U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

PALEONTOLOGY AND PHYSICAL STRATIGRAPHY OF THE USGS - PREGNALL NO. 1 CORE (DOR-208), DORCHESTER COUNTY, SOUTH CAROLINA

by

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Open-file Report 97-145

Prepared in cooperation with the
U.S. Department of Energy - Savannah River Site

[1] Reston, Virginia

1997

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ABSTRACT

Pregnall No. 1, a 346-ft-deep corehole in northern Dorchester County, South Carolina, recovered sediments of late Paleocene, middle and late Eocene, and late Oligocene age. The core bottomed in the Chicora Member of the Williamsburg Formation (Black Mingo Group) of late Paleocene age (calcareous nannofossil Zones NP 7/8 (?) and NP 9). The Chicora (346 to 258 ft depth) consists of two contrasting lithologic units, a lower siliciclastic section of terrigenous sand, silt, and clay, and an upper carbonate section of moldic pelecypod limestone. The Chicora is overlain unconformably by the middle Eocene Moultrie Member of the Santee Limestone (Orangeburg Group). The Moultrie (258.0 to 189.4 ft) consists primarily of bryozoan-pelecypod-peloid packstones and grainstones, which are assigned to calcareous nannofossil Zone NP 16. Unconformably above the Moultrie are the locally shelly, microfossiliferous limestones of the Cross Member of the Santee Limestone (Orangeburg Group), which are assigned to middle Eocene Zone NP 17 and upper Eocene Zone NP 18. The Cross Member (189.4 to 90.9 ft) is unconformably overlain by a very thin, basal section of the upper Eocene Harleyville Formation (Cooper Group). The thin Harleyville section consists of fossiliferous limestone, primarily pelecypod-foraminifer-peloid packstones (90.9 to 85.8 ft), and is assigned to Zone NP 18, although samples from thicker Harleyville sections in the region typically are assigned to upper Eocene Zone NP 19/20. The Harleyville is overlain unconformably by the upper Oligocene Ashley Formation (Cooper Group). The Ashley Formation (85.8 to 30.0 ft) consists of a relatively homogeneous section of calcareous, microfossiliferous, silty and sandy clays assigned to Zones NP 24 and NP 25 (?). Neogene and (or) Quaternary deposits present in the upper 30 ft of the Pregnall section are assigned provisionally to an unnamed unit (30 to 22 ft) and to the Waccamaw Formation(?)(22 to 0 ft).

INTRODUCTION

The U.S. Geological Survey (USGS) drilled two stratigraphic test holes in northern Dorchester County, South Carolina, in 1982 (fig. 1). The Pregnall test hole was drilled in January and February by USGS personnel at a site near the community of Pregnall. The St. George test hole (Reid and others, 1986; Self-Trail and Gohn, 1996) was drilled in the summer of 1982 by a commercial driller at a site southwest of the community of Byrd, about 3 miles southeast of the town of St. George and about 3 miles west of Pregnall. Both drill sites are located in the Coastal Plain physiographic province.

The Pregnall test hole was continuously cored to a total depth of 346 ft and recovered Paleocene, Eocene, and Oligocene sections that were largely unsampled at St. George. The St. George test hole was drilled to a total depth of 2,067 ft and bottomed in Jurassic(?) basalt beneath a Cretaceous and Cenozoic Coastal Plain section. The St. George test hole was continuously cored from a depth of 300 ft to 2,067 ft; only a few poorly recovered spot cores were taken in the lower Tertiary sediments above 300 ft (Reid and others, 1986).

The USGS-Pregnall core site (fig. 1) is located in the southwest quarter of the Harleyville 7.5-minute quadrangle (1:24,000 scale). The site is located about 500 ft north of highway 78, about 2,400 ft northwest of the railroad intersection at Pregnall and about 1,100 ft southeast of St. Marks Church. Reid and others (1986) placed the site at lat 33°09'08"N, long 80°28'14"W. Ground elevation at the site is +85 ft. The Pregnall test hole is designated as drill hole DOR-208 by the USGS and as drill hole 24Z-d2 by the South Carolina Department of Natural Resources. The Pregnall core currently (April 1997) is stored at the USGS Herndon warehouse near the USGS National Center, Reston, Virginia.

In this report, we provide stratigraphic, lithologic, and paleontologic data and analyses for the Paleogene section in the Pregnall core. Calcareous nannofossils, dinoflagellates, and pollen were studied from units of Paleocene, Eocene, and Oligocene age. The results from this core may be compared with results from the intensively studied USGS-Clubhouse Crossroads No. 1 core, located in southern Dorchester County (Hazel and others, 1977; Frederiksen and Christopher, 1978; Frederiksen, 1980b; Gohn and others, 1983). Comparison of the Pregnall core and the St. George No. 1 core (Self-Trail and Gohn, 1996) with the Coastal Plain section near the Savannah River (Aadland and others, 1995; Falls and others, 1997) illustrates substantial

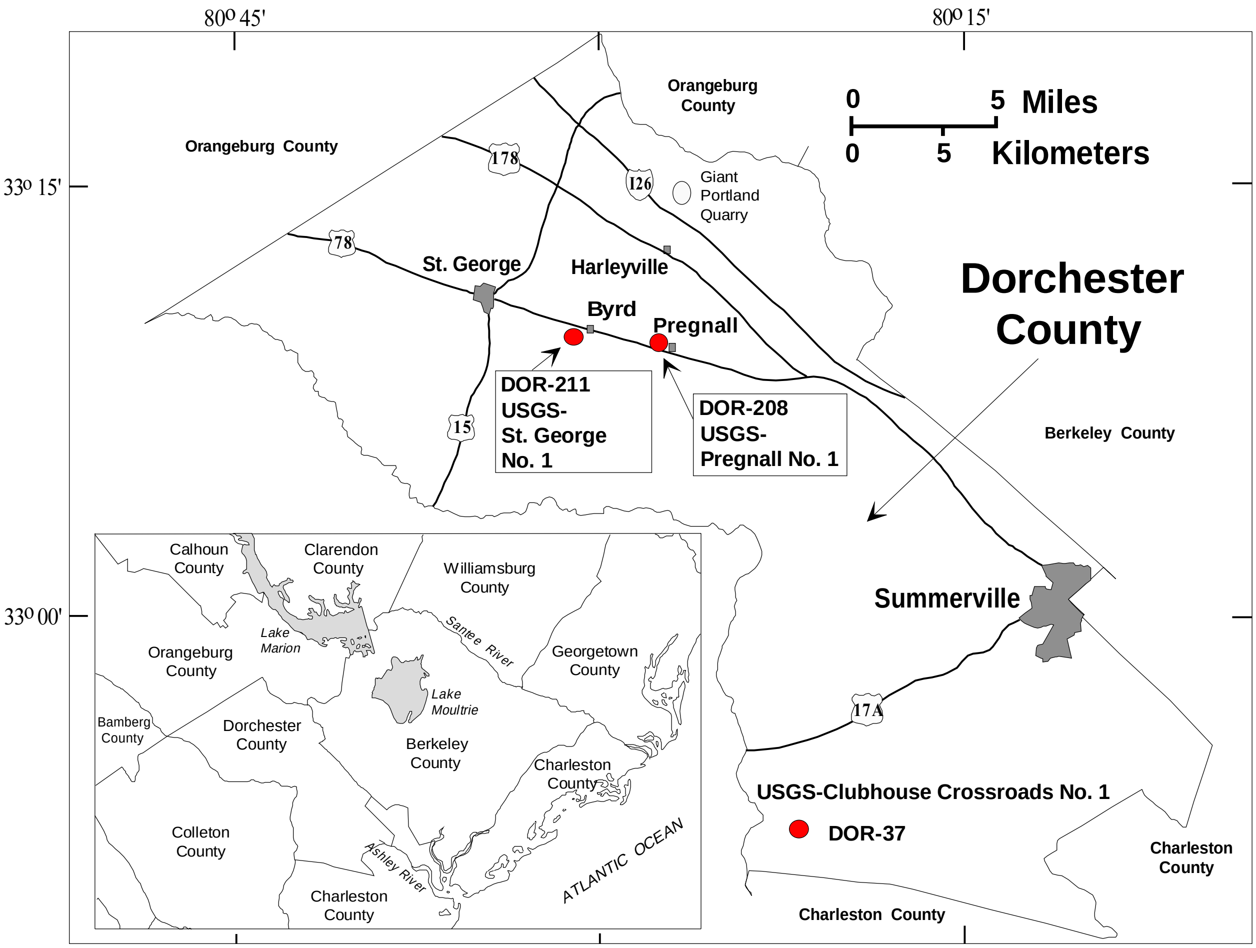

Figure 1. Index map showing location of the Pregnall No. 1 core site.

regional differences in the distributions, facies, and thicknesses of Cretaceous and Tertiary stratigraphic units.

Coastal Plain biostratigraphic studies are often difficult due to poor recovery of any particular fossil group in one or more parts of the section. Integrated studies using both calcareous and noncalcareous microfossils can provide more complete stratigraphic coverage and, by documenting ranges of noncalcareous fossils where calcareous fossils give good resolution, will allow accurate correlations in future updip applications.

Acknowledgments

Funding for the stratigraphic analysis of the Pregnall core was provided by the U.S. Department of Energy - Savannah River Site. The Pregnall corehole was drilled by USGS drillers Dennis W. Duty and Donald G. Queen using a hydraulic-rotary, wireline coring rig. We thank Thomas P. Sheehan (USGS) for processing the palynological samples and Jean M. Self-Trail (USGS) and Amanda Chapman (USGS and George Mason University) for processing the calcareous nannofossil samples. Reviews by W. Fred Falls (USGS), Tommy J. Temples (DOE), and Robert E. Weems (USGS) are gratefully acknowledged.

Unit conversions

U.S. customary units are used throughout this report except for descriptions of grain size and pore size, and measurements used in processing methods, which are given in metric units. To convert millimeters to inches, multiply the value in millimeters by 0.03937. To convert micrometers to inches, multiply the value in micrometers by 0.00003937.

METHODS

Lithology

General lithologic descriptions of the sediments and notations of the stratigraphic contacts were prepared during an initial examination of the Pregnall core. This general information was supplemented by a more detailed lithologic analysis of 54 samples from the core. The samples were examined using a 10x hand lens and a low-power binocular microscope. Notations of gross lithologies, grain size, textures, mineralogy, fossil content, colors, structures, and porosity were obtained using standard charts and visual aids. No thin sections were examined. All sediment colors mentioned in the text refer to dry samples.

Dunham's (1962) classification of limestones by depositional texture was used to characterize the Paleocene and Eocene limestones in the core. Folk's (1962, table II) grain-size scale was used to characterize the size of allochems (principally fossils) in the limestones. Porosity in the limestones was described using Choquette and Pray's (1970) terminology for the classification of carbonate porosity. However, percentages of basic porosity types were not estimated. Instead, qualitative estimates of total porosity are given as low, moderate, high, and very high. In Choquette and Pray's classification, modifiers used for the size of pore spaces are: micro- (less than 0.0625 mm), meso- (0.0625 to 4.0 mm), and mega- (4 to 256 mm).

Paleontology

Calcareous nannofossils. Thirty-four calcareous nannofossil samples were collected from the Pregnall core at approximately 5- to 10-ft intervals. For each sample, a small amount of sediment was extracted from the central portion of a core segment (freshly broken where possible). The samples were dried in a convection oven to remove residual water, and the resultant sediment was placed in vials for long-term storage in the calcareous nannofossil laboratory at the U.S. Geological Survey in Reston, Virginia. A small amount of sample was placed in a beaker, stirred, and settled through 2 cm of water. The first settling time was one minute to remove the coarse material; the second settling time was 10 minutes to remove finer material. Smear slides then were prepared from the remaining suspended material. Cover slips were attached to the slides using Norland Optical Adhesive (NOA-65), a clear adhesive that bonds glass to glass and cures when exposed to ultraviolet radiation. All samples were examined initially using a Zeiss Photomicroscope III. A few samples, which were determined to have the best preservation and the highest abundances of calcareous nannofossils, were later scanned using a JEOL 35 scanning electron microscope.

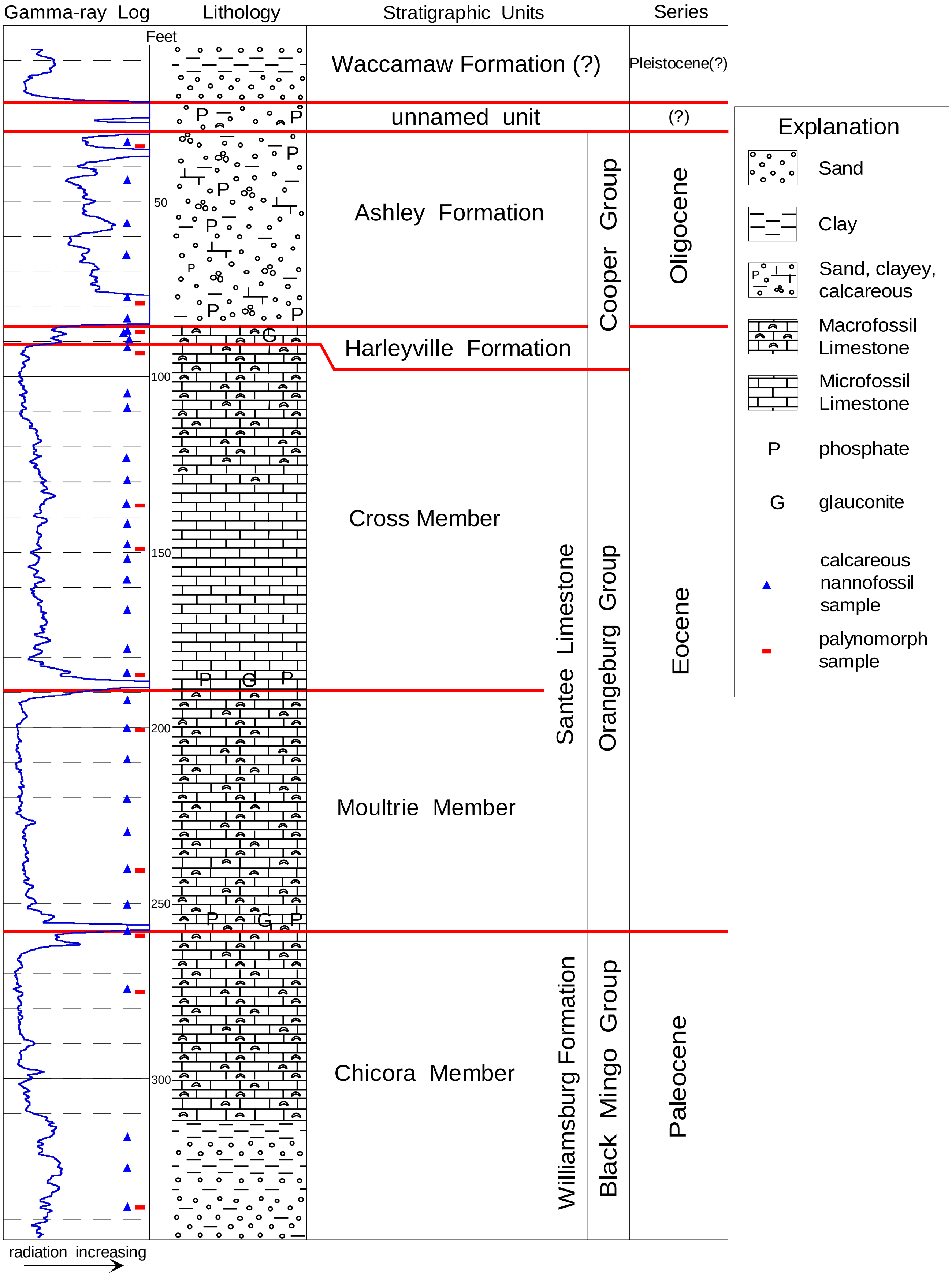

Figure 2. Stratigraphic column and gamma-ray log for Pregnall No. 1.

Palynology. Twelve samples were selected for palynological examination. Samples were treated with hydrochloric and hydrofluoric acids. Organic material was separated by using a series of soap washes and swirling. Material was stained with Bismark brown, sieved at 10 to 200 micrometers, and mounted for light microscope observation using glycerin jelly. All samples were examined for marine palynomorphs (dinocysts and acritarchs). Only two samples, both from the Ashley Formation, yielded sufficient pollen and spores to merit further study for nonmarine palynomorphs.

RESULTS AND STRATIGRAPHIC DISCUSSIONS

Stratigraphy

The Pregnall corehole penetrated 316 feet of Paleogene sediments beneath 30 ft of Neogene and (or) Quaternary deposits (fig. 2). Only a small amount of the section above 30 ft was recovered. The Paleogene section is assigned to the upper Paleocene Chicora Member of the Williamsburg Formation of the Black Mingo Group, the middle Eocene Moultrie Member of the Santee Limestone of the Orangeburg Group, the late middle and late Eocene Cross Member of the Santee Limestone of the Orangeburg Group, the upper Eocene Harleyville Formation of the Cooper Group, and the upper Oligocene Ashley Formation of the Cooper Group. Discussions of the stratigraphy, lithologies, and paleontology of these units are given in the following sections. These results are summarized in figure 3.

Paleontology

The calcareous nannofossil zonation used for the Cenozoic strata is based primarily upon the calcareous nannofossil zonation of Martini (1971) and supplementally upon the zonation of Bukry (1973, 1978) and Okada and Bukry (1980). Nannofossil biostratigraphy is based on the highest and lowest occurrences of calcareous nannofossil species; FAD indicates a first appearance datum and LAD indicates a last appearance datum. Important FAD's and LAD's are given in Appendix 1. A list of calcareous nannofossil species considered in this report is given in Appendix 2.

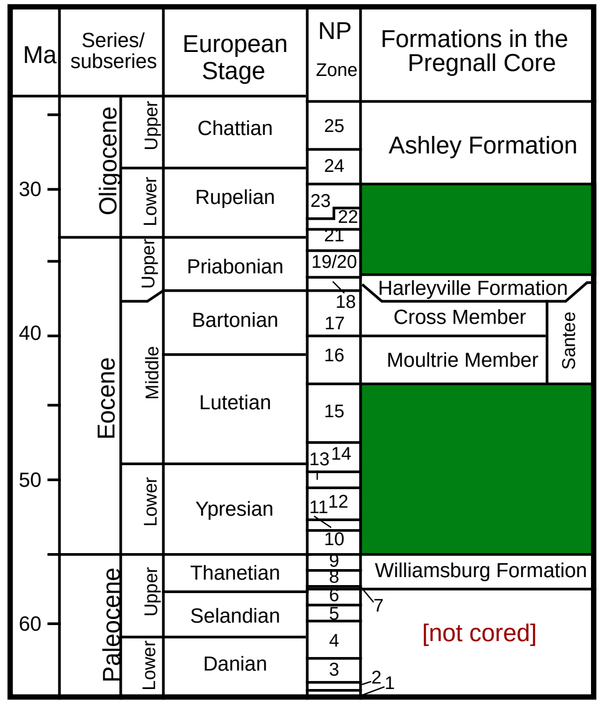

Figure 3. Series, stages, nannofossil (NP) zones, and formations in the Pregnall core. NP zones from Martini (1971), ages from Berggren and others (1995). Ma is millions of years ago. Coincidence of formation and zone boundaries does not imply that the formation spans the entire zone.

The calcareous nannofossil assemblages were sufficient in numbers of specimens, diversity of taxa, and preservational state in the Pregnall samples to allow a dating accuracy within one or two calcareous nannofossil zones (fig. 4). Calcareous nannofossil contamination is confined primarily to occasional reworked specimens of Cretaceous species. However, two samples taken from a moldic limestone of the Williamsburg Formation (at 274.8 and 258.8 ft) showed a significant amount of contamination.

Occurrences of dinocysts in 12 samples from the Pregnall core are shown in figure 5 and discussed in detail in Appendix 3. Occurrences of pollen and spores are discussed in Appendix 4. Significant contamination was observed in one sample taken from moldic limestone in the Williamsburg Formation (275.4 to 275.0 ft).

Formation	Williamsburg					Santee Ls. (Moultrie)							Santee Limestone (Cross Member)													Harleyville			Ashley					
Age	Late Paleocene					Middle Eocene																Late Eocene							Late Eoc/Early Olig.					
Calcareous Nannofossil Zone	NP 7/8 (?)	NP 9	NP 9	Contaminated	Contaminated	NP 16	NP 16	NP 16	NP 16	NP 16	NP 16	NP 16	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 18	NP 18	NP 18	NP 18	NP 18	NP 18	NP 18	NP 24	NP 24	NP 24	NP 24	NP 24	NP 25 (?)
Depth (feet)	337.0	326.3	317.1	274.8	258.8	251.4	241.0	230.9	221.5	209.0	201.6	193.6	186.5	178.8	167.3	158.5	152.6	148.7	142.8	137.6	130.9	123.3	109.5	105.6	92.7	90.3	88.7	87.4	84.3	78.8	66.2	57.3	44.6	33.8
Biscutum spp.	x																																	
Blackites spinosus/scabrosus													x																					
Blackites tenuis																						?												
Blackites spp.							x																			x								
Braarudosphaera bigelowii		x		x			x	x			x			x	x	x	x	x		x				x	x		x	x	x	x		?		
Braarudosphaera spp.																						x												
Braarudosphaera spp. tall							x																											
Bramletteius serraculoides															x																			
Campylosphaera dela	1					x	x		x		x		x																					
Cepekiella lumina							x		x				x	x		x	x	x	x	x		x			x		x							
Chiasmolithus bidens	x	x	x						x		2	2																						
Chiasmolithus grandis							x																											
Chiasmolithus oamaruensis																						1	x	x										
Chiasmolithus spp.						x						x																						
Chiasmolithus spp. large														x																				
Chiasmolithus spp. small unsplit							x		x		x	x					x													x				
Coccolithus eopelagicus				C		x	x	x	x		x		x				x		x	x										x	x	x		
Coccolithus pelagicus	x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cribrocentrum reticulatum	C			C				x				x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x						
Cruciplacolithus spp.		x					x												x	x	x										?			
Cyclagelosphaera prima	x		x																															
Cyclococcolithus formosus	C			C		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					1	
Cyclococcolithus protoannulus						x	x	x	x				x	x		x	x	x	x	x		x		x	x	x	x	x						
Cyclococcolithus spp.																															x			
Dictyococcites bisectus							x						x	x	x	x	x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
Dictyococcites scrippsae				C								x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Discoaster barbadiensis				C		x	x	x					x	x			x	x	x	x		x												
Discoaster distinctus/deflandrei							x																											
Discoaster kuepperi								?																										
Discoaster lenticularis		x																																
Discoaster megastypus							?																											
Discoaster mohleri	x																																	
Discoaster multiradiatus		x	x																															
Discoaster nodifer						?																												
Discoaster saipanensis	C							x				x	x	x	x	x	x	x	x	x			x				x	x						
Discoaster salisburgensis		x																																
Discoaster tanii																	?																	
Discoaster spp.									x				x	x										x								x		
Discoturbella moorei																				x														
Ericsonia obruta				C			x	x	x				x	x					x						x		x	x	x	x		x	x	x
Ericsonia subpertusa	x	x	x																															
Fasciculithus alanii		x	x																															
Fasciculithus aubertae		?	?																															
Fasciculithus involutus	x	x	x																															
Fasciculithus tympaniformis		x																																
Goniolithus fluckigeri																x						x								x				
Helicosphaera bramlettei							?																							x	x	x		x
Helicosphaera carteri																													x	x	x	x	x	x
Helicosphaera compacta													x	x	x				x	x		x												
Helicosphaera euphratis																													x		x		x	
Helicosphaera intermedia							?																							x	x	x		x
Helicosphaera lophota						x								x																				
Helicosphaera recta																													x		x			
Helicosphaera reticulata														x																				
Helicosphaera seminulum														x					x															
Abundance	C-	F+	F+	F+	R	C+	C+	C+	C-		F-	C-	F+	C-	C+	A	C-	A	A	C+	A	C-	A	C	C-	C-	C-	C-	C-	C+	A	C-	A	C-	C+
Preservation	F	F-	F	F-	P	P	F-	P	P	P	P-	P	P	P	P	P	P	P	P	P	P-	P	P	P	P	P	P	P	F	F+	F	F	F-	F-

Figure 4. Calcareous nannofossil occurrences in the Pregnall No. 1 core, South Carolina. In the body of the table: x, present; 1, only one specimen observed in entire sample; C, specimens likely from reworking or downhole contamination; ? possible occurrence. For Abundance row: A, abundant or greater than 10 specimens per field of view at 500x; C, common or 1 to 10 specimens per field of view at 500x; F, frequent or 1 specimen per 1 to 10 fields of view at 500x; R, rare or 1 specimen in greater than 10 fields of view at 500x. For Preservation row: F, fair; P, poor.

Formation	Williamsburg					Santee Ls. (Moultrie)							Santee Limestone (Cross Member)													Harleyville			Ashley					
Age	Late Paleocene					Middle Eocene																Late Eocene							Late Eoc/Early Olig.					
Calcareous Nannofossil Zone	NP 7/8 (?)	NP 9	NP 9	Contaminated	Contaminated	NP 16	NP 16	NP 16	NP 16	NP 16	NP 16	NP 16	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 18	NP 18	NP 18	NP 18	NP 18	NP 18	NP 18	NP 24	NP 24	NP 24	NP 24	NP 24	NP 25 (?)
Depth (feet)	337.0	326.3	317.1	274.8	258.8	251.4	241.0	230.9	221.5	209.0	201.6	193.6	186.5	178.8	167.3	158.5	152.6	148.7	142.8	137.6	130.9	123.3	109.5	105.6	92.7	90.3	88.7	87.4	84.3	78.8	66.2	57.3	44.6	33.8
Helicosphaera seminulum/bramlettei																x																		
Helicosphaera spp.																x																		
Heliolithus spp.	2																																	
Markalius inversus						x	x	x				x		x	x	x	x	x	x	x		x	x		x	x	x	x						
Micrantholithus crenulatus						?																												
Micrantholithus flos																															?			
Micrantholithus procerus														x																				
Micrantholithus spp.														x	x	x	x													x		x		
Neochiastozygus concinnus	x	x	x																															
Neochiastozygus imbriei	x																																	
Neococcolithes dubius																	x																	
Neococcolithes spp.	x			x		x	x		x			x	x	x	x	x		x	x	x		x	x											
Neocrepidolithus spp.	x																																	
Pedinocyclus larvalis															x			x																
Pemma basquense												x	x							x					x		x	x						
Pemma basquense/serratum																		x																
Pemma papillatum														x																				
Pemma serratum														x																				
Pemma stradneri								x																										
Pemma spp.																			x	x														
Placozygus sigmoides	x																																	
Pontosphaera multipora																																		
Pontosphaera wechesensis																	x																	
Pontosphaera spp.				x		x	x						x	x	x		x	x	x	x		x	x			x	x	x		x	x	x	x	x
Prinsius spp.	x																																	
Pseudotriquetrorhabdulus inversus						x	x	x	x			x	x	x																				
Reticulofenestra abisecta																											1		x		x		x	x
Reticulofenestra daviesii				C					x		x	x	x	x	x			x		x	x	x	x	x	x	x	x		x	x	x	x	x	x
Reticulofenestra floridana				C		x	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x	x	x						
Reticulofenestra hillae						x			x		x	x	x	x		x	x		x	x		x				x		x						
Reticulofenestra pseudolockeri																		?											x	x	x		x	x
Reticulofenestra umblicus				C		x	x	x	x		x	x	x	x		x			x	x		x				x	x		2					
Reticulofenestra spp.	C				C										x															x		x		
Reticulofenestra spp. small							x		x	x	x	x	x			x		x	x	x	x	x	x	x		x	x	x	x		x			x
Rhabdosphaera spp.				C		x	x	x	x			x		x	x	x	x	x	x	x		x	x	x	x	x	x	x			x			
Scapholithus apertus	x																																	
Sphenolithus distentus																														x	x	x	x	
Sphenolithus moriformis				C		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Sphenolithus predistentus																													?					
Sphenolithus primus	x																																	
Sphenolithus pseudoradians s.l.						x		x																		x	x			x				
Sphenolithus radians							x					x																						
Sphenolithus spp.									x																									
Thoracosphaera spp.	x																																	
Toweius callosus	x	x																																
Toweius eminens eminens	x	x																																
Toweius eminens tovae	x	x																																
Toweius pertusus	x	x	x	C																														
Toweius serotinus			x																															
Transversopontis pulcher				C					x																									
Transversopontis pulcheroides				C				x	x					x	x		x	x		x				x	x					x				
Transversopontis pulchriporus							x		x																									
Transversopontis zigzag																	x	x		x		x			x		x					x		
Transversopontis spp																												x						
Zygodiscus herlyni	x	x																																
Zygrhablithus bijugatus						x	x	x	x		x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
Abundance	C-	F+	F+	F+	R	C+	C+	C+	C-	F-	C-	F+	C-	C+	A	C-	A	A	C+	A	C-	A	C	C-	C-	C-	C-	C-	C+	A	C-	A	C-	C+
Preservation	F	F-	F	F-	P	P	F-	P	P	P	P-	P	P	P	P	P	P	P	P	P	P-	P	P	P	P	P	P	P	F	F+	F	F	F-	F-

Figure 4. continued

Formation	Williamsburg			Santee						H	Ashley	
Member	Chicora			Moultrie		Cross						
Species / depth (ft)	337	275	259	241	201	186	149	137	93	87	79	34
Areosphaeridium diktyoplokus (Klumpp) Eaton						x						
Wetzeliella simplex (Bujak) Lentin & Vozzhennikova						x						
Impagidinium sp.						x						
Hystrichostrogylon membraniphorum Agelopoulos				?								
Hystrichokolpoma rigaudiae Deflandre & Cookson		C		x		x	x	x	x	x		x
Lingulodinium polyedrum (Stein) Dodge		C		x		x	x	x	x	x	x	x
Dinopterygium cladoides Deflandre *sensu* Morgenroth (1966)		C		x			x	x	x		x	x
Spiniferites pseudofurcatus (Klumpp) Sarjeant				x		x						x
Cyclopsiella vieta Drugg & Loeblich				x		x	x	x	x	x	x	
Tectatodinium pellitum Wall				x		x	x	x	x	x	x	
Charlesdowniea coleothrypta (Wms & Downie) Lentin & Vozz.				x		x	x	x		x		
Enneadocysta arcuata (Eaton) Stover & Williams				x			x	x				
Histiocysta sp. of Stover and Hardenbol (1993)				x				x				
Pentadinium goniferum Edwards				x		x	x	x				
Cribroperidinium giuseppei (Morgenroth) Helenes				x		x	x					
Pentadinium membranaceum (Eisenack) Stover & Evitt				x		x						
Eocladopyxis n. sp.				x							R	?
Phthanoperidinium sp.				x								
Amphorosphaeridium ? *multispinosum* (Davey & Wms) Sarj.				x								
Melitasphaeridium pseudorecurvatum (Morgenroth) Bujak et al.				x								
Glaphyrocysta intricata (Eaton) Stover and Evitt				x								
Systematophora placacantha Deflandre & Cookson		x		x		x	x	x	x	x	x	
Thalassiphora pelagica (Eisenack) Eisenack & Gocht		x		x		x						
Operculodinium centrocarpum (Deflandre & Cookson) Wall	x					x	x	x	x			x
Polysphaeridium zoharyi (Rossignol) Bujak et al.	x											x
Spiniferites spp.	x	?		x		x	x	x	x	x	x	x
Cordosphaeridium gracile (Eisenack) Davey & Williams	x						x	x	x			
Diphyes colligerum (Deflandre & Cookson) Cookson	x			x				x				
Eocladopyxis peniculata Morgenroth	x	x						x				
Heteraulacacysta spp.	?					x						
Adnatosphaeridium williamsii Islam	x											
Apectodinium homomorphum (Defl. & Cookson) Lentin & Wms	x											
Apectodinium quinquelatum (Wms & Downie) Costa & Downie	x											
Hystrichokolpoma unispinum Williams & Downie	x											
Kallosphaeridium brevibarbatum De Coninck	x											
Membranosphaera maastrichta Samoilovitch	x											
Senegalinium ? *dilwynense* (Cookson & Eis.) Stover & Evitt	x											
Turbiosphaera sp. aff. *T. magnifica* Eaton of Edwards (1989)	x											
Carpatella cornuta Grigorovich				R								

Figure 5. Occurrences of dinocyst taxa in the Pregnall No. 1 core. H= Harleyville Formation, X= present, R=reworked, C=contaminated, ?=questionable, cf =compares with.

Formation	Williamsburg			Santee						H	Ashley	
Member	Chicora			Moultrie		Cross						
Species / depth (ft)	337	275	259	241	201	186	149	137	93	87	79	34
Apteodinium australiense (Deflandre & Cookson) Williams		C										x
Chiropteridium lobospinosum (Gocht) Gocht		C										x
Chiropteridium spp.												x
Distatodinium paradoxum (Brosius) Eaton												x
Batiacasphaera sphaerica Stover		C									x	x
Saturnodinium pansum (Stover) Brinkhuis et al.											x	x
Wetzeliella symmetrica Weiler											x	x
Apteodinium spiridoides Benedek											x	
Batiacasphaera hirsuta Stover											x	
Cyclopsiella chateauneufii Head et al.											x	
Membranophoridium aspinatum Gerlach											x	
Charlesdowniea stellata Damassa										x		
Samlandia chlamydophora Eisenack *sensu stricto*										x		
Trigonopyxidia fiscellata de Coninck										x		
Pentadinium laticinctum Gerlach (vermiculate forms)		C							x		x	x
Deflandrea heterophlycta Deflandre & Cookson								cf	x		x	
Adnatosphaeridium sp.									x	x		
Heteraulacacysta porosa Bujak									x			
Hystrichokolpoma cinctum Klumpp									x			
Hystrichosphaeropsis sp.									x			
Operculodinium placitum Drugg & Loeblich									x			
Samlandia sp.								x				x
Lejeunecysta sp.		C						x				x
Corrudinium incompositum (Drugg) Stover & Evitt								x		x		
Phthanoperidinium stockmansii (de Coninck) Lentin & Wms								x		x		
Nematosphaeropsis ? sp.								x				
Heteraulacacysta ? *leptalea* Eaton								x				
Cordosphaeridium minimum (Morgenroth) Benedek								x				
Thalassiphora fenestrata Liengjarern et al.							x	x	x			
Wetzeliella articulata Eisenack *sensu amplo*		C					x	x	x			
Cordosphaeridium cantharellus (Brosius) Gocht							x	x	x			
Hystrichostrogylon coninckii Heilmann-Clausen ?							x	?				
Dapsilidinium pseudocolligerum (Stover) Bujak et al.						x			x		x	x
Deflandrea phosphoritica Eisenack						x				x		x
Homotryblium plectilum Drugg & Loeblich		C				x				x	x	x
Lentinia serrata Bujak						x	x	x	x		x	
Operculodinium centrocarpum (Deflandre & Cookson) Wall		C				x	x		x		x	
Palaeocystodinium golzowense Alberti						x	x	x			x	
Achilleodinium biformoides (Eisenack) Eaton						x	x			x		
Pentadinium laticinctum Gerlach subsp. *laticinctum*						x	x	x	x	x		
Samlanidia chlamydophora Eis. *sensu* Stover and Hardenbol (1993)						x	x		x	x		
Phthanoperidinium comatum (Morgenroth) Lentin & Williams						x	x	x	x			
Areoligera-Glaphyrocysta complex						x	x	x				
Distatodinium ellipticum (Cookson) Eaton						x		x				
Millioudodinium sp. I of Edwards (1984)						x		x				

H= Harleyville Formation, x=present, R=reworked, C=contaminated, ?=questionable, cf=compares with

Figure 5. continued

Chicora Member of the Williamsburg Formation (Black Mingo Group)

(346 - 258 ft)

Stratigraphy. The Williamsburg Formation is named for exposures in Williamsburg County and Berkeley County, South Carolina. Sloan (1908) originally called this unit the Williamsburg pseudobuhr, a subdivision of his Black Mingo phase. This unit was abandoned by Cooke (1936) but was reinstated as the Williamsburg Formation of the Black Mingo Group by Van Nieuwenhuise and Colquhoun (1982).

Van Nieuwenhuise and Colquhoun (1982) proposed a composite stratotype consisting of outcrops at Lower Bridge (highway 377 bridge) on the Black River (Williamsburg County) that represent their Lower Bridge Member of the Williamsburg Formation and outcrops just downstream from Wilson's Landing on the Santee River (Berkeley County) that represent their Chicora Member of the Williamsburg. Van Nieuwenhuise and Colquhoun (1982) assigned a late Paleocene age to the Williamsburg Formation and indicated its distribution in drill holes in Georgetown, Williamsburg, Berkeley, and Dorchester Counties.

In the areas east and south of the Pregnall drill site, the Williamsburg Formation is underlain by the lower Paleocene Rhems Formation, which was defined from outcrops in Georgetown County by Van Nieuwenhuise and Colquhoun (1982). The Williamsburg Formation is overlain by the middle Eocene Santee Limestone (of the Orangeburg Group) in northern Dorchester County, northeastern Charleston County, and Berkeley, Williamsburg, and Georgetown Counties. In southern Dorchester County and areas to the southwest, the Williamsburg Formation is overlain by the lower Eocene Fishburne Formation (Gohn and others, 1983).

As described by Van Nieuwenhuise and Colquhoun (1982, p. 57), the older Lower Bridge Member of the Williamsburg Formation consists of arenaceous shales, fullers earth, and fossiliferous, argillaceous sands. The younger Chicora Member consists of fossiliferous, argillaceous sands and mollusk-rich, bioclastic limestones.

Examination of drill-hole records from northern Dorchester County indicates that the typically fine-grained Lower Bridge Member lies at depths greater than that reached by the Pregnall corehole (for example, see Reid and others, 1986, p. 7-8). Based on this information and on lithologic characteristics, the entire section of the Williamsburg Formation in the Pregnall core is assigned to the Chicora Member.

Lithology. The partial section of the Chicora Member of the Williamsburg Formation recovered at Pregnall consists of two contrasting lithologic units, a lower siliciclastic section of terrigenous sand, silt, and clay, and an upper carbonate section of moldic pelecypod limestone. A 4-ft-thick unrecovered interval separates these lithologic units; the gamma-ray log suggests that the contact between these units is at 312 ft. Although they superficially resemble overlying Eocene limestones, moldic, quartz-bearing pelecypod limestones are typical of the upper part of the Chicora Member throughout its extent, including the type area and other areas in Berkeley County (Pooser, 1965; Powell and Baum, 1981; Van Nieuwenhuise and Colquhoun, 1982), a core section in Georgetown County (Powell and Baum, 1981), and the Clubhouse Crossroads No. 1 core in southern Dorchester County (Gohn and others, 1977).

The siliciclastic section is present from the base of the core at 346 ft upward to a depth of 312 ft, a thickness of 34 ft. This section consists of interlaminated and thinly interbedded silty clays and clayey to moderately well sorted silts and very fine sands. The silts and sands typically contain a few percent of very fine to locally very fine to coarse mica and sand-sized lignite. The lignite is locally abundant on some parting surfaces. Fine-grained glauconite occurs in trace amounts. Mollusk fragments are locally sparse to common; the fragments are typically sand sized but locally may be as large as 0.5 in. Microfossils are present but are very sparse. The silty clays are finely micaceous and contain small silt- and sand-filled burrows. Most of the siliciclastic section is calcareous, producing slight to moderate reactions with dilute acid. The clays are medium gray (N5), medium light gray (N6) and greenish gray

(5GY5/1). The silts and sands are light gray (N7) to light brownish gray (5YR6/1). Observable porosity in the siliciclastic section is limited to interparticle porosity in the thin sand and silt layers.

The limestone part of the Chicora Member is present from 312 ft to the formation contact at 258 ft, a thickness of 54 ft. This section consists of indurated, generally highly porous, pelecypod packstones with allochems in the medium calcarenite to very coarse calcirudite size range. The limestone contains very abundant calcitic pelecypod valves and sand-sized to 2-in. valve fragments, principally oysters. Gastropods, echinoids, and bryozoans are distinctly less abundant. The microfauna consists primarily of sparse benthic foraminifers and very sparse ostracodes. A few percent of very fine to coarse quartz is present throughout the unit, along with trace amounts to a few percent of very fine to fine glauconite. The upper five feet of the limestone section contains 1 to 3 percent of glauconite and phosphate sand and granules introduced from the basal bed of the overlying Eocene section. The color of the Chicora limestones varies from very light gray (N8) to a very light yellowish gray (5Y8/1).

Much of the Chicora was not recovered in the Pregnall core below a depth of 278 ft. Core loss occurred in both the siliciclastic section and the limestone section. Lost material may represent loose quartz sands, a common lithology in Chicora sections throughout the region (Van Nieuwenhuise and Colquhoun, 1982; Powell and Baum, 1981, fig. 2).

The Chicora limestones have a moderate to locally very high, solution-enhanced, meso- to megamoldic porosity produced by the dissolution of aragonitic mollusks. A drusy to acicular coating of clear calcite spar is present on all surfaces in the upper 10 ft of the limestone, thereby producing a locally slight to large reduction of porosity. Powell and Baum (1981, table 1) reported a mean total porosity of 29 percent for the upper 8.7 ft of Chicora limestone (their pelecypod-mold biomicrudite facies of the “Thanetian Black Mingo Formation”) in a core from southwestern Georgetown County.

Paleontology. The Chicora Member of the Williamsburg Formation is dated as late Paleocene and represents calcareous nannofossil Zone NP 9 and questionably Zone NP 7/8. Three samples in the upper part of the unit (at 275.0, 274.8, and 258.8 ft) show obvious contamination from overlying units; middle Eocene nannofossils and late Oligocene dinocysts are conspicuous.

Calcareous nannofossils were examined from five samples in the Williamsburg Formation (fig. 4). The oldest sample, from 337.0 ft, is questionably placed in the late Paleocene Zones NP 7 or NP 8 because it contains *Discoaster mohleri* (FAD marks the base of Zone NP 7) and does not contain *Discoaster multiradiatus* (FAD defines the base of Zone NP 9); however, dinocysts in the adjacent sample are most likely correlative to NP 9. *Heliolithus riedelii* (FAD defines the base of Zone NP 8) was not recognized in this sample, although two poorly preserved specimens of the genus *Heliolithus* (first appears in the upper half of Zone NP 5) are present, and there is a possibility that they could be this species. Samples from 326.3 and 317.1 ft are placed in Zone NP 9 because they do contain *D. multiradiatus* and lack Eocene markers. Two samples from the moldic pelecypod limestone in the upper part of the Williamsburg Formation at 274.8 and 258.8 ft contain primarily middle Eocene specimens and only a few Paleocene specimens. The presence of middle Eocene calcareous nannofossils in these samples is presumed to be the result of contamination from higher in the corehole.

Of the three palynological samples taken in the Williamsburg (fig. 5), only one yielded a diagnostic, in-place dinocyst assemblage. R5115 L (337.0 to 336.8 ft) contains a moderately well preserved, moderately diverse dinocyst assemblage dominated by *Eocladopyxis peniculata* and various species of *Spiniferites*. The presence of *Kallosphaeridium brevibarbatum* indicates an age no older than late in the late Paleocene. This species has its lowest occurrence in the Tuscahoma Formation in Alabama (Edwards, 1980). R5115 K (275.0 to 275.4 ft) was taken from a moldic limestone, and most of the dinocysts present are of Oligocene age and presumed to be transported down the hole. *Eocladopyxis peniculata* may be in place.

Moultrie Member of the Santee Limestone (Orangeburg Group)

(258.0 - 189.4 ft)

Stratigraphy. Sloan (1908) named the Santee Limestone for the Santee River and established its type section at Eutaw Springs, Orangeburg County, South Carolina. The Santee Limestone is a widespread outcrop and shallow subcrop unit in Orangeburg, Berkeley, and Georgetown Counties (and adjacent areas) where it has been studied primarily in large quarry exposures (Banks, 1977; Ward and others, 1979; Baum and others, 1980; Powell and Baum, 1981, 1982).

Ward and others (1979) defined two members in the Santee, a lower Moultrie Member consisting primarily of macrofossiliferous limestone and an upper Cross Member consisting typically of finer grained, microfossiliferous limestone. Baum and others (1980) subsequently raised the Cross Member to formation status and restricted the name Santee Limestone to the interval assigned to the Moultrie Member by Ward and others (1979). This restriction of the Santee is undesirable under Article 19, remark (g) of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983).

Traditionally, the ages of the Santee Limestone and related Eocene units have been determined through the use of macro-invertebrates. Cooke and MacNeil (1952) first assigned a middle Eocene (Claibornian) age to the Santee Limestone based on the presence of *Ostrea* (now *Cubitostrea*) *sellaeformis* at numerous Santee Limestone exposures. Older sections containing *Ostrea* (now *Cubitostrea*) *lisbonensis* were considered to represent the Warley Hill marl (now Formation) (Cooke and MacNeil, 1952; also see Willoughby and Nystrom, 1992).

Ward and others (1979) recognized *Cubitostrea sellaeformis* in their Moultrie Member of the Santee Limestone, whereas other authors reported *Cubitostrea lisbonensis* in the Moultrie below the beds containing *C. sellaeformis* (Banks, 1977; Powell and Baum, 1982). Both of these oysters indicate a middle Eocene age.

Lithology. The Moultrie Member of the Santee Limestone is present between depths of 258.0 ft and 189.4 ft in the Pregnall core, a thickness of 68.6 ft. This section consists primarily of bryozoan-pelecypod limestones. The contact with the underlying pelecypod limestones of the Williamsburg Formation is sharp, occurring at a break between core segments. Glauconite and quartz sand, and phosphate sand and granules, are concentrated in the basal few feet of the Santee. Glauconite and phosphate have infiltrated downward from the basal contact into the underlying Paleocene section.

The Moultrie in the Pregnall core consists primarily of bryozoan-pelecypod-peloid packstones and grainstones. Gastropods, serpulid worm tubes, and corals are distinctly less abundant allochems. The peloids may be fecal pellets or rounded fossil fragments, or both. Benthic foraminifers are the most abundant microfaunal element, although ostracodes and planktonic foraminifers are present in small numbers. The allochems range from the fine calcarenite to coarse-calcirudite size classes. Micrite in the Moultrie decreases upward significantly between approximately 240 and 230 ft. Packstones predominate below about 235 ft, whereas grainstones and packstones are present above that depth.

Very fine to medium-grained glauconite occurs in trace amounts throughout most of the Moultrie section, except where it is more abundant (with phosphate) at the basal contact. Quartz is virtually absent except at the base where it is likely reworked from the underlying Paleocene section. The Moultrie sediments are typically massive with few, if any, discernible sedimentary structures. The Moultrie limestones are very light colored; most are nearly white with a light yellowish cast that is much lighter than yellowish gray (5Y8/1).

Within the Moultrie section, porosity is low to moderate below about 230 ft and moderate to high above that depth. Throughout the section, meso-intraparticulate porosity is present primarily as void space in bryozoans and foraminifers. Meso-interparticulate porosity is more common, particularly in the grainstones. Minor reduction of the porosity by calcite cement is present throughout the unit. Powell and Baum (1981, tables 2, 3, and 4) reported mean total porosities of 25.8 and 14.2 percent in two micritic sections, and 31.7 percent in a micrite-poor section, of the Moultrie Member of the Santee Limestone in Georgetown County.

On the gamma-ray log, the Moultrie Member of the Santee Limestone is bounded by two large spikes that represent glauconite-phosphate lag deposits at the base of the Santee and the base of the overlying Cross Member of the Santee Limestone. Between the spikes, appropriately low gamma-ray values represent the carbonate lithologies of the Moultrie. The gamma-ray values are slightly but uniformly higher below 226 ft than above. These log values may indicate a small amount of detrital clay in the lower part of the section.

Paleontology. The Moultrie Member of the Santee Limestone is dated as middle Eocene, representing calcareous nannofossil Zone NP 16. One sample, R5115 I (241.0 to 240.7 ft), contains middle Eocene dinocysts as well as specimens reworked from lower Paleocene deposits.

Calcareous nannofossils were examined from seven samples in the Moultrie Member of the Santee Limestone (fig. 4). Based on the presence of *Chiasmolithus bidens/solitus* (LAD defines the top of Zone NP 16), *Cribrocentrum reticulatum* (FAD in Zone NP 16), and large forms of *Reticulofenestra umbilicus* (FAD in Zone NP 16), these samples are placed in the middle Eocene Zone NP 16.

Of the two palynological samples examined from the Moultrie (fig. 5), the lower one (241.0 to 240.7 ft) contains a moderately well preserved, diverse dinocyst assemblage but virtually no pollen. The assemblage is of mixed ages. *Pentadinium goniferum* and *Pentadinium membranaceum* (late middle or early late Eocene) are present as are specimens of a new species of *Eocladopyxis* (known from the early part of the middle Eocene). The early Paleocene species *Carpatella cornuta* is presumably reworked. The higher sample (201.6 to 201.2 ft) is completely barren of both dinocysts and pollen.

Cross Member of the Santee Limestone (Orangeburg Group)
189.4-90.9 ft

Stratigraphy. The Cross Member of the Santee Limestone was defined by Ward and others (1979). The unit was subsequently removed from the Santee and raised to formation rank by Baum and others (1980), but their usage is not followed here because it can result in confusion about what is or is not part of the Santee. Conflicting biostratigraphic results have been reported; the Cross has been assigned both a middle Eocene age (Ward and others, 1979, p. 9) and a late Eocene age (Baum and others, 1980, p. 23).

The Cross Member of the Santee Limestone is a widespread unit in Dorchester, Berkeley, Charleston, and southern Orangeburg Counties. It is typically underlain by the Moultrie Member of the Santee Limestone and overlain by formations of the Cooper Group.

Lithology. The 98.5-ft-thick Cross Member of the Santee Limestone is present between 189.4 ft and 90.9 ft in the Pregnall core. The Cross consists primarily of locally shelly, microfossiliferous limestone. The basal contact is a burrowed unconformity with about 0.5 in. of relief seen in the core. Glauconite and phosphate-filled burrows extend over a foot into the underlying Moultrie Member from the basal glauconite-phosphate bed of the Cross. The upper surface of the Moultrie is partially coated with a phosphate crust.

The lower part of the Cross, from the basal contact to a depth of about 135 ft, consists of foraminiferal-peloid packstones. Pelecypods, bryozoans, and serpulid worm tubes are present but are typically sparse in this interval. The allochems are primarily in the very fine to medium calcarenite size range. There is a broad gradational interval from about 135 to 125 ft in which there is a significant upward increase in macrofossils, primarily pelecypods, serpulid worm tubes, and bryozoans. Pelecypod-serpulid-foraminifer-peloid packstones dominate the section from about 135 to 110 ft. There is a moderate decrease in micrite content in the upper 20 feet of the Cross, which consists of foraminifer-peloid-pelecypod grainstones and packstones. Glauconite and quartz occur only in trace amounts in the Cross, except at the base, where abundant glauconite and phosphate and minor quartz are present.

Low micro-interparticulate porosity is typical of the packstones in the lower part of the Cross (189.4 -135.0 ft). The macrofossil packstones above 135 ft have low to moderate meso-intraparticulate porosity as well as low to moderate, micro-to meso-interparticulate porosity. There is little cement reduction of porosity throughout the Cross.

The gamma-ray log for the lower part of the Cross Member of the Santee Limestone (basal contact to approximately 112 ft) has higher values than the limestones of the Williamsburg and Moultrie sections. In the absence of significant amounts of glauconite, these higher gamma-ray values probably indicate a few percent of detrital clay in the lower part of the Cross. The upper 21 ft of the Cross have low gamma-ray values that suggest a decrease in clay content.

Paleontology. The Cross Member of the Santee Limestone is dated as both late middle Eocene and late Eocene, representing calcareous nannofossil Zones NP 17 and NP 18. Calcareous nannofossils were examined from 13 samples in the Cross (fig. 4). The lower nine samples from 186.5 to 130.9 ft are placed in Zone NP 17 due to the absence of *Chiasmolithus bidens/solitus* and the presence of *Helicosphaera compacta* (FAD in the uppermost part of Zone NP 16). The upper four samples from 123.3 to 92.7 ft are placed in Zone NP 18 because they contain *Chiasmolithus oamaruensis* (FAD defines the base of Zone NP 18) and do not contain *Isthmolithus recurvus* (FAD defines the base of Zone NP 19/20).

Four samples from the Cross Member of the Santee Limestone were studied for dinocysts. These samples are of late middle Eocene and late Eocene age. Species present here that have their lowest occurrences in the Barton Beds (NP 17) in England include: *Wetzeliella simplex*, *Homotryblium plectilum*, *Lentinia serrata*, *Cordosphaeridium cantharellus*, and *Corrudinium incompositum* (Bujak and others, 1980). The highest occurrence of *Pentadinium goniferum* is found in the sample at 137.6 to 137.4 ft. Based on the nannofossil data from this core, this highest occurrence may be used to approximate the NP 17/NP 18 boundary. The upper three dinocyst samples from the Cross contain *Thalassiphora fenestrata* and are in subzone D12nb of Köthe (1990), which she places in the late Eocene. The highest sample (92.7 to 92.4 ft) shows the range overlap of *Heteraulacacysta porosa*, *Operculodinium placitum*, and *T. fenestrata*, an assemblage reported from "Eo-Oligocene" deposits in the Netherlands by de Coninck (1986).

Harleyville Formation (Cooper Group)

90.9-85.8 ft

Stratigraphy. The Harleyville Formation originally was defined as a member of the Cooper Formation by Ward and others (1979) with its type locality at the Giant Portland Cement Company quarry just north of Harleyville in Dorchester County, South Carolina. The Harleyville type section had previously been grouped with the Ashley Formation in an undivided section assigned to the Cooper Marl (Cooke and MacNeil, 1952; Sanders, 1974, note that the location given in the text is correct, but fig. 1 location of the quarry is incorrect; Banks, 1977).

Weems and Lemon (1984) raised the two younger members of the Cooper Formation defined by Ward and others (1979), the Parkers Ferry Member and the Ashley Member, to formation status and raised the Cooper Formation to group status. By analogy, the Harleyville unit of the now-revised Cooper Group is considered to be the Harleyville Formation.

The Harleyville Formation typically consists of clayey fine-grained limestone and calcareous clay; it is late Eocene in age (Ward and others, 1979). The Harleyville is a widespread subsurface unit in Dorchester, western Berkeley, and central and southern Charleston Counties. It is typically underlain by the Cross Member of the Santee Limestone and overlain by the Parkers Ferry Formation or the Ashley Formation of the Cooper Group (Ward and others, 1979).

Lithology. A thin section of the Harleyville Formation (5.1 ft) is present between depths of 90.9 and 85.8 ft in the Pregnall core. Its basal contact is a sharp, unconformable contact with slight relief seen in the core.

This thin Harleyville section consists of fossiliferous limestone, primarily pelecypod-foraminifer-peloid packstones. Allochem grain sizes range from very fine calcarenite to medium calcirudite; abundant pelecypods and less common bryozoans and echinoids are present. Sanders (1974), Banks (1977), and Ward and others (1979) noted an abundance of small pelecypods (primarily pectens) in the basal few feet of the Harleyville at the nearby

Giant Portland quarry. The microfauna is sparse, consisting primarily of benthic foraminifers. Clay and very fine quartz are present only in trace amounts; very fine to fine glauconite is more common, about 5 to 10 percent. The sediment color is close to yellowish gray (5Y8/1). The Harleyville has moderately high values on the gamma-ray log that reflect the significantly large amount of glauconite (which contains radioactive potassium) in the recovered section.

The Harleyville packstones have low meso-intraparticulate porosity and moderate, meso- to small mega-moldic porosity. No pore-filling cements were noted macroscopically.

The thinness of the Harleyville section indicates erosion of the unit along the Harleyville-Ashley unconformity. In areas south of Pregnall, thicker sections of the Harleyville, plus the upper Eocene Parkers Ferry Formation, occur between the basal beds of the Harleyville seen at Pregnall and the base of the Ashley Formation (Ward and others, 1979).

Paleontology. The Harleyville sediments at Pregnall are dated as late Eocene, representing calcareous nannofossil Zone NP 18. Calcareous nannofossils were examined from three samples of the Harleyville Formation (fig. 4). The three samples are placed in Zone NP 18 because they overlie samples containing *Chiasmolithus oamaruensis* (FAD defines the base of Zone NP 18) and do not contain specimens of *Isthmolithus recurvus* (FAD defines the base of Zone NP 19/20). *Isthmolithus recurvus* is a robust species that is resistant to dissolution and remains identifiable even with significant recrystallization. Therefore, dissolution or recrystallization does not explain the absence of this species in the Harleyville Formation. Thicker sections of the Harleyville Formation in nearby areas typically are assigned to calcareous nannofossil Zones NP 19/20 (L.M. Bybell, unpublished data); hence the contact between Zone NP 18 and Zone NP 19/20 is assumed to occur near the base of the Harleyville.

A single palynological sample from the Harleyville Formation (87.5 to 87.1 ft) contains a moderately well preserved dinocyst assemblage that is dominated by *Pentadinium laticinctum* (vermiculate forms). On the basis of the dinoflagellates present, the Harleyville is late Eocene in age. Biostratigraphically important species include *Corrudinium incompositum, Phthanoperidinium echinatum,* and *Trigonopyxidia fiscellata.*

Ashley Formation (Cooper Group)

85.8-30.0 ft

Stratigraphy. Tuomey (1848) and Sloan (1908) applied the name Ashley to beds in marl pits along the Ashley River in Dorchester County, South Carolina. Subsequent authors generally included these beds in a loosely defined Cooper marl until Ward and others (1979) re-established the unit as the Ashley Member of the Cooper Formation. Weems and Lemon (1984) later raised the status of these units, resulting in the Ashley Formation of the Cooper Group. Hazel and others (1977) assigned a late Oligocene age to beds subsequently assigned to the Ashley Formation in the USGS-Clubhouse Crossroads No. 1 core, Dorchester County.

The Ashley Formation is a widespread shallow-subsurface unit in Dorchester, Charleston, and western Berkeley Counties. It is typically underlain by the Harleyville or Parkers Ferry Formations of the Cooper Group or the Cross Member of the Santee Limestone and overlain by a wide variety of generally thin Neogene and Quaternary units.

Lithology. The Ashley Formation is present between depths of 85.8 and 30.0 ft in the Pregnall core, a thickness of 55.8 ft. The basal contact is a burrowed, unconformable surface with about 1 in. of relief observed in the core. Burrows containing phosphatic Ashley sediments extend downward into the underlying Harleyville Formation. The upper contact of the Ashley Formation with the surficial deposits was not recovered in the Pregnall core; however, burrows containing sediment from the overlying unit are present in the top foot of the Ashley.

The Ashley Formation consists of a relatively homogeneous section of calcareous, microfossiliferous, silty and sandy clays. Parts of the section may be sufficiently calcareous to warrant their description as clayey, very fine microfossil calcarenites. The siliciclastic fraction consists of silty clay, which is largely pelletal in appearance, and very fine to fine-grained quartz sand. Quartz is most abundant (10-20 percent) and coarsest (very fine sand to granules) in the basal few feet of the Ashley. Above the basal interval, quartz drops below 5 percent and then gradationally increases to 10 to 20 percent in the upper 20 feet of the unit. Very fine to fine-grained glauconite and phosphate sand are present in small amounts throughout the Ashley section, except in the basal 10 feet where the phosphate increases in grain size (very fine sand to granules) and abundance (locally 1 percent with 5 to 10 percent at the base).

Microfossils are abundant throughout the Ashley Formation. Benthic foraminifers are very abundant, whereas planktonic foraminifers and ostracodes are locally sparse to common. Sand-sized to 0.25-inch fragments of typically thin-valved pelecypods are locally sparse to very sparse.

The Ashley sediments typically are massive or faintly texture-mottled, suggesting thorough bioturbation. The color of dry Ashley sediments approximates yellowish gray (5Y7/2) with a lighter yellowish gray color in the upper 20 feet of the section.

The Ashley has characteristically high values on the Pregnall gamma-ray log. This distinctive log signature results from the relatively abundant phosphate, which tends to contain significant amounts of thorium and uranium. The concentration of phosphate grains in a lag deposit at the base of the unit typically produces a large gamma-ray spike, the base of which marks the unconformable lower contact of the Ashley. Banks (1977, upper conglomerate, p. 119) and Ward and others (1979) called attention to the basal Ashley contact in the Giant Portland quarry near Harleyville. At that large exposure, the basal 3 feet of the Ashley contain abundant phosphate, glauconite, and bored and phosphatized intraclasts. In the Pregnall core, comparatively low gamma-ray values at the top of the Ashley (35 to 31 ft), and an underlying high gamma-ray spike (38 to 35 ft) probably represent a leached zone and an underlying zone of secondary phosphate concentration (that contains thorium and uranium) as described by Force and others (1978).

Paleontology. The Ashley Formation is dated as late Oligocene and is assigned to calcareous nannofossil Zones NP 24 and 25 (?). Calcareous nannofossils were examined from six samples of the Ashley Formation taken between 84.3 and 33.8 ft (fig. 4). The lower five samples (84.3 to 44.6 ft) are in the late Oligocene Zone NP 24, and the highest sample (33.8 ft) is probably in Zone NP 25, the youngest calcareous nannofossil zone in the Oligocene (fig. 4). *Helicosphaera recta* (FAD occurs near the base of Zone NP 24) is present in the lowest Ashley sample, and *Sphenolithus distentus* (LAD defines the top of Zone NP 24) is present in the sample at 44.6 ft, thus restricting this entire interval to Zone NP 24. The sample at 33.8 ft is presumed to be in Zone NP 25 because it does not contain *S. distentus*, but does contain both *Zygrhablithus bijugatus* and *Dictyococcites bisectus* (LAD's near the top of Zone NP 25).

Dinocysts in the Ashley indicate a late Oligocene age. The overlap of the ranges of *Apteodinium spiridoides*, *Batiacasphaera sphaerica*, *Saturnodinium pansum*, and *Wetzeliella symmetrica* indicate correlation with calcareous nannofossil Zones NP 24 or NP 25. The dinocyst assemblages indicate correlation with the Old Church Formation in Virginia (Edwards, 1989; de Verteuil and Norris, 1996).

Pollen in two Ashley samples (78.4-78.8 and 33.6-33.8 ft, Appendix 4) is consistent with a late Oligocene age. *Pinus haploxylon* type is still present in this region today, but pollen of *Pinus diploxylon* type has a much higher relative frequency in modern sediment samples from the region. The Ashley samples with mainly or entirely *haploxylon* type pine pollen are probably older than middle Miocene (Appendix 4). The presence of the *Momipites spackmanianus* group as the sole representative of the genus in the Ashley samples suggests that these samples are no older than late Oligocene. The presence of *Liquidambar* pollen in the Ashley Formation of the Pregnall No. 1 core documents the Oligocene occurrence of the genus in eastern North America. *Tetracolporopollenites megadolium*, probably produced by the Sapotaceae, indicates a tropical to warm-temperate terrestrial climate.

Surficial Deposits

30.0-0 ft

Two units are recognized in the upper 30 ft of the Pregnall section, despite very poor core recovery in that interval. The older unit is represented by very high values on the gamma-ray log between depths of 30 ft and 22 ft. This high gamma signature likely represents a large phosphate content in that interval, perhaps erosionally derived from the underlying Ashley sediments. Neogene and Quaternary units in northern Dorchester County typically do not contain large amounts of phosphate (Blackwelder and Ward, 1979; McCartan, 1990), and we are unable to assign the 30- to 22-ft interval to a known stratigraphic unit. We refer to this unit as the "unnamed unit."

No core material was recovered from the unnamed unit. However, the upper foot of the Ashley section contains burrows filled with light-olive-gray sand containing phosphate granules, shell fragments, and clasts of Ashley sediment. The burrow fills are distinctly darker than the enclosing Ashley sediments. The sediments in these burrows are assumed to represent the unnamed unit above the Ashley.

Above the unnamed unit, the gamma-ray log indicates relatively clay-free sand from 22 to 14 ft and clay from 14 ft to the top of the log at 7 ft. A single core from 10.5 to 9.0 ft consists of highly oxidized, red, yellow, and light-gray, sandy clay. We provisionally assign this section (22 ft to top of section) to the early Pleistocene Waccamaw Formation (?), which McCartan and others (1990) equate with their informal units Q5 and Q6. Unit Q6 is an extensive surficial unit in the Pregnall area.

DISCUSSION AND CONCLUSIONS

The units present in the Pregnall core may be compared with those in the USGS Clubhouse Crossroads No. 1 core in the southwestern part of Dorchester County, which is downdip from the Pregnall core. The base of the Williamsburg Formation was not reached in the Pregnall core. The Black Mingo Group in the Clubhouse Crossroads No. 1 core contains sediments of both early and late Paleocene age. The Moultrie Member of the Santee Formation is in Zone NP 16 in both the Pregnall core and the Clubhouse Crossroads No. 1 core. The Cross Member of the Santee Limestone is placed in Zones NP 17 and NP 18 in the Pregnall core. In the Clubhouse Crossroads No. 1 core, the Cross contains Zone NP 17 sediments, but Zone NP 18 is missing. The upper part of the Harleyville (Zone NP 19/20) presumably has been removed in the Pregnall core because in the Clubhouse Crossroads No. 1 core, the lower part of the Harleyville Formation is in Zone NP 18, and the upper part is in Zone NP 19/20. The Ashley Formation in the Pregnall core is dated as both Zone NP 24 and NP 25 (?). The Ashley Formation in the Clubhouse Crossroads Core No. 1 cannot be dated any more accurately than being in either Zone NP 24 or NP 25 because diagnostic calcareous nannofossil species such as *Sphenolithus distentus* and *Sphenolithus ciperoensis* are absent.

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Appendix 1. Important calcareous nannofossil datums.

The following calcareous nannofossil species can be used to date sediments of late Paleocene to late Oligocene age. Many, but not all, of these species are present in the Pregnall core. FAD indicates a first appearance datum, and LAD indicates a last appearance datum. Zonal markers for the Martini (1971) NP zones are indicated with an *, and a # indicates a zonal marker for the Bukry (1973, 1978) and Okada and Bukry (1980) CP zones. One of us (LMB) has found the remaining species to be biostratigraphically useful in the Gulf and Atlantic Coastal Plains.

LAD *Zygrhablithus bijugatus* - top of Zone NP 25, late Oligocene
LAD *Dictyococcites bisectus* - top of Zone NP 25, late Oligocene
LAD *#*Sphenolithus distentus* - top Zone NP 24, top of Zone CP 19a, late Oligocene
FAD *Helicosphaera recta* - lower Zone NP 24, early Oligocene
FAD *#*Sphenolithus ciperoensis* - base of Zone NP 24, base of Zone CP 19a, early Oligocene
FAD *Sphenolithus distentus* - within Zone NP 23, base of Zone CP 18, early Oligocene
LAD *#*Reticulofenestra umbilicus* - top of Zone NP 22, top of Zone CP 16c, early Oligocene
LAD **Cyclococcolithus formosus* - top Zone NP 21, early Oligocene
LAD *Isthmolithus recurvus* - within Zone NP 21
LAD *#*Discoaster saipanensis* - top of Zone NP 19/20, top of Zone CP 15b, late Eocene
LAD #*Discoaster barbadiensis* - top of Zone NP 19/20, top of Zone CP 15b - late Eocene; actually has its LAD slightly below the LAD of *D. saipanensis*
LAD *Cribrocentrum reticulatum* - very near top of Zone NP 19/20, late Eocene
FAD **Isthmolithus recurvus* - base of Zone NP 19/20 - late Eocene
FAD *#*Chiasmolithus oamaruensis* - base of Zone NP 18, base CP 15a, late Eocene
FAD *Helicosphaera compacta* - within the uppermost part of Zone NP 16; can be used to approximate the Zone NP 16/17 boundary, middle Eocene.
LAD *#*Chiasmolithus bidens/solitus* - these two species are not differentiated in this study; top of Zone NP 16, middle Eocene
FAD *Cribrocentrum reticulatum* - within Zone NP 16, middle Eocene
FAD *Dictyococcites scrippsae* - within Zone NP 16, middle Eocene
FAD #*Reticulofenestra umbilicus* - large forms first appear near base of Zone NP 16, base Zone CP 14a, middle Eocene
FAD *#*Discoaster multiradiatus* - base Zone NP 9, base CP 8a, late Paleocene
FAD **Heliolithus riedelii* - base of Zone NP 8, late Paleocene
FAD *#*Discoaster mohleri* - base Zone NP 7, base CP 6, late Paleocene

Appendix 2. Calcareous nannofossil species considered in this report (in alphabetical order by genus).

Blackites scabrosus (Deflandre *in* Deflandre and Fert, 1954) Roth, 1970
Blackites spinosus (Deflandre & Fert, 1954) Hay & Towe, 1962
Blackites tenuis (Bramlette & Sullivan, 1961) Sherwood, 1974
Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre, 1947
Bramletteius serraculoides Gartner, 1969
Campylosphaera dela (Bramlette & Sullivan, 1961) Hay & Mohler, 1967
Cepekiella lumina (Sullivan, 1965) Bybell, 1975
Chiasmolithus bidens (Bramlette & Sullivan, 1961) Hay & Mohler, 1967
Chiasmolithus grandis (Bramlette & Riedel, 1954) Hay, Mohler, & Wade, 1966
Chiasmolithus oamaruensis (Deflandre *in* Deflandre and Fert, 1954) Hay, Mohler, & Wade, 1966
Chiasmolithus solitus (Bramlette & Sullivan, 1961) Hay, Mohler, & Wade, 1966
Coccolithus eopelagicus (Bramlette & Riedel, 1954) Bramlette & Sullivan, 1961
Coccolithus pelagicus (Wallich, 1877) Schiller, 1930
Cribrocentrum reticulatum (Gartner & Smith, 1967) Perch-Nielsen, 1971
Cyclagelosphaera prima (Bukry, 1969) Bybell & Self-Trail, 1995
Cyclococcolithus formosus Kamptner, 1963
Cyclococcolithus protoannulus (Gartner, 1971) Haq & Lohmann, 1976
Dictyococcites bisectus (Hay, Mohler, & Wade, 1966) Bukry & Percival, 1971
Dictyococcites scrippsae Bukry & Percival, 1971
Discoaster barbadiensis Tan Sin Hok, 1927
Discoaster deflandrei Bramlette & Riedel, 1954
Discoaster distinctus Martini, 1958
Discoaster kuepperi Stradner, 1959
Discoaster lenticularis Bramlette & Sullivan, 1961
Discoaster megastypus (Bramlette & Sullivan, 1961) Perch-Nielsen, 1984
Discoaster mohleri Bukry & Percival, 1971
Discoaster multiradiatus Bramlette & Riedel, 1954
Discoaster nodifer (Bramlette & Riedel, 1954) Bukry, 1973
Discoaster saipanensis Bramlette & Riedel, 1954
Discoaster salisburgensis Stradner, 1961
Discoaster tanii Bramlette & Riedel, 1954
Discoturbella moorei Bukry, 1971
Ericsonia obruta Perch-Nielsen, 1971
Ericsonia subpertusa Hay & Mohler, 1967
Fasciculithus alanii Perch-Nielsen, 1971
Fasciculithus aubertae Haq & Aubry, 1981
Fasciculithus involutus Bramlette & Sullivan, 1961
Fasciculithus tympaniformis Hay & Mohler *in* Hay and others, 1967
Goniolithus fluckigeri Deflandre, 1957
Helicosphaera bramlettei (Müller, 1970) Jafar & Martini, 1975
Helicosphaera carteri (Wallich, 1877) Kamptner, 1954
Helicosphaera compacta Bramlette & Wilcoxon, 1967
Helicosphaera euphratis Haq, 1966
Helicosphaera intermedia Martini, 1965
Helicosphaera lophota (Bramlette & Sullivan, 1961) Locker, 1973
Helicosphaera recta (Haq, 1966) Jafar & Martini, 1975
Helicosphaera reticulata Bramlette & Wilcoxon, 1967
Helicosphaera seminulum Bramlette & Sullivan, 1961
Markalius inversus Bramlette & Martini, 1964
Micrantholithus crenulatus Bramlette & Sullivan, 1961
Micrantholithus flos Deflandre *in* Deflandre and Fert, 1954
Micrantholithus procerus Bukry & Bramlette, 1969
Neochiastozygus concinnus (Martini, 1961) Perch-Nielsen, 1971
Neochiastozygus imbriei Haq & Lohmann, 1975
Neococcolithes dubius (Deflandre *in* Deflandre and Fert, 1954) Black, 1967

Pedinocyclus larvalis Bukry & Bramlette, 1971
Pemma basquense (Martini, 1959) Bybell & Gartner, 1972
Pemma papillatum Martini, 1959
Pemma serratum (Chang, 1969) Bybell & Gartner, 1972
Pemma stradneri (Chang, 1969) Perch-Nielsen, 1971
Placozygus sigmoides (Bramlette & Sullivan, 1961) Romein, 1979
Pontosphaera multipora (Kamptner ex Deflandre, 1959) Roth, 1970
Pontosphaera wechesensis (Bukry & Percival, 1971) Aubry, 1986
Pseudotriquetrorhabdulus inversus (Bukry & Bramlette, 1969) Wise *in* Wise and Constans, 1976
Reticulofenestra abisecta (Müller, 1970) Roth & Thierstein, 1972
Reticulofenestra daviesii (Haq, 1968) Haq, 1971
Reticulofenestra floridana (Roth & Hay *in* Hay and others, 1967) Theodoridis, 1984
Reticulofenestra hillae Bukry & Percival, 1971
Reticulofenestra pseudolockeri Jurasova, 1974
Reticulofenestra umbilicus (Levin, 1965) Martini & Ritzkowski, 1968
Scapholithus apertus Hay & Mohler, 1967
Sphenolithus ciperoensis Bramlette & Wilcoxon, 1967
Sphenolithus distentus (Martini, 1965) Bramlette & Wilcoxon, 1967
Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967
Sphenolithus predistentus Bramlette & Wilcoxon, 1967
Sphenolithus primus Perch-Nielsen, 1971
Sphenolithus pseudoradians Bramlette & Wilcoxon, 1967
Sphenolithus radians Deflandre *in* Grassé, 1952
Toweius callosus Perch-Nielsen, 1971
Toweius eminens var. *eminens* (Bramlette & Sullivan, 1961) Gartner, 1971
Toweius eminens var. *tovae* Bybell & Self-Trail, 1995
Toweius pertusus (Sullivan, 1965) Romein, 1979
Toweius serotinus Bybell & Self-Trail, 1995
Transversopontis pulcher (Deflandre *in* Deflandre and Fert, 1954) Perch-Nielsen, 1967
Transversopontis pulcheroides (Sullivan, 1964) Báldi-Beke, 1971
Transversopontis pulchriporus (Reinhardt, 1967) Sherwood, 1974
Transversopontis zigzag Roth & Hay *in* Hay and others, 1967
Zygodiscus herlyni Sullivan, 1964
Zygrhablithus bijugatus (Deflandre *in* Deflandre and Fert, 1954) Deflandre, 1959

Appendix 3. Dinocyst sample descriptions from the Pregnall No. 1 core.

The Pregnall core (DOR-208, SCDNR #24Z-d2) was assigned U.S. Geological Survey Paleobotanical Number R5115.

Chicora Member of the Williamsburg Formation

R5115 L (336.8-337.0 ft) contains a moderately well preserved, moderately diverse dinocyst assemblage dominated by *Eocladopyxis peniculata* and various species of *Spiniferites.* Dinocysts are:

Adnatosphaeridium williamsii Islam
Apectodinium homomorphum (Deflandre & Cookson) Lentin & Williams
Apectodinium quinquelatum (Williams & Downie) Costa & Downie
Cordosphaeridium gracile (Eisenack) Davey & Williams
Diphyes colligerum (Deflandre & Cookson) Cookson
Eocladopyxis peniculata Morgenroth
Heteraulacacysta ? sp.
Hystrichokolpoma unispinum Williams & Downie
Kallosphaeridium brevibarbatum de Coninck
Membranosphaera maastrichta Samoilovitch
Operculodinium centrocarpum (Deflandre & Cookson) Wall
Polysphaeridium zoharyi (Rossignol) Bujak et al.
Senegalinium ? *dilwynense* (Cookson & Eisenack) Stover & Evitt
Spiniferites spp.
Turbiosphaera sp. aff. *T. magnifica* Eaton of Edwards (1989)

The lowest occurrence of *Kallosphaeridium brevibarbatum* indicates an age no older than late Paleocene, approximately correlative to calcareous nannofossil Zone NP 9.

R5115 K (275.0-275.4 ft) was taken in a moldic limestone. It contains:

+*Apteodinium australiense* (Deflandre & Cookson) Williams
+*Batiacasphaera sphaerica* Stover
+*Chiropteridium lobospinosum* (Gocht) Gocht
+*Dinopterygium cladoides* Deflandre *sensu* Morgenroth (1966)
Eocladopyxis peniculata Morgenroth
+*Homotryblium plectilum* Drugg & Loeblich
+*Hystrichokolpoma rigaudiae* Deflandre & Cookson
+*Lejeunecysta* sp.
+*Lingulodinium machaerophorum* (Deflandre & Cookson) Wall
+*Operculodinium centrocarpum* (Deflandre & Cookson) Wall
+*Pentadinium laticinctum* Gerlach (vermiculate forms)
+*Spiniferites* spp.
Systematophora placacantha Deflandre & Cookson
Thalassiphora pelagica (Eisenack) Eisenack & Gocht
+*Wetzeliella* sp.

+also present in sample R5115 A

Most of the dinocysts present are of Oligocene age and presumed to be transported down the hole. *Eocladopyxis peniculata* may be in place.

R5115 J (258.4-258.8) contains a single unidentifiable dinocyst fragment.

Moultrie Member of the Santee Limestone

R5115 I (240.7-241.0 ft) contains a moderately well preserved, diverse dinocyst assemblage. Dinocysts are:

Amphorosphaeridium? *multispinosum* (Davey & Williams) Sarjeant
Carpatella cornuta Grigorovich
Charlesdowniea coleothrypta (Williams & Downie) Lentin & Vozzhennikova
Cribroperidinium giuseppei (Morgenroth) Helenes

Cyclopsiella vieta Drugg & Loeblich
Dinopterygium cladoides Deflandre *sensu* Morgenroth (1966)
Diphyes colligerum (Deflandre & Cookson) Cookson
Enneadocysta arcuata (Eaton) Stover & Williams
Eocladopyxis n. sp.
Histiocysta sp. of Stover and Hardenbol (1993)
Glaphyrocysta intricata (Eaton) Stover and Evitt
Hystrichokolpoma rigaudiae Deflandre & Cookson
Hystrichostrogylon membraniphorum Agelopoulos
Lingulodinium machaerophorum (Deflandre & Cookson) Wall
Melitasphaeridium pseudorecurvatum (Morgenroth) Bujak et al. ?
Pentadinium goniferum Edwards
Pentadinium membranaceum (Eisenack) Stover & Evitt
Phthanoperidinium sp.
Spiniferites pseudofurcatus (Klumpp) Sarjeant
Spiniferites spp.
Systematophora placacantha Deflandre & Cookson
Tectatodinium pellitum Wall
Thalassiphora pelagica (Eisenack) Eisenack & Gocht

The assemblage is of mixed ages. *Pentadinium goniferum* and *Pentadinium membranaceum* (late middle or early late Eocene) are present as are specimens of a new species of *Eocladopyxis* (known from the early part of the middle Eocene). *Carpatella cornuta* is restricted to the lower Paleocene, and thus presumably reworked.

R5115 H (201.2-201.6 ft) is completely barren; it contains no dinocysts and no pollen.

Cross Member of the Santee Limestone

R5115 G (186.3-186.5 ft) contains a well preserved, diverse dinocyst assemblage in which no particular species is dominant. Dinocysts are:

Achilleodinium biformoides (Eisenack) Eaton
Areoligera/Glaphyrocysta complex
Areosphaeridium diktyoplokus (Klumpp) Eaton
Charlesdowniea coleothrypta (Williams & Downie) Lentin & Vozzhennikova
Cribroperidinium giuseppei (Morgenroth) Helenes
Cyclopsiella vieta Drugg & Loeblich
Dapsilidinium pseudocolligerum (Stover) Bujak et al.
Deflandrea phosphoritica Eisenack
Diphyes colligerum (Deflandre & Cookson) Cookson
Distatodinium ellipticum (Cookson) Eaton
Gochtodinium simplex Bujak ?
Heteraulacacysta spp.
Homotryblium plectilum Drugg & Loeblich
Hystrichokolpoma rigaudiae Deflandre & Cookson
Impagidinium sp.
Lentinia serrata Bujak
Lingulodinium machaerophorum (Deflandre & Cookson) Wall
Millioudodinium sp. I of Edwards (1984)
Operculodinium centrocarpum (Deflandre & Cookson) Wall
Palaeocystodinium golzowense Alberti
Pentadinium goniferum Edwards
Pentadinium membranaceum (Eisenack) Stover & Evitt
Pentadinium laticinctum Gerlach subsp. *laticinctum*
Phthanoperidinium comatum (Morgenroth) Lentin & Williams
Samlandia chlamydophora Eisenack *sensu* Stover and Hardenbol (1993)
Spiniferites pseudofurcatus (Klumpp) Sarjeant
Spiniferites spp.
Systematophora placacantha Deflandre & Cookson

Tectatodinium pellitum Wall
Thalassiphora pelagica (Eisenack) Eisenack & Gocht

The age is latest middle Eocene or earliest late Eocene. The sample contains forms transitional between *Pentadinium goniferum* and *Pentadinium membranaceum*.

R5115 F (148.5-148.7 ft) contains a well preserved, diverse dinocyst assemblage in which no particular species is dominant. Dinocysts are:

Achilleodinium biformoides (Eisenack) Eaton
Areoligera/Glaphyrocysta complex
Charlesdowniea coleothrypta (Williams & Downie) Lentin & Vozzhennikova
Cordosphaeridium cantharellus (Brosius) Gocht
Cordosphaeridium gracile (Eisenack) Davey & Williams
Cribroperidinium giuseppei (Morgenroth) Helenes
Cyclopsiella vieta Drugg & Loeblich
Dinopterygium cladoides Deflandre *sensu* Morgenroth (1966)
Diphyes colligerum (Deflandre & Cookson) Cookson
Enneadocysta arcuata (Eaton) Stover & Williams
Hystrichokolpoma rigaudiae Deflandre & Cookson
Hystrichostrogylon coninckii Heilmann-Clausen ?
Lentinia serrata Bujak
Lingulodinium machaerophorum (Deflandre & Cookson) Wall
Operculodinium centrocarpum (Deflandre & Cookson) Wall
Palaeocystodinium golzowense Alberti
Pentadinium goniferum Edwards
Pentadinium laticinctum Gerlach subsp. *laticinctum*
Phthanoperidinium comatum (Morgenroth) Lentin & Williams
Samlandia chlamydophora Eisenack *sensu* Stover and Hardenbol (1993)
Spiniferites spp.
Systematophora placacantha Deflandre & Cookson
Tectatodinium pellitum Wall
Thalassiphora fenestrata Liengjarern et al.
Wetzeliella articulata Eisenack *sensu amplo*

The age is latest middle Eocene or earliest late Eocene.

R5115 E (137.4-137.6 ft) contains a well preserved, diverse dinocyst assemblage in which no particular species is dominant. Dinocysts are:

Adnatosphaeridium sp.
Charlesdowniea coleothrypta (Williams & Downie) Lentin & Vozzhennikova
Cordosphaeridium cantharellus (Brosius) Gocht
Cordosphaeridium gracile (Eisenack) Davey & Williams
Cordosphaeridium minimum (Morgenroth) Benedek
Corrudinium incompositum (Drugg) Stover & Evitt
Cyclopsiella vieta Drugg & Loeblich
Deflandrea phosphoritica-Deflandrea heterophlycta intermediate forms
Dinopterygium cladoides Deflandre *sensu* Morgenroth (1966)
Diphyes colligerum (Deflandre & Cookson) Cookson
Distatodinium ellipticum (Cookson) Eaton
Enneadocysta arcuata (Eaton) Stover & Williams
Heteraulacacysta ? *leptalea* Eaton
Histiocysta sp. of Stover and Hardenbol (1993)
Hystrichokolpoma rigaudiae Deflandre & Cookson
Hystrichostrogylon coninckii Heilmann-Clausen ?
Lejeunecysta sp.
Lentinia serrata Bujak
Lingulodinium machaerophorum (Deflandre & Cookson) Wall
Millioudodinium sp. I of Edwards (1984)
Nematosphaeropsis ? sp.

Palaeocystodinium golzowense Alberti
Pentadinium goniferum Edwards
Pentadinium laticinctum Gerlach subsp. *laticinctum*
Phthanoperidinium comatum (Morgenroth) Lentin & Williams
Phthanoperidinium stockmansii (de Coninck) Lentin & Williams
Samlandia sp. (fragment)
Spiniferites spp.
Systematophora placacantha Deflandre & Cookson
Tectatodinium pellitum Wall
Thalassiphora fenestrata Liengjarern et al.
Wetzeliella articulata Eisenack *sensu amplo* (*Wetzeliella* sp. cf. *W. gochti* of Köthe, 1990)

The age is latest middle Eocene or earliest late Eocene. The sample contains the highest occurrence of *Pentadinium goniferum* in the Pregnall No. 1 core.

R5115 D (92.4-92.7 ft) contains a well preserved, diverse dinocyst assemblage in which no particular species is dominant. Dinocysts are:

Adnatosphaeridium sp.
Cordosphaeridium cantharellus (Brosius) Gocht
Cordosphaeridium gracile (Eisenack) Davey & Williams
Cyclopsiella vieta Drugg & Loeblich
Dapsilidinium pseudocolligerum (Stover) Bujak et al.
Deflandrea heterophlycta Deflandre & Cookson
Dinopterygium cladoides Deflandre *sensu* Morgenroth (1966)
Heteraulacacysta porosa Bujak
Homotryblium plectilum Drugg & Loeblich
Hystrichokolpoma cinctum Klumpp
Hystrichokolpoma rigaudiae Deflandre & Cookson
Hystrichosphaeropsis sp.
Lentinia serrata Bujak
Lingulodinium machaerophorum (Deflandre & Cookson) Wall
Operculodinium centrocarpum (Deflandre & Cookson) Wall
Operculodinium placitum Drugg & Loeblich
Pentadinium laticinctum Gerlach (vermiculate forms)
Pentadinium laticinctum Gerlach subsp. *laticinctum*
Phthanoperidinium comatum (Morgenroth) Lentin & Williams
Samlandia chlamydophora Eisenack *sensu* Stover and Hardenbol (1993)
Spiniferites spp.
Systematophora placacantha Deflandre & Cookson
Tectatodinium pellitum Wall
Thalassiphora fenestrata Liengjarern et al.
Wetzeliella articulata Eisenack *sensu amplo*

The age as determined by this assemblage could be middle or late Eocene or early Oligocene. Important species occurrences are *Operculodinium placitum*, which is found in the Shubuta and Bumpnose Formations of the Gulf Coast (Drugg and Loeblich, 1967; Edwards, unpublished data) and *Heteraulacacysta porosa*, which has a short range (Zone NP 16 and 17 only) in England (Powell, 1992), but which may range higher elsewhere.

Harleyville Formation

R5115 C (87.1-87.5 ft) contains a moderately well preserved dinocyst assemblage dominated by *Pentadinium laticinctum laticinctum*. Dinocysts are:

Achilleodinium biformoides (Eisenack) Eaton
Adnatosphaeridium sp.
Charlesdowniea coleothrypta (Williams & Downie) Lentin & Vozzhennikova
Charlesdowniea stellata Damassa and forms intermediate to *Wetzeliella*
Corrudinium incompositum (Drugg) Stover & Evitt
Cyclopsiella vieta Drugg & Loeblich

Deflandrea phosphoritica Eisenack
Hystrichokolpoma rigaudiae Deflandre & Cookson
Lingulodinium machaerophorum (Deflandre & Cookson) Wall
Pentadinium laticinctum Gerlach subsp. *laticinctum*
Phthanoperidinium stockmansii (de Coninck) Lentin & Williams
Samlandia chlamydophora Eisenack *sensu stricto*
Samlandia chlamydophora Eisenack *sensu* Stover and Hardenbol (1993)
Spiniferites spp.
Systematophora placacantha Deflandre & Cookson
Tectatodinium pellitum Wall
Trigonopyxidia fiscellata de Coninck

Age of this assemblage is latest middle Eocene or late Eocene, and more likely to be late Eocene. Important species include *Corrudinium incompositum, Phthanoperidinium echinatum,* and *Trigonopyxidia fiscellata.*

Ashley Formation

R5115 B (78.4-78.8 ft) contains a well preserved dinocyst assemblage dominated by *Membranophoridium aspinatum*. Dinocysts are:

Apteodinium spiridoides Benedek
Batiacasphaera hirsuta Stover
Batiacasphaera sphaerica Stover
Cyclopsiella chateauneufii Head et al.
Cyclopsiella vieta Drugg & Loeblich
Dapsilidinium pseudocolligerum (Stover) Bujak et al.
Deflandrea heterophlycta Deflandre & Cookson
Dinopterygium cladoides Deflandre *sensu* Morgenroth (1966)
Eocladopyxis n. sp.
Homotryblium plectilum Drugg & Loeblich
Hystrichokolpoma sp.
Lentinia serrata Bujak
Lingulodinium machaerophorum (Deflandre & Cookson) Wall
Membranophoridium aspinatum Gelach
Operculodinium centrocarpum (Deflandre & Cookson) Wall
Palaeocystodinium golzowense Alberti
Pentadinium laticinctum Gerlach (vermiculate forms)
Saturnodinium pansum (Stover) Brinkhuis et al.
Spiniferites spp.
Systematophora placacantha Deflandre & Cookson
Tectatodinium pellitum Wall
Wetzeliella sp.

The age is late Oligocene, probably correlative to calcareous nannofossil Zone NP 24 or 25, based on the co-occurrence of *Batiacasphaera sphaerica* and *Saturnodinium pansum*. These two species overlap in the late Oligocene Old Church Formation in Virginia (Edwards, 1989; de Verteuil and Norris, 1996). In contrast to the sample above it, this sample contains no *Chiropteridium* spp. A poorly preserved specimen of ?*Eocladopyxis* n. sp. may indicate Eocene reworking or contamination.

R5115 A (33.6-33.8 ft) contains a well preserved, moderately diverse dinocyst assemblage in which no particular species is dominant. Dinocysts are:

Apteodinium australiense (Deflandre & Cookson) Williams
Batiacasphaera sphaerica Stover
Chiropteridium lobospinosum (Gocht) Gocht
Chiropteridium spp.
Dapsilidinium pseudocolligerum (Stover) Bujak et al.
Deflandrea phosphoritica Eisenack
Dinopterygium cladoides Deflandre *sensu* Morgenroth (1966)
Distatodinium paradoxum (Brosius) Eaton

Eocladopyxis n. sp.
Homotryblium plectilum Drugg & Loeblich
Hystrichokolpoma rigaudiae Deflandre & Cookson
Lejeunecysta sp.
Lingulodinium machaerophorum (Deflandre & Cookson) Wall
Operculodinium centrocarpum (Deflandre & Cookson) Wall
Polysphaeridium zoharyi (Rossignol) Bujak et al.
Pentadinium laticinctum Gerlach (vermiculate forms)
Samlandia sp.
Saturnodinium pansum (Stover) Brinkhuis et al.
Spiniferites pseudofurcatus (Klumpp) Sarjeant
Spiniferites spp.
Wetzeliella symmetrica Weiler

The age is late Oligocene, probably correlative to calcareous nannofossil Zone NP 24 or 25, based on the co-occurrence of *Batiacasphaera sphaerica* and *Saturnodinium pansum*. In contrast to the sample below it, this sample does not contain *Membranophoridium aspinatum*.

Appendix 4. Pollen studies of the Pregnall No. 1 core.

Five samples were examined for pollen from the Pregnall core. Three of these were barren of pollen or nearly so:

240.7-241.0 ft
275.0-275.4 ft
336.8-337.0 ft.

Two samples, R5115B (78.4-78.8 ft) and R5115A (33.6-33.8 ft) from the Ashley Formation contained sparse pollen grains, but several of the taxa are significant for age determination. Pine pollen mainly or entirely of *haploxylon* type indicates a probable age that is older than middle Miocene. The presence of the *Momipites spackmanianus* group as the sole representative of the genus suggests an age no older than late Oligocene. The presence of *Liquidambar* pollen in the Ashley Formation of the Pregnall core documents the Oligocene occurrence of the genus in eastern North America.

	R5115B 78.4-78.8 ft	R5115A 33.6-33.8 ft
Betula (birch)		X
Carya (hickory)	X	X
Eleagnaceae (silverberry)	X	X
Liquidambar (sweet-gum)	X	
Momipites spackmanianus group	X	X
Pinus (pine) *haploxylon* type	X	X
Quercus (oak)	X	X
Tetracolporopollenites megadolium		X
Tilia (basswood)	X	
Ulmus (elm)	X	X
Several species of fern spores	X	X

Many of these genera and families still exist in eastern North America. *Pinus haploxylon* type is still present in this region, but pollen of *Pinus diploxylon* type has a much higher relative frequency in modern sediment samples from the region. *Pinus haploxylon* type is much the more abundant of the two pine pollen types in the Eocene, but only sparse data are available from the region on the timing of the rise in relative frequency of the *Pinus diploxylon* type during the middle and late Tertiary. However, several items of information may be cited:

1. In the late Oligocene Old Church Formation of Virginia, *Pinus haploxylon* types were much more abundant than *Pinus diploxylon* types (Frederiksen, 1984a).
2. In two middle Miocene samples from Massachusetts, the two pine pollen types were of roughly equal abundance (Frederiksen, 1984b).
3. A Pliocene sample from Massachusetts (discussed in Frederiksen, 1984b) was reexamined, and it was found that of 50 pine pollen grains that could be classified, 42 were of *diploxylon* type and 8 were of *haploxylon* type.

In summary, based on few but probably reasonably reliable data, a sample with mainly or entirely *haploxylon* type pine pollen is probably older than middle Miocene.

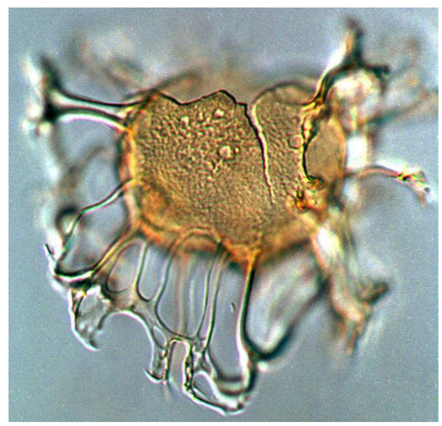
Tetracolporopollenites megadolium (Potonié 1931) Frederiksen 1980 was probably produced by the Sapotaceae, a tropical to warm temperate family which now does not range farther north than North Carolina and Tennessee although it extended as far north as Massachusetts in the Miocene (Frederiksen, 1984b) and probably also in the Eocene and Oligocene.

Pollen of *Liquidambar* has not been found in the lower Oligocene and lowermost upper Oligocene of the eastern Gulf Coast (Frederiksen, 1980a; Oboh and Morris, 1995) nor in the Ashley Formation (upper Oligocene) of the U.S. Geological Survey Clubhouse Crossroads No. 1 core in Dorchester County, South Carolina (Frederiksen, 1980b). However, the limestones of the Ashley have only a low-diversity pollen flora; thus, the apparent absence of pollen of this genus in the Clubhouse Crossroads core may not be significant. The oldest known occurrence of *Liquidambar* pollen in eastern North America is in the Old Church Formation of Virginia, which as stated is late Oligocene (planktonic foraminifer zone N.4a, Poag, 1989), and pollen of this genus is common throughout at least the lower and middle Miocene of the Atlantic Coastal Plain (Rachele, 1976; Frederiksen, 1984b; Traverse, 1994) and remains a common constituent of modern eastern North American forests. In summary, the presence of *Liquidambar* pollen in the Ashley Formation of the Pregnall No. 1 core provides corroborative evidence that the range base of the genus in eastern North America is in the upper Oligocene.

The *Momipites spackmanianus* group of Frederiksen (1984a) was produced by the walnut family, Juglandaceae, and probably by ancestors of the genera *Oreomunnea* and *Alfaroa*, which are presently confined to Mexico, Central America, and northern South America. The *M. spackmanianus* group has its lowest occurrence in the upper Eocene of Texas (Frederiksen, 1981) but does not become abundant until the upper Oligocene (Ashley Formation of the Clubhouse Crossroads No. 1 core), where it makes up most or all of the specimens of *Momipites* in the samples (Frederiksen and Christopher, 1978). The species group is common in the lower and middle Miocene (Rachele, 1976; Frederiksen, 1984b; Traverse, 1994) and dies out north of Mexico probably no later than the beginning of the Pliocene. In summary, the presence of the *Momipites spackmanianus* group as the sole representative of the genus in the present samples suggests that they are no older than late Oligocene.

PLATE 1. Dinocysts from the Pregnall No. 1 core

Kallosphaeridium brevibarbatum *Apectodinium homomorphum*
Chicora Member of the Williamsburg Formation (336.8-337.0 ft)



Pentadinium goniferum *Areoligera/Glaphyrocysta* complex
Cross Member of the Santee Formation (148.5-148.7 ft)

50 µm

Heteraulacacysta porosa
Cross Member of the Santee Formation (92.4-92.7 ft)