terrestrial pollen records often contain hiatuses in deposition as well as radiometric dating problems, Heusser and Shackleton (1979) determined that pollen in marine deposits was ideal for establishing the progression of continental climatic events by direct correlation with the chronostratigraphic marine oxygen

isotope record. Heusser (1985) stated that pollen in the sediment of North American marine cores directly correlates to regional and global continental stratigraphic and paleoecological data and that when continental pollen deposits are sparse, offshore sediments may provide a vegetation and climate record. Rossignol-Strick (1995) has determined that pollen and oxygen isotope data from marine cores from the Mediterranean yield a more precise record of vegetation events during the Younger Dryas than the terrestrial record that contains contaminated ^{14}C and therefore, erroneous dates of vegetation change .

Heusser (1985) and others (Mudie, 1982; Groot and Groot, 1966) have verified that recent marine pollen accurately reflects the regional and local vegetation onshore in the Atlantic and Gulf of Mexico. This marine pollen record is considered to be an accurate indicator of onshore vegetation.

Application of marine pollen research has been applied to problems of post-Pleistocene sea levels (Stanley, 1965), reconstruction of onshore vegetation and past climate (Muller, 1959) and the positions of river deltas and ocean current patterns (Stanley, 1965, 1966; Woods, 1955). Present attempts at marine-continental pollen record correlations (using diatoms, foraminifera, clay minerals, and oxygen isotopes) have been successful in determining paleotemperatures and paleovegetation on the northeastern, northwestern, and southwestern coasts of the United States (Heusser and Shackleton, 1979, Balsam and Heusser, 1976, and Sancetta, et. al., 1985) and southern South America (Groot and Groot, 1966).

To date there is a paucity of palynological data from the Georgia Coastal Plain. Challenges of pollen analysis in the southeast during the late-Quaternary

have been noted by Delcourt and Delcourt (1985), including the difficulty in vegetational reconstructions due to the diversity of physiographic regions and plant communities and the lack of suitable lake environments (except for the Carolina Bays and karst ponds in central Florida). These factors impede the development of reliable palynological chronologies in the southeast. Additionally, Jackson and Whitehead (1993) confirm the high potential for errors in ^{14}C dates from wetland and pond sites due to shallow and fluctuating water levels and low sedimentation rates.

The majority of pollen data from Georgia with valid radiocarbon dates are from terrestrial upland or inland sites (Watts, 1970;1971;1973; Carbone et al.,1982; Cohen, et al., 1984). Chronostratigraphic pollen data from the Georgia Coastal Plain and the submerged Georgia Bight are sparse or non-existent and are necessary to fill in the gaps and resolve contradictory results from the southeastern United States.

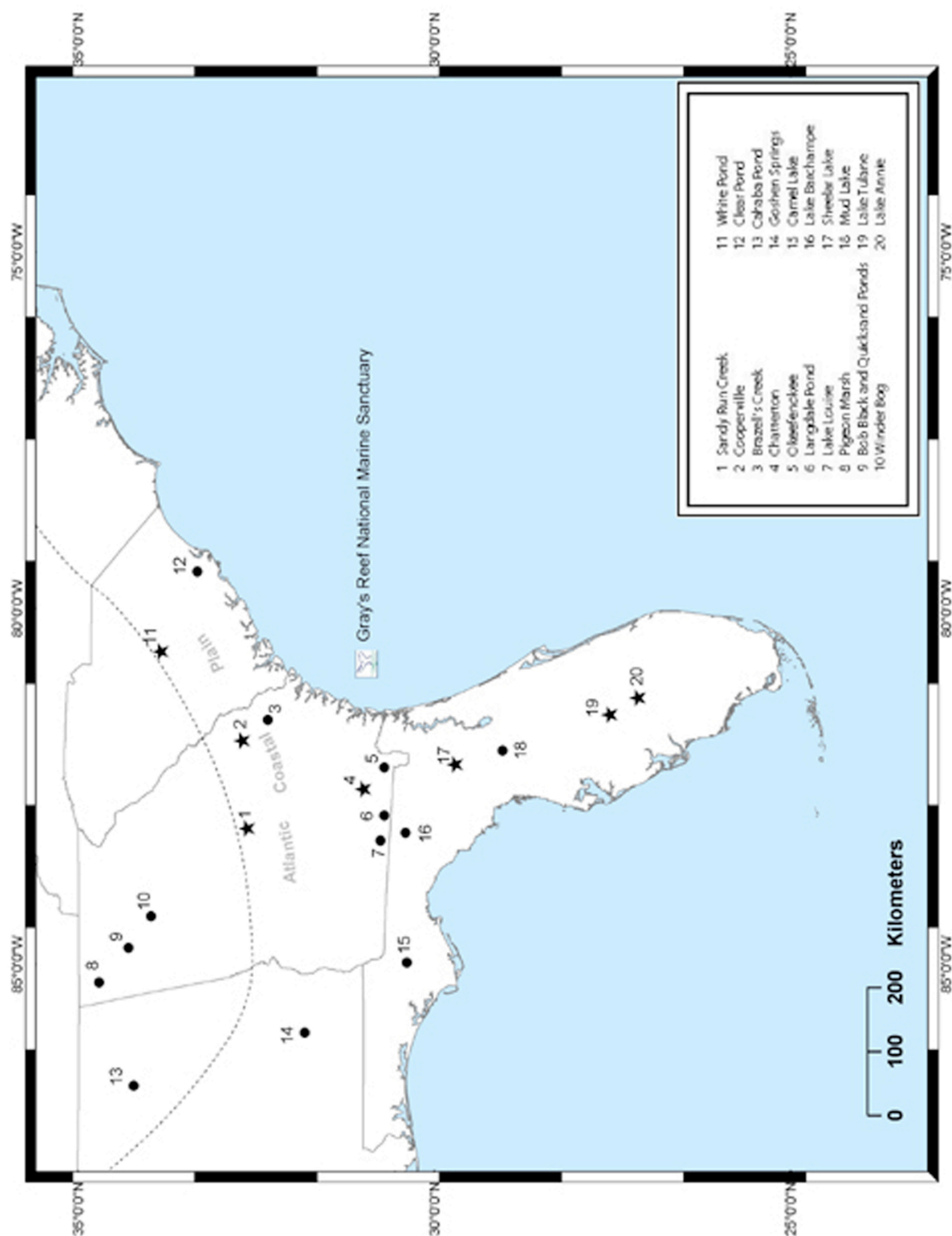


Figure 1 Pollen Sites in the Southeastern United States
 (Coastal Plain sites marked with a star contain Late Pleistocene/Early Holocene records)

Vegetation History of the Southeastern United States

Full Glacial – 23,000 BP – 16,500 BP

Pollen records from the southeast indicate the Full Glacial of the southeastern United States was colder and drier than the present climatic regime. The southern limit for boreal forests was displaced more than 1200 km south of its modern southern border in Canada (Delcourt and Delcourt, 1985). What is not known for the southeastern United States and the Atlantic Coastal Plain, is the distribution of vegetational refugia of mesic, temperate and deciduous forest species and the southern limit of the distribution of boreal forest species (Delcourt and Delcourt, 1985).

Pollen records from the Piedmont at the Nodoroc site (Jackson and Whitehead, 1993) in Barrow County, Georgia, were dominated by pine and oak, with significant amounts of hickory, spruce, and fir. From the Valley and Ridge regions of Georgia, pollen records from Bob Black and Quicksand Ponds (Watts, 1970) and Cahaba Pond (Delcourt, et al., 1983) indicate the dominance of northern pine (jack pine, *Pinus banksiana*) with a decrease in oak. The base of a core taken at Pigeon Marsh at Lookout Mountain (Watts, 1975) revealed a dominance of pine with significant amounts of oak, hickory, and herbs during this time period.

Although these records reveal significant climatic indicators for the northern region of Georgia, they are not indicative of vegetation, and hence, climate, in the Atlantic Coastal Plain during this time.

Pollen records from the Atlantic Coastal Plain revealed the dominance of northern jack pine (*Pinus banksiana*) spruce (*Picea*) and fir (*Abies*) and herbs such as *Ambrosia* sp. and chenopods from White Pond in South Carolina (Watts, 1980). Deciduous tree pollen was infrequent.

Records from Sheelar Lake in Northern Florida indicate that pine dominated, with considerable amounts of oak (*Quercus*) and hickory (*Carya*) until 18,500 BP. At Lake Annie, in the central peninsula of Florida, presence of rosemary (*Cerattolia* sp.), *Polygonella* species (sand dune scrub) and high levels of *Ambrosia* (ragweed) and *Graminae* (grasses) infer a dry, arid, climate from 37,000 BP to 13,000 BP (Watts, 1975). Lake Tulane, in this same vicinity, boasts a continuous, uninterrupted 50,000- year pollen record (Watts and Hansen, 1988). This core records pine woodlands with herbs during this time, indicating a colder, drier climate. In the Florida panhandle, spruce (*Picea*) pollen was also found at Camel Lake (Watts et al., 1992).

Recent cores taken in the central Georgia Coastal Plain help to refine the pollen record for this area. Brook (1996) looked at pollen from Cooperville, Georgia, (a region between White Pond, South Carolina and Lake Tulane, Florida), and found that the area was an open deciduous forest dominated by pine, oak and herbs, with trace amounts of northern species such as spruce from 18,000-12,000 BP.

Lamoreaux (1999) developed a regional model for the Georgia Coastal Plain from a core taken at Sandy Run Creek, Georgia. From 25,000-15,000 BP, pine, spruce, and fir dominated, interspersed with dry prairie. Pollen influx was low

indicating sparse vegetation and the temperature was inferred to be at least 10-15° C lower, with 12% less precipitation.

Late Glacial – 16,500 to 12,500 BP

The end of the Full Glacial is marked by the beginning of climatic amelioration. Ice sheets began to melt with warmer temperatures and sea level rose. Overall, the pollen records from the southeast Atlantic Coastal Plain reveal a warming trend with greater precipitation at this time, although terminal Pleistocene pollen records from this region are sparse and not well understood because of conflicting records from different areas of the southeast.

Two marine cores off Cape Hatteras and Chesapeake Bay indicate high amounts of pine, spruce, and fir around 15,000 years BP. This boreal forest extended east onto the continental shelf. By 14,000 BP, these boreal forests to the north were replaced by mixed conifer forests and in the southeast the vegetation consisted of mixed deciduous forests.

Delcourt and Delcourt (1985) found that around 12,000-10,000 BP, north of 33° latitude, vegetation shifted from Full Glacial vegetation of spruce, fir, and jack pine, to mixed hardwoods like birch, elm, hickory, and oak. At Cahaba Pond, in the Ridge and Valley of Georgia, the base of the core dated to 12,000 BP reveals increasing amounts of beech, hophornbeam/ironwood and other deciduous pollens (Delcourt, et al., 1983). In the Atlantic Coastal Plain, an increase in hickory, oak, southern pine and riverine hardwoods began sometime after 14,000 BP. By 10,000 BP, this vegetational regime expanded north of the fall line and along major rivers (Delcourt and Delcourt, 1985).

At White Pond, SC, Watts (1980) found that by 14,000 BP, summers were warmer, winters colder, and precipitation increased as indicated by mesic broad leaved forests replacing boreal conifers. The record from Camel Lake, FL, (Watts, et al., 1992) indicated a transition from spruce and hickory to an oak, deciduous forest. On the Florida peninsula, both Sheelar Lake and Lake Annie pollen records reveal an increase in oak, hickory, beech and prairie scrub vegetation beginning around 14,600 BP, indicating a drier, warmer climate.

From the Georgia Coastal Plain, Lamoreaux (1999) found an increase in oak, herbs, grasses, and riparian species such as alder, at 12,500 BP, indicating a cool and moist climate and by 11,200 BP, pine, oak, and herbs replace most mesic species. Brook (1996) also found increasing oak and alder during this time in the Georgia Coastal Plain. Additional evidence from paleo sand dunes formed between 15,000 BP and 5,000 BP (Markewich & Markewich, 1994) may suggest a monsoonal climate with warm, wet summers and dry, windy winters.

Early Holocene – 12,500 – 8,500 BP

The terminal Pleistocene/early Holocene is characterized by rapid changes in vegetation and climate. Temperatures continued to rise and vegetation at White Pond, South Carolina, was dominated by oak, hickory, and beech until 9,500 BP when pine and oak became the dominant species (Watts, 1980). In Florida, Watts (1975) discovered that many small lakes were completely dry and oak prairie was the dominant vegetation. Additional evidence from Sheelar Lake (Watts and Struiver, 1980), Lake Annie (Watts, 1975), Camel Lake (Watts et

al., 1992) and Lake Tulane (Watts and Hansen, 1988) confirms an increase in oak and herbs indicating a warmer, drier climate.

In marine sediment cores from the Gulf of Mexico, Heusser (1985) found that glacial sediment was characterized by greater than 50% of pine pollen and reworked pollen and spores. The deglacial pollen assemblage showed a decrease in pine and other conifer pollen and an increase in oak, ash, sweetgum elm, hickory, tupelo and tulip tree as well as an increase in herbs. From the Northern Atlantic, she also found temperate deciduous forests replacing boreal forests around 10,000 years BP.

On the Georgia Coastal Plain the vegetation was oak dominated with a diverse deciduous hardwood forest (Brook, 1996). Lamoreaux (1999) found that this time period was characterized by oaks and a riparian and backswamp environment with alder, bald cypress, sweet gum and black tupelo. Based on these data, the temperature was inferred to be 2.8° C warmer than present with an increase in precipitation. From the same vicinity, Seielstad (1994) discovered that the Georgia Coastal Plain was initially dominated by oak until about 4,000 BP, when it changed to pine-dominated forests.

These conflicting data from Florida and Georgia have been explained by Lamoreaux (1999) as indicating a monsoonal climate for this time period. Kutzbach (1987) found that increased summer solar radiation and decreased winter radiation cause monsoonal climates in coastal areas from 12,000 - 4,000 BP. Watts and Hansen (1988) attribute the aridity in Florida due to Gulf air masses.

Essentially modern climate and vegetation (an increase in pine uplands and swamp wetland species) was established by 4,000 BP.

Present Climate and Vegetation

The coastal plain of Georgia is humid and sub-tropical with substantial precipitation during the year. The mean annual temperature is 18° C (65° F) with a January mean of 9° C (48° F) and a July mean of 27° C (81° F). Annual precipitation is 1122 mm/year (Department of Agriculture, 1968).

Kuchler (1964) defined the present vegetation of the coastal plain as Southern Mixed Forest on uplands and Wetland Vegetation along river systems. Combining these, Braun (1950) designated this region the Southeastern Evergreen Forest.

Uplands are sandy, mesic to well-drained, and consist of pine, oak, hickory, sweetgum and beech. The bottomland hardwood swamp, which is higher up in the floodplain, consists of oaks, water/black tupelo, river birch, willow, sweetgum, red maple, hickory, tulip poplar, ash, and hophornbeam/ironwood with interspersed with holly, vitis, smilax. Wet floodplains and backswamps consist of bald cypress and water/black tupelo.

CHAPTER 3

GEOLOGICAL CONTEXT AND LATE PLEISTOCENE SEA LEVEL

Location

Gray's Reef National Marine Sanctuary is located 17.5 nautical miles (32 km) due east of Sapelo Island, Georgia, at the 20-meter bathymetric contour. It is one of the largest natural live bottom reefs in the South Atlantic Bight (SAB). This 17 square mile (58 sq. km) sanctuary consists of calcarenite ridges formed during the Pliocene that make up the "patch" reefs that support abundant epifauna (Figure 2). Now submerged in 20 meters of water, this coastal plain area was exposed sub-aerially during the Last Glacial Maximum when sea level was as much as 130 meters below its present stand.

The South Atlantic Bight ranges from 27 - 45 degrees North latitude and includes the continental shelf between Cape Hatteras, North Carolina, and West Palm Beach, Florida. Width of the shelf ranges from just 50 km at Cape Canaveral to 120 km off Savannah, Georgia (Atkinson, et al. 1983), with a gradient of less than 3m/km (Uchupi, 1967). The shelf break occurs around the 60-meter bathymetric contour. Within the southern region of the SAB, Gray's Reef National Marine Sanctuary lies within the Georgia Embayment, also known as the Georgia Bight. This area is a structural low between the Cape Fear Arch to the north and the Peninsular Arch to the south that is subsiding faster than the rest of the shelf.

Barrier islands, estuaries, and level coastline characterize the near shore environment. The offshore continental shelf environment includes the inner, middle, and outer shelves. The inner shelf ranges from the coastline to the 20-meter bathymetric contour, the middle shelf from 21-40 meter bathymetric contour, and the outer shelf, from 41-75 meter bathymetric contour (Atkinson, et al. 1983). Gray's Reef National Marine Sanctuary straddles the transition between the inner and middle shelf (15-25 meters).

Water and Circulation

The Georgia coast is mesotidal with a 2-4 meter spring tide range. While wave energy is typically low, the large tidal range at the central portion of the embayment (off Savannah, GA) causes strong tidal currents to rush in and out of the numerous tidal inlets resulting in the reworking of innershore and nearshore sediments. Hurricanes and extra-tropical storms are uncommon. Most of the energy of deepwater waves is deflected through frictional effects as the waves pass over the broad, shallow shelf (Science Applications, 1981).

Although the Gulf Stream is responsible for large, erosional features on the Blake Plateau (over 400 meters deep), present data suggest that the Gulf Stream does not directly influence interior portions of the continental shelf (Science Applications, 1981). Atkinson et al. (1983) stated that the Gulf Stream occasionally penetrates the middle shelf area, but that circulation on the inner and middle shelf is mainly controlled by local wind forcing, as well as tidal currents and river runoff. The main circulation pattern in the southern South Atlantic Bight is northerly during the spring and southerly or variable during the

remainder of the year (Emery and Uchupi, 1972). The main water mass that affects Gray's Reef is known as the Georgia Water (GW) mass. The GW extends approximately 100 km offshore and is warmer and less saline due to river runoff (Pietrafesa, et al. 1985).

Sediment and Lithostratigraphy

Two types of sediment exist on the continental shelf in the South Atlantic Bight, recent and palimpsest. Recent sediment consists of fine-grained sand, clays and silts derived from rivers. This sediment is trapped by extensive estuaries along the coast or is transported directly to the continental slope via cross-shelf transport (Milliman et al. 1972). Estimates of recent sedimentation on the Atlantic continental shelf are thought to be 1–5 cm/1000 years. DePratter and Howard (1977) have reported little or no net Holocene sedimentation past 10 km on the shelf in the Georgia Bight.

Palimpsest sediment consists of medium to coarse-grained sands and was deposited during the last Pleistocene low stand. Holocene transgression has reworked most of this sediment and removed the fine fraction, although Pilkey et al. (1981) found that fine-grained back barrier sediment deposited from the last regression do occur in small areas on the inner and central shelf. Pilkey and Frankenburg (1964) have found this palimpsest sediment at the relict-recent boundary to occur consistently at the 11 meter bathymetric contour off the coast of Georgia and that this boundary ranges from 10-15 meters along the South Atlantic Bight.

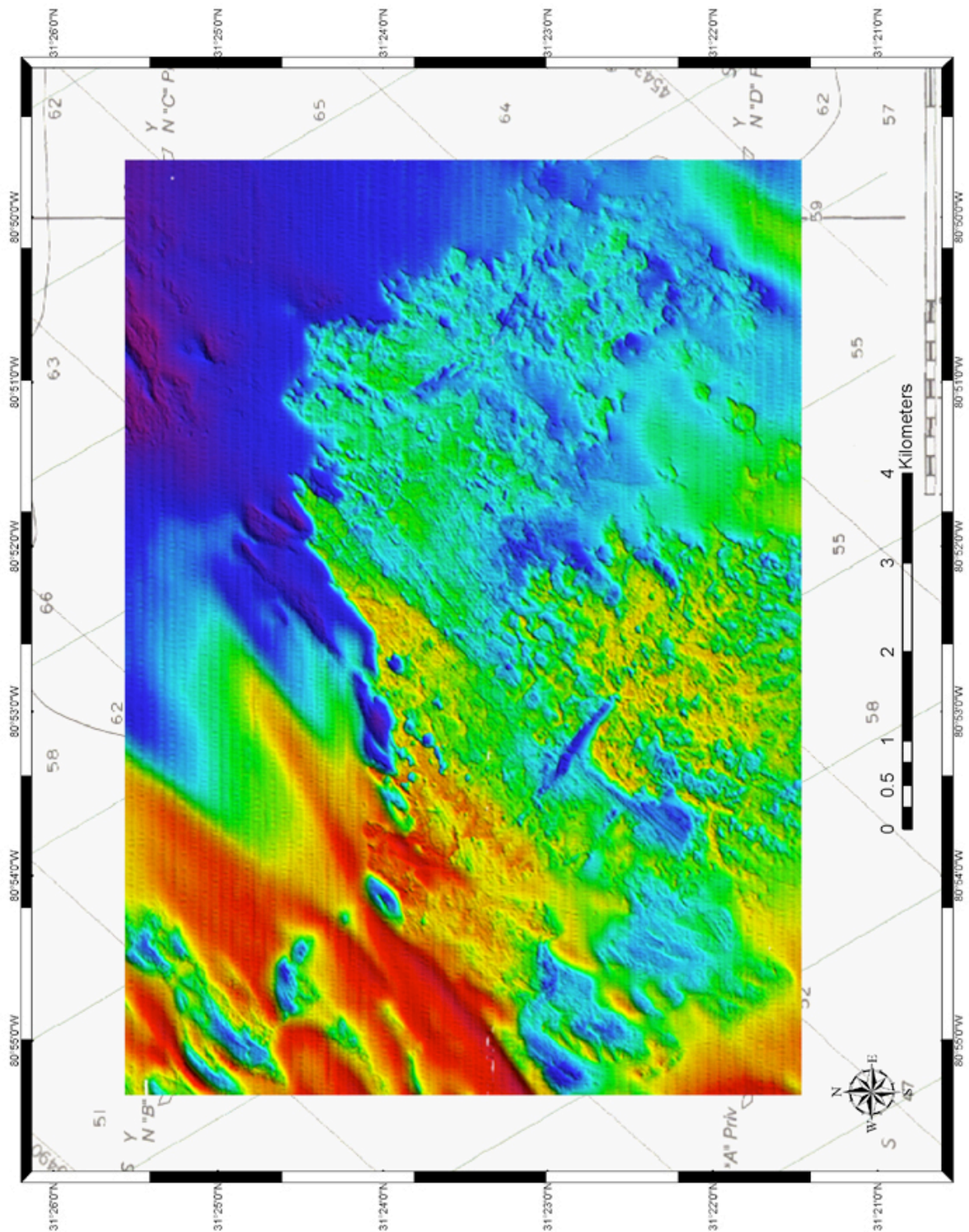


Figure 2 Multi-beam bathymetric image of Gray's Reef National Marine Sanctuary taken by the NOAA ship *Whiting* in 2001
(Red is the highest relief and blue the lowest.)

Huddlestun (1988) reinterpreted the previous literature on the stratigraphy of the Georgia Bight (Henry and Hoyt, 1968; Hunt, 1974; Woolsey, 1977; Milliman, et al., 1972; Blackwelder et al., 1979) using coring and seismic profiling technology. He identified six marine terraces characterized by barrier- island and back barrier marshes associated with higher stands of sea level. These are called the Wicomico, Talbot, Penholloway, Pamlico, Princess Anne and the Silver Bluff-Holocene.

The Silver Bluff terrace was reoccupied by the Holocene transgression and “its terracing event” (Huddlestun, 1988). The sediment in this area has been repeatedly exposed and inundated. Both the Silver Bluff marsh and barrier islands were re-occupied by the Holocene marshes and barrier islands after transgression of the sea that began at the end of the Pleistocene around 18,000 years BP. Hails and Hoyt (1974) obtained a radiocarbon date of 25,000 to 32,000 years BP for the Silver Bluff formation. Additional infinite radiocarbon dates greater than 37,000 BP were obtained and indicate that submergence began around 30,000 - 37,000 BP. Littman’s (2000) two infinite dates from J Reef cores taken in the paleo-Medway river channel fill strengthen this hypothesis.

Gray’s Reef is situated over the Silver Bluff-Holocene marine terrace that overlies the Satilla Formation (supra). Huddlestun (1988) determined that the Satilla Formation was deposited during construction of Pamlico, Princess Anne, and Silver Bluff/Holocene marine terraces. He also discovered that the sediment of the Satilla Formation underlying one marine terrace could not be differentiated

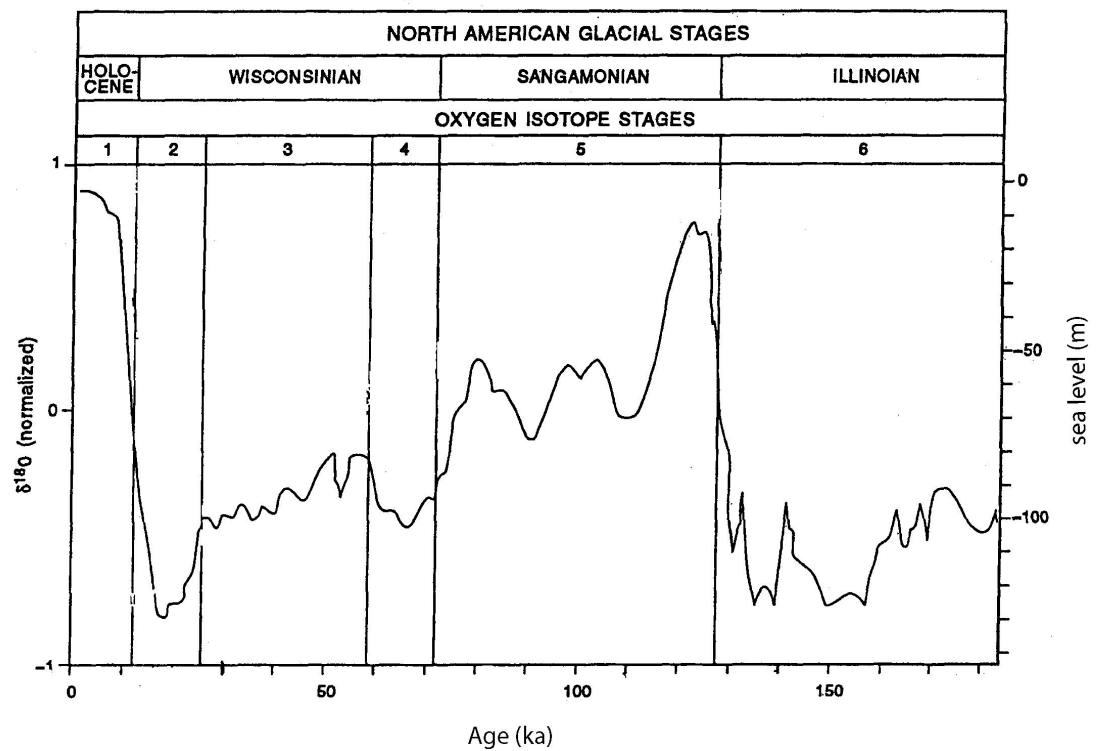
from that of the other marine terraces. Littman (2000) defined the Satilla Formation as a multi-depositional formation composed of lithologically undifferentiated sediment of Late Pleistocene and Holocene age. This sediment is consistent with Huddlestun's (1988) description of shelly sand and the sediment encountered in both core 3 and core 5 of the present study.

Late Pleistocene Sea Level

The Quaternary was a time of extreme and often rapid changes, climatically and environmentally. One of the more important recent geological events during the latter half of the Quaternary was the end of the Wisconsin glaciation. Global oceanic waters were tied up in continental glaciers, exposing vast areas of the now-submerged continental shelves worldwide. Chappell and Shackleton (1986) derived Late Quaternary sea level curves from oxygen isotope data that demonstrate eustatic fall and rise due to expansion and melting of continental ice sheets throughout the past 135,000 years (Figure 3). The most recent lowstand of sea level, called the Last Glacial Maximum (LGM), occurred during isotope stage 2 about 18,000 years BP. The rapid transgression of the sea that began after the LGM influenced the settlement, dispersal, and ecological adaptation of plants and animals, as well as early humans.

Factors affecting global and regional sea level include tectonism, glacial and hydro-isostasy, geoidal changes, and glacio-eustasy. The main dynamic in global (eustatic) sea level is the change in the volume of oceanic waters in response to the expansion and shrinkage of glaciers. The mechanism for the

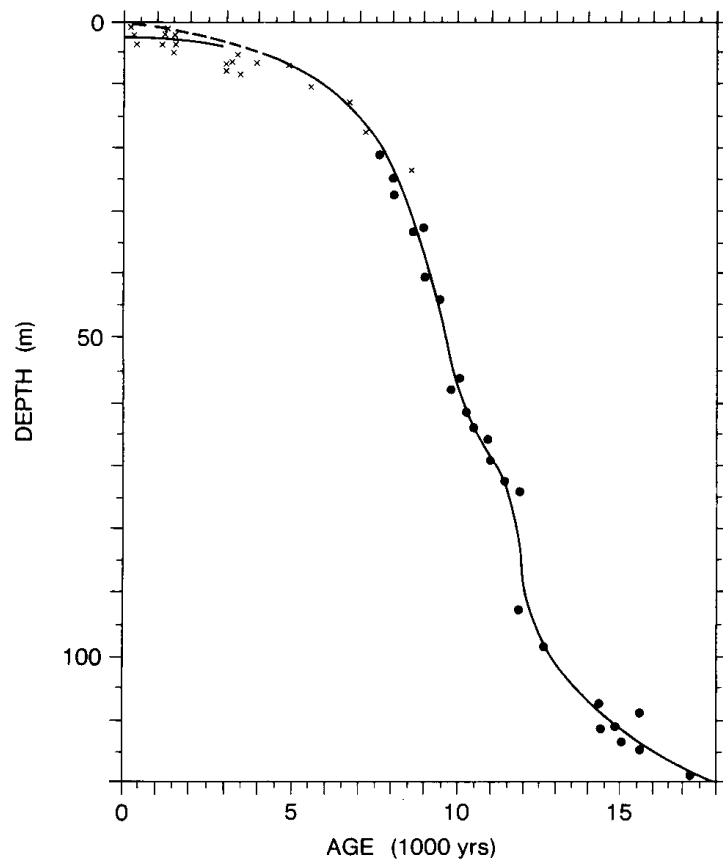
growth and decay of glaciers throughout time has been attributed to changes in the orbital parameters of the earth, known as the Milankovitch cycle.

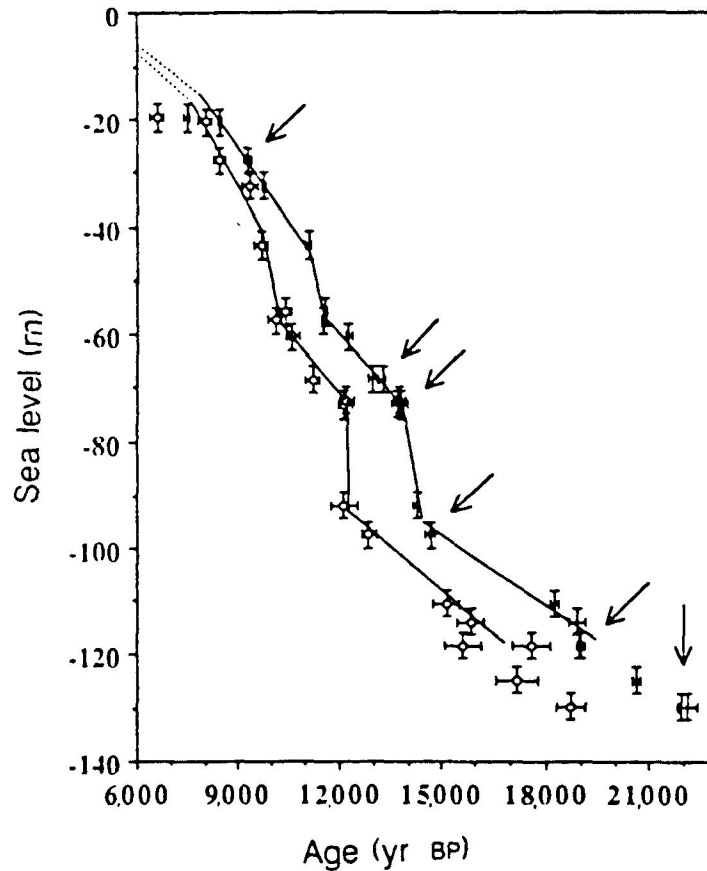


**Figure 3 Oxygen Isotope Record of Sea Level
(Chappell and Shackleton, 1986)**

Regional discrepancies in sea level have been attributed to tectonic activity and glacial and hydro-isostasy in addition to eustatic sea level. These regional variations must be taken into account when making projections about sea level and possible locations of submerged archaeological sites on the shelf.

From a continental perspective, researchers generally agree that sea level was about -100 to -130 meters below its present stand from 20,000 -14,000 BP (Fairbridge, 1961; Curray, 1965; Milliman and Emery, 1968; Blackwelder et al., 1979). Fairbanks et al.'s (1989) study of the Barbados corals, *Acropora palmata*, a shallow water (1-5 meter) species, yielded a detailed, eustatic sea level record for the past 20,000 years. According to this record, sea level began to rise somewhat slowly around 20,000 BP. Rates of transgression as much as 30mm/year (30m/1000 years) have been suggested from these data. A pulse of meltwater caused a rapid rise in sea level that began around 14,000 -12,000 BP and then slowed. A climatic oscillation called the Younger Dryas occurred from 11,800 to 10,000 BP during which temperature decreased and glaciers re-advanced. Subsequently, sea level either lowered or maintained its level. Glacial melting resumed and a second meltwater pulse occurred 10,000 - 8,000 BP causing a rapid sea level rise once again. After 8,000 BP, sea level rise slowed and gradually rose to its present level about 6,000 to 4,000 BP (Figure 4). Bard, et al. (1990) refined this eustatic sea level chronology for the LGM based on uranium series (^{230}Th) dates of the *Acropora palmata* coral (Figure 5).





Crosses correspond to U-Th ages and the open circles to ^{14}C ages. The highest and two lowest samples are composed of *Porites asteroides* and thus only represent the lower bound for sea level at those times. All other samples are *Acropora palmata*. The age errors are quoted as 2 sigma. The samples marked by the arrows correspond to duplicate analyses of the same coral sample by U-Th mass spectrometry (Bard, et al., 1990).

Figure 5 Bard's Sea Level Curve from U-Th dates of *Acropora palmata*

Regionally, the first Holocene sea level curves for the Atlantic were constructed in the 1960s using radiocarbon dated salt marsh peats and oyster shells (Curry, 1965; Emery and Garrison, 1967; Milliman and Emery, 1968). Erroneous radiocarbon dates, lack of valid in-place paleo-shoreline indicators and the disregard of the effects of tectonic and isostatic adjustments of the crust led to discrepancies in various sea level curves.

Dillon and Oldale (1978) refined the sea level curve for the shelf south of New Jersey after discovering that it downwarped, making sea level curves about 40 meters too deep. Blackwelder et al. (1979) also derived a shallower sea level curve (by 30 meters) for the Southeast Atlantic shelf using valid in-place shoreline indicators. His estimate places sea level in the Georgia Bight at -60 meters msl around 17,000 BP.

Despite recent sea level adjustments for the continental shelf south of Cape Hatteras, the date and depth of maximum lowstand of sea level still has not been established. The oldest in place date is 16,500 BP at 60 meters near the shelf break at Cape Hatteras, North Carolina (Science Applications, Inc., 1981). Attempts have been made to construct a sea level curve for South of Cape Hatteras, North Carolina in order to make projections about the location and duration of archaeological sites on the Atlantic shelf (Science Applications, Inc., 1981). This sea level curve indicates the rate of sea level rise was less than older curves suggested. In the vicinity of Gray's Reef National Marine Sanctuary (~20 meters below sea level), the time interval at or above sea level is estimated to be from 9,500 to 20,000 years BP and the duration of exposed

surface area is estimated to be at least 10,000 years (Science Applications, Inc., 1981). Blackwelder et. al (1979) also placed sea level at -22 meters msl around 10,000 years BP in the Georgia Bight. This projects the 20- meter bathymetric contour at Gray's Reef National Marine Sanctuary at or near the shoreline during the Latest Pleistocene and Early Holocene.

CHAPTER 4

SEDIMENT ANALYSES AND RESULTS

Methodology

Two cores were taken from GRNMS March 29, 2000, on the NOAA ship *Ferrel* (Cruise FE-00-06-GR). (See Figure 6 for locations.) The sediment was extracted using a vibracorer with a penetrometer built by Neil Gielstra at Coastal Carolina University (See Figure 7.) The penetrometer allowed the cores to be driven to absolute refusal. The cores were then taken to the University of Georgia Paleoecology Laboratory.

The cores were split and photographed April 4, 2000. After initial grain size analysis and color classification by Munsell Color Chart (reference), they were promptly conserved in the cooler at Riverbend Laboratory.

Samples from the cores were collected June, 2000. Except for a 2-3 cm clay cap on core 5 (Figure 8), no stratigraphy was apparent so a systematic, arbitrary sampling strategy was used to maintain comparability within and between the two cores. Attempts were made to X-ray the cores for stratigraphy invisible to the naked eye but with negative results.

Both halves of the cores were used for sampling and every attempt was made to keep the samples from each half at the same interval. This was done in order to correlate pollen density and distribution with loss on ignition, grain size, and magnetic susceptibility results.

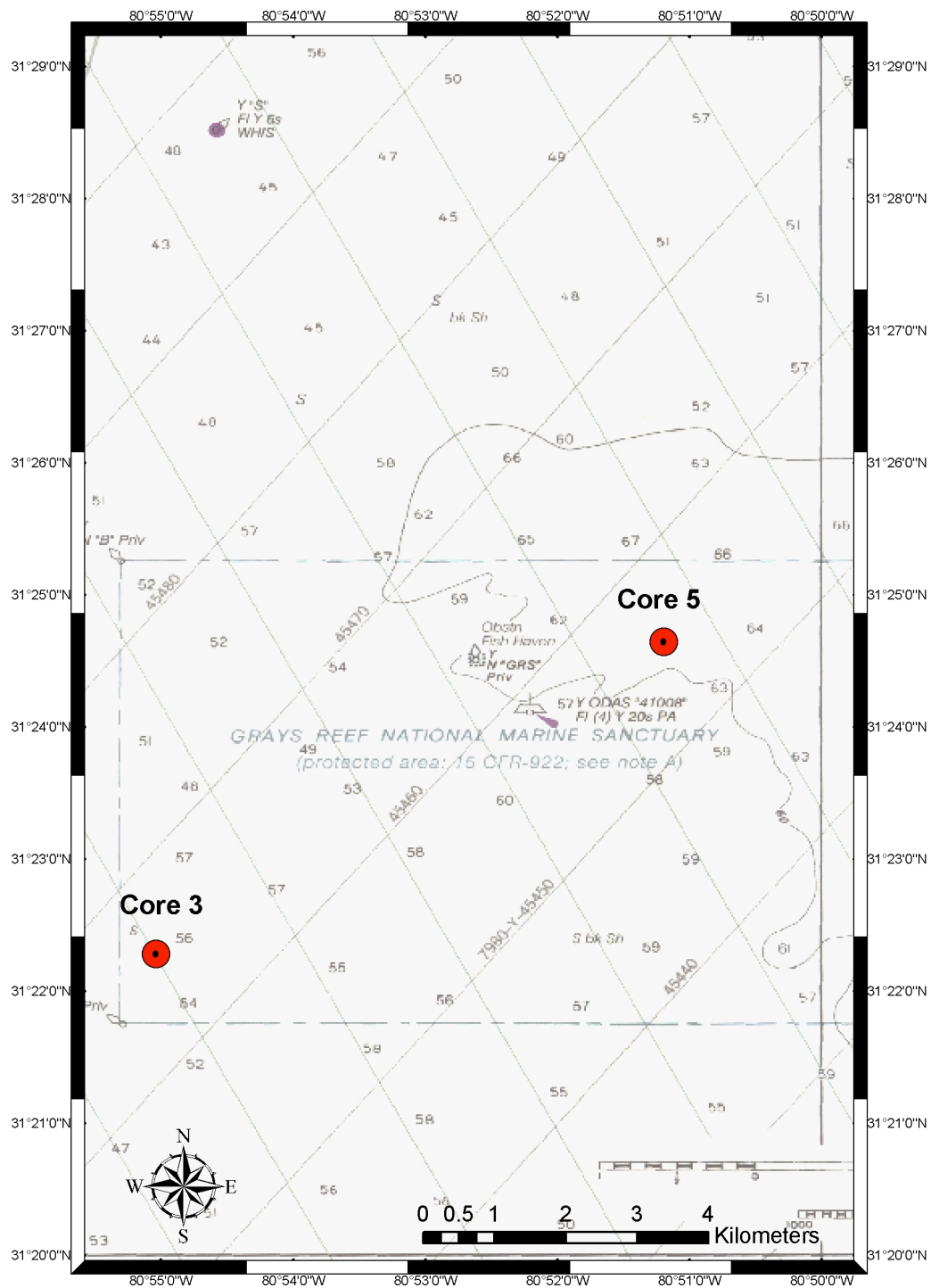


Figure 6 Core locations in Gray's Reef National Marine Sanctuary



Figure 7 Vibracorer used to collect cores

Core 3, 1.36 meters in length, was sampled at the surface, the base, and every ten centimeters except where previous x-ray sampling and large shell fragments had disturbed the core. The color of the sediments according to the Munsell Color Chart was 2.5Y 5/1, gray (Figure 9). Core 3 produced 15 samples.

Core 5, 2.04 meters in length, was sampled at the surface, the base, and every ten centimeters. There were no disturbances in core 5 and 21 samples were collected. The color of the surface clay layer according to the Munsell Color Chart was 2.5 Y 5/1, gray and the remaining sediment was 2.5 Y 5/2, grayish-brown (Figure 8 and 9).

Magnetic Susceptibility

Magnetic susceptibility was measured on the sediments of both cores. Currie and Bornhold (1983) have used magnetic susceptibility of marine sediments to identify depositional history during lower sea level. Ellwood et al. (1995) have also used this method to identify cultural and paleoclimatic markers in sediments of an archaeological site.

Five grams of air-dried, sieved sediment (< 2mm) was used per sample. Attempts were made not to grind or crush the sample. A Williams magnetic susceptibility bridge was used to measure magnetic susceptibility in SI units. The regression formula used for this meter was: $Y = 2 \times 10^{15}(X) + 5 \times 10^{15}$

where: Y= the susceptibility of the sediment

$X = (\text{sample weight}) \times (\text{meter reading})$

Then: $Y \div 4 \times 10^{15} = \text{SI units of magnetic susceptibility}$



Figure 8 Top of Core 5

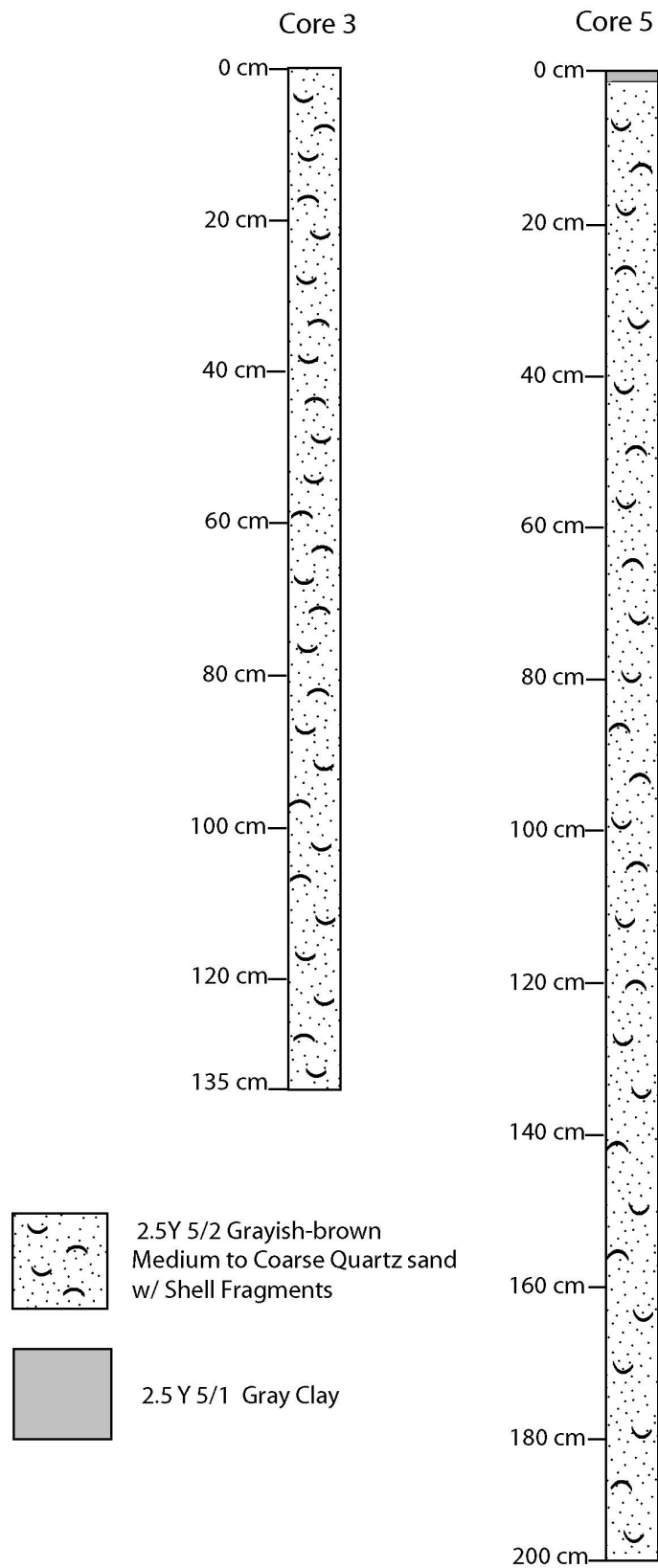


Figure 9 Core 3 and Core 5 Diagrams

Loss on Ignition

Since pollen density is directly correlated to organic content, the organic content of all samples was determined using loss on ignition (LOI) procedure (Dean, 1974). Each sample contained 15 grams of sediment and after being crushed, dried, and weighed was placed in the furnace at 450 degrees Celsius for eight hours.

Particle Size Analysis

Samples were analyzed for particle size in the UGA Soil Laboratory using the Fleaker method (Indurante, et al. 1990). Carbonates were first removed using the method described by Jackson (1969). Ten grams of sediment was used per sample.

Results

Magnetic Susceptibility

Magnetic susceptibility of the sediments of both cores 3 and 5 failed to yield significant results regarding magnetic materials indicative of sub-aerial exposure. All measures were typical of siliceous sand that is not magnetically susceptible. The surface clay in core 5 did not indicate a magnetic susceptibility different from the other samples. Results of the magnetic susceptibility are presented in Appendix A.

Particle Size Analysis

Measurement of particle size by the Fleaker method (Indurante, et al., 1990) indicated that all sediments consisted of sand (94-98% sand) except for the surface clay layer in core 5. These results are typical of this part of the

continental shelf. The surface clay layer contained 48% sand and 52% clay and silt. The origin of this layer is unknown. Results are shown in Appendix A.

Loss on Ignition

The organic content of the samples was determined by loss on ignition (LOI) according to Dean (1974). Percent organic matter in the sediment of both cores was extremely low (less than 1%) except for the surface clay layer of core 5.

These results are typical of siliceous and carbonate sediments.

Core 3 contained the highest percentage of organic content at the surface and the base of the core, .819% and .855%, respectively. The lowest percent LOI was .49% at the 90 cm interval.

Loss on ignition percentages were somewhat higher for core 5. The surface clay layer yielded a 6.74% LOI. The remainder of the samples ranged from .389% at 80 cm to 1.025% at 10 cm. Results are shown in Appendix A.

CHAPTER 5

POLLEN ANALYSIS AND RESULTS

Methodology

Typically, samples for pollen processing contain peat or clay and only 1cc of sediment is collected for processing. Since the sediments in both cores contained sand (except for the surface of core 5) and therefore, less organic content, more sediment (10-15 cc) was required to obtain pollen concentrations comparable to those of 1cc of peat or clay. Heusser and Stock (1984) have shown this to be an effective strategy and equivocal to smaller samples collected from peat. The United States Geological Survey (USGS) also recommends the use of larger samples in sandy sediment to obtain a significant number of countable pollen grains (Deb Willard, personal communication). This technique was confirmed in a previous attempt to extract pollen from a small core taken from Gray's Reef (Weaver, 1999). Larger samples yielded more countable pollen.

Core 3 pollen samples were collected within 1 cm intervals and contained 10cc or about 13-15 grams of sediment. All attempts were made to avoid fragments of shell in the collection process and obtain exactly 10cc of sediment.

Pollen processing and analysis is very time-consuming. In order to efficiently process samples from both cores, some samples were eliminated. In core 3, this was randomly done every other 10 cm beginning at the surface. Eight

samples were produced for pollen analysis from core 3. Finer resolution processing would be considered after initial processing and analysis, if needed.

Core 5 pollen samples were also collected within 1 cm intervals and contained 15cc or about 16-18 grams of sediment. Amount of sediment sampled was adjusted upwards to obtain greater pollen concentration in case core 3 samples failed to yield substantial amounts for counting. No attempt was made to make the surface clay sample equivalent to the sand samples to adjust for pollen density. All attempts were made to avoid fragments of shell in the collection process and obtain exactly 15cc of sediment. Core 5 produced 9 samples that were selected on the basis of higher organic content and relevant spacing in the core. Finer resolution processing would be considered after initial processing and analysis, if needed.

Pollen processing was conducted according to Shane (1992). *Eucalyptus* spike was used as exotic marker pollen and standardized according to Shane (1992). Both core 3 and core 5 samples received 5 ml of *Eucalyptus* spike. Processing involved the use of hot 10% KOH to remove organic acids. After sieving through 180 micron mesh to remove sand, the samples were treated with hot 10% HCl and concentrated HF to remove inorganics and silicates. Acetolysis removed remaining organics and then stained the pollen grains. Pollen was then mounted in silicone oil for viewing.

Pollen slides were counted along systematic transects on a Zeiss microscope at 400x magnification. A minimum of 300 pollen grains per sample interval were counted. Unknown, indeterminate (crumpled and deteriorated), and

Eucalyptus pollen grains were also counted. Number of slides per sample interval ranged from 1.5 to 7 to achieve a total of 300 grains of pollen per interval.

Identification of the pollen taxa to family or genus was based on the reference collection at the University of Georgia Paleoecology Laboratory. Several pollen identification books were also used (Faegri and Iverson, 1989; Jones, et al., 1995; Kapp, 1969; McAndrews, et al., 1973; Moore and Webb, 1978).

Interpretation Problems

Before using pollen as proxy data of past vegetation and subsequently climate, many biases inherent in collection, processing, and analysis must be considered before an accurate interpretation can be achieved.

Differences in preservation of pollen can bias interpretation. The substance in the outer covering (exine) of the pollen grain, sporopollenin, is variously resistant to decay, depending on the species. Pine (*Pinus*) pollen is the most resistant, while maple (*Acer*) is very susceptible to decay.

Production of pollen is also variable between species. A single pine tree produces about 10 billion grains per year compared with flax, which produces only 20,000 grains per year. Hence, species may be either over-represented or under-represented in the pollen record.

Mode of dispersion also determines representation in the pollen record. Pollen transported via wind tends to be over-represented, as grains of pine and *Ephedra* can be found hundreds of kilometers from where they grow. Pine pollen

has even been found in the Arctic. Animal transport tends to under-represent pollen with dispersal distance only a few meters.

Pollen also undergoes taphonomic processes associated with water transport. Heusser found that 90% of pollen in marine sediments was transported by rivers. Muller (1959) and Traverse and Ginsburg (1966) found that pollen was transported by ocean currents and deposited with silt in the sorting process. In a body of water, pollen grains settle out differentially. The smaller, lighter grains remain in the littoral zone while the larger grains settle out more quickly and move into deeper water.

Resuspension and redeposition of pollen may occur due to turbulent water mixing such as waves and river influx. In deeper ocean environments on the continental shelf, storm wave base and currents also affect final deposition.

Other taphonomic factors can also bias deposition of pollen. Degradation from sub-aerial and biological oxidation causes damage to the sculpturing of the exine that is necessary for identification. Drying and compaction of sediments, wet-dry cycles, and mechanical damage during transport can cause crumpling and crushing of the pollen grain, obscuring pores and furrows that aid in identification. Growth of fungi and pyrite crystals within the pollen grain after deposition can also prevent positive identification.

Additionally, some pollen grains are difficult to distinguish from each other even under the microscope. Because of morphological similarities, *Taxodium* (bald cypress) and *Juniperus* (eastern red cedar) are grouped together for

identification purposes. Pollen of *Carpinus* (hophornbeam), *Ostrya* (ironwood) and *Myrica* (wax myrtle) are also treated in this manner.

Most pollen taxa can only be identified to genus or family and may contain species that are adapted to different environments. In the Southeast, there are currently 12 species of pine and 21 species of oak, each with different tolerances to moisture and soil type (Jackson and Whitehead, 1993). Some upland Coastal Plain species of pine are even tolerant of seasonally wet conditions (Delcourt and Delcourt, 1985). Hence, interpretations based on increases and decreases of either pine and/or oak are problematic. Periods of high oak and low pine pollen have been interpreted as moist conditions (Seielstad, 1994), but Grimm et al. (1993) associated increased pine with lower temperatures. Conversely, high amounts of pine pollen in Florida have been related to increased precipitation from warm, Gulf air masses (Watts and Hansen, 1994).

By considering the entire pollen assemblage, and not just one species, a more accurate interpretation of shifts in pine and oak pollens can be achieved. Grimm et al. (1993) concluded that oak pollen associated with grass, *Asteracea*, and *Chenopodiaceae* pollen indicated a dry, open, oak forest. Oak paired with ragweed was interpreted as aridity in the Lake Tulane core (Watts and Hansen, 1994). When mesic species, such as hickory, sweet gum, cedar and beech are found with oak, moist conditions are inferred (Watts and Struiver, 1980).

Pollen Analysis and Interpretation

Pollen diagrams were constructed based on percentage of each taxa of the pollen sum for each sample including trees and shrubs, herbs and grasses, and

ferns and mosses. This method is called relative pollen frequency and is based on each pollen taxon expressed as a percentage of the total pollen sum. The disadvantage of this method is that the percentage values of each pollen taxon are interdependent upon each other (Faegri and Iverson, 1989). Before the introduction of radiocarbon dating this was the only method available for interpretation of pollen data.

The alternate method, absolute pollen frequency, can only be calculated using radiometric dates and is capable of producing pollen influx (number of pollen grains per unit of surface area and per unit of time, measured in pollen grains per cm²/year) and sediment accumulation rate (the net thickness of sediment accumulated per unit of time, measured in cm/year). Because of the absence of datable material in both cores, neither absolute pollen frequency, pollen influx, nor sediment accumulation rate could be calculated.

Pollen concentration was calculated using the exotic marker, or spike, *Eucalyptus*. By knowing the concentration of spike added to a sample and the number of pollen grains counted, the following equation can be used to determine concentration of fossil pollen in a unit of sediment (measured in pollen grains/cm²)

$$\frac{\text{Fossil pollen concentration}}{\text{Exotic pollen concentration}} = \frac{\text{Fossil pollen counted}}{\text{Exotic pollen counted}}$$

$$\text{Fossil pollen concentration} = \frac{\text{Fossil pollen counted}}{\text{Exotic pollen counted}} \times \text{Exotic pollen concentration}$$

Pollen percentage was also calculated without aquatics, unknown and indeterminate pollen grains for zonation purposes. Since aquatic pollen is indicative of local conditions, because it is not transported very far from its source, it was eliminated from interpretation. Arboreal and herb pollen is used to indicate regional vegetation because it is transported some distance from the source, and was used to interpret these data.

Appendix B contains the raw pollen data, relative frequency percentages, and pollen concentration.

Pollen Analysis and Interpretation

Pollen diagrams were divided into different zones to assist in the interpretation of the pollen data. Zonation was performed by visual inspection of the pollen diagrams for changes in pollen stratigraphy. Attempts were made to use CONISS (Grimm, 1987), a statistical cluster analysis program used for pollen zonation, however, the data were too minimal due to low pollen frequency of arboreal types other than pine and oak and failed to produce significant results that would assist in interpretation.

Based primarily on pine and oak frequencies, core 3 contained two zones. Zone I (121-134 cm) contains sample interval 8 at the base of the core. Zone I was defined where the pine increases slightly (93.16%) and oak frequency decreases significantly (4.31%). Zone II (0-121 cm) contains sample intervals 1-7 and is defined by similar ratios of pine (72.69-82.14%) to oak (9.74-17.7%) in the sample intervals. Figures 10 and 11 show core 3 percent pollen diagrams for arboreal and non-arboreal pollen.

Core 5 was also delineated into three zones based primarily on pine and oak frequencies. Zone I (171-198 cm) contained sample interval 20. The percentage of pine is 80.42% and oak is 15.06%. In Zone II (151-171 cm) the pine and oak frequencies change with pine increasing to 91% and oak decreasing significantly to 5%. Zone II consists of sample interval 19.

In Zone III (0-151 cm), pine and oak pollen frequencies are similar to Zone I and the ratio is maintained throughout the sample intervals. Zone I includes the clay surface layer and contained sample intervals 9, 10, 11, 12, 14, 16, and 18. Figures 12 and 13 show core 5 percent pollen diagrams for arboreal and non-arboreal pollen.

Core 3
Zone I 121-134 cm
Zone II 0-121 cm

Core 5
Zone I 171-198 cm
Zone II 151 – 171 cm
Zone III 0-151 cm

Before attempting a vegetation and climatic interpretation of the pollen data from Gray's Reef National Marine Sanctuary, several assumptions have been made due to low pollen density and frequency, absence of sediment stratigraphy and radiometric dates from both cores. Interpretations have been prepared from the pollen diagrams from Gray's Reef by considering the following premises :

1. There has been no net Holocene sedimentation past 10 km (DePratter and Howard, 1977, Pilkey, et al., 1964) on the shelf, since the establishment of the present sea level around 6,000 – 4,000 BP.

2. The sediment at Gray's Reef is of late Pleistocene and early Holocene age as established by Littman (2000).

Core 3 - 134 cm

Zone I (121-134 cm)

Zone I reflects different vegetation from the present, perhaps with no modern analog, with cooler, and perhaps wetter conditions. The general trends in this sample reveal a sharp decrease in *Quercus* (oak) (4.31%) with increasing *Pinus* (pine) (93.16%), extremely low bottomland hardwood swamp and herb species and no cypress/gum swamp species.

Pine and oak make up 97% of the upland community tree species, with less than 1% of *Carya* (hickory) present. Bottomland hardwood swamp species *Liquidambar* (sweet gum) and *Carpinus/Ostrya* (hornbeam) represent 2% of the pollen sum. Cypress gum swamp species, *Nyssa* (water tupelo) and *Taxodium/Juniperus* (Bald Cypress/cedar) are completely absent. Herbs (*Ambrosia*) constitute less than 1% of the total pollen sum.

Zone I, with its increasing pine and decreasing oak, trace amounts of bottomland hardwood swamp species, except for *Liquidambar* (sweetgum), and absolute lack of cypress/gum swamp species is inferred to represent a cooler, and perhaps wetter climate.

The absence of cypress/gum swamp species *Nyssa*(black/water tupelo) and *Taxodium/Juniperus* (Bald Cypress/cedar) in this zone at the base of the core might be taken to indicate the lack of preservation of certain less well-preserved species downcore. However, the sample interval in this zone at the base of the

core had the highest percent of organic matter and the highest pollen concentration (5,640 grains/cc) - over twice that of the average pollen concentration of the upper sample intervals (2,057 grains/cc).

Zone I suggests a cooler, and perhaps wetter climate. Increases of pine and decreases of oak have been associated with cooler temperatures (Grimm et al., 1993). Interestingly, *Liquidambar* (sweet gum) remains, while other species indicative of moisture are absent. This may be due to the fact that sweet gum has a high tolerance to varying temperatures, growing from New England to Central Florida in its present day range.

It is possible that this zone represents a cooler time period with no modern analog with which to compare it.

Zone II (0-121cm)

Zone II reflects the onset of modern vegetation and increasing temperatures. General trends indicate increasing amounts in *Quercus* (oak), herbs, backswamp and mesic hardwood species toward the surface of the core. Upland plant communities that occupy well-drained, sandy ridges are represented (92%) and include *Pinus* (pine), *Quercus* (oak), *Carya* (hickory) and *Fagus* (beech). *Liquidambar styraciflua* (sweet gum), *Betula* (river birch), and *Carpinus/Ostrya* (hornbeam) and *Ulmus* (elm), that compose bottomland hardwood swamps, represent 5% of the pollen sum. The cypress/gum backswamp species *Taxodium/Juniperus* (Bald Cypress) and *Nyssa* (water tupelo) represent 1% of the pollen sum. Herbs (*Ambrosia* and *Chenopods*) only represent 2% of the total pollen sum.

It is inferred that Zone II represents the onset and presence of modern vegetation and climate. Taxa associated with warmer, wetter climates increase towards the surface of the core from 121 cm where Zone I begins. Amounts of *Taxodium/Juniperus* (Bald Cypress), *Betula nigra* (river birch) and *Fagus* (beech) rise toward the surface of the core, indicating an increasingly warmer, wetter climate. Weeds (Chenopods) increase, as well, perhaps indicating deforestation that is often observed with rising human populations and the onset of agriculture. *Nyssa* (water tupelo) was present in trace amounts in the surface and in the center of the core, and is also indicative of a warmer, wetter climate. This zone is considered to represent vegetation and climate similar to the present consisting of pine dominated forests and hammocks of deciduous species, riverine bottomlands and cypress swamps.

Core 5 – 198 cm

Zone I (171-198 cm)

Zone I, at the base of core 5, reflects a warm climate, similar to the present. Upland plant species comprise 97% of the total pollen sum. The Pine pollen frequency is 80%, and oak is 15%, beech at 1% and alder less than 1%. Bottomland hardwood swamp species form 4% of the total pollen sum, with gum at 2% and river birch at 2%. Cypress/gum swamp species, although composing less than 1% of the total pollen sum, are present. This zone contained the lowest concentration of pollen (1312 grains/cc) yet a high amount organic matter as compared to the remainder of the core, except for the surface clay layer. The absence of herbs in this zone cannot be explained by poor preservation or a low

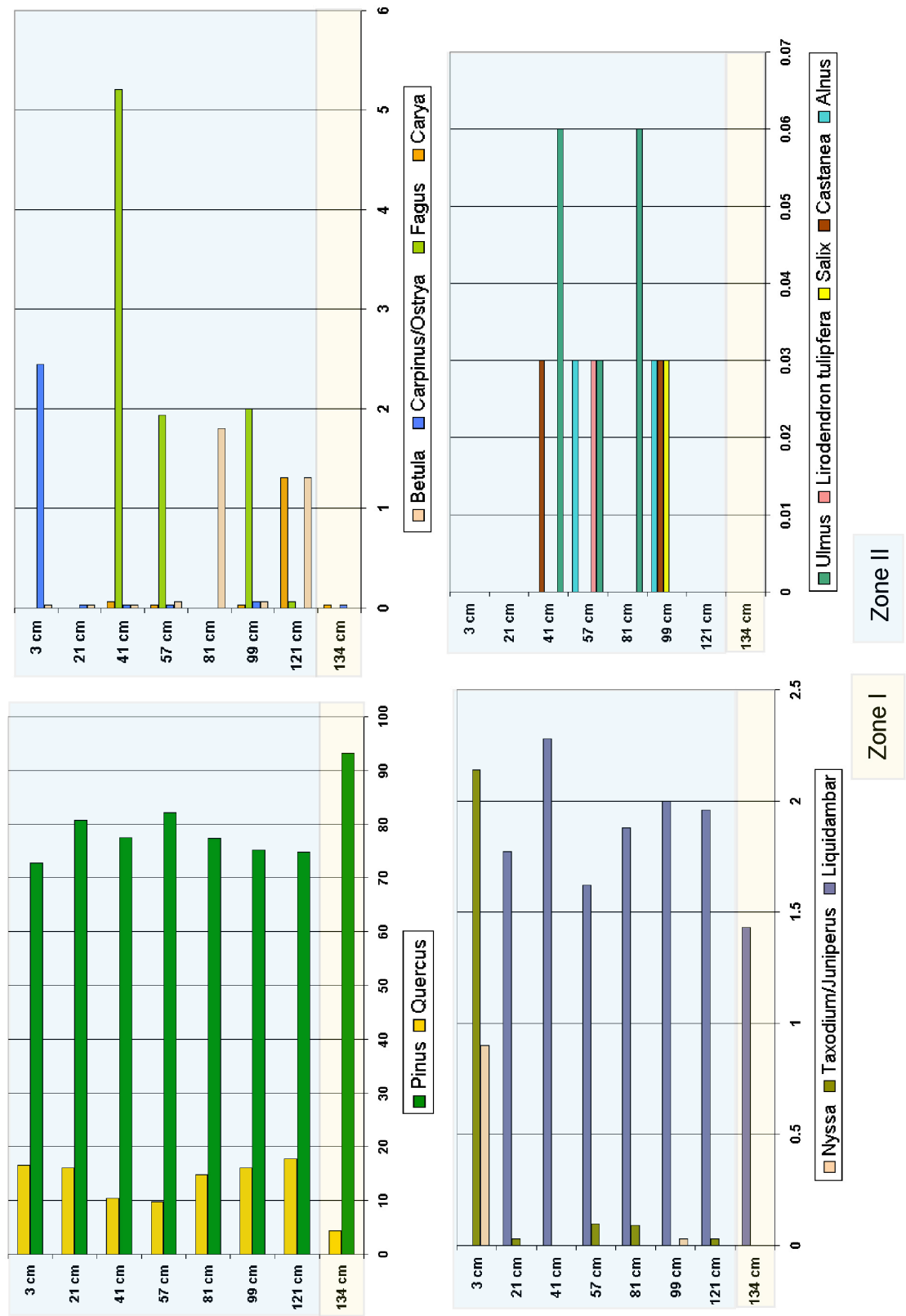


Figure 10 Core 3 Arboreal Percent Pollen Diagram

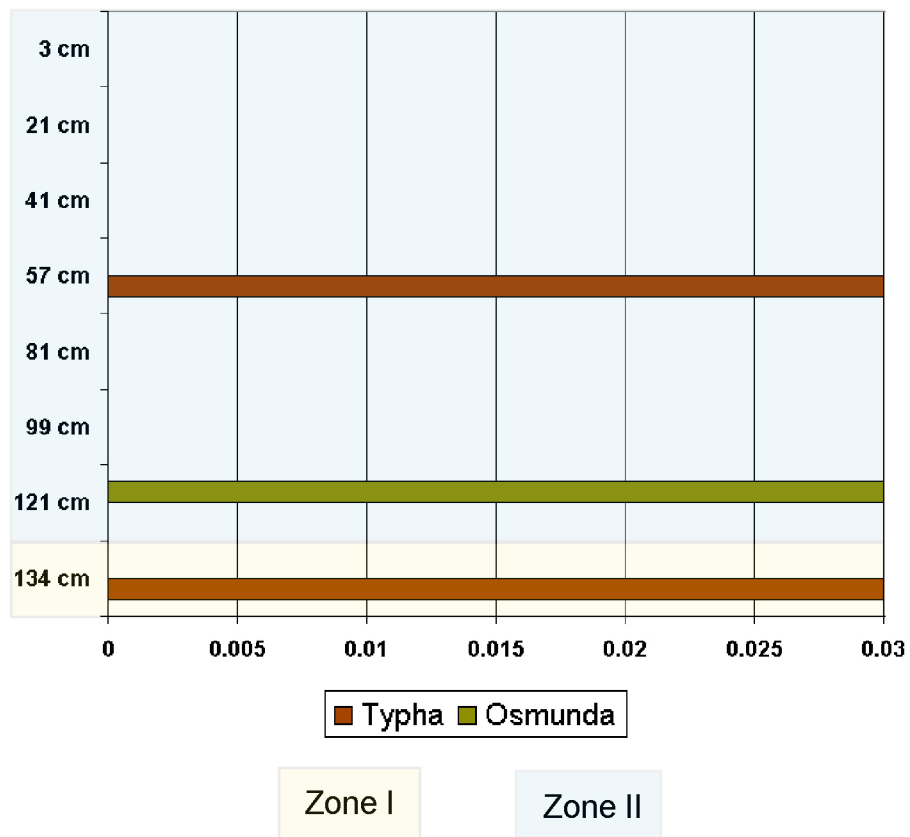
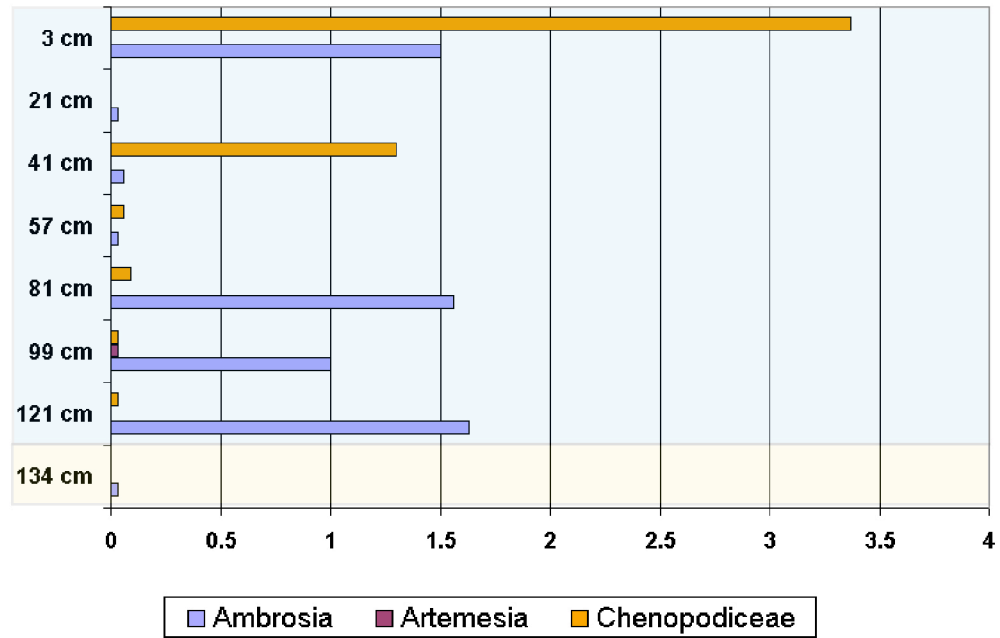


Figure 11 Core 3 Non-arboreal Percent Pollen Diagram

total organic content downcore alone, since grains of *Nyssa* (water tupelo) and *Taxodium/Juniperus* (Bald Cypress), which are often poorly preserved, were found in this sample. Perhaps this zone represents a vegetation and climate with no modern analog, an enclosed, forest of pine and deciduous species with riverine bottomlands and cypress/gum swamps.

Zone II (151-171 cm)

Zone II reflects different vegetation from the present, perhaps with no modern analog, and cooler conditions. The general trends in this sample reveal a sharp decrease in oak with increasing pine, extremely low mesic hardwood and herb species and no cypress/gum swamp species.

Upland plant community species pine, oak, hickory and beech comprise 97% of the total pollen sum. Individually, pine increases to 91%, oak decreases to 5%, hickory at 1% and beech less than 1%. Mesic hardwood species of the bottomland hardwood swamp comprise 3% of the total pollen sum. Gum forms 2% and river birch 1%, with hornbeam absent. Cypress/gum swamp species Bald Cypress and water tupelo are completely absent. Herbs, *Ambrosia*, comprise less than 1% of the total pollen sum.

Zone II of core 5 again mirrors Zone I of core 3 and suggests a cool, perhaps wetter climate, possibly with no modern analog. Pine increases and oak decreases and there is a complete absence of cypress/gum swamp species and a decline in bottomland hardwood species in all but *Liquidambar* (sweetgum). Herbs (*Ambrosia*) also decline.

Zone III – (0-151 cm)

Zone III reflects the onset of modern vegetation and increasing temperatures. General trends indicate increasing amounts in oak, herbs, bottomland hardwood swamp and cypress/gum swamp species toward the surface of the core.

Representing upland plant communities, pine, oak, hickory and beech comprise 94% of the total pollen sum (pine – 79%, oak – 14%, hickory – 1 %, beech – less than 1%). Mesic hardwood species of the bottomland hardwood swamp community represent 4% of the total pollen sum (gum – 2%, hornbeam – 1%, birch – 1%, *Alnus* (alder), *Ulmus* (elm), *Liriodendron tulipifera* (tulip poplar), *Salix* (willow) and *Acer rubrum* (maple) and *Ilex* (holly) – each with less than 1%). Cypress/gum swamp species form 1% of the total pollen sum (Bald Cypress - 1% and water tupelo less than 1%). Herbs form 2% of the total pollen sum (*Ambrosia* – 1%, *Chenopodiceae* – 1% and *Artemesia* less than 1%).

Zone III of core 5 mirrors Zone I of core 3. The general trend is that of increasing temperature and moisture toward the surface. This is evidenced by an increase of *Taxodium/Juniperus* and bottomland hardwood swamp species *Carpinus/Ostrya* (hornbeam) and *Betula nigra* (river birch). *Nyssa* (water tupelo) is present in trace amounts throughout the core towards the surface. Herbs *Ambrosia* and *Chenopodiceae* also increase upcore. These species are associated with warmer and wetter climate regimes. Both *Pinus* (pine) and *Quercus* (oak) maintain their ratios, although their frequency is diminished in the first sample interval. This is because the first sample interval was taken from the

surface clay layer, and contained a greater species density than the remaining sample intervals. The surface clay layer also contained the highest amount of organic matter and consisted of 52% clay and silt. It follows that it also contained the highest pollen concentration (45,512 grains/cc) and the best preservation, hence the presence of *Acer rubrum* (maple), which is typically a poorly preserved pollen grain.

The surface clay layer was included in Zone III, despite it being a separate sediment stratum, because it contained pollen that reflects modern vegetation and climate. Presently, the origin of the surface clay layer is unknown.

This zone is considered to represent vegetation and climate similar to the present day, consisting of pine dominated forests and hammocks of deciduous species, riverine bottomlands and cypress swamps.

Accepting the aforementioned assumptions, the lack of net sedimentation on the continental shelf after sea level rose to its present position (DePratter and Howard, 1977), and that the sediments in this region have been dated to the late Pleistocene and Early Holocene (Littman, 2000), it can only be speculated Zone I of core 3 and Zone II of core 5 may represent the Younger Dryas (12,500 – 11,400 BP), the only cooler phase that would be recorded in this sediment at this depth and distance on the continental shelf. Zone 1 of core 5 contains species that are indicative of warmer climate and may possibly represent the initial warming period after glacial retreat and sea level rise (16,500 BP-12,500 BP) up until the Younger Dryas (12,500-11,400 BP) (Zone I of core 3 and Zone II of core 5). During the Younger Dryas, the climate reverted to colder conditions (12-13° C

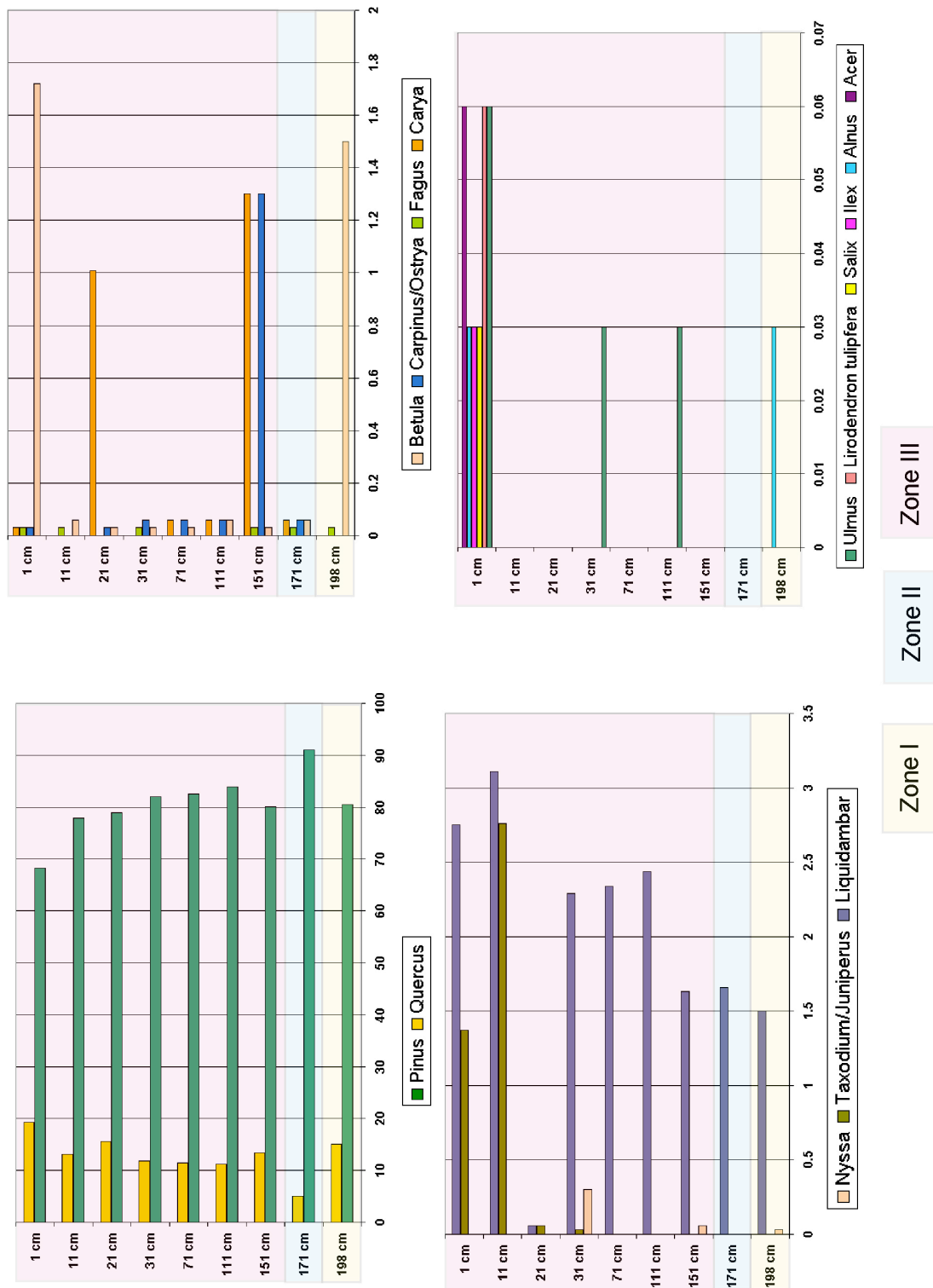


Figure 12 Core 5 Percent Arboreal Pollen Diagram

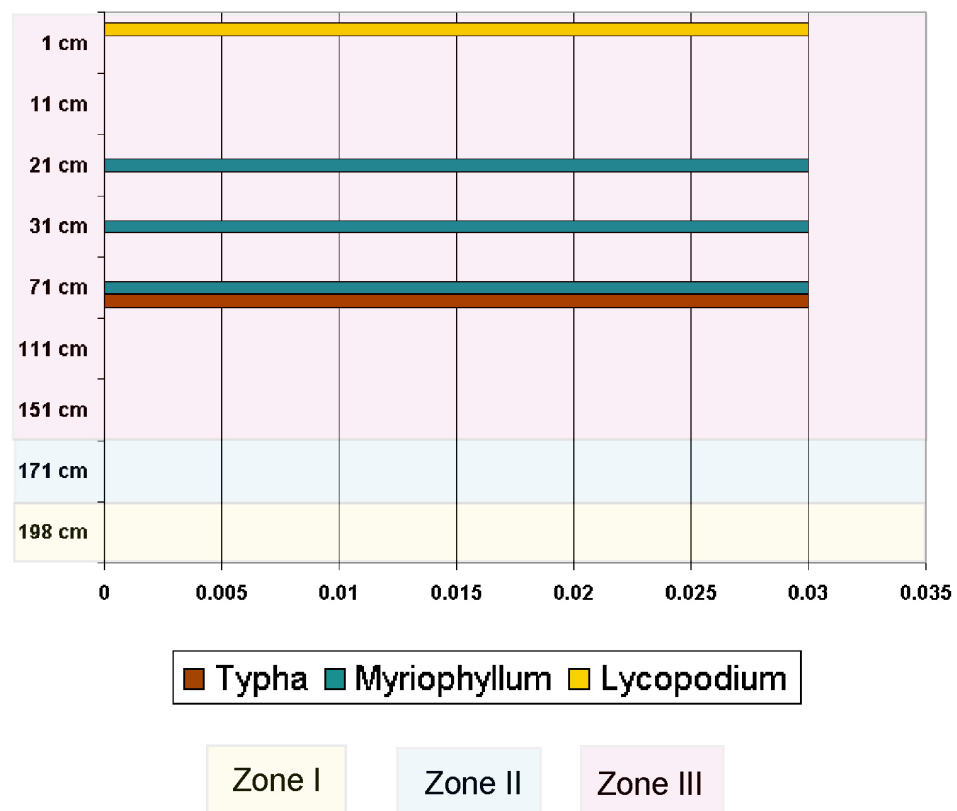
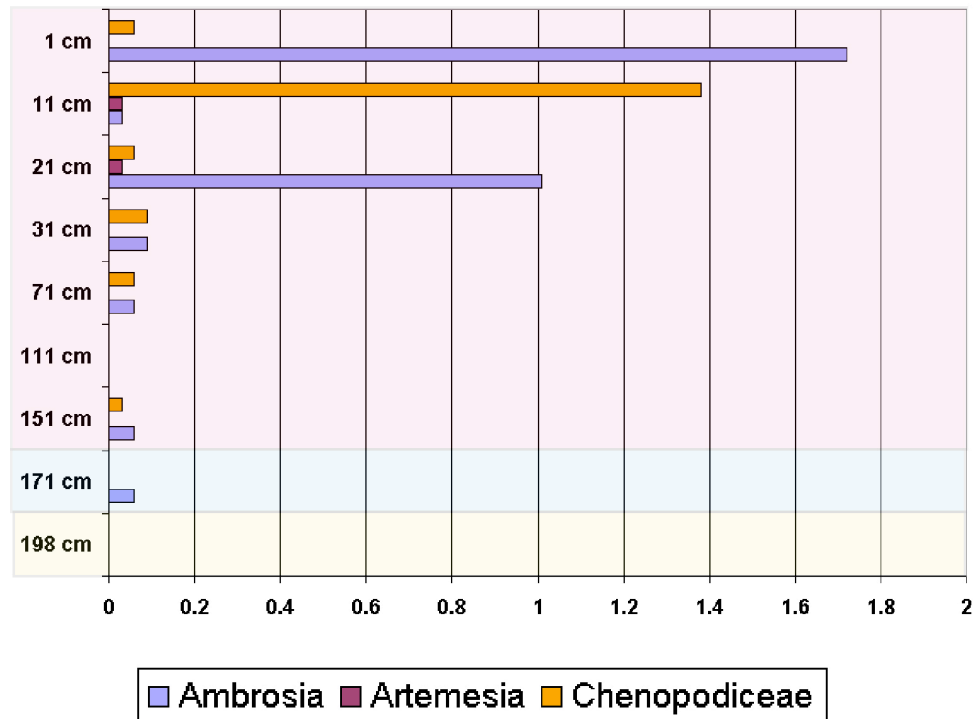


Figure 13 Core 5 Percent Non-Arboreal Pollen Diagram

colder) and the glaciers re-advanced after the initial climatic amelioration that began during the Late Glacial.

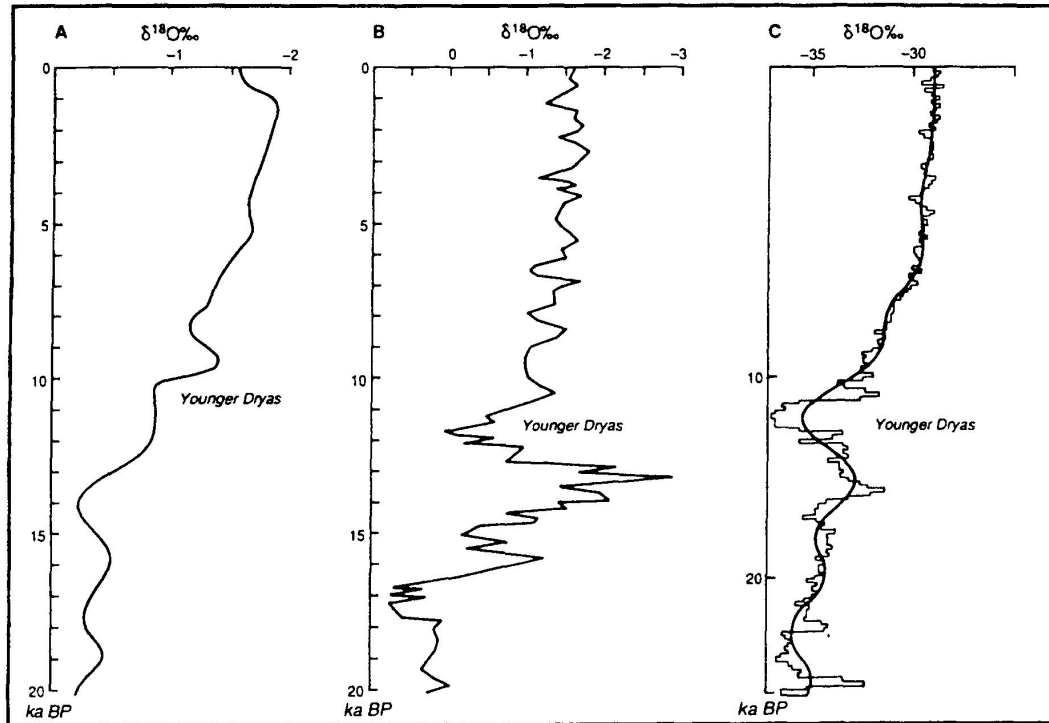
Sea level either reached a still stand or lowered in response. Oxygen isotope records from Greenland and the Gulf of Mexico reveal the return to glacial conditions during the Younger Dryas (Figure 14).

The decline in oak pollen, increase in pine pollen, and complete absence of bald cypress and tupelo would be indicative of a return to glacial conditions. Rossignol-Strick (1995) found evidence for the Younger Dryas in marine cores taken from the Mediterranean. An increase in Chenopod pollen, indicating aridity, marked the Younger Dryas. Subsequent increases in oak pollen, indicative of rising moisture, marked the amelioration of this short-lived return to glacial conditions. Lamoreaux (2000) found a similar situation in her data from the Georgia Coastal Plain. Around 11,200 BP, pine, oak, and herbs replace most mesic species. However, the presence of *Liquidambar*, a mesic species, in Zone I of core 3 and Zone II of core 5 speculated to be representative of the Younger Dryas, may also indicate that there was also more moisture on the Coastal Plain than in the interior, hence a cooler and wetter climate regime.

The lack of herbs and grasses in these pollen assemblages may be due to the dominance of pine that created enclosed forests, similar to today's pine barrens. There may be evidence for this no-analog situation from the Florida pollen data. Watts and Hansen (1988, pg. 315) stated their data indicated that the Holocene oak prairies were "...preceded by a period of abundant pine with a limited range of associated genera, either of trees or herbs. It appears to have

been an unfavorable time for mesic trees, nor did it encourage the strong development of prairie species (such as grasses) which followed in the early Holocene.”

Rapid warming around 10,000 to 9,000 BP, brought about the end of the Younger Dryas. It is suspected that complete amelioration of the Younger Dryas was accomplished in 10-20 years, resulting in an increased temperature of 7°C and up to 50% increased precipitation (Williams, et al., 1998). From the re-evaluation of existing pollen records, Shuman, et al. (2002) have found that the vegetation of Eastern North America, both on a site- specific and continental scale, shifted abruptly and dramatically at the beginning and end of the Younger Dryas. This dramatic shift is possibly recorded in these sediment cores.



Oxygen isotope record for the last 20ka indicating the Younger Dryas stadial. (A) Composite equatorial Atlantic Ocean record, based on an assumed constant sedimentation rate (from Berger et al., 1985). (B) Record from the marine sediments in the Gulf of Mexico dated by ^{14}C (from Leventer et al., 1982). (C) Record from the Greenland Dye-3 ice core dated by counting annual accumulation layers (from Dansgaard et al., 1989). (Williams, et al., 1998).

Figure 14 Oxygen Isotope Record for the Younger Dryas

CHAPTER 6

DISCUSSION AND CONCLUSION

The marine sediment collected from Gray's Reef National Marine Sanctuary contains countable and identifiable pollen and has produced a preliminary pollen record for the Georgia Bight, supporting the aforementioned hypotheses at the beginning of this study (Figure 15). However, the vegetational and paleoclimatic interpretations from the pollen data from Gray's Reef National Marine Sanctuary are debatable. In addition to the low density and frequency of pollen other than pine and oak, the lack of sediment stratigraphy and radiometric dates places serious limitations on vegetational and paleoclimatic inferences.

The low pollen density can be attributed to the sandy, shelly sediment of the continental shelf. The fine fraction that would normally trap and preserve pollen has been winnowed out during the last transgression. The provenience of the surface clay layer in core 5 is questionable. Since the pollen in the clay is indicative of the current climatic and vegetational regime, it may have been deposited in a modern storm event.

Pine and oak pollen are always over-represented in the pollen record because they are both prolific producers and preserve well due to high sporopollenin content. Pine, especially, tends to be overrepresented in marine sediment due to its baccate morphology that allows it to be wind transported great distances in addition to water transport by rivers (Heusser, 1985).

The lack of grasses and low amounts of herbs is problematic. Cooler climates are often signified by increases in grasses (*Graminae*, *Poacea*) and herbs (*Ambrosia*, *Artemesia*, *Chenopodiceae*) along with evergreen species (pine, spruce, fir). The complete absence of grasses, especially, (*Graminae*, *Poacea*) may be due to problems in identification. These large pollen grains crumple easily during transport due to a large diameter to wall thickness ratio (Davis, 2000) that renders them unidentifiable. However, the trace amount of ragweed (*Ambrosia*) and absence of *Artemesia* and *Chenopodiaceae* is puzzling and cannot be attributed solely to lack of preservation as they are usually very well preserved.

The absence of spruce and fir indicating a colder climate in the past may also seem problematic, but Brook (1996) discovered that despite the presence of spruce and fir in pollen assemblages in Northwestern Georgia, only trace amounts were found in Coastal Plain terrestrial sediment. The absence of these species in both cores from Gray's Reef may indicate that the sub-aerial continental shelf was a region for mesic and deciduous refugia located in now relict, submerged river valleys.

Despite these limiting factors, these data may serve as a rudimentary proxy for paleoclimatic and vegetational reconstruction of the Georgia Coastal Plain, which at one time extended to the shelf break during the past 20,000 years. It is remarkable that both cores yielded almost identical results of pine and oak pollen percentages changing in the same direction and magnitude downcore, especially since they were collected more than 5 km from each other. This biostratigraphic

marker could be representative of a past vegetation event. It is tempting to assign this event to the Younger Dryas because of a seemingly abrupt, vegetation change associated with cooler temperatures and the placement of the Younger Dryas sea level (-20 meters msl) in this area of the Georgia Bight at Gray's Reef.

Additional data need to be collected to confirm whether the identified biostratigraphic marker in cores 3 and 5 truly represents a vegetational event. The lack of radiometric dates and stratigraphy in this data render the pollen interpretation speculative, but will assist in further studies of prehistory at Gray's Reef National Marine Sanctuary.

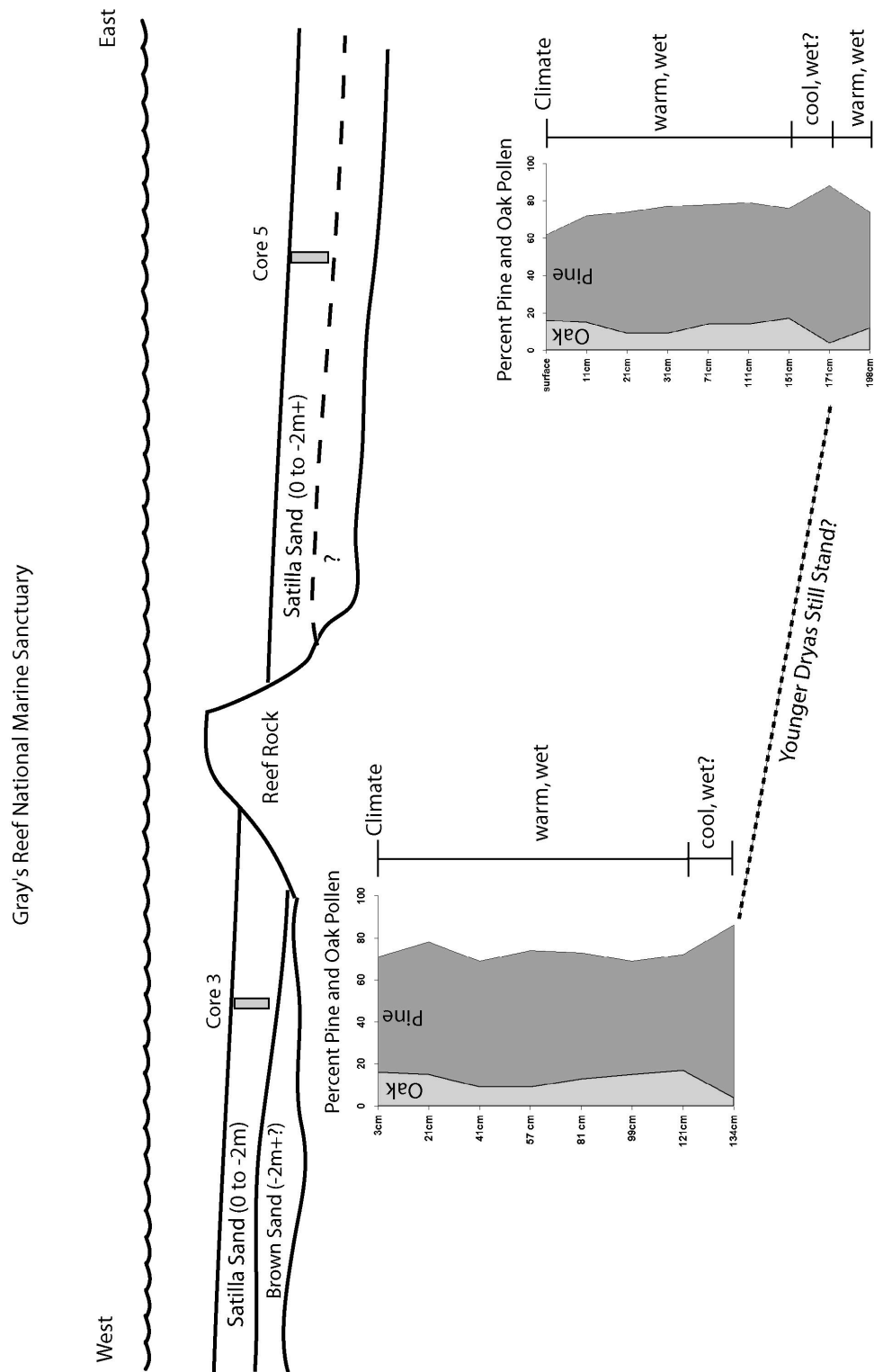


Figure 15 Geomorphological Model of Gray's Reef National Marine Sanctuary

ADDENDUM

Two dates from core 5 were obtained via Optically Stimulated Luminescence (OSL). The date at 30 cm was 24,023 +/- 4954 years and at 170 cm, 23,702 +/-5499 years. The earlier hypothesis of the core 5 pollen assemblage at 170 cm representing the Younger Dryas is now untenable. However, these dates may represent a vegetational and climatic fluctuation within the Plum Point interstadial during the Last Glacial Maximum.

It is possible that the Younger Dryas may be found in the sediments above 30 cm or that it is not expressed at all in the pollen assemblage in the Southeastern United States. Additional cores and a finer resolution pollen record need to be obtained to determine whether the Younger Dryas is expressed in these sediments.

Additionally, the exciting discovery of an Archaic (8,000 -1,000 BC) projectile point at the reef in August, 2002, should provide impetus to further archaeological and paleoenvironmental research at Gray's Reef National Marine Sanctuary. The date of this projectile point corresponds agreeably to the earlier discovery of a bison (*Bison bison*) bone dated to 8,000 years BP (6,000 years BC).

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APPENDIX A
RESULTS OF SEDIMENT ANALYSES

Sample Number	Interval	SI Units
1	2-3 cm (surface)	3.93×10^{-5}
	10-11 cm	2.64×10^{-5}
2	20-21 cm	2.97×10^{-5}
	30-31 cm	3.1×10^{-5}
3	40-41 cm	2.91×10^{-5}
	49-50 cm	2.01×10^{-5}
4	56-57 cm	1.91×10^{-5}
	68-69 cm	3.71×10^{-5}
5	80-81 cm	4.65×10^{-5}
	90-91 cm	3.29×10^{-5}
6	100-101 cm	2.26×10^{-5}
	110-111 cm	6.43×10^{-5}
7	120-121 cm	3.49×10^{-5}
	130-131 cm	3.41×10^{-5}
8	135-136 cm (base)	3.41×10^{-5}

Core 3 Magnetic Susceptibility Results

Sample Number	Interval	SI Units
9	0-1 cm (surface)	4.99×10^{-5}
10	10-11 cm	1.74×10^{-5}
11	20-21 cm	1.38×10^{-5}
12	30-31 cm	$.92 \times 10^{-5}$
	40-41 cm	1.15×10^{-5}
13	50-51 cm	$.63 \times 10^{-5}$
	60-61 cm	$.8 \times 10^{-5}$
14	70-71 cm	1.42×10^{-5}
	80-81 cm	1.07×10^{-5}
15	90-91 cm	1.22×10^{-5}
	100-101 cm	1.07×10^{-5}
16	110-111 cm	$.92 \times 10^{-5}$
	120-121 cm	$.73 \times 10^{-5}$
17	130-131 cm	1.09×10^{-5}
	140-141 cm	$.98 \times 10^{-5}$
18	150-151 cm	2.01×10^{-5}
	160-161 cm	2.16×10^{-5}
19	170-171 cm	1.68×10^{-5}
	180-181 cm	$.84 \times 10^{-5}$
	190-191 cm	1.24×10^{-5}
20	199-200 cm (base)	1.4×10^{-5}

Core 5 Magnetic Susceptibility Results

Sample Number	Interval	Sand %	Clay/Silt %
Core 3			
1	2-3 cm (surface)	96	4
2	20-21cm	94	6
3	40-41cm	96	4
4	56-57cm	96	4
5	80-81cm	96	4
6	98-99cm	96	4
7	120-121cm	97	3
8	135-136cm	96	4
Core 5			
9	0-1cm (surface)	48	52
10	10-11cm	97	3
11	20-21cm	97	3
12	30-31cm	96	4
14	70-71cm	97	3
16	110-11cm	97	3
18	150-151cm	97	3
19	170-171cm	97	3
20	199-200 (base)	98	2

Fleaker Particle Size Analysis Results

Sample Number	Interval	LOI
Core 3		
1	2-3 cm (surface)	0.819
	10-11 cm	0.675
2	20-21 cm	0.62
	30-31 cm	0.687
3	40-41 cm	0.555
	49-50 cm	0.577
4	56-57 cm	0.621
	68-69 cm	0.534
5	80-81 cm	0.542
	90-91 cm	0.49
6	98-99 cm	0.557
	110-111 cm	0.558
7	120-121 cm	0.639
	130-131 cm	0.774
8	135-136 cm (base)	0.855
Core 5		
9	0-1cm (surface)	6.744
10	10-11 cm	1.025
11	20-21 cm	0.843
12	30-31 cm	0.6
	40-41 cm	0.51
13	50-51 cm	0.504
	60-61 cm	0.545
14	70-71 cm	0.528
	80-81 cm	0.389
15	90-91 cm	0.505
	100-101 cm	0.497
16	110-111 cm	0.487
	120-121 cm	0.499
17	130-131 cm	0.45
	140-141 cm	0.515
18	150-151 cm	0.675
	160-161 cm	0.617
19	170-171 cm	0.731
	180-181 cm	0.629
	190-191 cm	0
20	199-200 cm (base)	0.872

Loss on Ignition Results

APPENDIX B
RESULTS OF POLLEN ANALYSIS

Sample Number	Interval	Grains/cm ³
Core 3		
1	2-3 cm (surface)	3,559
2	20-21cm	2,501
3	40-41cm	1,467
4	56-57cm	2,478
5	80-81cm	1,019
6	98-99cm	902
7	120-121cm	2,479
8	135-136cm	5,640
Core 5		
9	0-1cm (surface)	45,512
10	10-11cm	3,680
11	20-21cm	2,985
12	30-31cm	2,944
14	70-71cm	2,315
16	110-111cm	2,346
18	150-151cm	2,432
19	170-171cm	2,870
20	199-200 (base)	1,312

Pollen Concentration

TAXA	3 cm	21cm	41cm	57cm	81cm	99cm	121cm	134cm
<i>Pinus</i>	237	227	238	253	247	225	228	259
<i>Picea</i>	0	0	0	0	0	0	0	0
<i>Taxodium/Juniperus</i>	7	1	0	3	3	0	1	0
<i>Quercus</i>	54	45	32	30	47	48	54	12
<i>Nyssa</i>	3	0	0	0	0	1	0	0
<i>Alnus</i>	0	0	0	1	0	1	0	0
<i>Liquidambar styraciflua</i>	0	5	7	5	6	6	6	4
<i>Betula</i>	1	1	1	2	6	2	4	0
<i>Carpinus/Ostrya</i>	8	1	2	1	0	2	0	1
<i>Carya</i>	0	0	2	1	0	1	4	1
<i>Ulmus</i>	0	0	2	1	2	0	0	0
<i>Liriodendron tulipifera</i>	0	0	0	1	0	0	0	0
<i>Fagus</i>	0	0	16	6	0	6	2	0
<i>Salix</i>	0	0	0	0	0	1	0	0
<i>Acer</i>	0	0	0	0	0	0	0	0
<i>Castanea</i>	0	0	1	0	0	1	0	0
<i>Ilex</i>	0	0	0	0	0	0	0	0
<i>Smilax</i>	0	0	0	1	0	0	0	0
<i>Ambrosia type</i>	5	1	2	1	5	3	5	1
<i>Artemesia</i>	0	0	0	0	0	1	0	0
<i>Chenopodiaceae</i>	11	0	4	2	3	1	1	0
<i>Lycopodium</i>	0	0	0	0	0	0	0	0
<i>Osmunda</i>	0	0	0	0	0	0	1	0
<i>Myriophyllum</i>	0	0	0	0	0	0	0	0
<i>Typha</i>	0	0	0	1	0	0	0	1
Unknown & Indeterminate	9	11	37	32	18	29	10	21
<i>Eucalyptus</i>	2883	3575	7180	4215	10133	11137	3904	1629

Core 3 Raw Pollen Data

TAXA	3 cm	21cm	41cm	57cm	81cm	99cm	121cm	134cm
<i>Pinus</i>	72.69	80.78	77.52	82.14	77.42	75.25	74.75	93.16
<i>Picea</i>	0	0	0	0	0	0	0	0
<i>Taxodium/Juniperus</i>	2.14	0.03	0	0.097	0.09	0	0.03	0
<i>Quercus</i>	16.56	16.01	10.42	9.74	14.73	16.05	17.7	4.31
<i>Nyssa</i>	0.09	0	0	0	0	0.03	0	0
<i>Alnus</i>	0	0	0	0.03	0	0.03	0	0
<i>Liquidambar styraciflua</i>	0	1.77	2.28	1.62	1.88	2	1.96	1.43
<i>Betula</i>	0.03	0.03	0.03	0.06	1.8	0.06	1.31	0
<i>Carpinus/Ostrya</i>	2.45	0.03	0.03	0.03	0	0.06	0	0.03
<i>Carya</i>	0	0	0.06	0.03	0	0.03	1.31	0.03
<i>Ulmus</i>	0	0	0.06	0.03	0.06	0	0	0
<i>Liriodendron tulipifera</i>	0	0	0	0.03	0	0	0	0
<i>Fagus</i>	0	0	5.21	1.94	0	2	0.06	0
<i>Salix</i>	0	0	0	0	0	0.03	0	0
<i>Acer</i>	0	0	0	0	0	0	0	0
<i>Castanea</i>	0	0	0.03	0	0	0.03	0	0
<i>Ilex</i>	0	0	0	0	0	0	0	0
<i>Smilax</i>	0	0	0	0.03	0	0	0	0
<i>Ambrosia type</i>	1.5	0.03	0.06	0.03	1.56	1	1.63	0.03
<i>Artemesia</i>	0	0	0	0	0	0.03	0	0
<i>Chenopodiaceae</i>	3.37	0	1.3	0.06	0.09	0.03	0.03	0

Core 3 Percent Pollen Data

TAXA	1cm	11cm	21cm	31cm	71cm	111cm	151cm	171cm	198cm
<i>Pinus</i>	198	225	233	250	246	240	245	273	267
<i>Picea</i>	0	0	0	0	0	0	1	0	0
<i>Taxodium/Juniperus</i>	4	8	2	0	1	0	0	0	0
<i>Quercus</i>	56	38	46	36	34	32	41	15	50
<i>Nyssa</i>	0	0	0	1	0	0	2	0	1
<i>Alnus</i>	1	0	0	0	0	0	0	0	1
<i>Liquidambar styraciflua</i>	8	9	2	7	7	7	5	5	5
<i>Betula</i>	5	2	1	1	1	2	1	2	5
<i>Carpinus/Ostrya</i>	1	0	1	2	2	2	3	0	0
<i>Carya</i>	1	0	3	0	2	2	4	2	0
<i>Ulmus</i>	2	0	0	1	1	1	0	0	0
<i>Liriodendron tulipifera</i>	2	0	0	0	0	0	0	0	0
<i>Fagus</i>	1	1	0	1	0	0	1	1	3
<i>Salix</i>	1	0	0	0	0	0	0	0	0
<i>Acer</i>	2	0	0	0	0	0	0	0	0
<i>Castanea</i>	0	0	0	0	0	0	0	0	0
<i>Ilex</i>	1	0	0	0	0	0	0	0	0
<i>Smilax</i>	0	0	0	0	0	0	0	0	0
<i>Ambrosia type</i>	5	1	3	3	2	0	2	2	0
<i>Artemisia</i>	0	1	1	0	0	0	0	0	0
<i>Chenopodiaceae</i>	2	4	2	3	2	0	1	0	0
<i>Lycopodium</i>	1	0	0	0	0	0	0	0	0
<i>Osmunda</i>	0	0	0	0	0	0	0	0	0
<i>Myriophyllum</i>	0	0	1	1	1	0	0	0	0
<i>Typha</i>	0	0	0	0	1	0	0	0	0
Unknown and Indeterminate	30	22	20	17	13	19	18	9	28
<i>Eucalyptus</i>	144	2157	2693	2240	2761	2654	2720	2198	4199

Core 5 Raw Pollen Data

TAXA	1cm	11 cm	21 cm	31 cm	71 cm	111 cm	151 cm	171 cm	198 cm
<i>Pinus</i>	68.27	77.85	79	81.96	82.55	83.9	80.1	91	80.4
<i>Picea</i>	0	0	0	0	0	0	0.03	0	0
<i>Taxodium/Juniperus</i>	1.37	2.76	0.06	0.03	0	0	0	0	0
<i>Quercus</i>	19.31	13.14	15.6	11.8	11.4	11.2	13.4	5	15.1
<i>Nyssa</i>	0	0	0	0.03	0	0	0.06	0	0.03
<i>Alnus</i>	0.03	0	0	0	0	0	0	0	0.03
<i>Liquidambar styraciflua</i>	2.75	3.11	0.06	2.29	2.34	2.44	1.63	1.66	1.5
<i>Betula</i>	1.72	0.06	0.03	0.03	0.03	0.06	0.03	0.06	1.5
<i>Carpinus/Ostyra</i>	0.03	0	0.03	0.06	0.06	0.06	1.3	0.06	0
<i>Carya</i>	0.03	0	1.01	0	0.06	0.06	1.3	0.06	0
<i>Ulmus</i>	0.06	0	0	0.03	0	0.03	0	0	0
<i>Liriodendron tulipifera</i>	0.06	0	0	0	0	0	0	0	0
<i>Fagus</i>	0.03	0.03	0	0.03	0	0	0.03	0.03	0.03
<i>Salix</i>	0.03	0	0	0	0	0	0	0	0
<i>Acer</i>	0.06	0	0	0	0	0	0	0	0
<i>Castanea</i>	0	0	0	0	0	0	0	0	0
<i>Ilex</i>	0.03	0	0	0	0	0	0	0	0
<i>Smilax</i>	0	0	0	0	0	0	0	0	0
<i>Ambrosia type</i>	1.72	0.03	1.01	0.09	0.06	0	0.06	0.06	0
<i>Artemesia</i>	0	0.03	0.03	0	0	0	0	0	0
<i>Chenopodiaceae</i>	0.06	1.38	0.06	0.09	0.06	0	0.03	0	0

Core 5 Percent Pollen Data