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Geology and Paleontology of Five Cores from Screven and Burke Counties, Eastern Georgia

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1603

Prepared in cooperation with the
U.S. Department of Energy and the
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U.S. Geological Survey

Geology and Paleontology of Five Cores from Screven and Burke Counties, Eastern Georgia

Edited by Lucy E. Edwards

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1603

Prepared in cooperation with the
U.S. Department of Energy and the
Georgia Geologic Survey

A description of the Cretaceous and Tertiary geology and paleontology of five cores of sediments below the coastal plain in Screven and Burke Counties, Georgia. Chapters A–I are issued as a single volume and are not available separately.

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

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VOLUME CONTENTS

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CONVERSION FACTORS

Various units used in chapters A–I are listed in the first column below.

Multiply	By	To obtain
	Length	
micrometer (µm)	0.00003937	inch
millimeter (mm)	0.03937	inch
centimeter (cm)	0.3937	inch
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Mass	
gram (g)	0.03527	ounce avoirdupois

Sea level.—In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea-Level Datum of 1929.

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Stratigraphy and Depositional Environments of Sediments from Five Cores from Screven and Burke Counties, Georgia

By W. Fred Falls and David C. Prowell

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1603–A

Prepared in cooperation with the
U.S. Department of Energy and the
Georgia Geologic Survey

GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Edited by Lucy E. Edwards

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SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Stratigraphy and Depositional Environments of Sediments from Five Cores from Screven and Burke Counties, Georgia

By W. Fred Falls and David C. Prowell

ABSTRACT

Five deep stratigraphic test holes were drilled from 1991 to 1993 in support of multidisciplinary investigations to determine the stratigraphy of Upper Cretaceous and Tertiary sediments of the coastal plain in east-central Georgia. Cored sediment and geophysical logs from the Millhaven test hole in Screven County and the Girard and Millers Pond test holes in Burke County are the primary sources of lithologic and paleontologic information for this report. Lithologic and paleontologic information from the Thompson Oak and McBean test holes in Burke County supplements the discussion of stratigraphy and sedimentation in the updip part of the study area near the Millers Pond test hole.

The Cretaceous sections in the studied cores are divided into the Cape Fear Formation, the Middendorf Formation, the Black Creek Group, and the Steel Creek Formation. These four geologic units consist of siliciclastic sediments. Evidence of possible unconformities allows us to recognize two subunits in the Middendorf Formation and three subunits in the Black Creek Group. Sediments in the Cretaceous section generally are coarser grained and more oxidized in updip areas. Each contact between units is a regional unconformity and denotes a considerable hiatus in sedimentation. The sediments in all four geologic units have been interpreted as being part of large deltaic systems that prograded across the paleo-continental shelf in east-central Georgia and western South Carolina. The lithofacies observed in the Upper Cretaceous units tend to be coarser grained in proximal-deltaic environments and finer grained in distal-deltaic environments.

The Tertiary sections are divided into the Ellenton and Snapp Formations of Paleocene age; the Fourmile Branch/Congaree/Warley Hill unit and Santee Limestone of Eocene age; and the Barnwell unit, which contains strata of Eocene to Miocene age. The Tertiary section, with the exception of the Snapp Formation, generally is more calcareous and has a more diverse and abundant marine microflora and fauna in the downdip Millhaven core, relative to the updip McBean and Millers Pond cores. For these units, sedimentary and paleontologic evidence suggests open-marine shelf environments at the Millhaven site and marginal-marine environments at the Millers Pond site.

The Snapp Formation is nearly barren of fossils and is a noncalcareous sequence of oxidized sand and clay. Sedimentary characteristics of the Snapp Formation suggest a fluvially dominated depositional environment such as an upper delta plain or an incised alluvial valley. The presence of a sparse marine microflora suggests some marine influence on deposition in the downdip area near Millhaven. Differences in the thickness of this formation in the study area suggest that channels containing the basal sand of the Snapp Formation are incised into laminated black clay of the Ellenton Formation.

INTRODUCTION

Five deep stratigraphic test holes were drilled in east-central Georgia from 1991 to 1993 in support of multidisciplinary investigations by the U.S. Geological Survey (USGS) and the Georgia Geologic Survey (GGS) of the Georgia Department of Natural Resources. These investigations were conducted to determine the geology and hydrology of the Georgia Coastal Plain sediments in the vicinity of the U.S. Department of Energy Savannah River Site (SRS) in South Carolina (fig. 1). In this region, poorly consolidated Cretaceous and Cenozoic strata form a southeastward-thickening wedge of fluvial and marine deposits underlain by Paleozoic crystalline rocks and Triassic–Jurassic sedimentary rocks. This wedge of sediment is more than

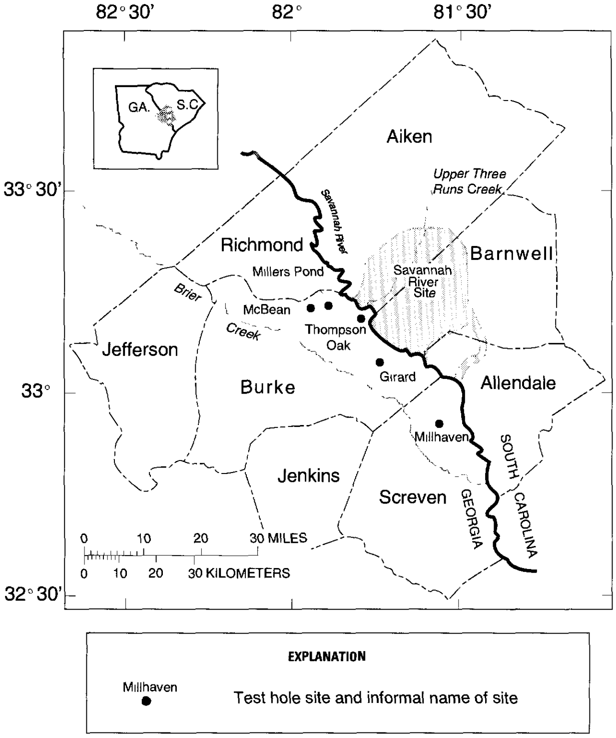


Figure 1. Index map showing the Savannah River Site and the location of stratigraphic test holes in the study area.

1,450 ft thick in the downdip Millhaven core in Screven County.

Previously, the Upper Cretaceous section in the subsurface of the study area was penetrated partially by four cored test holes along the Savannah River in Burke County (Bechtel Corporation, 1972) and by a cored test hole near the town of Midville in the southwestern corner of Burke County (Prowell, Christopher, and others, 1985). The Cretaceous section also was studied by using geophysical logs and cuttings from local water wells (Clarke and others, 1985). The sedimentary history and stratigraphy of the Tertiary section in the study area already were known from outcrops (Huddlestun and Hetrick, 1978, 1979, 1986; Hetrick, 1992) and from several fully or partially cored test holes in northern Burke County (McClelland, 1987) and along the Savannah River in Burke and Screven Counties (Bechtel Corporation, 1972).

This chapter briefly describes the lithologic and stratigraphic character of the geologic units (fig. 2) recognized in the five cored sections to provide a framework for detailed discussions of the fauna and flora identified from paleontologic efforts. The paleontologic data presented in the other chapters of this volume are used with the core descriptions to infer correlation of these geologic units with stratigraphically equivalent units in the vicinity of the study area and to infer depositional environments.

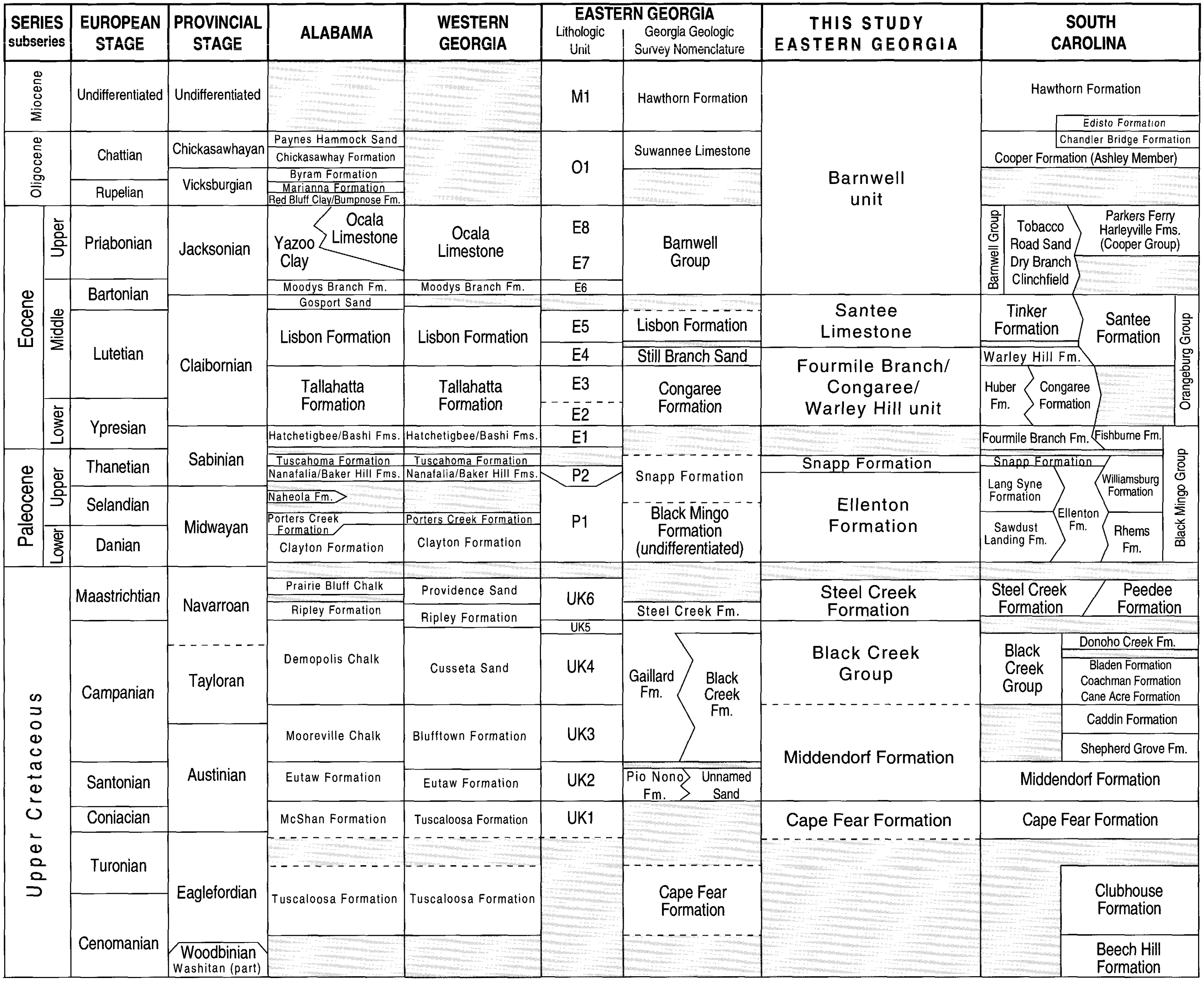
TEST HOLE AND CORE INFORMATION

The five test holes informally are named for local landmarks and formally are assigned either a GGS or a USGS identification number. The informal names used in this report are Millhaven, Girard, Thompson Oak, Millers Pond, and McBean. The five test holes were continuously cored with a wireline, mud-rotary coring system. The cores from the Millhaven, Girard, and Millers Pond test holes were examined for texture, mineralogy, sedimentary structures, diagenetic features, and the presence of macrofossils. Selected samples were examined microscopically for dinoflagellates, pollen, foraminifers, ostracodes, and calcareous nannofossils. The descriptions of the cores and the geophysical logs of the associated test holes at Millhaven, Girard, and Millers Pond are the primary sources of information for the following discussion of stratigraphic units (Clarke and others, 1994, 1996; Leeth and others, 1996).

The authors interpreted the stratigraphy of the Thompson Oak and McBean cores from descriptions published by the GGS (Huddlestun and Summerour, 1996) and have not personally examined these cores in detail. Samples for paleontologic examination were collected by P.F. Huddlestun of the GGS from the Thompson Oak and McBean cores. We used the paleontologic results (Frederiksen and others, this volume, chap. C; Edwards, this volume, chap. G; Frederiksen, this volume, chap. H) to interpret the stratigraphy and sedimentation of geologic units in the updip area near Millers Pond in Burke County, Ga. The stratigraphies of these two cores supplement the following discussion of stratigraphy in the updip part of Burke County near the Millers Pond test hole but are not illustrated as stratigraphic columns in this report.

Geophysical-logging surveys of the test holes, with the exception of the McBean test hole, include single-point and triple-point electric resistance, spontaneous potential, natural gamma ray, and hole diameter (caliper log). Formation instability and hole diameter of the Millhaven test hole prevented electric-logging surveys of the section from 571 to 530 ft and triple-point resistance logging below 900 ft. The McBean test hole is the only one studied that was not geophysically logged.

Figure 2. Generalized comparison of Cretaceous and ➤ Tertiary geologic units in the Southeastern United States (modified from Clarke and others, 1994). Shaded areas indicate missing stratigraphic sections. Dashed lines indicate formation boundary of uncertain stratigraphic position. Abbreviation used: Fm, formation. Source for the lithologic units of eastern Georgia: Prowell, Christopher, and others (1985). Sources for the Georgia Geologic Survey nomenclature in eastern Georgia: Huddlestun and Hetrick (1991), Summerour and others (1994), and Huddlestun and Summerour (1996). Sources for units of South Carolina: Colquhoun and others (1983), Gohn (1992), and Fallaw and Price (1995).



SERIES	subseries	EUROPEAN STAGE	PROVINCIAL STAGE	ALABAMA	WESTERN GEORGIA	EASTERN GEORGIA Lithologic Unit	EASTERN GEORGIA Georgia Geologic Survey Nomenclature	THIS STUDY EASTERN GEORGIA	SOUTH CAROLINA
Miocene		Undifferentiated	Undifferentiated			M1	Hawthorn Formation	Barnwell unit	Hawthorn Formation Edisto Formation
Oligocene		Chattian	Chickasawhayan	Paynes Hammock Sand Chickasawhay Formation		O1	Suwannee Limestone		Chandler Bridge Formation Cooper Formation (Ashley Member)
		Rupelian	Vicksburgian	Byram Formation Marianna Formation Red Bluff Clay/Bumpnose Fm.					
Eocene	Upper	Priabonian	Jacksonian	Yazoo Clay Ocala Limestone	Ocala Limestone	E8 E7	Barnwell Group		Barnwell Group: Tobacco Road Sand Dry Branch Clinchfield Parkers Ferry Harleyville Fms. (Cooper Group)
	Middle	Bartonian		Moodys Branch Fm.	Moodys Branch Fm.	E6			
			Claibornian	Gosport Sand					
		Lutetian		Lisbon Formation	Lisbon Formation	E5	Lisbon Formation	Santee Limestone	Tinker Formation Santee Formation (Orangeburg Group)
						E4	Still Branch Sand	Fourmile Branch/ Congaree/ Warley Hill unit	Warley Hill Fm.
				Tallahatta Formation	Tallahatta Formation	E3 E2	Congaree Formation		Huber Fm. Congaree Formation
	Lower	Ypresian	Sabinian	Hatchetigbee/Bashi Fms.	Hatchetigbee/Bashi Fms.	E1			Fourmile Branch Fm. Fishburne Fm.
Paleocene	Upper	Thanetian		Tuscahoma Formation Nanafalia/Baker Hill Fms.	Tuscahoma Formation Nanafalia/Baker Hill Fms.	P2	Snapp Formation	Snapp Formation	Snapp Formation (Black Mingo Group)
		Selandian	Midwayan	Naheola Fm.		P1	Black Mingo Formation (undifferentiated)	Ellenton Formation	Lang Syne Formation Ellenton Fm. Williamsburg Formation
	Lower	Danian		Porters Creek Formation Clayton Formation	Porters Creek Formation Clayton Formation				Sawdust Landing Fm. Rhems Fm.
Upper Cretaceous		Maastrichtian	Navarroan	Prairie Bluff Chalk Ripley Formation	Providence Sand Ripley Formation	UK6	Steel Creek Fm.	Steel Creek Formation	Steel Creek Formation Peedee Formation
		Campanian	Tayloran	Demopolis Chalk	Cusseta Sand	UK5 UK4	Gaillard Fm. Black Creek Fm.	Black Creek Group	Black Creek Group: Donoho Creek Fm. Bladen Formation Coachman Formation Cane Acre Formation
			Austinian	Mooreville Chalk	Blufftown Formation	UK3		Middendorf Formation	Caddin Formation Shepherd Grove Fm.
		Santonian		Eutaw Formation	Eutaw Formation	UK2	Pio Nono Fm. Unnamed Sand		Middendorf Formation
		Coniacian		McShan Formation	Tuscaloosa Formation	UK1		Cape Fear Formation	Cape Fear Formation
		Turonian	Eaglefordian						
		Cenomanian	Woodbinian Washitan (part)	Tuscaloosa Formation	Tuscaloosa Formation		Cape Fear Formation		Clubhouse Formation Beech Hill Formation

The Millhaven test hole was drilled by the USGS in late 1991 and early 1992 and formally designated as 33X048 (Clarke and others, 1996). The Millhaven site is located in Screven County, Ga., at lat 32°53'25" N., long 81°35'43" W. (fig. 1) and has a land surface elevation of 110 ft. The test hole was drilled from land surface to a total depth of 1,452 ft (fig. 3). This test hole was terminated in Upper Cretaceous sediments of the Cape Fear Formation and did not reach pre-Cretaceous rocks.

The USGS drilled the Girard test hole in the spring of 1992 and formally designated it as 32Y020 (Leeth and others, 1996). The Girard site is in Burke County, Ga., at lat 33°03'54" N., long 81°43'13" W. (fig. 1) and has a land surface elevation of 250 ft. The test hole was drilled from land surface to a total depth of 1,385 ft and penetrated 1,375 ft of coastal plain sediments (fig. 4) and 10 ft of continental red beds of probable Triassic or Jurassic age (Siple, 1967; Marine, 1979; Prowell, Christopher, and others, 1985).

The GGS drilled the Thompson Oak test hole in early 1993 and formally designated it as GGS–3794 (Summerour and others, 1994; Huddlestun and Summerour, 1996); it is also known as TR92–6 and Burke 12. The drill site is located in Burke County, Ga., at lat 33°10'42" N., long 81°47'10" W. (fig. 1) and has a land surface elevation of 240 ft. The test hole was drilled from land surface to a total depth of 1,010.5 ft and penetrated 996 ft of coastal plain sediments and 14.5 ft of biotite gneiss of probable Paleozoic age.

The GGS drilled the Millers Pond test hole, also known as Burke 2, in the summer of 1991 and formally designated it as GGS–3758 (Clarke and others, 1994). The site is located in Burke County, Ga., at lat 33°13'48" N., long 81°52'44" W. (fig. 1) and has a land surface elevation of 245 ft. The test hole was drilled from land surface to a total depth of 859 ft and penetrated 852 ft of coastal plain sediment (fig. 5) and 7 ft of biotite-hornblende gneiss of probable Paleozoic age. A nearby hole, Millers Pond test well 1, was logged for geophysical properties.

The GGS drilled the McBean test hole, also known as Burke 5, in 1991 and formally designated it as GGS–3757 (Summerour and others, 1994; Huddlestun and Summerour, 1996). The drill site is near the community of McBean in Burke County, Ga., at lat 33°13'38" N., long 81°55'50" W. (fig. 1) and has a land surface elevation of 297 ft. The test hole was drilled from land surface to a total depth of 327 ft and terminated in the upper part of the Upper Cretaceous section.

Stratigraphic tops, stratigraphic details, and samples for paleontologic analysis in this volume are reported as core depth below land surface. Geophysical logs for the Millhaven, Girard, and Millers Pond test holes were adjusted slightly to match core depth.

PREVIOUS WORK

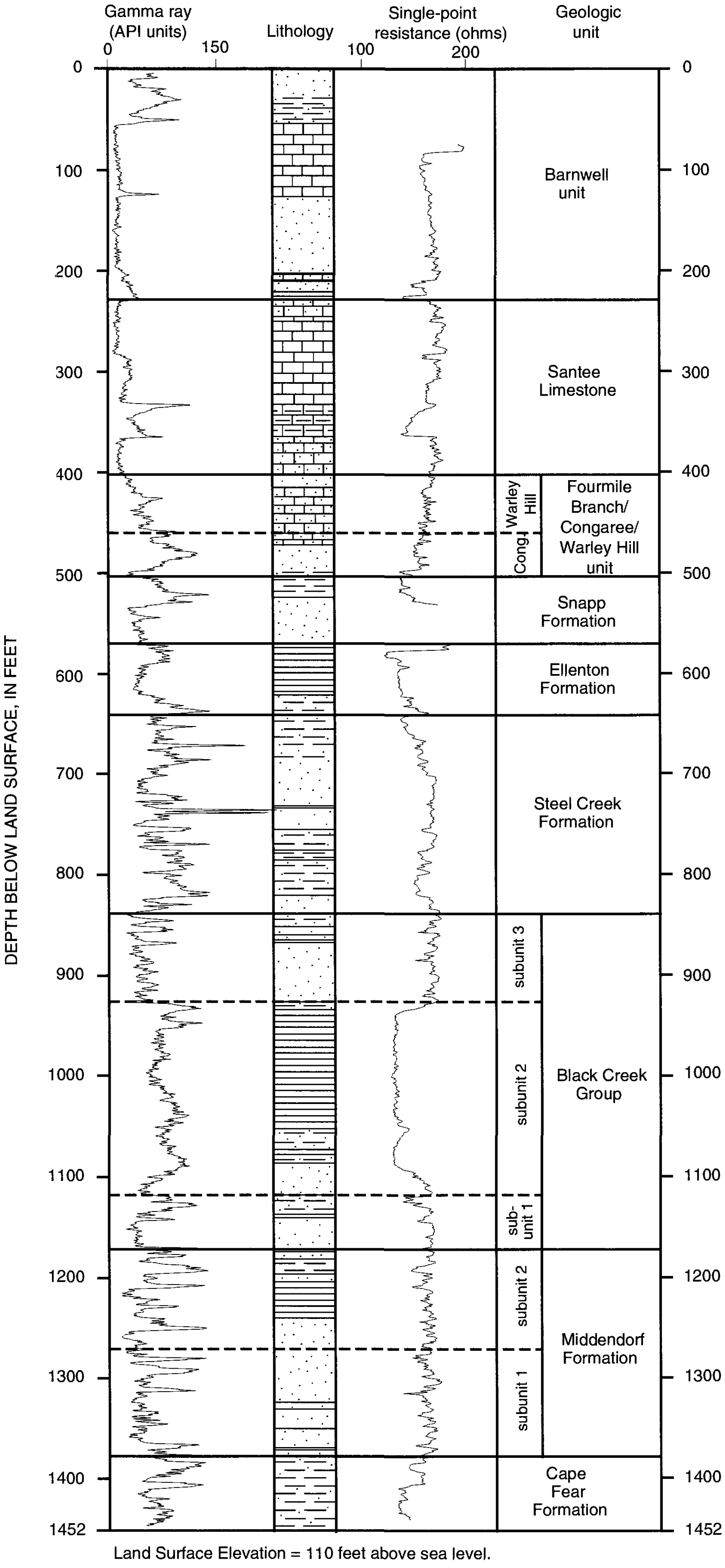
Previous reports on the geology of Burke and Screven Counties and adjacent areas of Georgia include those by Veatch and Stephenson (1911), Brantley (1916), Cooke and Shearer (1918), Cooke (1943), LaMoreaux (1946a,b), LeGrand and Furcon (1956), Herrick (1960, 1961, 1964, 1972), Herrick and Vorhis (1963), Herrick and Counts (1968), Bechtel Corporation (1972, 1973), Carver (1972), Buie (1978), Huddlestun and Hetrick (1978, 1979, 1986, 1991), Prowell and O'Connors (1978), Schroder (1982), McClelland (1987), Huddlestun (1988, 1992), Hetrick (1992), Clarke and others (1994, 1996), Huddlestun and Summerour (1996), Leeth and Nagle (1996), Leeth and others (1996), and Falls and others (1997). Geologic reports on Burke and Screven Counties and adjacent parts of South Carolina include those by Snipes (1965); Hurst and others (1966); Scrudato and Bond (1972); Daniels (1974); Marine and Siple (1974); Bechtel Corporation (1982); Faye and Prowell (1982); Huddlestun (1982); Prowell, Christopher, and others (1985); Colquhoun (1991, 1992); Edwards (1992); Fallaw and Price (1992, 1995); Harris and Zullo (1992); and Prowell (1994). Geologic reports on adjacent parts of South Carolina include those by Sloan (1908); Cooke (1936); Cooke and MacNeil (1952); Christl (1964); Siple (1967); Marine (1979); Smith (1979); Nystrom and Willoughby (1982); Zullo and others (1982); Colquhoun and others (1983); Bledsoe (1984, 1987, 1988); Colquhoun and Steele (1985); Steele (1985); Prowell, Edwards, and Frederiksen (1985); Nystrom and others (1986, 1991); Dennehy and others (1989); Logan and Euler (1989); Robertson (1990); Colquhoun and Muthig (1991); Price and others (1991); Fallaw and others (1992a,b); Snipes and others (1993); and Gellici and others (1995).

ACKNOWLEDGMENTS

The authors thank the U.S. Department of Energy for its support of this investigation. They also thank the Georgia Geologic Survey for allowing access to the Millers Pond core, and Paul F. Huddlestun for sampling and providing lithologic descriptions of the Thompson Oak and McBean cores. The authors also acknowledge the efforts of Donald G. Queen, Eugene F. Cobbs, and Gerald E. Idler during the coring and logging of the Millhaven and Girard sites.

STRATIGRAPHIC FRAMEWORK

Lithologic data from the Millhaven, Girard, and Millers Pond cores and geophysical logs from the three associated test holes were used to define the four Cretaceous and five Tertiary units in this study (fig. 2). Correlation of these geologic units in the Millhaven, Girard, and Millers Pond cores is presented in a dip-oriented cross section (fig. 6).



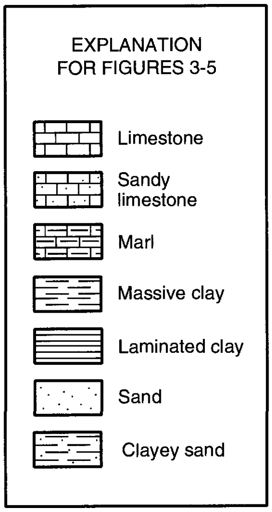
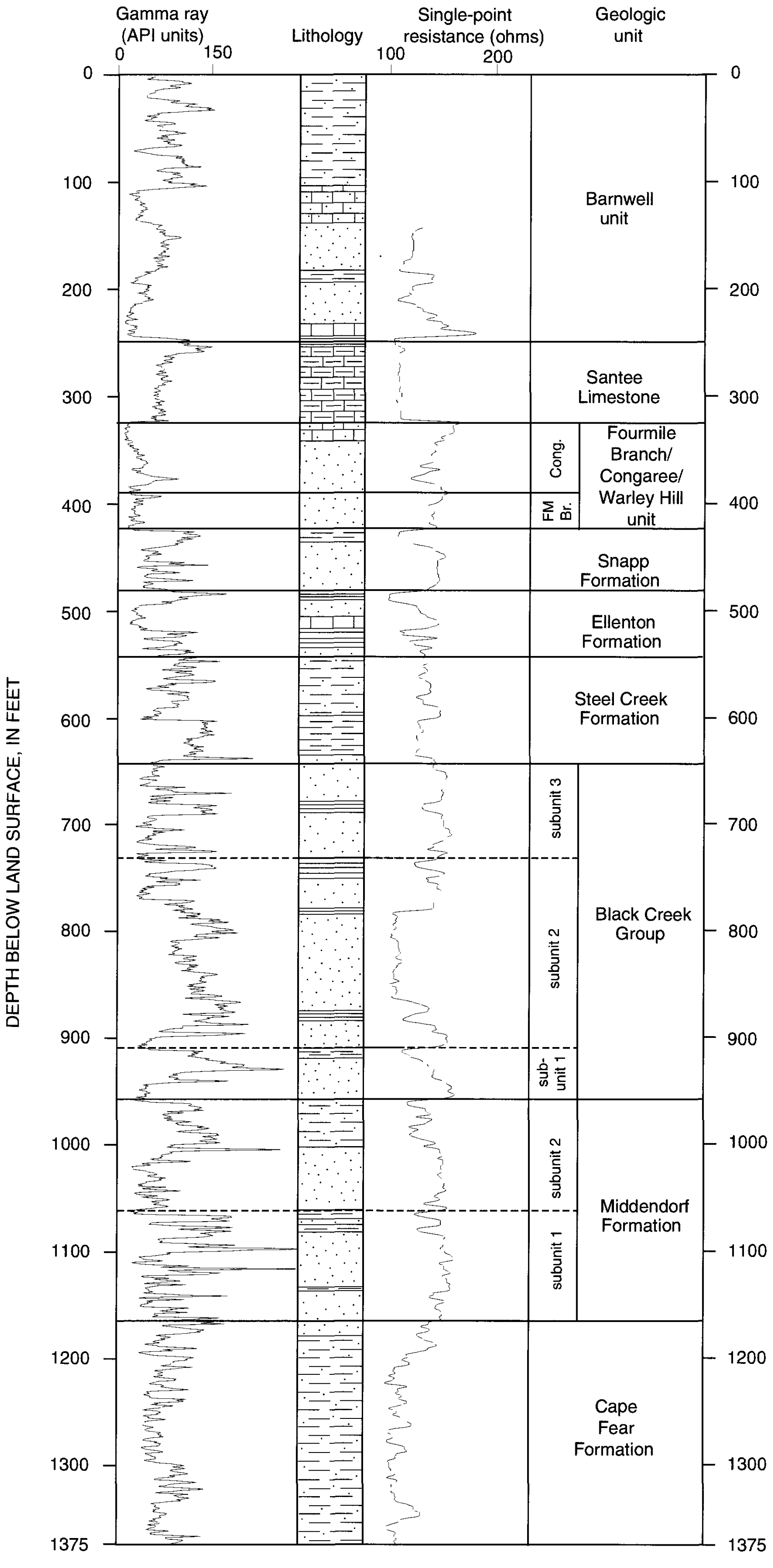


Figure 3. Gamma-ray, single-point resistance, and lithologic logs and geologic units of the Millhaven test hole in Screven County, Ga. Abbreviation used: API, American Petroleum Institute.



Land Surface Elevation = 250 feet above sea level.

Figure 4. Gamma-ray, single-point resistance, and lithologic logs and geologic units of the Girard test hole in Burke County, Ga. Abbreviation used: API, American Petroleum Institute. Lithologic patterns are explained in figure 3.

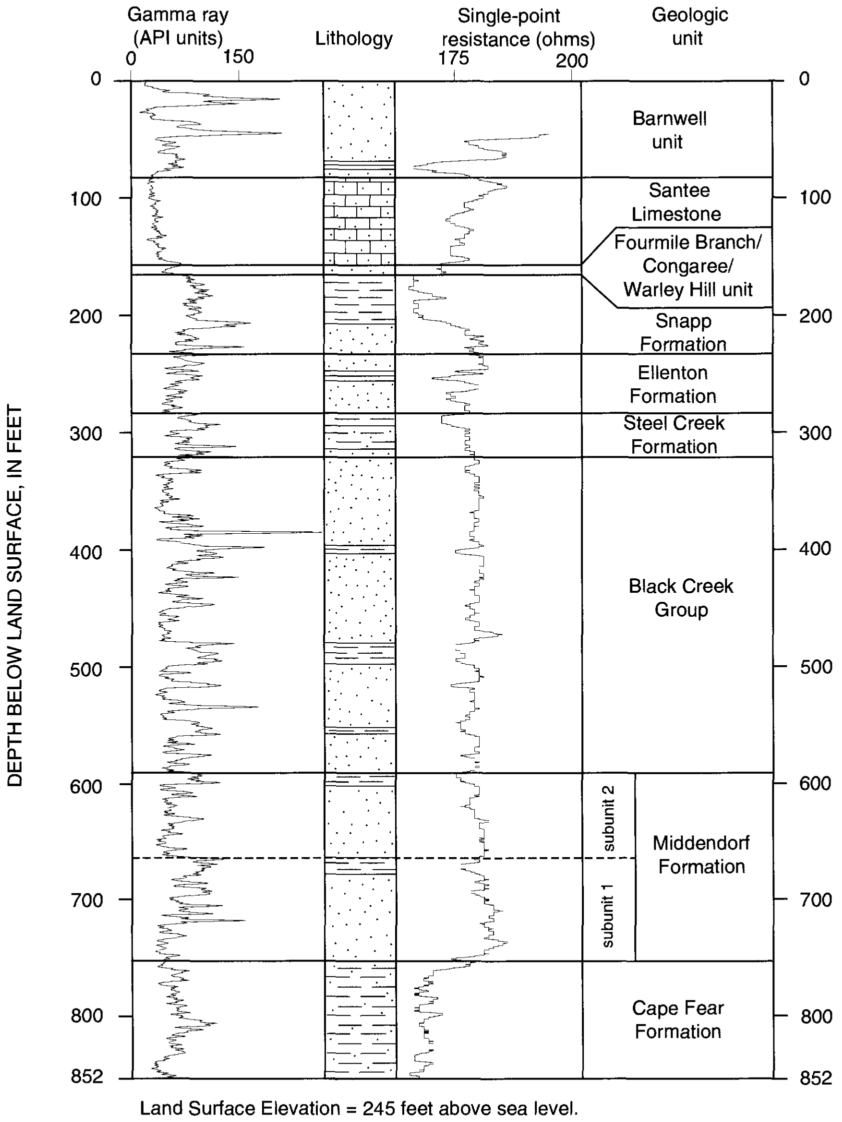


Figure 5. Gamma-ray, single-point resistance, and lithologic logs and geologic units of the Millers Pond test well 1 and test hole in Burke County, Ga. Abbreviation used: API, American Petroleum Institute. Lithologic patterns are explained in figure 3.

The section roughly parallels the Savannah River and reflects the thicknesses and stratigraphy of the geologic units from the updip Millers Pond site to the downdip Millhaven site. Datum for the section is sea level. The elevation and depth of the stratigraphic top of each geologic unit in these three cores and the Thompson Oak and McBean cores are listed in table 1.

Prowell, Christopher, and others (1985) correlated Cretaceous and Tertiary geologic units in the updip coastal plain from central Georgia to western South Carolina. They identified five of the six Upper Cretaceous units, two Paleocene units, six of the eight Eocene units, and one Oligocene unit in a South Carolina drill hole at the SRS (fig. 2). Their units were essentially chronostratigraphic units that were assigned alpha-numeric designations because of a lack of existing nomenclature. Subsequently, Fallaw and Price (1995) established a working nomenclature and described the stratigraphic units beneath the SRS. The stratigraphy and nomenclature used in this report result from combining information from these reports.

Huddlestun and Hetrick (1991), Summerour and others (1994), and Huddlestun and Summerour (1996) proposed a stratigraphic nomenclature for the updip part of the study area in east-central Georgia. A comparison of the stratigraphic units for previous studies with the stratigraphy in this study is shown in figure 2. The stratigraphy of the Millhaven, Girard, and Millers Pond cores is shown in figures 3, 4, and 5.

CRETACEOUS STRATIGRAPHY

The Cretaceous sediments in the study area are divided into the Cape Fear Formation, the Middendorf Formation, the Black Creek Group, and the Steel Creek Formation (fig. 2). These four geologic units consist of siliciclastic sediments, are coarser grained and more oxidized in updip

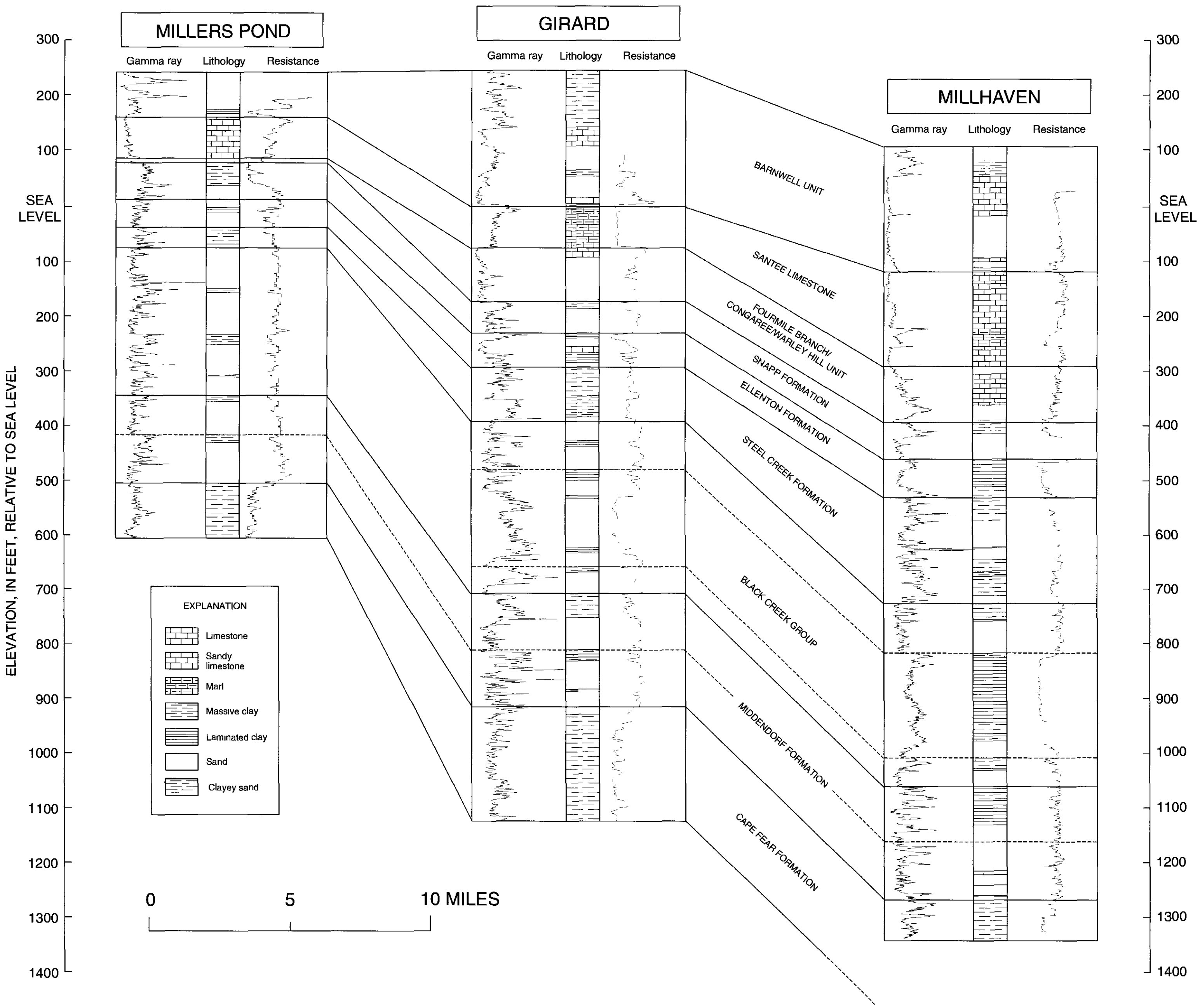


Figure 6. Gamma-ray, single-point resistance, and lithologic logs (from figs. 3–5) showing dip-oriented correlation of geologic units from the Millers Pond test hole to the Millhaven test hole. Datum is sea level.

Table 1. Elevations and depths of stratigraphic tops for geologic units and subunits in the Millhaven, Girard, Thompson Oak, Millers Pond, and McBean cores.

[The stratigraphic contacts in the Thompson Oak and the McBean cores are interpreted from lithologic descriptions provided by Paul F. Huddlestun, Georgia Geologic Survey, Atlanta, Georgia. The stratigraphic contacts and names for the Thompson Oak and McBean cores in this table represent the stratigraphic interpretations of the authors and do not agree with Huddlestun's interpretations in all cases. Elevations are in feet above or below sea level. Depths are in feet below land surface. Top of Barnwell unit equals land surface in each core. N.D., not determined; N.P., not penetrated]

Name of geologic unit	Elevation/depth of stratigraphic contact				
	Millhaven core	Girard core	Thompson Oak core	Millers Pond core	McBean core
Barnwell unit	110/0	250/0	240/0	245/0	297/0
Santee Limestone	–118/228	0/250	110/130	163/82	185/112
Fourmile Branch/Congaree/ Warley Hill unit	–291/401	–75/325	58/182	89/156	111/186
Warley Hill Formation	–291/401	absent	absent	absent	absent
Congaree Formation	–352/462	–75/325	58/182	89/156	111/186
Fourmile Branch Formation	absent	–140/390	–11/251	absent	absent
Snapp Formation	–394/504	–173/423	absent	80/165	75/222
Ellenton Formation	–460/570	–231/481	–34/274	13/232	25/272
Steel Creek Formation	–532/642	–292/542	–84/324	–39/284	–8/305
Black Creek Group	–729/839	–392/642	–166/406	–87/322	N.P.
Subunit 3	–729/839	–392/642	–166/406	–87/322	N.P.
Subunit 2	–817/927	–482/733	N.D.	N.D.	N.P.
Subunit 1	–1,009/1,119	–659/909	N.D.	N.D.	N.P.
Middendorf Formation	–1,062/1,172	–708/958	–445/685	–347/592	N.P.
Subunit 2	–1,062/1,172	–708/958	–445/685	–347/592	N.P.
Subunit 1	–1,162/1,272	–812/1,062	–485/725	–418/663	N.P.
Cape Fear Formation	–1,269/1,379	–913/1,163	–602/842	–507/752	N.P.
Bedrock	N.P.	–1,125/1,375	–756/996	–603/852	N.P.

areas, and become finer grained in a coastward direction. Unit contacts are typically overlain by lags of very poorly sorted sand containing granules, pebbles, and lithoclasts. Each contact is considered to be a regional unconformity and probably denotes a considerable hiatus in sedimentation. In the updip area, lithologic similarities among the units and the presence of only a few fossil-bearing beds make it difficult to identify unit contacts at Millers Pond. Evidence of possible unconformities is used to divide the Middendorf Formation into two subunits in the Millhaven, Girard, and Millers Pond cores, and the Black Creek Group into three subunits in the Millhaven and Girard cores. Prowell, Christopher, and others (1985) identified units UK1 through UK6 in their study but did not correlate their unit UK3 with units in the test holes at the SRS.

Biostratigraphic studies by Christopher (1978) and Prowell, Christopher, and others (1985) suggested that Cretaceous strata in east-central Georgia ranged in age from Coniacian to Maastrichtian. The sediments in the four units have been interpreted as parts of large deltaic systems that prograded across the paleo-continental shelf in east-central Georgia and western South Carolina (Prowell and others, 1985a; Fallaw and Price, 1995). Lithofacies observed in the Upper Cretaceous units accumulated in coarser grained proximal and finer grained distal deltaic settings.

CAPE FEAR FORMATION

The Cape Fear Formation consists of partially lithified to unlithified, poorly to very poorly sorted clayey sand and sandy clay with a few beds of silty clay. The sand is fine to very coarse with granules and pebbles and is predominantly angular to subangular quartz with some feldspar. Cristobalite in the clay matrix results in lithologies that are harder and denser than sediments in the other Cretaceous units. The cristobalitic clay matrix imparts a yellowish-green to greenish-gray color to most of the lithologies and occludes most of the intergranular porosity in the sand beds. Electric logs display low resistance in the sands and the clays in most of this unit. Sands in the upper 10 to 20 ft of this unit in the Millhaven and Girard cores are unlithified and have atypically high resistance values on the electric logs.

The Cape Fear Formation contains multiple fining-upward cycles that range in thickness from 3 to 15 ft. Each cycle grades upward from a basal coarse pebbly sand to clayey sand or clay. The clays are oxidized and are generally stained with reddish-brown and yellowish-brown patches of iron oxide. A root-trace pattern is present at the top of a few of the fining-upward cycles and at the top of this unit in the Millhaven core. Sediments directly beneath the upper contact of the Cape Fear Formation in the other cores are stained with iron oxides. Lag deposits at the base of the Cape Fear Formation contain clasts of saprolitic gneiss in the Millers Pond core and clasts of Triassic siltstone in the Girard core.

Most of the strata in this unit are barren of fossils, but a few samples of gray and olive-gray, silty clay from the Millers Pond core yielded low-abundance and low-diversity pollen assemblages. Palynologic analysis of these samples from the Millers Pond core (Frederiksen and others, this volume, chap. C) indicates a Coniacian microflora that is consistent with the microflora of the Cape Fear Formation of South Carolina and North Carolina (Christopher and others, 1979; Christopher, 1982; Sohl and Owens, 1991). Prowell, Christopher, and others (1985) and Fallaw and Price (1995) suggested a Santonian age for unit UK1 and the Cape Fear Formation at the SRS. Huddlestun and Summerour (1996) suggested that the Cape Fear Formation is equivalent to the Cenomanian-Turonian Tuscaloosa Formation of western Georgia. Samples from this formation were not processed for the other cores.

The presence of a terrestrial microflora and the absence of dinoflagellates and other marine fossils in the Cape Fear Formation suggest deposition in a nonmarine environment at Millers Pond. The Cape Fear Formation in the Millhaven and Girard cores is lithologically similar to the section in the Millers Pond core and also is interpreted as having been deposited in a nonmarine environment. The multiple fining-upward cycles, the coarse texture of the sands, the iron-oxide staining, and root-trace patterns in the clays suggest that most of this unit was deposited in channel and overbank environments during aggradation of a fluvially dominated, subaerially exposed part of a delta-plain environment.

MIDDENDORF FORMATION

The Middendorf Formation consists predominantly of unlithified sand, which is locally fine to very coarse or fine to medium quartz (figs. 3, 4, 5). The sand includes smoky-quartz granules and pebbles, mica, lignite, and generally very little clay matrix. The Middendorf sands are moderately to poorly sorted and are very porous and permeable in comparison with the sands in the underlying Cape Fear Formation. Black clay is present in laminae and thin beds that are less than 2 ft thick in the Millhaven core. Clay beds in the Millers Pond core and most of the Girard core generally are light gray to white and range in thickness from 1 to 10 ft.

The Middendorf Formation contains two distinct subunits in the Millhaven, Girard, and Millers Pond cores. Additional work in the study area may show these subunits to be separate, mappable formations. At present, they are informally referred to in ascending order as subunits 1 and 2 of the Middendorf Formation. Each subunit includes a basal lag deposit of poorly sorted sand that grades up to interbedded and interlaminated clay and sand. Micaceous and lignitic sand laminae are common in the Middendorf sections, particularly near the top of each subunit. Clay beds are generally thicker and display more abundant iron-oxide staining near the top of each subunit in the Millers Pond and Girard cores. A root-trace pattern is observed in the clay at the top of subunit 2 in the Girard core. Clays at the top of each subunit in the Millhaven core are not stained with iron oxides.

Lithologic data and geophysical log patterns seem to indicate that the upper contact of the Middendorf Formation in the Georgia cores correlates with the unit UK2/UK4 boundary of Prowell, Christopher, and others (1985) and the top of the Middendorf Formation as recognized by Fallaw and Price (1995) at the SRS. A Santonian age was reported for unit UK2 by Prowell, Christopher, and others (1985) and for the Middendorf Formation at the SRS by Fallaw and Price (1995). Samples collected at 1,138 and 1,012 ft in the Girard core and 1,212 ft in the Millhaven core contain pollen that suggests at least part of the Middendorf Formation may be correlative with the Shepherd Grove Formation, which overlies the Middendorf in South Carolina (Frederiksen and others, this volume, chap. C).

All or part of what has been described as Middendorf Formation in this part of Georgia may actually be correlative with part of the Black Creek Group or an updip lithofacies of either the Caddin or Shepherd Grove Formations, which Gohn (1992) identified as late Santonian to early Campanian in age. Evidence of subaerial exposure and erosional lags at the contacts between the upper and lower subunits support the possibility that unit UK2 (Prowell, Christopher, and others, 1985), as defined beneath the southeastern corner of the SRS, contains more than one depositional sequence and is equivalent in part to unit UK3.

Huddlestun and Hetrick (1991) applied the name Pio Nono Formation in updip areas of east-central Georgia to the Middendorf Formation as used here. Dinoflagellates and other marine indicators are sparse and suggest a marginal-marine environment at Millhaven and a nonmarine environment for this unit in the other cores.

BLACK CREEK GROUP

The Black Creek Group consists of three distinct subunits in the Millhaven and Girard cores: a basal lignitic sand in subunit 1, a laminated black clay and sand in subunit 2, and a coarsening-upward sand sequence in subunit 3 (figs. 3, 4, table 1). The lag deposits at the bases of the subunits suggest the possibility of unconformities in the Black Creek Group at Millhaven and Girard. The Black Creek Group at Millers Pond is coarser and sandier and is not divided into subunits (fig. 5).

Black Creek subunit 1 consists of moderately to poorly sorted, fine to coarse quartz sand that grades into overlying very fine to fine sand with a few thin beds of clay. The sand contains abundant interlaminated fine lignite and mica and very little clay matrix. This subunit is lithologically very similar to the underlying Middendorf Formation.

Black Creek subunit 2 in the Millhaven core has a sharp basal contact at 1,119 ft and a second sharp contact at 1,099 ft. Each contact is overlain by a basal lag deposit of very poorly sorted sand. The sand above the contact at 1,099 ft grades and fines into an overlying 161-ft section of predominantly silty laminated black clay. The 161-ft clay section also includes very fine to fine sand from 1,063 to 1,051 ft. Most of subunit 2 is calcareous and contains laminae and lenses of very fine sand and sand-filled burrows. Very fine to fine sand is interlaminated at the top of the clay from 934 to 927 ft. Subunit 2 in the Girard core is sandier and consists of very fine to fine sand with interbedded black clay. The sand at Millhaven and Girard includes mica, lignite, and minor amounts of glauconite.

Bioturbation features in subunit 2 at Millhaven and Girard include clay-lined burrows, mottled textures, and discontinuous laminae of clay in the sands. Subunit 2 at Millhaven and Girard yielded the most abundant and diverse marine macrofaunas and microfaunas and microfloras in the Cretaceous section in the study area, including shark teeth, pelecypods, ostracodes, benthic and planktonic foraminifers, spicules, dinoflagellates, pollen, and calcareous nannofossils (Bukry, this volume, chap. D; Frederiksen and others, this volume, chap. C; Gohn, this volume, chap. E).

Black Creek subunit 3 in the Millhaven core is a coarsening-upward sequence and consists of a very poorly sorted lag deposit from 927 to 926 ft; moderately to well-sorted, very fine to medium sand from 926 to 880 ft; and moderately sorted, fine to coarse sand from 880 to 826 ft. This subunit at Millhaven includes laminae and thin beds of dark-gray clay, large and small pieces of lignite, and mica; the subunit is crossbedded from 907 to 900 ft.

Black Creek subunit 3 in the Girard core has a sharp basal contact at 733 ft and a lag deposit of very poorly sorted sand and granules from 733 to 730 ft. The section includes beds of moderately to poorly sorted, medium to very coarse sand; and moderately sorted, fine to medium sand with 5 to 10 percent clay matrix. This section is crossbedded from 714 to 710 ft and 679 to 660 ft and includes one light-gray, iron-stained clay from 685 to 679 ft. The top of the clay at 679 ft is overlain by a lag deposit of very poorly sorted sand and granules.

The Black Creek Group at Millers Pond contains poorly sorted, fine to very coarse sand and beds of clay (fig. 5). Granules and pebbles are more abundant and form several very poorly sorted lags at the base of sand beds, which generally include clay clasts. The sand is unlithified and has minor amounts of clay matrix. The tops of clay beds generally are stained with yellow and red iron oxides.

Paleontologic data from the studied cores suggest a Campanian age for the Black Creek Group (Frederiksen and others, this volume, chap. C; Bukry, this volume, chap. D; Gohn, this volume, chap. E). Units UK4 and UK5 (Prowell, Christopher, and others, 1985) and the Black Creek Group at the SRS (Fallaw and Price, 1995) are assigned an age of Campanian to Maastrichtian. Huddlestun and Hetrick (1991) applied the name Gaillard Formation to the fluvial lithofacies in the updip Georgia Coastal Plain. Paleontologic data (Frederiksen and others, this volume, chap. C; Bukry, this volume, chap. D; Gohn, this volume, chap. E) suggest that the calcareous lithologies of subunit 2 at Millhaven are equivalent to the Donoho Creek Formation of the Black Creek Group (Owens, 1989; Sohl and Owens, 1991).

The diversity and abundance of dinoflagellates, the abundance of marine faunas, and the presence of glauconite at Millhaven and Girard suggest a strong marine influence during the deposition of subunit 2, probably in the distal part of a deltaic complex. Dinoflagellates in subunit 3 suggest a marginal-marine depositional environment. The composition of the microflora and the absence of other marine indicators suggest that subunit 1 at Millhaven and Girard and the entire section of the Black Creek Group at Millers Pond reflect sedimentation in a nonmarine part of the delta (Frederiksen and others, this volume, chap. C).

STEEL CREEK FORMATION

Most of the Steel Creek Formation in the Georgia test holes consists of poorly to very poorly sorted, fine to very coarse sand with granules and pebbles of smoky quartz and 5 to 15 percent clay matrix (figs. 3, 4, 5). The basal lags are overlain by thick intervals of oxidized clay in the Millhaven and Girard cores. Steel Creek sections include multiple fining-upward sequences with beds of coarser grained sand that become finer and grade into overlying clay beds. Many of the clay beds are stained with iron oxide and contain as much as 40 percent sand by volume. Root traces typically are present at the top of the thick oxidized clay near the base of the section and in some of the clay beds near the top of this unit. Crossbedding is common at Millhaven. Lignite and mica are common accessory constituents.

Kidd (1996) used a subtle difference in grain size and clay content and geophysical-log correlations with test holes on the SRS to identify the contact between the Black Creek Group and the Steel Creek Formation at 397 ft in the Millers Pond core. Huddlestun and Summerour (1996) identified the basal contact at 367 ft in the Millers Pond core and 414 ft in the Thompson Oak core; they described the contact between the Black Creek (Gaillard) and Steel Creek Formations as either conformable or paraconformable in updip parts of Burke County and as gradational in the Girard core. The contact between the Black Creek Group and the Steel Creek Formation is recognized as an unconformity at the Millhaven and Girard sites. This boundary is placed at the sharp contact at 322 ft in the Millers Pond core in this report on the basis of projecting the contact from the downdip Girard core.

Most of the sediments in the Steel Creek Formation are barren of fossils. Thin beds of brownish-gray clay in the Steel Creek section of the Millhaven core yielded Cretaceous and Paleocene palynomorphs, but more diagnostic taxa were not recovered (Frederiksen and others, this volume, chap. C). The presence of dinoflagellates and Paleocene palynomorphs in samples collected from the Steel Creek section in the Millhaven core is discounted as contamination of the samples with drilling mud (Edwards and others, this volume, chap. B). Paleontologic data from the underlying Black Creek Group and the overlying Ellenton Formation restrict the age of the Steel Creek Formation to the Maastrichtian.

Prowell, Christopher, and others (1985) identified a correlative section in wells at the SRS as middle Maastrichtian in age and designated it as unit UK6. They considered unit UK6 to be a biostratigraphic equivalent of the Providence Sand and part of the Ripley Formation in Georgia and the Peedee Formation in eastern South Carolina (fig. 2). Fallaw and Price (1995) described and named the Steel Creek Formation at the SRS. Huddlestun and Summerour (1996) also applied the name Steel Creek Formation to cored sections in east-central Georgia and considered the Steel Creek Formation to be early Maastrichtian.

Marine fossils, carbonate minerals, and glauconite are absent from the Steel Creek sections of the studied cores. The coarse sediments, fining-upward sequences, indications of rooting, and iron-oxide staining suggest channel and overbank deposits in a delta-plain environment.

TERTIARY STRATIGRAPHY

The Tertiary section in this report includes the Ellenton and Snapp Formations in the Paleocene strata and the Fourmile Branch/Congaree/Warley Hill unit, the Santee Limestone, and the Barnwell unit in the Eocene and younger strata (fig. 2). Each of the Eocene units in the Georgia cores can be lithologically, geophysically, or biostratigraphically correlated with more than one formal formation in the study area and is informally named in the report.

The stratigraphy proposed by Prowell, Christopher, and others (1985) at the southeastern corner of the SRS included two Paleocene units designated as units P1 and P2, six Eocene units designated as units E1, E3, E4, E5, E7, and E8, and an Oligocene unit designated as unit O1. Units E2, E6, and M1 were recognized and correlated in Georgia but were not correlated with units in the southeastern corner of the SRS (Prowell, Christopher, and others, 1985).

ELLENTON FORMATION

The Ellenton Formation in the Georgia cores is finer grained, calcareous, and very glauconitic in the downdip Millhaven and Girard cores. It is coarser grained and noncalcareous in the updip Millers Pond core (fig. 6). Lag deposits and sharp bedding contacts identify basal unconformities and possible unconformities within the Georgia sections.

The Ellenton Formation in the Millhaven core consists of glauconitic, calcareous, fine to coarse sand and laminated clay from 642 to 622 ft; well-laminated, slightly calcareous, silty black clay from 622 to 595 ft; and calcareous to noncalcareous clay from 595 to 570 ft (fig. 3). The Ellenton Formation in the Girard core consists of noncalcareous sand and black clay from 542 to 518 ft; sandy carbonate and limestone and calcareous sand with abundant glauconite from 518 to 491 ft; and well-laminated, noncalcareous silty clay from 491 to 481 ft (fig. 4). The section generally contains well-sorted, fine to medium quartz sand. The lag deposits at 638, 625, and 595 ft in the Millhaven core and 518 ft in the Girard core contain 10 to 20 percent glauconite, several rounded phosphatic clasts, and shark teeth. A high-angle shear defines a sharp contact at 491 ft in the Girard core.

The Ellenton Formation in the updip Millers Pond core consists of fine to very coarse sand with interbedded sandy clay from 284 to 263 ft; interlaminated black lignitic clay and very fine to medium sand from 263 to 247 ft; and fine to medium clayey sand from 247 to 232 ft (fig. 5). The laminated black clay is very dense and may contain as much as 5 percent mica. Recovery of sediment in the Millers Pond core was not as good as recovery in the Millhaven and Girard cores; however, poorly sorted pebble lag deposits at 284 and 271 ft and clay clasts at 263 and 244 ft suggest possible unconformities and reworking of the Ellenton Formation in the Millers Pond core.

Paleontologic results suggest that the Ellenton Formation in this report is equivalent to unit P1 (Prowell, Christopher, and others, 1985) and the Ellenton Formation in South Carolina (Prowell, Edwards, and Frederiksen, 1985). Huddlestun and Summerour (1996) described a unit that they identified as the Black Mingo Formation undifferentiated in Georgia. They recognized a lower and an upper unit that resemble lithologies of the Rhems, Williamsburg, and Lang Syne Formations of the Black Mingo Group (Van Nieuwenhuise and Colquhoun, 1982). Fallaw and Price (1995) divided the Ellenton section into the Sawdust Landing and Lang Syne Formations in wells near the southeastern border of the SRS. The noncalcareous, nonglauconitic sand and clay from 542 to 518 ft at Girard and from 284 to 263 ft at Millers Pond are lithologically similar to the Sawdust Landing Formation. However, a similar lithologic unit was not recognized at Millhaven. The rest of the Ellenton Formation at Millhaven and Girard is similar to the very glauconitic and silty lithologies of the Lang Syne Formation. The carbonate component at Millhaven and Girard is not described in the Lang Syne Formation at the SRS but is described as part of this unit beneath Allendale County in South Carolina (Fallaw and Price, 1995; Gellici and others, 1995).

Paleontologic studies identified a diverse microflora of dinoflagellates, pollen, and calcareous nannofossils and a faunal component of ostacodes, planktonic foraminifers, pelecypods, and gastropods in the downdip sections (Edwards and others, this volume, chap. B). The updip section at Millers Pond contains a low-diversity microflora of dinoflagellates and pollen (Clarke and others, 1994). The marine fossils, glauconite, and carbonate in downdip sediments indicate an open-marine environment, possibly distal prodelta. The low diversity and the low abundance of dinoflagellates and the absence of other marine indicators at Millers Pond suggest a change to a more restricted marginal-marine environment.

SNAPP FORMATION

The Snapp Formation at Millhaven, Girard, and Millers Pond consists of moderately to poorly sorted, fine to very coarse sand overlain by iron-stained, oxidized kaolin (figs. 3, 4, 5). The sand is unlithified and generally has granules, pebbles, and less than 10 percent clay matrix. Individual sand beds typically are coarse to very coarse in the lower part of each section. In the middle of each section, the sand beds are fine to medium. At the top of each section, the sand beds grade into white to very light gray kaolin. The clay is stained with red and yellow iron oxides. Pedogenic structures in the otherwise massive clay include root traces and desiccation cracks. Pyrite is disseminated in the clay and along desiccation cracks near the top of the Snapp Formation in the Millers Pond and Girard cores.

The Snapp Formation in Georgia is equivalent to unit P2 (Prowell, Christopher, and others, 1985) and the Snapp Formation at the SRS (Fallaw and Price, 1995). McClelland (1987) applied the name Rhems Formation (lower Paleocene part of the Black Mingo Group) to a combined section of the Snapp and Ellenton Formations in upper Burke County. The Snapp Formation holds the same upper Paleocene stratigraphic position as the Chicora Member of the Williamsburg Formation of the Black Mingo Group (Van Nieuwenhuise and Colquhoun, 1982). The Snapp Formation in the Georgia cores and in cores on the SRS (Fallaw and Price, 1995) is lithologically different from the marine sediment of the Chicora Member.

The Snapp Formation is absent from the Thompson Oak core (fig. 1, table 1). Fallaw and Price (1995) described an updip limit for the Snapp Formation near the Upper Three Runs Creek in Aiken County, S.C. Extension of this boundary into Georgia would place the Thompson Oak core near the updip limit of the Snapp Formation. The presence of Snapp sediments in the McBean core indicates that the updip limit is irregular in that it trends to the northwest from the Thompson Oak test hole across the northern part of Burke County, Ga. (fig. 1).

Paleontologic samples were not collected from the Snapp Formation in the Girard and Millers Pond cores because of the extensive oxidation of the sediments. A sample from the base of this formation in the Millhaven core yielded sparse dinoflagellates that are not age diagnostic (Edwards and others, this volume, chap. B). The stratigraphic position of this unit between the Ellenton Formation and the overlying early Eocene part of the Fourmile Branch/Congaree/Warley Hill unit suggests that the age of the strata is either late Paleocene (Prowell, Christopher, and others, 1985; Fallaw and Price, 1995) or early Eocene (Harris and Zullo, 1992). Paleontologic data from a sample at 264 ft in the McBean core indicated a Paleocene age; however, the authors have not independently verified that the sample at 264 ft is from the Snapp Formation. This sample of the McBean core is above the base of the Snapp Formation as selected by Huddlestun and Summerour (1996).

Sedimentary characteristics suggest a fluvially dominated depositional environment in either an upper delta plain or an incised alluvial valley. The presence of dinoflagellates in the Millhaven core suggests a marginal-marine environment in the downdip part of the study area. The Snapp Formation at Girard is 58 ft thick, which is roughly 20 ft thicker than the Snapp Formation in cores from the southeastern part of the SRS. The thicker section of the Snapp Formation in the Girard core overlies a section of the Ellenton Formation that is thinner by 20 ft relative to the Ellenton section in the southeastern part of the SRS. Structural-contour and isopach maps of the Black Mingo (Ellenton) and Snapp Formations also indicate thicker sections of the Snapp Formation over thinner sections of the Black Mingo (Ellenton) Formation in eastern Burke County and southern Barnwell County (Huddlestun and Summerour, 1996). This thickness change is interpreted here as evidence of channel incision of the Snapp Formation into the laminated black clay of the Ellenton Formation.

FOURMILE BRANCH/CONGAREE/WARLEY HILL UNIT

The lithologies of the Fourmile Branch/Congaree/Warley Hill unit range from mixed-siliciclastic-carbonate sections in the central and downdip Georgia cores to siliciclastic sections in the updip cores (figs. 3, 4, 5, 6). Paleontologic data suggest that the strata in this unit are correlative with three formally named formations at the SRS (fig. 2). However, all three formations are not consistently present in each of the Georgia cores (table 1).

In the downdip Millhaven core, the Fourmile Branch/Congaree/Warley Hill unit consists of interbedded quartz sand, marl, and limestone. The sand is very fine to fine below a depth of 415 ft and fine to medium above a depth of 415 ft and is moderately to well sorted throughout. Glauconite is a common accessory mineral and is abundant at 462 ft. The carbonate beds range from lithified to unlithified and include glauconite, clay matrix and fossils. Extensive burrowing is recognized in the sandy carbonate matrix.

In the Girard core, this unit consists of medium to coarse sand from 423 to 390 ft; fine to medium sand from 366 to 350 ft; and medium to coarse sand, sandy carbonate, and limestone from 342 to 325 ft. A large part of the unit from 390 to 366 ft and several other parts of the section were not recovered during coring. The section below 390 ft is predominantly noncalcareous with only trace amounts of glauconite, generally less than 5 percent clay matrix, clay laminae, and clay-lined burrows. Unlithified sandy carbonate and partially lithified calcareous sand are abundant above 366 ft.

This unit in the Millers Pond core consists of a 9-ft section of well-sorted, very fine to fine sand. The sand contains less than 5 percent clay matrix, but clay-lined burrows are present.

Surface mapping and drill hole evidence from this updip region in Georgia and adjacent areas of South Carolina indicate a thicker section of sand and clay (Nystrom and Willoughby, 1982; Nystrom and others, 1986; McClelland, 1987; Prowell, 1994). On the basis of data from augered holes that are 1 mile west of the Millers Pond core site, McClelland (1987) described a 40-ft section of the Huber Formation, a time-equivalent lithofacies of the Congaree Formation. In the Huber Formation described by McClelland (1987), the burrowed, fine sand observed at Millers Pond is overlain by a crossbedded, fine to coarse quartz sand and lenticular beds of massive, lignitic kaolinitic clay.

Dinoflagellates, pollen, and calcareous nannofossils were recovered from the core samples of the Fourmile Branch/Congaree/Warley Hill unit at Millhaven and Girard. Dinoflagellates and pollen were recovered from the Thompson Oak and Millers Pond cores. Paleontologic examination of these core samples indicates that this unit is early Eocene to early middle Eocene in age and that it includes more than one biostratigraphic unit (Bybell, this volume, chap. F; Frederiksen, this volume, chap. H; Edwards, this volume, chap. G). Other fossils observed in the Millhaven core included bryozoans, pelecypods, and foraminifers below 462 ft and pelecypods and foraminifers above 462 ft. In the Girard core, pelecypods, bryozoans, and shark teeth were observed above 342 ft. Biomoldic pores indicate that gastropods also were present.

The Fourmile Branch/Congaree/Warley Hill unit from 423 to 390 ft in the Girard core is lithologically and geophysically correlative with the Fourmile Branch Formation at the SRS (Fallaw and Price, 1995). The age of this part of the Girard core could not be determined from fossil evidence. An early Eocene age was determined with dinoflagellates from samples of the Thompson Oak core from 274 to 251 ft (Edwards, this volume, chap. G). These sections in the Girard and Thompson Oak cores appear to be equivalent to unit E2 of Prowell, Christopher, and others (1985) and the Fourmile Branch Formation at the SRS (Fallaw and Price, 1995). A biostratigraphically correlative section was not identified at Millhaven, Millers Pond, or McBean.

The section from 390 to 325 ft in the Girard core is biostratigraphically correlative with the sections from 504 to 462 ft in the Millhaven core and from 165 to 156 ft in the Millers Pond core, and with samples collected from depths of 210, 194, 192, and 183 ft in the Thompson Oak core. This part of the Fourmile Branch/Congaree/Warley Hill unit is equivalent to unit E3 (Prowell, Christopher, and others, 1985) and the Congaree Formation in South Carolina (Fallaw and Price, 1995) and Georgia (Huddlestun and Summerour, 1996).

The Fourmile Branch/Congaree/Warley Hill section from 462 to 401 ft in the Millhaven core is lithologically equivalent and geophysically correlative with at least part of the Congaree Formation as identified in the subsurface of Allendale County in South Carolina (Gellici and others, 1995). This section is biostratigraphically equivalent to the lower part of unit E4 (Prowell, Christopher, and others, 1985) and the Warley Hill Formation at the SRS (Fallaw and Price, 1995). A biostratigraphic equivalent to this part of the Fourmile Branch/Congaree/Warley Hill section is not identified in the other studied cores in Georgia.

Sedimentary characteristics of the Fourmile Branch sections in the Girard and Thompson Oak cores suggest a nearshore-marine environment. Sedimentary characteristics of the overlying Congaree beds suggest an open-marine shelf environment for deposits in the downdip core and a fluvially dominated to marginal-marine environment for deposits in the updip cores in the vicinity of Millers Pond. The Warley Hill Formation at Millhaven also was deposited in an open-marine shelf environment.

SANTEE LIMESTONE

The Santee Limestone consists predominantly of limestone and unlithified carbonate with a few beds of calcareous sand and clay. The Santee Limestone, as correlated in this report, includes lithologies assigned by others to the Warley Hill Formation (Steele, 1985; McClelland, 1987; Fallaw and Price, 1992, 1995), the Blue Bluff Marl of the Lisbon Formation (Huddlestun and Hetrick, 1986), the Santee Limestone (Sloan, 1908), and the McBean Formation (Veatch and Stephenson, 1911). These lithofacies are time equivalents of the Lisbon Formation of western Georgia (Prowell, Christopher, and others, 1985) and collectively are correlated as one package of sediment in this report (fig. 6), although we do recognize significant stratigraphic contacts within the unit.

The lower part of the Santee Limestone in the Millhaven core from a depth of 401 to 365 ft consists of calcareous sand with glauconite and pelecypods that grades into overlying sandy carbonate with large oyster shells and other pelecypods (fig. 3). The quartz sand is medium to coarse near the base of the section and fines upward to fine to medium. The carbonate in this part of the section ranges from unlithified to partially lithified. The contact between the lower and middle part of the section at 365 ft is phosphatized and pyritized. Pelecypod-moldic pores immediately beneath the contact are filled with the very fine sediments of the overlying marl.

The middle part of the Santee Limestone in the Millhaven core from 365 to 245 ft varies from marl to carbonate with very little quartz sand in both lithologies. Carbonate from 365 to 268 ft is well lithified and has biomoldic porosity. The marl is burrow mottled to wavy laminated with minor amounts of lignite and pyrite. Fossils in the marl include foraminifers, spicules, shark teeth, pelecypods, and gastropods. The marl grades into overlying well-lithified to partially lithified limestone. Fossils in the limestone are more abundant and more diverse than in the marl and include pelecypods, gastropods, bryozoans, echinoids, foraminifers, brachiopods, and shark teeth. A sharp bedding contact at 332 ft is underlain by biomoldic limestone with phosphatized fossil molds and shark teeth from 336 to 332 ft. Porosity in the middle part of the section is interparticle and biomoldic with irregular dissolution cavities from 258 to 252 ft.

The sandy carbonate in the upper part of the Santee Limestone in the Millhaven core from 245 to 228 ft includes fine to medium quartz sand and glauconite. Marine fossils include pelecypods, bryozoans, and gastropods.

The Santee Limestone in the Girard core includes a very sandy limestone from 325 to 322 ft and a marl and clayey sand from 322 to 250 ft (fig. 4). The limestone from 325 to 322 ft is glauconitic with abundant pelecypod-moldic porosity and is pyritic along the contact with the overlying marl. The marl is a very fine grained limestone unit with as much as 30 percent clay matrix. Very fine to fine quartz sand ranges from 2 percent near the base of the section to 25 percent near the top of the section. The marl and calcareous sand are burrow mottled and contain minor amounts of lignite and glauconite. Macrofossils are sparse and include pelecypods.

The Santee Limestone in the Millers Pond core consists of sandy limestone and calcareous sand (fig. 5). A thin basal lag of very poorly sorted sand from 156 to 154 ft includes quartz pebbles and granules, glauconite, and pelecypods. The quartz sand above 154 ft is fine to very coarse in calcareous sand beds and fine to medium in sandy limestone beds. The limestone below a depth of 121 ft is finely crystalline and contains glauconite and marine fossils, including pelecypods, spicules, foraminifers, and shark teeth. Marine fossils in the limestone above a depth of 100 ft include oysters and other pelecypods, foraminifers, and echinoid fragments. Biomoldic porosity also is present above a depth of 100 ft and reflects dissolution of aragonitic pelecypods and gastropods.

The Santee Limestone at Millers Pond is thicker than comparable sections in this updip area (Nystrom and Willoughby, 1982; Nystrom and others, 1986; McClelland, 1987; Prowell, 1994). McClelland (1987) described this unit as 40 ft thick in a drill hole located west of the Millers Pond site. This information, in conjunction with the evidence for the section missing from the underlying Fourmile Branch/Congaree/Warley Hill Formation, suggests that the basal contact of the Santee Limestone represents scour into the underlying unit and is possibly the result of localized channeling. Observations of similar channeling have been reported in nearby strip mines (Nystrom and others, 1986).

The Santee Limestone section from 156 to 139 ft in the Millers Pond core is biostratigraphically correlative with sections in the Millhaven core from 401 to 365 ft and in the Girard core from 325 to 322 ft and with samples collected at depths of 181.5, 174, 172, 164 and 154 ft in the Thompson Oak core and 181 ft in the McBean core (Edwards, this volume, chap. G; Bybell, this volume, chap. F; Frederiksen, this volume, chap. H). This part of the Santee Limestone in the studied cores is biostratigraphically equivalent to the upper part of the unit E4 (Prowell, Christopher, and others, 1985). Prowell, Christopher, and others (1985) identified their unit as correlative with part of the Warley Hill Formation underlying the southeastern part of the SRS. Gellici and others (1995) described a similar lithologic unit in the same stratigraphic position in the subsurface of Allendale County and designated the unit as the Warley Hill Formation. Steele (1985) and McClelland (1987) described a calcareous lithofacies of the Warley Hill Formation. Fallaw and Price (1995) described a sporadic sand lithofacies of the Warley Hill Formation at the base of the Tinker Formation in the updip part of the SRS.

The remainder of the Santee Limestone in the Millhaven, Girard, and Millers Pond cores is biostratigraphically equivalent to unit E5 (Prowell, Christopher, and others, 1985) and the Tinker Formation (Fallaw and Price, 1995). This part of the Santee Limestone is lithologically similar to the Blue Bluff Marl of the Lisbon Formation (Huddlestun and Hetrick, 1986), the Santee Limestone (Sloan, 1908), and the McBean Formation (Veatch and Stephenson, 1911). The siliciclastic lithologies of the Tinker Formation in South Carolina (Fallaw and Price, 1995) are correlative with the predominantly carbonate lithologies of the Santee Limestone but are not recognized in the Georgia cores.

Calcareous nannofossils, planktonic foraminifers, dinoflagellates, and pollen from the core localities indicate a late middle Eocene (late Claibornian) age for the Santee sections (Edwards and others, this volume, chap. B). Marine fossils and carbonate suggest that this unit was deposited in an open-marine, shallow-shelf environment. The distribution of siliciclastic sediments and the diversity of marine fossils in the carbonate facies suggest that the updip Millers Pond core is more proximal to a source of siliciclastic sediments than the downdip Millhaven core.

BARNWELL UNIT

The Barnwell unit derives its name from the Barnwell Group (Huddlestun and Hetrick, 1979, 1986). The Barnwell Group consists of the Clinchfield Formation, Dry Branch Formation, and Tobacco Road Sand that have been described and mapped on both sides of the Savannah River in the vicinity of the SRS (Huddlestun and Hetrick, 1978, 1979, 1986; Huddlestun, 1982; Prowell, 1994; Fallaw and Price, 1995). The informally named Barnwell unit in this report includes strata of the Barnwell Group and the post-Eocene strata in the study area.

The Barnwell unit in the Millhaven core includes calcareous clay from a depth of 228 to 223 ft, and moderately well to well-sorted calcareous quartz sand and partially lithified sandy limestone from 223 to 123 ft (fig. 3). The fine to medium sand includes 1 percent glauconite. Thin beds of silica-replaced limestone are common from a depth of 200 to 170 ft. The section from 123 to 54 ft consists of unlithified carbonate and partially lithified limestone with generally less than 10 percent quartz sand and 1 percent glauconite. Irregularly shaped phosphatized limestone clasts at the base of this part of the section produce a sharp spike on the gamma-ray log at 123 ft. The unit from 54 ft to land surface consists of a coarsening-upward sequence of clayey sand and sandy clay. Fossils observed in the core include pelecypods, bryozoans, echinoids, and foraminifers from 223 to 54 ft. Biomoldic pores are present from 67 to 34 ft and reflect dissolution of aragonitic pelecypods and gastropods.

The Barnwell unit in the Girard core consists of clay, sand, and carbonate lithologies in the lower part of the section from 250 to 104 ft and sand and clay in the upper part of the section from 104 ft to land surface (fig. 4). A basal calcareous clay from 250 to 244 ft is overlain by partially silicified, phosphatized, and glauconitic limestone from a depth of 244 to 234 ft; calcareous quartz sand from 234 to 193 ft; sandy limestone from 193 to 183 ft; marl from 183 to 136 ft; and a sandy limestone that grades into an overlying quartz sand from 136 to 104 ft. Fossils include pelecypods and bryozoans. Biomoldic porosity ranges from 5 to 20 percent in the limestone and reflects dissolution of aragonitic pelecypods. Sand is fine to coarse near the base and very fine to fine in the rest of the section from 250 to 104 ft. Clay matrix ranges from 20 to 40 percent in the sand. Clay laminae are abundant below 172 ft. The Barnwell unit from 104 ft to land surface is noncalcareous and contains clayey sand and clay. The sand ranges from fine to coarse and contains several flattened, ovoid pebbles at 88 ft.

The Barnwell unit at Millers Pond consists of siliciclastic sediments from a depth of 82 ft to land surface. The contact with the Santee Limestone was not recovered in coring. A thin, irregularly shaped bed of limestone at 75 ft is lithologically similar to the underlying Santee Limestone and is presumed to be a large reworked clast. The Barnwell unit from 78 to 67 ft includes thin beds of fine to medium and fine to very coarse sand, and thin beds of well-laminated clay. The sand has fine lignite, clay clasts, and 10 to 20 percent clay matrix. The section from 67 ft to land surface is a coarsening-upward sequence of sand and ranges from fine to medium sand up to fine to very coarse sand. The amount of clay matrix ranges from 5 to 25 percent. Sedimentary structures include clay laminae and clay wisps from 66 to 62 ft, 48 to 47 ft, and 38 to 27 ft. The sand from 49 to 42 ft contains granules and pebbles. The Barnwell unit is mapped as the uppermost stratigraphic unit at the Millers Pond site (Prowell, 1994), where it includes the Tobacco Road Sand and Irwinton Sand Member of the Dry Branch Formation. Partial recovery of sediments during coring makes selection of a formation contact within the Barnwell unit difficult.

The contact between the Barnwell Group and a post-Eocene unit, as mapped in the area of the Girard site (Prowell, 1994), was not identified in the Girard core. The post-Eocene unit was described and designated as map unit Tu (Prowell, 1994). The mapped contact was projected to a depth of 50 ft in the Girard section. A lag deposit and other evidence of an unconformity, if present in the Girard section, were not recovered during coring at this depth. The presence of post-Eocene sediments is acknowledged at the Girard site on the basis of previous studies, but a separate unit is not defined at this time.

Paleontologic data for the Millhaven and Girard cores suggest a late Eocene to questionably early Oligocene age for the Barnwell sections (Edwards and others, this volume, chap. B). The Barnwell unit is equivalent to units E6, E7, E8, and Ml (Prowell, Christopher, and others, 1985) and the Clinchfield Formation, Dry Branch Formation, and Tobacco Road Sand of the Barnwell Group at the SRS (Fallaw and Price, 1995). Throughout the study area, the abundance of carbonate, the presence of glauconite and phosphate, and the abundance of marine macrofossils and microfossils in the calcareous part of the section indicate that the Barnwell strata were deposited in open-marine environments. The calcareous sand probably was deposited in a shallow-shelf environment, and the fossil bed at the base is a lag deposit produced by a late Eocene marine transgression. The noncalcareous sand and clay, the ovoid flattened pebbles, and the clay wisps in the upper part of the Barnwell unit suggest that these strata were deposited in nearshore-marine environments.

SUMMARY

Five deep stratigraphic test holes were drilled from 1991 to 1993 in support of multidisciplinary investigations to determine the stratigraphy of Upper Cretaceous and Tertiary sediments of the coastal plain in east-central Georgia. Cored sediment and geophysical logs from the Millhaven test hole in Screven County and the Girard and Millers Pond test holes in Burke County are the primary sources of lithologic and paleontologic information for this report. Lithologic and paleontologic information from the Thompson Oak and McBean test holes in Burke County supplement the discussion of stratigraphy and sedimentation in the updip part of the study area near the Millers Pond test hole.

The Cretaceous sections in the studied cores are divided into the Cape Fear Formation, the Middendorf Formation, the Black Creek Group, and the Steel Creek Formation. These four geologic units consist of siliciclastic sediments. Evidence of possible unconformities is used to recognize two subunits in the Middendorf Formation and three subunits in the Black Creek Group. Sediments in the Cretaceous section generally are coarser grained and more oxidized in updip areas. Each contact between units is considered to be a regional unconformity and denotes a considerable hiatus in sedimentation. The sediments in all four units have been interpreted as being part of large deltaic systems that prograded across the paleo-continental shelf in east-central Georgia and western South Carolina. The lithofacies observed in the Upper Cretaceous units tend to be coarser grained in proximal-deltaic environments and finer grained in distal-deltaic environments.

The Tertiary sections are divided into the Ellenton and Snapp Formations of Paleocene age; the Fourmile Branch/Congaree/Warley Hill unit and Santee Limestone of Eocene age; and the Barnwell unit, which contains strata of Eocene to Miocene age. The Tertiary section, with the exception of the Snapp Formation, generally is more calcareous and has a more diverse and abundant marine microflora and fauna in the downdip Millhaven core, relative to the updip McBean and Millers Pond cores. For these units, sedimentary and paleontologic evidence suggests open-marine shelf environments at the Millhaven site and marginal-marine environments at the Millers Pond site.

The Ellenton Formation in the Georgia cores is finer grained, calcareous, and very glauconitic in the downdip Millhaven and Girard cores. It is coarser grained and noncalcareous in the updip Millers Pond core. Lag deposits and sharp bedding contacts identify basal unconformities and possible unconformities within the Georgia sections.

The Snapp Formation is nearly barren of fossils and is a noncalcareous sequence of oxidized sand and clay. Sedimentary characteristics of the Snapp Formation suggest a fluvially dominated depositional environment such as an upper delta plain or an incised alluvial valley. The presence of a sparse marine microflora suggests some marine influence on deposition in the downdip area near Millhaven. Differences in the thickness of this formation in the study area suggest that channels containing the basal sand of the Snapp Formation are incised into laminated black clay of the Ellenton Formation.

The lithologies of the Fourmile Branch/Congaree/Warley Hill unit range from mixed-siliciclastic-carbonate sections in the central and downdip Georgia cores to siliciclastic sections in the updip cores. Paleontologic data suggest that the strata in this unit are correlative with three formally named formations at the SRS. However, all three formations are not consistently present in each of the Georgia cores.

The Santee Limestone consists predominantly of limestone and unlithified carbonate with a few beds of calcareous sand and clay. The Santee Limestone, as correlated in this report, includes lithologies assigned by others to the Warley Hill Formation, the Blue Bluff Marl of the Lisbon Formation, the Santee Limestone, and the McBean Formation. These lithofacies are time equivalents of the Lisbon Formation of western Georgia and collectively are correlated as one package of sediment in this report.

The informally named Barnwell unit in this report includes strata of the Barnwell Group and the post-Eocene strata in the study area. The presence of post-Eocene sediments is acknowledged at the Girard site on the basis of previous studies, but a separate unit is not defined at this time.

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Overview of the Biostratigraphy and Paleoecology of Sediments from Five Cores from Screven and Burke Counties, Georgia

By Lucy E. Edwards, Norman O. Frederiksen, Laurel M. Bybell, Thomas G. Gibson, Gregory S. Gohn, David Bukry, Jean M. Self-Trail, and Ronald J. Litwin

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GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Edited by Lucy E. Edwards

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ABSTRACT

Five cores from Screven and Burke Counties, Georgia, form the basis for a multifaceted paleontological study of Cretaceous and Tertiary coastal plain sediments. The biostratigraphy and paleoecology of these cores are summarized within the lithostratigraphic framework given in this volume. The basal Cretaceous unit, the Cape Fear Formation, is of probable Coniacian age and is nonmarine. The Middendorf Formation may represent similar lithofacies of different ages, one representing undifferentiated pollen Zone V (late Coniacian and Santonian) and one slightly younger (latest Santonian(?) or early Campanian). The Black Creek Group is Campanian. It is marginal marine to nonmarine in its lower part (subunit 1). In all but the most updip core, subunit 2 of the Black Creek contains Campanian marine sediments. Subunit 3 of the Black Creek shows a marine influence in the most basinward (downdip) Millhaven core. The Steel Creek Formation is Maastrichtian in the Millhaven core and is nonmarine except for its lowest part.

The basal Tertiary unit, the Ellenton Formation, is of early, early late, and middle late Paleocene age. It is marine throughout the study area. The overlying Snapp Formation yields pollen of late, but not latest, Paleocene age. It is mostly nonmarine but contains rare marginal marine palynomorphs. The Fourmile Branch Formation, present only in the Girard and Thompson Oak cores, is a marine unit of early Eocene age. The Congaree Formation is of early middle Eocene age and is present and contains marine fossils in all five cores. The middle Eocene Warley Hill Formation is present only in the Millhaven core. These sediments probably were deposited in less than 100 ft of water. The Santee Limestone is of late middle Eocene age. Foraminifers indicate inferred water depths of less than 200 ft. The Barnwell unit is difficult to date paleontologically but is late Eocene and questionably early Oligocene and is marine. This chapter contains highlights from the individual chapters in this volume.

INTRODUCTION

At the Savannah River Site (SRS) in Aiken, Barnwell, and Allendale Counties, S.C., various hazardous materials have been manufactured, disposed of, and stored since the early 1950's. Ground-water contamination has been detected on the site, and the potential exists for contamination in areas adjacent to the site. In 1991, the U.S. Department of Energy (DOE) funded a multidisciplinary study by the U.S. Geological Survey (USGS) to determine whether ground water flows from the SRS through aquifers in South Carolina into aquifers in Georgia and to determine under what pumping scenarios such flow could occur in the future. Following the detection of tritium in a public water supply well in Burke County, Ga., additional DOE funding was provided to the Georgia Geologic Survey (GGS) of the Georgia Department of Natural Resources for subsurface investigations (Clarke and others, 1994; Summerour and others, 1994).

Accurate ground-water modeling in the Atlantic Coastal Plain depends on an understanding of the stratigraphy. Numerous investigations of subsurface stratigraphy have been conducted in western South Carolina, from Siple (1967) to Fallaw and Price (1995), but relatively little has been published about the subsurface of eastern Georgia (Prowell and others, 1985; Huddlestun and Summerour, 1996). In order to understand the stratigraphy in eastern Georgia, detailed paleontological investigations were under-taken. In 1991, we began our investigation of the Millers Pond core, which had been drilled recently by the GGS in northern Burke County (fig. 1). The USGS drilled two additional test holes—one in northern Screven County (Millhaven test hole) and one in central Burke County (Girard test hole). The cores from these three test holes were designed to serve as the basis for stratigraphic correlation in the area of Georgia adjacent to the SRS. Two other cores, drilled by the GGS, provide additional biostratigraphic information. This report synthesizes the biostratigraphic and paleoecologic investigation of these five cores collected from Burke and Screven Counties, Ga.

The multidisciplinary paleontologic studies summarized here, and described in more detail in the individual chapters that follow, are based on the microfossils found in the cores. Palynomorphs and calcareous-walled microfossils were studied. Palynomorphs include pollen and spores from terrestrial plants, the cysts of marine dinoflagellates, and probable cysts of uncertain origin (acritarchs). Palynomorphs are described in chapters by Frederiksen and others (this volume, chap. C) for Cretaceous sediments and by Edwards (this volume, chap. G) and Frederiksen (this volume, chap. H) for Tertiary sediments. Calcareous microfossils studied here include calcareous nannofossils (Bukry, this volume, chap. D) and ostracodes (Gohn, this volume, chap. E) for Cretaceous material, and calcareous nannofossils (Bybell, this volume, chap. F) and foraminifers (Gibson, this volume, chap. I) for Tertiary material.

Because few readers are familiar with every fossil group, we include a brief introduction to each. For the purpose of formal names of species and genera, palynomorphs and calcareous nannofossils are classified by using the International Code of Botanical Nomenclature (Greuter and others, 1994); ostracodes and foraminifers are classified by using the International Code of Zoological Nomenclature (Ride and others, 1985). Under the botanical code, names of original authors and transferring authors are part of the formal name of a species; under the zoological code, names of original authors are part of the formal name. Under both codes, the name of the original author is placed in parentheses if the species has been reassigned.

POLLEN

Pollen grains are the sperm-carrying reproductive bodies of higher plants; that is, gymnosperms (such as conifers and cycads) and angiosperms (the flowering plants). Pollen grains are very small, typically between 0.01 and 0.1 millimeter (mm) in size.

Pollen grains are produced mostly by plants living in land areas. The first gymnosperms evolved in the Devonian Period (about 385 million years ago), and the first angiosperms evolved from gymnosperms early in the Cretaceous Period (about 140 million years ago). Pollen grains are some of the most abundant fossils to be found in sediments that were deposited on land (terrestrial sediments); however, pollen grains are easily transported by wind and streams to the sea. Therefore, pollen grains are very useful for correlating terrestrial sediments and sedimentary rocks from one place to another, but they are also important for correlating sequences of terrestrial sediments with sequences of marine sediments.

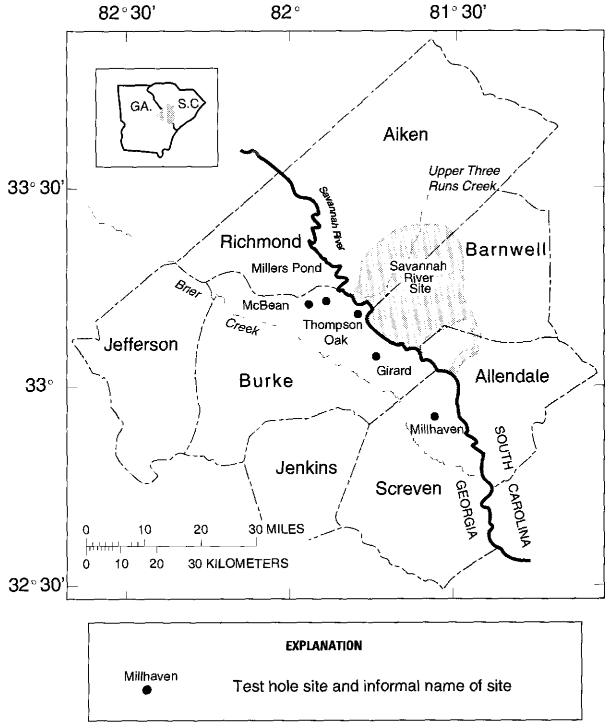

Figure 1. Index map showing the Savannah River Site and the location of test holes in the study area.

The standard pollen zonation for the Upper Cretaceous of the Gulf and Atlantic Coastal Plains was developed in a series of abstracts and papers by various authors and summarized by Christopher (1982a). This zonation was based on material mainly from the Middle Atlantic States. The only pollen zonation for the lower Tertiary of eastern North America was proposed by Frederiksen (1991, 1998) for the Paleocene. This zonation was based on material from the eastern Gulf Coast, but it has also been applied to sections on the Atlantic Coastal Plain (Frederiksen, 1991, 1998). No pollen zonation has been proposed for the Eocene and Oligocene of eastern North America, but chronostratigraphic ranges of the main pollen taxa in the Eocene and Oligocene of this region were displayed by Frederiksen (1979, 1980, 1988).

DINOFLAGELLATES AND ACRITARCHS

Dinoflagellates are single-celled organisms that live in oceans, estuaries, lakes, and ponds. Here, they are considered to be plants because many of them are photosynthetic. Some dinoflagellates are herbivores, carnivores, parasites, or symbionts.

Many dinoflagellates have a complex life cycle that includes a resting stage. During this stage, the organism may live in a very durable capsule called a dinocyst. Nearly all fossil dinoflagellates studied by paleontologists are cysts; however, the genera *Alisogymnium* and *Dinogymnium* in the Cretaceous may be the covering from the motile stage. Nearly all dinocysts that are preserved in the fossil record are from marine dinoflagellates.

Dinoflagellates form distinctive and rapidly evolving fossils that may be found in marine rocks wherever a silt-sized component is present. There is, as yet, no widely accepted standard zonation for them. Important lowest and highest occurrence datums are used to correlate locally and intercontinentally. The presence of fossil dinoflagellates can generally be used to infer marine deposition, and the abundance of dinoflagellates from major taxonomic categories, typically families such as the Peridiniaceae and Areoligeraceae, may be used to infer additional paleoenvironmental conditions.

Acritarchs are, by definition, palynomorphs of uncertain origin. Two distinctive acritarchs are included with the dinoflagellates in the Tertiary study (Edwards, this volume, chap. G).

CALCAREOUS NANNOFOSSILS

Calcareous nannofossils are fossil remains of golden-brown, single-celled algae that live only in the oceans. They are one of the primary organisms at the base of the food chain. These algae make tiny calcite platelets inside their cells. These platelets are the calcareous nannofossils that fall to the ocean bottom and become part of the clay-sized fraction in the sediment. Most calcareous nannofossils are formed by coccolithophorid algae and can also be called coccoliths.

Calcareous nannofossils have been living in the world's oceans from the Triassic Period, and they have evolved and changed rapidly and constantly over time. They are extremely useful for dating marine sediments because existing zonations have a precision of 1 million to 4 million years or even less.

In the last three decades, relatively stable standard biostratigraphic zonations have been developed for calcareous nannofossils. A lowest or highest stratigraphic occurrence (FAD, first appearance datum; LAD, last appearance datum) is used to define the base and top of each zone. For the Cretaceous, we use the biostratigraphic zonation of Perch-Nielsen (1985), modified from Sissingh (1977), in which each zone has a formal name and an informal abbreviation ("CC" followed by a number). For the Cenozoic, we use the zonation of Martini (1971) in which each nannoplankton zone is designated by "NP" followed by a number. Calibration to the Cenozoic zonation of Bukry (1973, 1978) and Okada and Bukry (1980) also is provided.

OSTRACODES

Ostracodes are a group of fossil and modern, small, bivalved crustaceans; modern species inhabit a wide variety of aquatic environments. They are well represented in the fossil record primarily by their hinged, smooth or ornamented, calcified-chitinous valves and are common in marine deposits of the Atlantic Coastal Plain. Typical Cretaceous and Cenozoic forms in the coastal plain range in size from 0.6 mm to 1.1 mm.

Ostracodes are mostly a benthic group. Accordingly, the compositions of ostracode assemblages, and the distributions and morphologies of individual taxa, are strongly influenced by environmental factors, including water depth, turbidity, salinity, oxygen content, and food supply. As a result, ostracode assemblages tend to be useful in the paleoenvironmental analysis of sedimentary sections. They also are useful biostratigraphic indicators in local and regional studies where the effects of paleoenvironmental conditions on species distributions are reasonably well known. The ostracode interval zones of Hazel and Brouwers (1982; modified by Pitakpaivan and Hazel, 1994) are frequently used in biostratigraphic studies of ostracodes from Upper Cretaceous sediments in the Atlantic Coastal Plain.

FORAMINIFERS

Foraminifers are similar to amoeboid organisms in cell structure but differ in having granular rhizopodia and elongate pseudopodia that emerge from the cell body. Foraminifers are covered with an organic test and typically have a wall composed of calcite or an agglomeration of mineral grains embedded in the organic test. Foraminifers are composed of two primary groups: planktonic foraminifers (marine floaters), and benthic foraminifers (sea-floor dwellers). Fossils of both groups are included here.

Benthic foraminiferal morphologies are very diverse, from simple single-chambered to multichambered, complex forms with tests composed of calcite or mineral grains. Benthic foraminifers occupy a wide range of marine environments, from brackish estuaries to the deep ocean basins, and occur at all latitudes. They can be used to infer the salinity and water depths for sedimentary deposits and to recognize oxygen and productivity levels of environments. Planktonic foraminifers, which typically provide more precise age control than benthic species, occur in low numbers in the cores examined in this study; however, they are valuable in the recognition of the upper lower Paleocene strata in the Millhaven core. As is typical in shallow-water deposits, the few planktonic specimens recovered from the remaining samples consist mainly of juvenile individuals.

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MATERIAL AND METHODS

This study is based on the paleontology in five cores in east-central Georgia (fig. 1). They are listed here in order from the most basinward to the most onshore (updip).

- The Millhaven test hole (33X048) was drilled by the U.S. Geological Survey (USGS) in 1991–92 in northern Screven County on the Millhaven Plantation, 2 miles (mi) northeast of Brier Creek and about 7 mi west of the Savannah River at lat 32°53'25" N., long 81°35'43" W. Surface elevation is 110 feet (ft) above sea level. This hole was cored to a depth of 1,452 ft and bottomed in the Upper Cretaceous Cape Fear Formation.
- The Girard test hole (32Y020) was drilled by the USGS in 1992 in southern Burke County at the lookout tower on Griffins Landing Road, 2 mi north of the town of Girard at lat 33°03'54" N., long 81°43'13" W. Surface elevation is 250 ft above sea level. This hole was cored to a depth of 1,385 ft and bottomed in pre-Cretaceous red beds.
- The Thompson Oak test hole (GGS–3794, TR92–6, Burke 12) was drilled by the Georgia Geologic Survey (GGS) in 1993 in northeastern Burke County, 21 mi south of Augusta just above the flood plain of the Savannah River at lat 33°10'42" N., long 81°47'10" W. Surface elevation is 240 ft above sea level. The hole was cored to a depth of 1,010.5 ft and bottomed in gneissic basement rock.
- The Millers Pond test hole (GGS–3758, Burke 2) was drilled by the GGS in 1991 in northern Burke County, about 2 mi west of the Savannah River, 16 mi south of Augusta at lat 33°13'48" N., long 81°52'44" W. Surface elevation is 245 ft above sea level. The hole was cored to a depth of 859 ft and bottomed in gneissic basement rock. A nearby hole, Millers Pond test well 1, was logged for geophysical properties.
- The McBean test hole (GGS–3757, Burke 5) was drilled by the GGS in 1991 in northern Burke County on the north shoulder of Collins Road 1.1 mi east of the intersection of Georgia Route 56 and Collins Road at lat 33°13'38" N., long 81°55'50" W. Surface elevation is 297 ft above sea level. The hole was cored to a depth of 327 ft and bottomed in the Upper Cretaceous Steel Creek Formation.

STRATIGRAPHIC FRAMEWORK

The stratigraphic framework of the coastal plain section in Screven and Burke Counties is discussed in detail by Falls and Prowell (this volume, chap. A). From oldest to youngest, the lithostratigraphic units that are considered are the Cretaceous Cape Fear Formation, Middendorf Formation, Black Creek Group, and Steel Creek Formation and the Tertiary Ellenton Formation, Snapp Formation, Fourmile Branch Formation, Congaree Formation, Warley Hill Formation, Santee Limestone, and Barnwell unit. In the Middendorf Formation and Black Creek Group, informal subunits can be recognized lithostratigraphically in some cores. We have used Falls and Prowell's lithostratigraphic framework as a starting point to discuss the biostratigraphy and paleoecology.

Figure 2 shows some of the terminology that has been used for lithostratigraphic units in the Atlantic and Gulf of Mexico Coastal Plains and their chronostratigraphic correlations. In the Upper Cretaceous, we use the European stage boundaries summarized by Burnett and others (1992) and Gradstein and others (1995). The Campanian-Maastrichtian boundary position these authors use is stratigraphically higher (younger) than some previous interpretations of this boundary.

Important biostratigraphic and paleoecologic information from the three primary cores (Millhaven, Girard, and Millers Pond) is given in graphic form in figures 3, 4, 5, 6, 7, and 8.

BIOSTRATIGRAPHY AND PALEOECOLOGY

CAPE FEAR FORMATION

The Cape Fear Formation consists of gravels, sands, silts, and clays that typically are arranged in fining-upward sequences. It was sampled only in the Millers Pond core. Four clay layers were sampled, and two of these samples yielded palynomorphs. The pollen present in the lower sample (847–852 ft) represents undifferentiated pollen Zone V

(Frederiksen and others, this volume, chap. C) of late Coniacian and Santonian age. The upper sample (827–832 ft) represents the combined *Complexiopollis exigua-Santalacites minor* and *Pseudoplicapollis longiannulata-Plicapollis incisa* Zones but most likely belongs to the *Complexiopollis exigua-Santalacites minor* Zone (= Subzone V-A) of Christopher (1977, 1979, 1982a,b) of Coniacian age (Sohl and Owens, 1991). The absence of marine palynomorphs (dinoflagellates, acritarchs) and microforaminiferal linings suggests a nonmarine environment of deposition.

MIDDENDORF FORMATION

The Middendorf Formation consists predominantly of moderately to poorly sorted, unlithified sand. It is subdivided into two subunits that each consist of a basal lag deposit, sand, and interbedded and interlaminated clay and sand (Falls and Prowell, this volume, chap. A). Palynomorphs from the Middendorf Formation were studied from the Millhaven, Girard, and Millers Pond cores (Frederiksen and others, this volume, chap. C). In the Millhaven core (1,212 ft, subunit 2), pollen taxa represent undifferentiated Zone V, which is of late Coniacian and Santonian age. Each of two samples from the Girard core (1,138–1,139 ft, subunit 1, and 1,012.0–1,012.3 ft, subunit 2) contains a seemingly heterogeneous set of pollen taxa whose known occurrences are Coniacian to Santonian, Campanian, and Maastrichtian. The pollen flora of the Girard sample from subunit 2 suggests a latest Santonian(?) or earliest Campanian age.

The available data do not provide an unequivocal age for the Middendorf Formation. Two different ages may be present, one representing undifferentiated pollen Zone V and one slightly younger (perhaps correlative with the Shepherd Grove Formation in South Carolina).

Rare dinocysts in the Middendorf Formation from the Millhaven core (1,212 ft, subunit 2) suggest a marginal marine or very nearshore marine environment. The two samples from the Girard core and the sample from the Millers Pond core lack marine palynomorphs.

BLACK CREEK GROUP

The Black Creek Group consists of sands and clays. Although it is not differentiated into component formations in this study, Falls and Prowell (this volume, chap. A) recognize three distinct subunits in the two most downdip (bas-inward) cores. These subunits are recognized on the basis of lag deposits and possible unconformities, but they cannot be related directly to named formations of the Black Creek Group that are recognized in South Carolina (Gohn, 1992). The Black Creek Group was studied for palynomorphs in the Millhaven, Girard, Thompson Oak, and Millers Pond cores. The calcareous part of subunit 2 of the Black Creek Group in the Millhaven core was studied for calcareous nannofossils and ostracodes.

Subunit 1 of the Black Creek Group is probably mid-Campanian, pollen Zone CA-4 (Wolfe, 1976), in the Millhaven core (one sample, at 1,124.3–1,124.7 ft). Subunit 1 was not examined for pollen in the other cores (Frederiksen and others, this volume, chap. C).

The calcareous part of subunit 2 of the Black Creek in the Millhaven core (1,077–968 ft) is dated by calcareous nannofossils as late Campanian, calcareous nannofossil Zone CC 22, based on the co-occurrence of *Quadrum trifidum* (Stradner) Prins & Perch-Nielsen and *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen (Bukry, this volume, chap. D). The total range of the ostracode *Haplocytheridea sarectaensis* Brown is limited to the upper part of Zone CC 22 in the Millhaven core and in South Carolina sections. Its highest occurrence can be used as a regional marker that approximates the Campanian-Maastrichtian boundary (Gohn, this volume, chap. E).

A distinctive dinoflagellate assemblage containing *Palaeohystrichophora infusorioides* Deflandre, *Xenascus ceratioides* (Deflandre) Lentin & Williams, *Cordosphaeridium fibrospinosum* Davey & Williams, and *Andalusiella spicata* (May) Lentin & Williams is found in and slightly above subunit 2 in the Millhaven core (1,029.5–913.8 ft). This dinoflagellate assemblage is used to assign a late Campanian age to correlative sections containing this assemblage in the Girard (867.7–738.6 ft) and Thompson Oak (505 ft) cores (Frederiksen and others, this volume, chap. C).

Subunit 3 of the Black Creek Group in the Millhaven core (one sample, at 849.3–849.6 ft) is dated as late Campanian by dinocysts based on the presence of *Palaeohystrichophora infusorioides* Deflandre (Frederiksen and others, this volume, chap. C).

In the Millers Pond core, the Black Creek Group is not differentiated into subunits. One sample from 578 ft contains pollen indicating a possible latest Santonian or earliest Campanian age, or some poorly defined younger age. A second sample from 517 ft contains pollen indicating an apparent mid-Campanian age.

In the Millhaven and Girard cores, subunit 1 of the Black Creek Group yielded only nonmarine palynomorphs, whereas subunits 2 and 3 yielded both marine and nonmarine palynomorphs. In the Millhaven core, part of subunit 2 contains marine calcareous nannofossils and inner-neritic ostracode assemblages. The two samples studied from the Thompson Oak core were not assigned to a subunit but contain marine palynomorphs. In the Millers Pond core, only nonmarine palynomorphs were recovered in the Black Creek Group (Frederiksen and others, this volume, chap. C).

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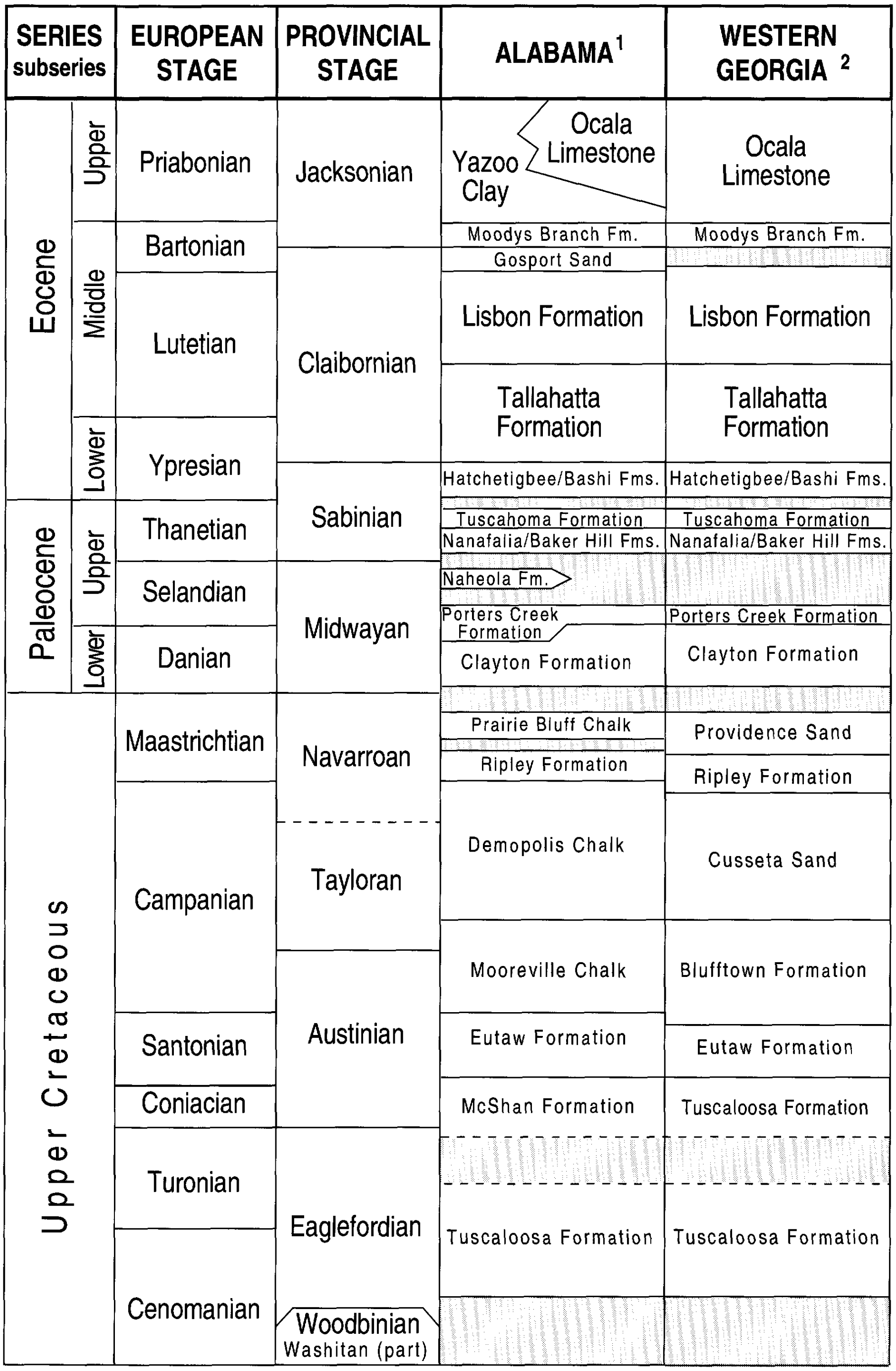
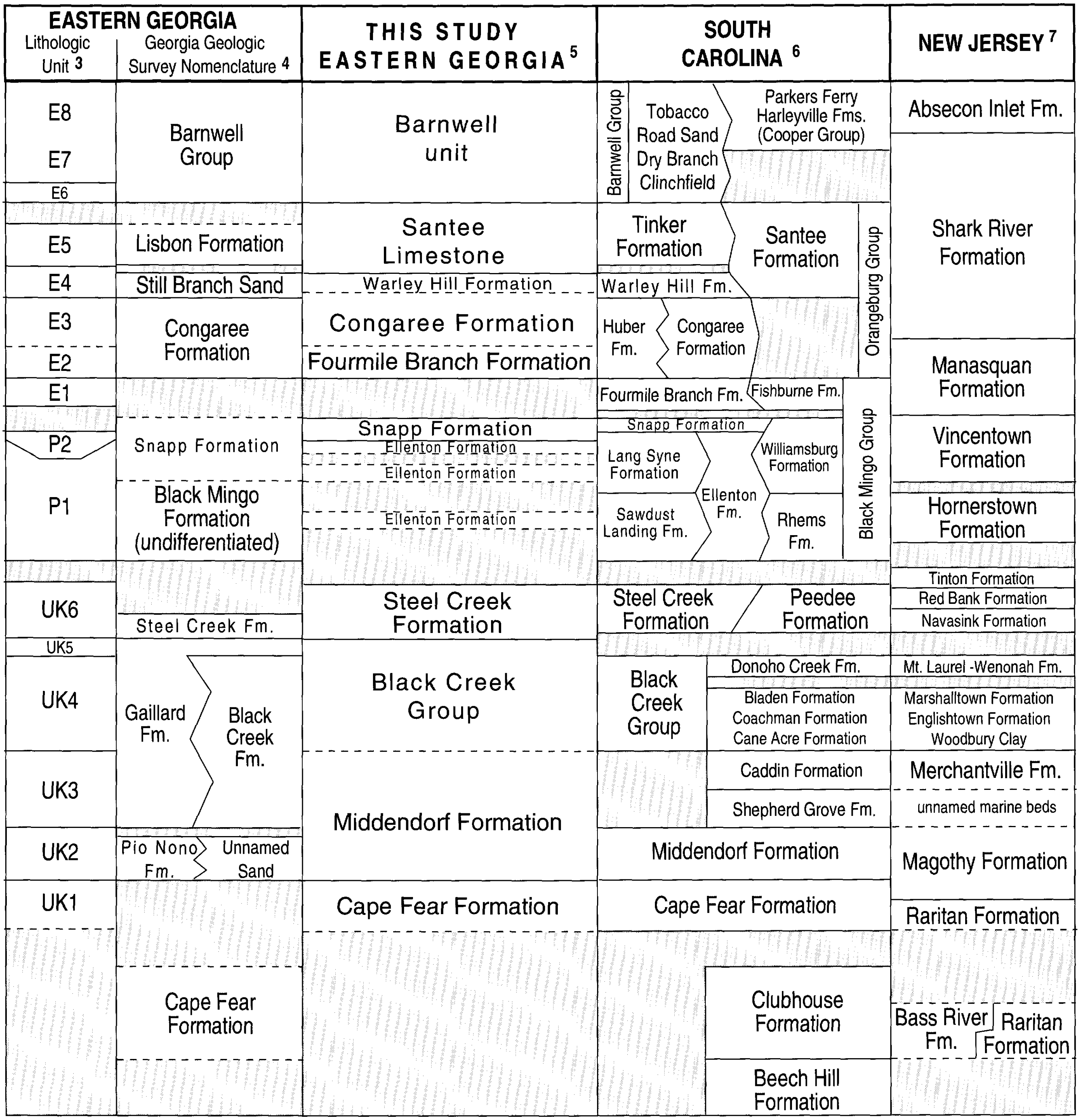


[1]Alabama column is based on Hazel (1990), Moshkovitz and Habib (1993), and Mancini and others (1996).

[2]Western Georgia column is based on Prowell and others (1985) and Clarke and others (1994).

Figure 2. Chart showing terminology that has been used for lithostratigraphic units in the eastern United States and our interpretations of their chronostratigraphic correlations. Mesozoic series and stages are from Burnett and others (1992) and Gradstein and others (1995); the Tertiary series, subseries, and stages are from Berggren and others (1995).



[3] Lithologic unit column for eastern Georgia is based on Prowell and others (1985).

[4] Column of Georgia Geologic Survey nomenclature for eastern Georgia is based on Huddlestun and Summerour (1996).

[5] The column of names for this study of eastern Georgia shows separate entries for the Fourmile Branch Formation, the Congaree Formation, and the Warley Hill Formation. In chapter A, these three formations are combined into one unit as all three formations are not consistently present in the five cores studied.

[6] South Carolina column is based on Van Nieuwenhuise and Colquhoun (1982), Frederiksen (1991), Gohn (1992), Fallaw and Price (1995), Self-Trail and Gohn (1996), and Edwards and others (1997).

[7] New Jersey column is based on Owens and others (1970, 1988), Litwin and others (1993), Self-Trail and Bybell (1995), Kennedy and others (1995), and Browning and others (1997).

Figure 2. Continued.

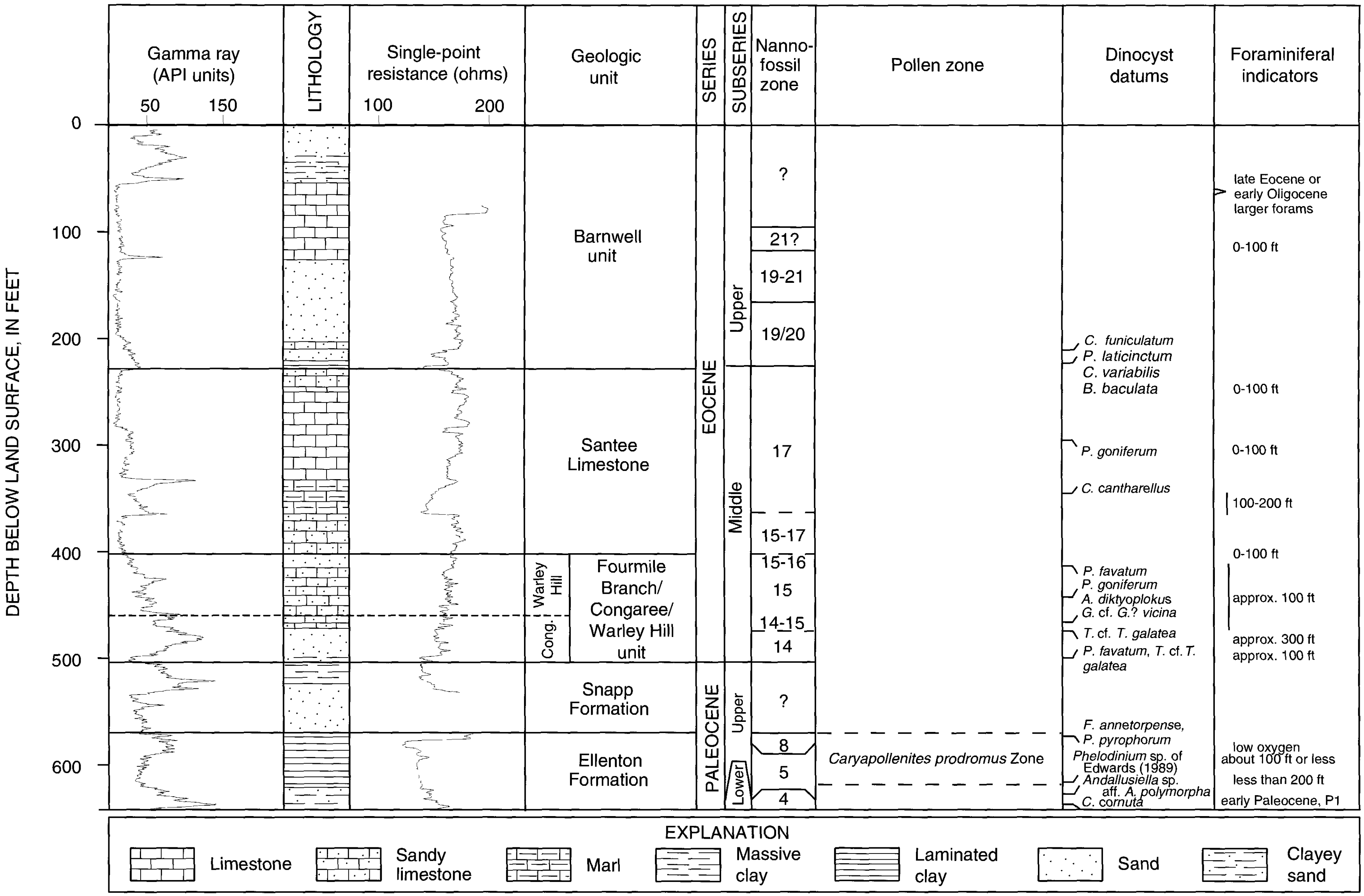


Figure 3. The stratigraphic and paleontologic summary of the Tertiary part of the Millhaven core. The lithology is from Clarke and others (1996), and the lithostratigraphy and geophysical logs are from Falls and Prowell (this volume, chap. A). Paleontologic data are from chapters F (nannofossil column), G (dinocyst column), H (pollen column), and I (foraminiferal indicators column). API, American Petroleum Institute.

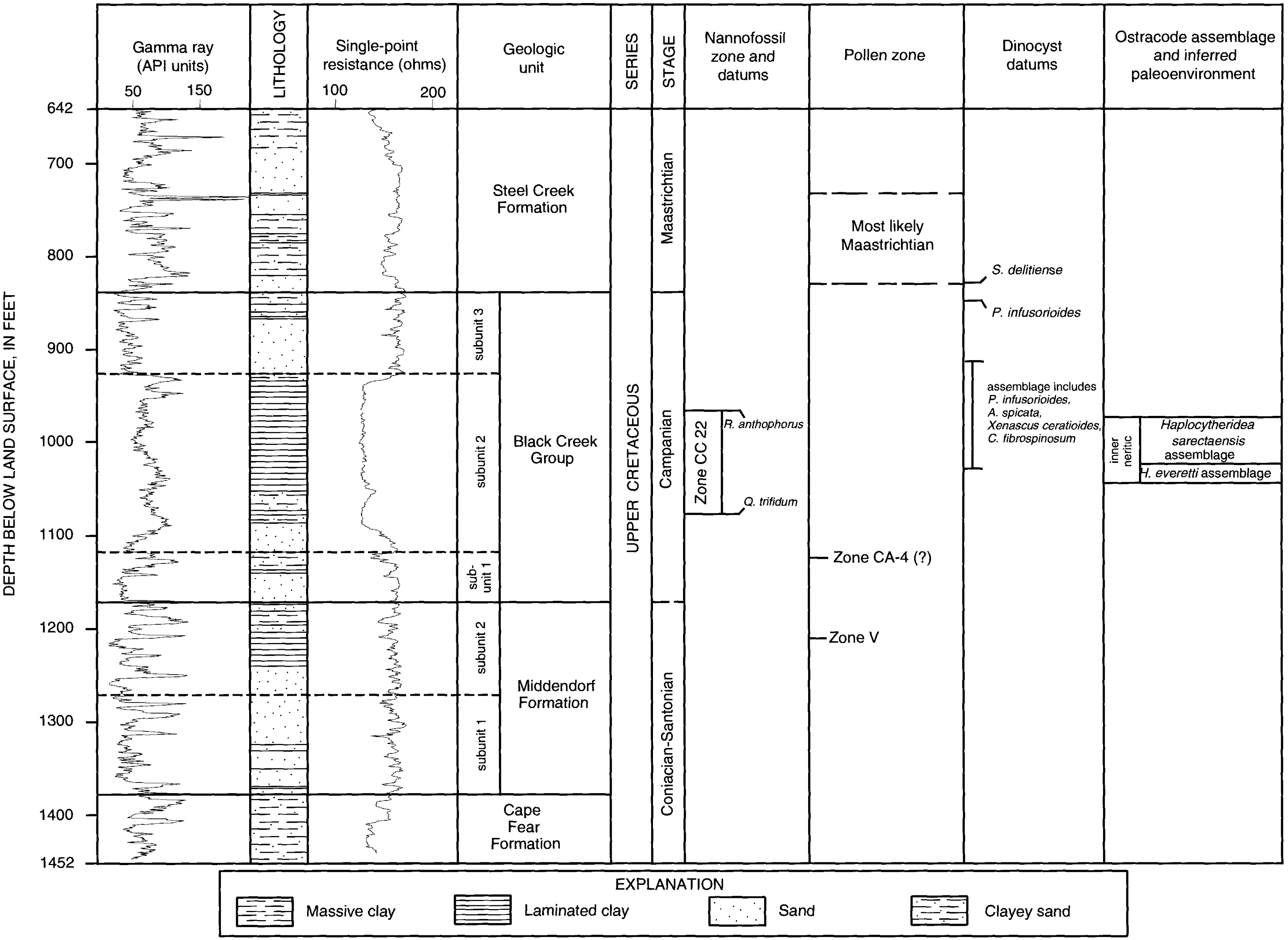


Figure 4. The stratigraphic and paleontologic summary of the Cretaceous part of the Millhaven core. The lithology is from Clarke and others (1996), and the lithostratigraphy and geophysical logs are from Falls and Prowell (this volume, chap. A). Paleontologic data are from chapters C (pollen and dinocyst columns), D (nannofossil column), and E (ostracode column). API, American Petroleum Institute.

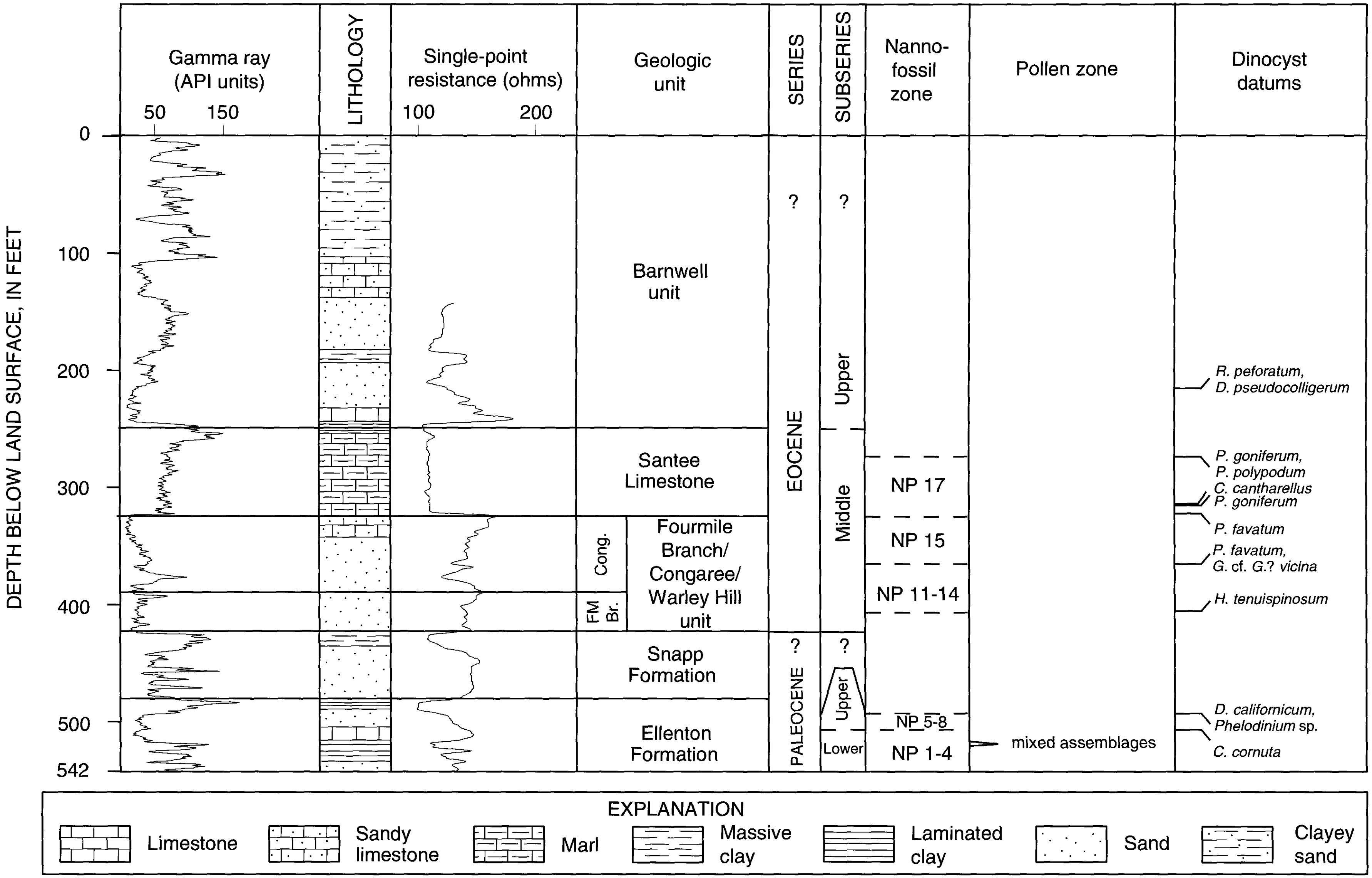


Figure 5. The stratigraphic and paleontologic summary of the Tertiary part of the Girard core. The lithology is from Leeth and others (1996), and the lithostratigraphy and geophysical logs are from Falls and Prowell (this volume, chap. A). Nannofossil zones are inferred from palynological evidence. Other paleontologic data are from chapters G (dinocyst column) and H (pollen column). API, American Petroleum Institute.

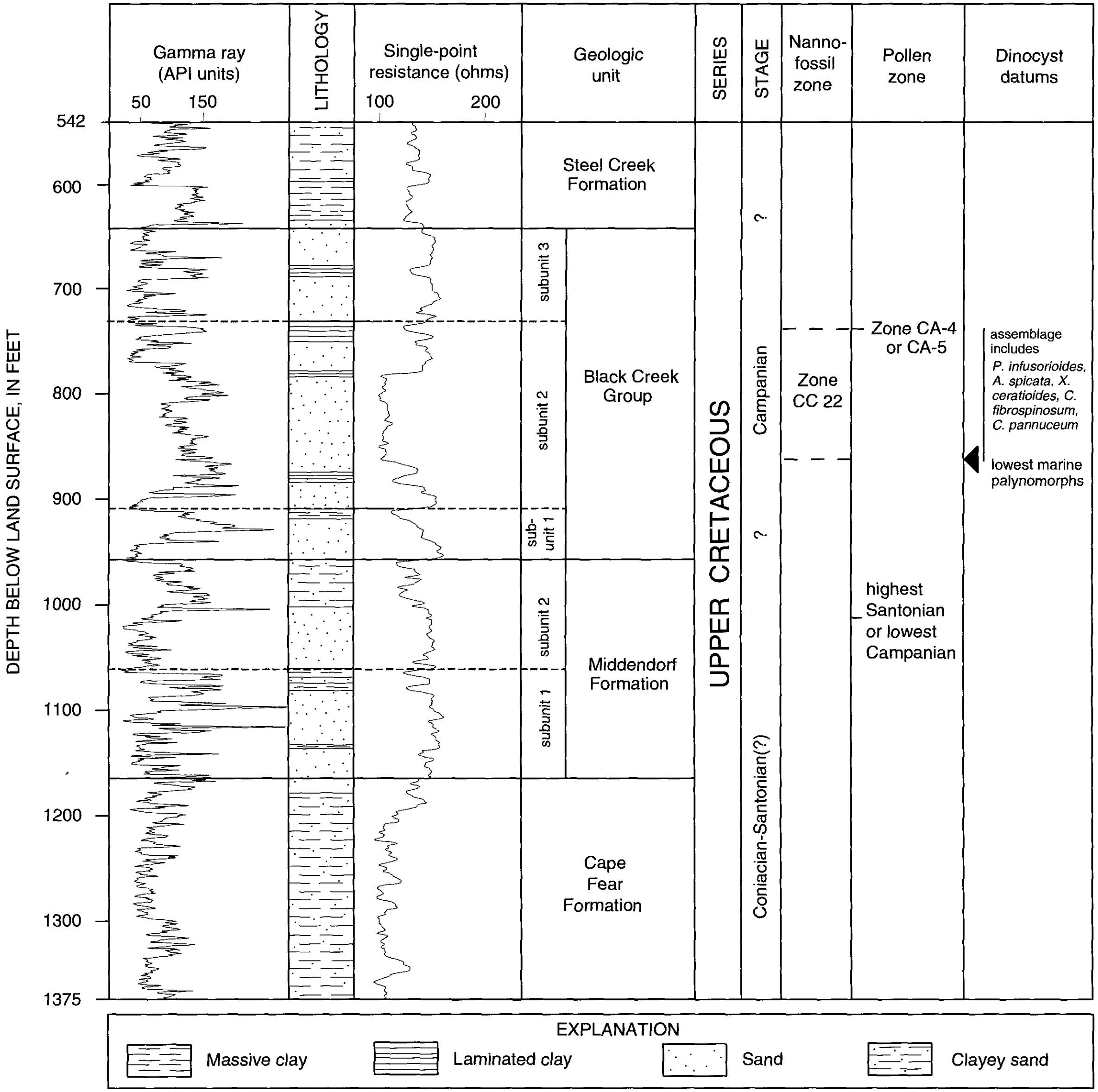


Figure 6. The stratigraphic and paleontologic summary of the Cretaceous part of the Girard core. The lithology is from Leeth and others (1996), and the lithostratigraphy and geophysical logs are from Falls and Prowell (this volume, chap. A). Nannofossil Zone CC 22 is inferred from palynological evidence. Other paleontologic data are from chapter C. API, American Petroleum Institute.

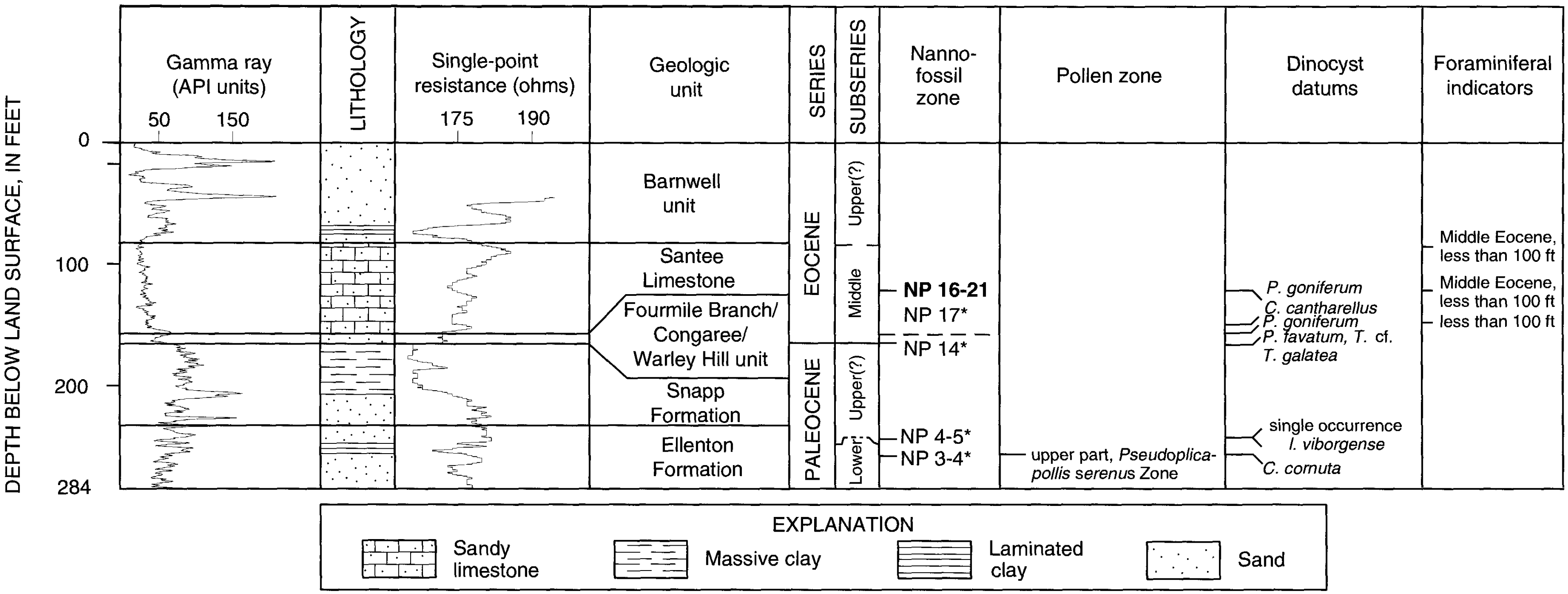


Figure 7. The stratigraphic and paleontologic summary of the Tertiary part of the Millers Pond core. The lithology is from Clarke and others (1994), and the lithostratigraphy and geophysical logs are from Falls and Prowell (this volume, chap. A). Nannofossil zone in bold is based on observed calcareous nannofossils (chapter F); nannofossils zones with an asterisk are inferred from palynological evidence (chapters G and H). Other paleontologic data are from chapters G (dinocyst column), H (pollen column), and I (foraminiferal indicators column). API, American Petroleum Institute.

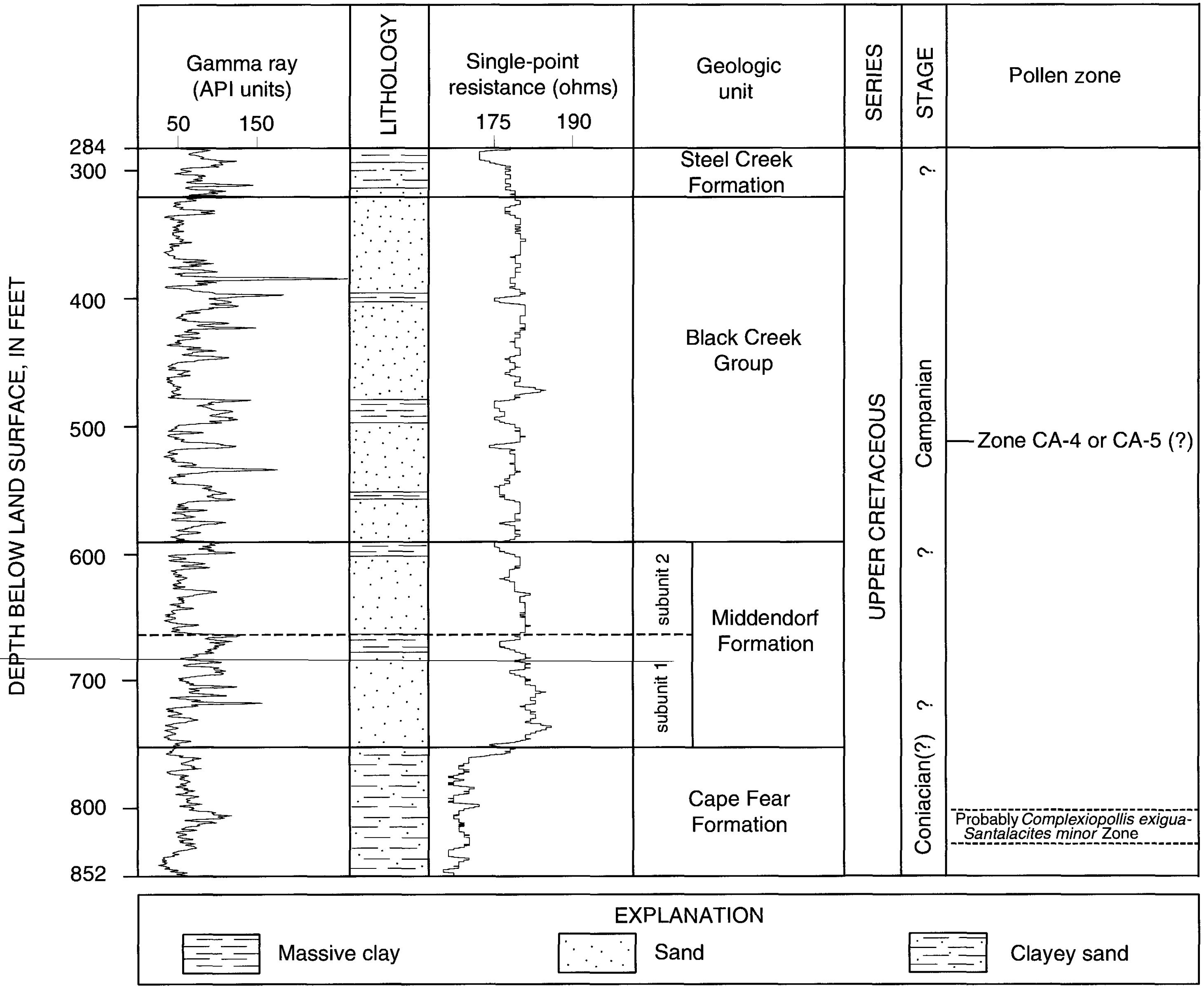


Figure 8. The stratigraphic and paleontologic summary of the Cretaceous part of the Millers Pond core. The lithology is from Clarke and others (1994), and the lithostratigraphy and geophysical logs are from Falls and Prowell (this volume, chap. A). The pollen data are from chapter C. API, American Petroleum Institute.

STEEL CREEK FORMATION

The Steel Creek Formation consists of multiple fining-upward sequences of gravel, sand, and clay, in which many of the clay beds are stained with iron oxide (Falls and Prowell, this volume, chap. A). The formation was sampled unproductively in the Millers Pond core and was not sampled in the Girard and Thompson Oak cores. Ten samples from the Millhaven core were examined for palynomorphs (Frederiksen and others, this volume, chap. C).

The lowest Steel Creek samples contain pollen taxa that were not found to range below this formation in the Millhaven core. A new species, *Momipites* n. sp. 1, is known only from the Maastrichtian. These samples are correlative with middle or late Maastrichtian units in New Jersey, or perhaps the unconformity below them. The sample at 830.3–830.5 ft contains a rather sparse dinoflagellate assemblage that includes *Spongodinium delitiense* (Ehrenberg) Deflandre (lowest occurrence is in the uppermost Campanian in New Jersey). Samples at 768.8–769.0 and 733.2–733.3 ft contain long-ranging Cretaceous forms of pollen, and a sample at 680.8–681.0 ft is barren of palynomorphs and contains only plant debris. Samples from the correlative interval (based on geophysical logs) in the C-10 core (Allendale County, S.C.) yielded nonmarine assemblages dated as Maastrichtian (Joyce Clark, 1989, written commun. to the South Carolina Water Resources Commission). Thus, a combination of pollen and dinoflagellate data suggests that the Black Creek Group-Steel Creek Formation boundary approximates the Campanian-Maastrichtian boundary in the Millhaven core.

The lowest Steel Creek sample in the Millhaven core contains a few marine dinoflagellates. No marine fossils were recovered higher in the unit.

ELLENTON FORMATION

The Ellenton Formation consists of sands and clays that are partly glauconitic and calcareous in the Millhaven core (most basinward) and lignitic in the Millers Pond core (Falls and Prowell, this volume, chap. A). This unit was studied for calcareous nannofossils, foraminifers, and marine and nonmarine palynomorphs in the Millhaven core. It was studied for palynomorphs in the Girard, Thompson Oak, and Millers Pond cores. A very thin lower Paleocene (Danian) section is present in at least three of the Georgia cores. Most of the Ellenton is early late Paleocene (Selandian). Two samples in the Millhaven core are middle late Paleocene (Thanetian).

In the Millhaven core, the Ellenton yields three distinct calcareous nannofossil zones: NP 4 (early Paleocene, 639.6–635.4 ft), NP 5 (early part of the late Paleocene, 631.3–579.2 ft), and NP 8 (middle part of the late Paleocene, 578.0–577.2 ft) (Bybell, this volume, chap. F). Although calcareous nannofossil Zone NP 4 includes both early and late Paleocene time, dinocysts and planktonic foraminifers indicate that only the early Paleocene part of the zone is present in this core. Two samples from the Girard core were examined for calcareous nannofossils; both proved barren.

A distinctive early Paleocene dinocyst assemblage that includes *Carpatella cornuta* Grigorovich, *Spinidinium pulchrum* (Benson) Lentin & Williams, *Tectatodinium rugulatum* (Hansen) McMinn, and *Tenua* sp. cf *T. formosa* of Kurita and McIntyre (1995) is present in the lowest Ellenton in the Millhaven core (one sample at 639.5 ft), the Girard core (521.2–517.9 ft, questionably to 514 ft), and the Millers Pond core (one sample at 252–257 ft). In the Millhaven core, the late Paleocene dinoflagellate assemblage includes *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant and *Fibradinium annetorpense* Morgenroth in the highest sample (571 ft).

Early Paleocene (Danian) pollen was identified in the Millers Pond core in the lowest Tertiary sample (252–257 ft). In the Girard core, the pollen assemblage in one of the Ellenton samples (521.0–521.2 ft) consists of species that normally do not occur together. Although alternative interpretations are possible, contamination from above into lower Paleocene material is most likely. In the Thompson Oak core, pollen at 302 ft depth could be either late early or early late Paleocene. Late Paleocene pollen was found in six samples in the Millhaven core (620.8–571.0 ft) and in the Thompson Oak core (281 ft). In the McBean core, the Ellenton was barren of pollen (Frederiksen, this volume, chap. H).

In the Ellenton of the Millhaven core, five intervals with differing foraminiferal assemblages are present: (1) a highly altered, low-diversity assemblage of early, but not earliest, Paleocene age, planktonic foraminiferal Zone P1 (636.8 ft); (2) an assemblage containing apparent mixing of specimens from lower Paleocene beds with early late Paleocene specimens (631.3 ft); (3) an assemblage suggesting normal productivity and oxygen levels with a probable water depth range of 100 to 200 ft (628.7 ft); (4) an assemblage suggestive of water depths of less than 100 ft but having high-productivity or low-oxygen conditions or both (621.2–599.1 ft); and (5) an assemblage suggestive of water depths of less than 100 ft with normal marine oxygen conditions (593.7–581 ft). Age-diagnostic planktonic foraminifers are present only in the lowest part of the Ellenton, but benthic species and immature planktonic species are present throughout (Gibson, this volume, chap. I).

SNAPP FORMATION

The Snapp Formation consists of a lower sand-dominated part and an upper clay-dominated part. The formation was studied for palynomorphs in the Millhaven and

McBean cores. No samples from the Snapp Formation were taken from the Millers Pond and Girard cores, and the formation is absent from the Thompson Oak core. In the McBean core, where the Snapp Formation consists only of sand with no overlying kaolin, nonmarine palynomorphs are present (Frederiksen, this volume, chap. H). The overlapping ranges of pollen taxa in the one productive sample (254 ft) indicate an age no older than earliest late Paleocene and no younger than middle late Paleocene age (Selandian or Thanetian).

A single Snapp sample in the Millhaven core (564–565 ft) yielded rare dinocyst fragments that are not age diagnostic but indicate at least marginally marine conditions (Edwards, this volume, chap. G).

FOURMILE BRANCH FORMATION

The Fourmile Branch Formation, a medium to coarse sand, was recognized only in the Girard and Thompson Oak cores (Falls and Prowell, this volume, chap. A). It was examined for palynomorphs in these cores.

A distinctive dinocyst assemblage, containing both *Hafniasphaera goodmanii* Edwards and primitive forms of *Pentadinium favatum* Edwards, was found in the Fourmile Branch Formation in the Thompson Oak core. *Homotryblium abbreviatum* Eaton is also present. These species are also found in the lower part of the Tallahatta Formation in Alabama and thus suggest correlation with lower Eocene calcareous nannofossil Zones NP 12 or NP 13. Sediments in the Fourmile Branch Formation in the Girard core contain *Dracodinium varielongitudum* (Williams & Downie) Costa & Downie and *Homotryblium tenuispinosum* Davey & Williams and are probably of early Eocene age as well (Edwards, this volume, chap. G).

Pollen from the Fourmile Branch Formation indicates an early Eocene age, or possibly early middle Eocene, in the Girard core. The dinocysts present indicate that sediments from the Fourmile Branch Formation are marine.

CONGAREE FORMATION

The Congaree Formation consists of quartz sand, marl, and limestone. Samples from the Congaree Formation were studied for calcareous nannofossils, foraminifers, and palynomorphs from the Millhaven core and for palynomorphs in the Girard, Thompson Oak, Millers Pond, and McBean cores.

In the Millhaven core, the Congaree Formation yields calcareous nannofossils that are placed in Zone NP 14 (early and middle Eocene, 497.4–473.5 ft); the uppermost sample (465.5 ft) could be either NP 14 or NP 15 (middle Eocene) (Bybell, this volume, chap. F).

Two distinctive dinocyst assemblages, both of early middle Eocene age, can be recognized in the Congaree Formation in the studied cores (Edwards, this volume, chap. G). Both assemblages contain *Pentadinium favatum* Edwards. One assemblage, which contains *Turbiosphaera* cf. *T. galatea* Eaton, is found in the lower part of the Congaree Formation in the Millhaven core (498.5–473.5 ft), the Thompson Oak core (231.5 ft), and the Millers Pond (165 ft) core. The dinocysts in this assemblage appear to be correlative with those in the upper part of the Tallahatta Formation in Alabama and unit E3 of Prowell and others (1985) in Georgia. A second assemblage, which contains *Glaphyrocysta* cf. *G.*? *vicina* (Eaton) Stover & Evitt, is found in the Millhaven core at 466 ft and also in the Girard (362.3–327.3 ft) and Thompson Oak (194–183.5 ft) cores. This assemblage is correlative with that from the lower part of the Lisbon Formation in Alabama.

Pollen studies of the Congaree yielded generally broad age possibilities: early or middle Eocene in the Millhaven core and correlative with calcareous nannofossil Zone NP 12 to early NP 16 in the Thompson Oak core (Frederiksen, this volume, chap. H).

Foraminifers from the Congaree Formation in the Millhaven core indicate a middle Eocene age and generally indicate a water depth of approximately 100 ft. A single sample at 481 ft indicates much deeper water, approximately 300 ft (Gibson, this volume, chap. I).

WARLEY HILL FORMATION

The Warley Hill Formation, a sandy limestone, was recognized only in the Millhaven core (Falls and Prowell, this volume, chap. A). It was studied for calcareous nannofossils, foraminifers, and palynomorphs.

Most samples from the Warley Hill Formation in the Millhaven core (458.1–413.0 ft) are assigned to the middle Eocene calcareous nannofossil Zone NP 15. The lowest sample (462 ft) could be either NP 14 or NP 15, and the highest sample (404 ft) could be either NP 15 or 16. Preservation in all samples is fair or poor.

The dinocyst assemblage from the Millhaven samples at 442 and 413 ft contains both *Pentadinium goniferum* Edwards and *P. favatum* Edwards. These two species are found together only in sediments from a narrow interval in the middle Eocene that is probably correlative with the middle part of the Lisbon Formation in Mississippi and with an unconformity or condensed interval within the Lisbon Formation in Alabama (Edwards, this volume, chap. G). These species were observed to overlap in part of unit E4 of Prowell and others (1985).

Foraminifers from samples at 455 and 426.5 ft in the Millhaven core were probably deposited in 100-ft water depth or slightly deeper, whereas those in samples at 413 and 404 ft in the core were probably deposited in less than 100 ft of water (Gibson, this volume, chap. I).

SANTEE LIMESTONE

The Santee Limestone consists primarily of limestone and unlithified carbonate sediments with a few beds of calcareous sand and clay (Falls and Prowell, this volume, chap. A). Samples from the Santee were studied for calcareous nannofossils, foraminifers, and palynomorphs from the Millhaven and Millers Pond cores and for palynomorphs from the Girard, Thompson Oak, and McBean cores.

In the Millhaven core, the samples from 400.0–370.9 ft have poorly preserved calcareous nannofossil assemblages and could be in Zones NP 15, 16, or 17 (middle Eocene). Beginning at 368.0 ft and continuing to the top of the formation, calcareous nannofossils indicate late middle Eocene Zone NP 17. The Santee Limestone in the Millers Pond core contains Eocene calcareous nannofossils that are not very age diagnostic. The Santee Limestone was not studied for calcareous nannofossils in the other three cores because of the anticipated poor assemblages (Bybell, this volume, chap. F).

In the Millhaven core, dinocyst samples have poor recovery in the lower part of the Santee Limestone but have abundant and distinctive assemblages above 346 ft that are typical of the late middle Eocene, correlative with the upper part of the Lisbon Formation in Alabama and perhaps the Gosport Formation. In the Girard, Thompson Oak, Millers Pond and McBean cores, the Santee Limestone contains late middle Eocene dinocyst assemblages similar to those found in the Millhaven core (Edwards, this volume, chap. G).

Foraminifera from the Millhaven and Millers Pond cores indicate a middle Eocene age, and most samples contain the distinctive benthic species *Cibicides westi* Howe (Gibson, this volume, chap. I).

The Santee Limestone contains only poorly dated pollen (Frederiksen, this volume, chap. H).

Foraminifers indicate paleo-water depths of 100 to 200 ft in the lower part of the Santee Limestone and less than 100 ft in its upper part in the Millhaven core and water depths of less than 100 ft in the Millers Pond core (Gibson, this volume, chap. I).

BARNWELL UNIT

The Barnwell unit is a mixed lithologic sequence of sandy limestone, marl, clay, and sand. It is treated as a unit, although unconformities can be recognized within it (Falls and Prowell, this volume, chap. A). Sediments of the unit are poorly fossiliferous. The unit was sampled in the Millhaven core for calcareous nannofossils and palynomorphs and in the Girard core for palynomorphs only. Sediments of the Barnwell unit from the Thompson Oak, Millers Pond, and McBean cores either were not sampled in this study or did not contain palynomorphs.

In the Millhaven core, nannofossil samples from 225.9 to 168.5 ft are late Eocene (Zone NP 19/20). Samples from 118.0 to 95.0 ft are questionably dated as Zone NP 21 (latest Eocene or earliest Oligocene).

Dinocysts from Millhaven samples at 216.5, 210, and 205 ft are most likely of late Eocene age, and the two upper samples suggest correlation with the upper Eocene Yazoo Clay in Alabama and the Harleyville and Parkers Ferry Formations in South Carolina. Samples at 195, 118, and 105 ft were barren of dinocysts. In the Girard core, the sample at 211.1–211.3 ft contains dinocyst species that suggest a late Eocene age. The sample at 146.7 ft contains a very sparse and nondiagnostic dinocyst assemblage, and samples at 104 and 64 ft were barren of dinocysts.

Most samples from the Barnwell unit yielded marine calcareous microfossils and marine palynomorphs. The foraminiferal assemblage suggests shallow-marine environments, probably in the deeper portion of the 0- to 100-ft depth interval.

SUMMARY AND IMPLICATIONS

The Cape Fear Formation, where studied, is of probable Coniacian age and is nonmarine.

The available data do not provide an unequivocal age for the Middendorf Formation. Two different ages may be present, one representing undifferentiated pollen Zone V (late Coniacian and Santonian) and one slightly younger (latest Santonian(?) and early Campanian, perhaps correlative with the Shepherd Grove Formation in South Carolina). The possibility of similar lithofacies representing different ages should be considered and investigated further. Most of the Middendorf Formation is nonmarine. Rare dinocysts in a single sample from the Millhaven core (1,212 ft, subunit 2) suggest a marginal marine or very nearshore marine environment.

The Black Creek Group is dated as Campanian. It is nonmarine in its lower part (subunit 1). In all but the most updip core, the Black Creek Group includes marine fossils in its upper part (subunits 2 and 3). Subunit 2 contains ostracodes correlative with those in the Donoho Creek Formation, the highest formation in the Black Creek Group in central South Carolina (Gohn, 1992). Subunit 3 may represent deposition in Georgia that has no counterpart in central South Carolina.

The Steel Creek Formation is Maastrichtian in the Millhaven core. It contains a few marine dinoflagellate cysts near its base; no marine fossils were recovered higher in the unit.

The placement of the Cretaceous-Tertiary boundary in all cores is, of necessity, based on the lithostratigraphy (Falls and Prowell, this volume, chap. A). Thick undated intervals are found between the Maastrichtian of the Steel

Creek Formation or Campanian of the Black Creek Group and the Danian of the Ellenton Formation.

A very thin lower Paleocene (Danian) section is present at the base of the Ellenton Formation in at least three cores. Most of the Ellenton Formation is early late Paleocene (Selandian). Two samples in the Millhaven core are middle late Paleocene (Thanetian). The oldest Paleocene material contains a significant component of planktonic foraminifers and, thus, represents deeper water deposition than the remainder of the Ellenton Formation.

The Snapp Formation is present in varying thicknesses in four of the five cores and is dated as late Paleocene (Selandian or Thanetian). It is mostly nonmarine. A single sample from the Millhaven core yielded dinocyst fragments that indicate marginally marine conditions.

The Snapp Formation is conspicuously absent from the Thompson Oak core, and the upper kaolinitic part is not present in the McBean core. Because the Snapp Formation is present in the most updip cores, it was probably also present in the Thompson Oak area originally but subsequently removed. Faulting is well documented in South Carolina (Snipes and others, 1993), but the Thompson Oak core is located on the downthrown side of the Pen Branch fault (Huddlestun and Summerour, 1996). We suggest that erosion by a predecessor to the Savannah River should be considered and investigated further.

The Fourmile Branch Formation is early Eocene and is only found in the Thompson Oak and Girard cores. Erosion of the underlying Snapp Formation in the Thompson Oak core may have facilitated preservation of these early Eocene sediments. The presence of dinocysts indicates that sediments from the Fourmile Branch Formation are marine.

The Congaree Formation is of middle Eocene age. It contains two recognizable dinocyst assemblages that are roughly equivalent to those from the upper part of the Tallahatta Formation and from the lower part of the Lisbon Formation of the Gulf Coast. Foraminifers from the Congaree Formation in the Millhaven core generally indicate a water depth of approximately 100 ft; a single sample at 481 ft indicates much deeper water, approximately 300 ft.

The Warley Hill Formation, a marine unit of middle Eocene age, is recognized only in the Millhaven core. Foraminifers from samples at 455 and 426.5 ft in the Millhaven core were probably deposited in 100-ft water depth or slightly deeper; whereas those from higher samples were probably deposited in less than 100 ft of water.

The Santee Limestone is of late middle Eocene age. It contains calcareous fossils even in the most updip cores. Not surprisingly, the paleo-water depth increases basinward. In the Millers Pond core, inferred depths are less than 100 ft throughout the unit; in the Millhaven core, inferred depths range from 100 to 200 ft in the lower part of the formation and are less than 100 ft near the top.

Sediments of the Barnwell unit are poorly fossiliferous. Where they can be dated, they are late Eocene to questionably early Oligocene. Most samples are shallow marine.

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Palynomorph Biostratigraphy and Paleoecology of Upper Cretaceous Sediments from Four Cores from Screven and Burke Counties, Georgia

By Norman O. Frederiksen, Lucy E. Edwards, and Ronald J. Litwin

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GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Edited by Lucy E. Edwards

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SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

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ABSTRACT

Fifty-two Upper Cretaceous samples were examined for palynomorphs (pollen grains and dinoflagellates) from four cores (Millhaven, Girard, Thompson Oak, and Millers Pond) from Screven and Burke Counties, Georgia. Two pollen-bearing samples from the Cape Fear Formation of the Millers Pond core are both of Coniacian or early Santonian age.

Three pollen-bearing samples were obtained from the overlying Middendorf Formation of the Millhaven and Girard cores; one of them is Coniacian or Santonian, one apparently is latest Santonian(?) or earliest Campanian, and one sample is of uncertain age. Dinoflagellate data indicate that the Middendorf Formation in the Millhaven core represents, at least in part, marginal or very nearshore marine conditions, whereas the Middendorf of the updip Girard core appears to be entirely nonmarine.

Seven samples from the Black Creek Group (overlying the Middendorf Formation) of the Millhaven, Girard, and Millers Pond cores had usable pollen assemblages, and these are mid-Campanian to possibly Maastrichtian. Marine strata, particularly in the middle part of the Black Creek Group in the Millhaven, Girard, and Thompson Oak cores, contain late Campanian dinoflagellates. The Black Creek Group in the Millhaven core represents (in upward sequence) marginal or very nearshore marine conditions (subunit 1) and normal marine to nearshore marine conditions (subunits 2 and 3). The Black Creek in the more updip Girard core represents nonmarine, then nearshore marine, then nonmarine deposition. Two samples from the Black Creek Group in the still more updip Thompson Oak core represent, in ascending order, apparent nonmarine and nearshore marine paleoenvironments, respectively.

Five pollen-bearing samples from the Steel Creek Formation (overlying the Black Creek Group) of the Millhaven core appear to be Maastrichtian in age. One sample from the Steel Creek Formation may have at least marginal-marine dinoflagellates. All Cretaceous samples from the most updip Millers Pond core lack dinoflagellates.

INTRODUCTION

At the Savannah River Site (SRS) in Aiken, Barnwell, and Allendale Counties, S.C. (fig. 1), various hazardous materials have been manufactured, disposed of, and stored since the early 1950's. The U.S. Geological Survey, in cooperation with the U.S. Department of Energy and the Georgia Geologic Survey of the Georgia Department of Natural Resources, is conducting a study of the subsurface geology, hydrology, and water quality in the vicinity of the SRS with the goal of understanding the present and possible future ground-water flow in the aquifers of the area.

Many test holes have been drilled in Georgia and South Carolina to study the flow of ground water in the SRS region (Aadland, 1992; Harris and others, 1992; Strom and others, 1992; Clarke, 1993; Gellici and Logan, 1993; Clarke and others, 1994, 1996; Clarke and West, 1994; Leeth and others, 1996). The Cretaceous and Cenozoic aquifers are difficult to correlate from area to area because of structural movement and rapid facies changes. Some biostratigraphic research has been completed toward the goal of correlating aquifers between some of the test holes (for example, Prowell, Edwards, and Frederiksen, 1985; Edwards, 1992; Edwards and Clarke, 1992; Edwards and Frederiksen, 1992; Lucas-Clark, 1992; Falls and others, 1993, 1997; Clarke and others, 1994, 1996; Leeth and others, 1996; Edwards and others, 1997), but much biostratigraphic study remains to be done in the region.

Palynomorphs are abundant and well-preserved fossils in some of the Cretaceous subsurface sediments in the SRS

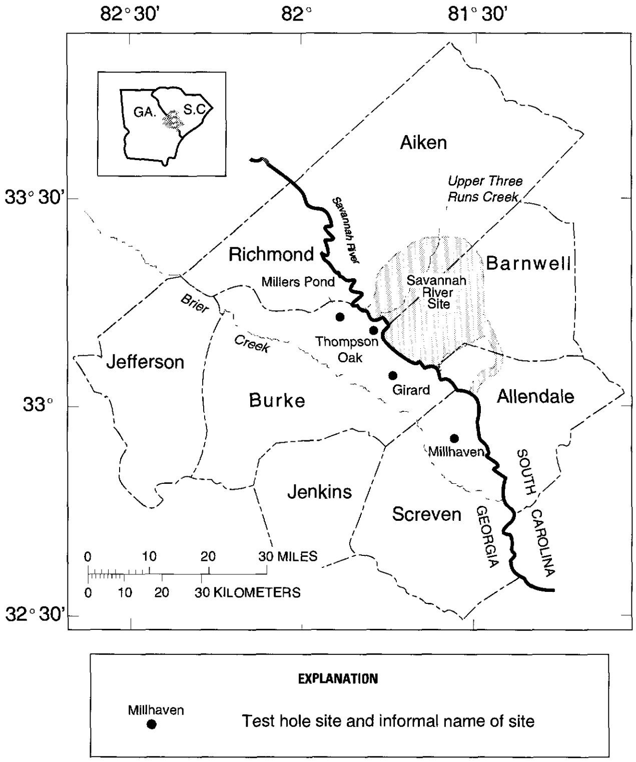

Figure 1. Index map showing the Savannah River Site and locations of stratigraphic test holes in the study area.

region. Palynomorphs include pollen grains and spores from terrestrial plants as well as the cysts—or in a few cases, perhaps thecae—of mainly marine dinoflagellates. The purpose of this paper is to use Cretaceous palynomorphs in core samples to provide biostratigraphic and paleoenvironmental data on both marine and nonmarine sediments in the area. The core samples were taken from four Georgia test holes (Millhaven, Girard, Thompson Oak, Millers Pond) in Screven and Burke Counties, Ga., directly across the Savannah River from the SRS. Table 1 summarizes the number of samples examined from each stratigraphic unit in each test hole.

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We thank U.S. Geological Survey colleagues John S. Clarke, W. Fred Falls, R. Farley Fleming, Gregory S. Gohn, and David C. Prowell, as well as Paul F. Huddlestun (Georgia Geologic Survey, Atlanta) and palynological consultant Joyce Lucas-Clark (Fremont, Calif.) for the sharing of data and ideas and the sometimes lively discussions that helped shape the ideas in this paper. We are grateful to Raymond A. Christopher (Clemson University) and G.S. Gohn for very helpful reviews of the first draft of this paper.

MATERIAL AND METHODS

The core samples discussed in this paper were cleaned and scraped and then treated in hydrochloric acid and hydrofluoric acid to remove carbonate and silicate material, respectively. Samples were then oxidized in nitric acid and centrifuged in laboratory detergent to remove fine debris. Sample residues were stained in Bismark brown and screened on 8- or 10-micrometer (μm) sieves for pollen and on 20-μm sieves for dinoflagellates. The residues were swirled in a watch glass and mounted on slides in glycerin jelly for light-microscope observation.

In table 2, which shows the slide numbers and microscope coordinates of photographed pollen specimens, the slide designations show the sample number with the slide number in parentheses. Coordinates locate the specimens on Leitz microscope 871956 at the U.S. Geological Survey, Reston, Va. On this microscope, the coordinates for the center point of a standard 25.4×76.2-millimeter (mm) slide are 38.8 and 102.5 for the horizontal and vertical axes. The horizontal coordinates increase toward the right edge of the stage, and the vertical coordinates increase toward the front of the stage.

The slide numbers and microscope coordinates of photographed dinoflagellates (table 3) locate the specimens on Olympus Vanox microscope 201526 at the U.S. Geological Survey, Reston, Va. On this microscope, the coordinates for the center point of a standard 25.4×76.2-mm slide are 27.5 and 112.7 for the vertical and horizontal axes. The vertical coordinates increase as the stage is moved up, and the horizontal coordinates increase as the slide is moved from left to right.

All palynological slides are stored at the U.S. Geological Survey, Reston, Va.

LITHOSTRATIGRAPHY AND PREVIOUS BIOSTRATIGRAPHY

Details of the geologic framework are presented elsewhere (Falls and Prowell, this volume, chap. A). Falls and Prowell recognize three formations and one group within the Cretaceous, and their terminology and correlations are followed here. The Cape Fear Formation is the lowermost unit studied and consists of partially lithified to unlithified, poorly to very poorly sorted clayey sand and sandy clay. It is overlain by the Middendorf Formation, a poorly consolidated, poorly sorted sand that contains thin clay beds; Falls and Prowell (this volume, chap. A) divide the Middendorf into two informal subunits. Above the Middendorf Formation, Falls and Prowell (this volume, chap. A) recognize the Black Creek Group, which they divide into three informal subunits that do not coincide with named formations that have been studied elsewhere. The uppermost Cretaceous

Table 1. Pollen and dinoflagellate occurrences in samples from the Upper Cretaceous units of the Millhaven, Girard, Thompson Oak, and Millers Pond cores, Screven and Burke Counties, Georgia.

[Sample depths are in feet below land surface. Symbols in the last four columns are defined next.

P (pollen) column: Y (yes), sample contains pollen that is biostratigraphically useful; N (no), sample contains pollen that is not biostratigraphically useful; C, sample contains contaminants only; o, pollen was observed in the sample but not studied.

D (dinoflagellate) column: Y (yes), has dinoflagellates; C, has only contaminant dinoflagellates; o, dinoflagellates were observed in the sample but not studied.

B (barren) column: X, sample is barren of all palynomorphs.

ND (no dinoflagellates) column: X, sample was examined for dinoflagellates, but none were found; however, at least some pollen was observed in the sample]

Sample R number	Depth (ft)	Unit (subunit)	P	D	B	ND
		Millhaven core, Screven County, Ga.				
R4664 CG	680.8–681	Steel Creek	---	---	X	---
R4664 CF	733.2–733.3	Steel Creek	Y	---	---	X
R4664 FG	755–755.3	Steel Creek	C	Y?C	---	---
R4664 GB	755.3–755.6	Steel Creek	C	C	---	---
R4664 CE	768.8–769	Steel Creek	---	---	X	---
R4664 GA	769.0–769.3	Steel Creek	Y	---	---	---
R4664 FF	789.7–790	Steel Creek	---	---	X	---
R4664 FE	824.1–824.4	Steel Creek	Y	---	---	X
R4664 DA	829.5–829.8	Steel Creek	Y	---	---	---
R4664 CD	830.3–830.5	Steel Creek	Y	Y	---	---
R4664 CC	849.3–849.6	Black Creek Group (3)	N	Y	---	---
R4664 CB	913.8–914.2	Black Creek Group (3)	Y	Y	---	---
R4664 FD	941.7–941.9	Black Creek Group (2)	Y	Y	---	---
R4664 BB	1029.5	Black Creek Group (2)	Y	Y	---	---
R4664 CA	1124.3–1124.7	Black Creek Group (1)	Y	Y	---	---
R4664 BA	1212	Middendorf (2)	Y	Y	---	---
		Girard core, Burke County, Ga.				
R4705 BH	720.3–720.5	Black Creek Group (3)	o	---	---	X
R4705 BG	738.3–738.6	Black Creek Group (2)	Y	Y	---	---
R4705 CE	784–784.3	Black Creek Group (2)	o	Y	---	---
R4705 CD	799.7–799.9	Black Creek Group (2)	o	o	---	---
R4705 CC	822.8–823	Black Creek Group (2)	o	o	---	---
R4705 CB	834.6–834.8	Black Creek Group (2)	o	Y	---	---
R4705 CA	859.5–859.8	Black Creek Group (2)	o	---	---	---
R4705 BF	868.5–868.7	Black Creek Group (2)	o	Y	---	---
R4705 BE	883.5–883.8	Black Creek Group (2)	o	---	---	X
R4705 DD	910–910.5	Black Creek Group (1)	o	---	---	X
R4705 BD	924.8–925.2	Black Creek Group (1)	o	---	---	X
R4705 BC	ca. 960?	Middendorf (2)	---	---	X	---
R4705 DC	993.5–994	Middendorf (2)	---	---	X	---
R4705 BA	1012–1012.3	Middendorf (2)	Y	---	---	X
R4705 DB	1013	Middendorf (2)	o	---	---	X
R4705 AC	1025.8–1026.2	Middendorf (2)	o	---	---	X
R4705 DA	1046.6–1047	Middendorf (2)	o	---	---	X
R4705 AB	1063	Middendorf (1)	---	---	X	---
R4705 AA	1138–1139	Middendorf (1)	Y	---	---	X
		Thompson Oak core, Burke County, Ga.				
R4836 B	505	Black Creek Group	o	Y	---	---
R4836 A	561	Black Creek Group	o	Y	---	---
		Millers Pond core, Burke County, Ga.				
R4581 O	282–287	Steel Creek	---	---	X	---
R4581 N	332–337	Black Creek Group	---	---	X	---
R4581 M	397–402	Black Creek Group	---	---	X	---
R4581 L	447–453	Black Creek Group	---	---	X	---
R4581 K	481	Black Creek Group	---	---	X	---
R4581 J	497.5	Black Creek Group	---	---	X	---
R4581 I	517	Black Creek Group	Y	---	---	---
R4581 H	557.5–558	Black Creek Group	N	---	---	---
R4581 G	578	Black Creek Group	Y	---	---	---
R4581 F	608	Middendorf	---	---	X	---
R4581 E	662–671	Middendorf	---	---	X	---
R4581 D	778	Cape Fear	---	---	X	---
R4581 C	797–802	Cape Fear	Y	---	---	---
R4581 B	827–832	Cape Fear	Y	---	---	---
R4581 A	847–852	Cape Fear	---	---	X	---

Table 2. Coordinates of photographed pollen specimens on Leitz microscope 871956 at the U.S. Geological Survey, Reston, Virginia.

Figure	Sample R no. (slide no.)	Coordinates
	Plate 1	
1	R4705 AA(5)	60.6 × 94.9
2	R4664 DA(3)	56.3 × 103.0
3	R4664 FE(1)	55.5 × 103.0
4	R4581 I(5)	55.2 × 108.0
5	R4664 FE(1)	50.1 × 105.2
6, 7	R4664 DA(3)	32.1 × 109.9
8	R4664 CD(4)	65.3 × 100.3
9	R4664 DA(3)	56.5 × 112.1
10	R4664 FE(1)	58.6 × 110.3
11	R4664 DA(3)	54.0 × 107.8
12	R4664 FE(1)	60.6 × 95.7
13	R4705 BG(4)	50.2 × 99.4
14	R4664 FD(1)	59.5 × 96.4
15, 16	R4664 DA(3)	54.8 × 101.7
17	R4664 GA(1)	55.1 × 102.1
18	R4664 CA(6)	54.8 × 99.8
19–21	R4664 GA(1)	62.3 × 105.1
	Plate 2	
1	R4664 FD(1)	49.9 × 110.3
2	R4664 DA(3)	52.7 × 95.8
3, 4	R4664 FD(1)	52.2 × 105.8
5	R4581 I(5)	56.5 × 111.5
6, 7	R4664 GA(1)	57.2 × 99.0
8	R4581 C(1)	56.5 × 95.2
9	R4581 C(1)	60.5 × 95.3
10	R4581 B(1)	45.9 × 97.3
11	R4705 BA(4)	50.2 × 106.2
12	R4581 C(1)	57.0 × 94.2
13	R4581 C(1)	54.6 × 99.1
14	R4664 CA(6)	64.1 × 104.4
15	R4581 B(1)	52.5 × 95.2
16	R4664 FD(1)	51.2 × 107.4
17–19	R4581 B(1)	56.3 × 97.3
20	R4664 CA(6)	42.8 × 93.3
21	R4581 C(1)	58.5 × 102.6
	Plate 3	
1	R4705 AA(5)	58.0 × 96.8
2	R4664 CA(6)	53.7 × 102.5
3	R4664 CA(6)	60.4 × 94.7
4, 5	R4664 CA(6)	66.4 × 101.6
6, 7	R4581 C(1)	51.8 × 102.6
8	R4581 C(1)	54.6 × 102.3
9	R4581 I(5)	61.4 × 101.9
10, 11	R4581 I(5)	58.0 × 99.2
12	R4664 GA(1)	56.2 × 111.0
13	R4664 GA(1)	54.0 × 101.2
14, 15	R4705 BG(4)	62.1 × 94.8
16	R4664 GA(1)	51.8 × 108.4
	Plate 4	
1, 2	R4664 DA(3)	33.3 × 101.2
3	R4581 I(5)	59.6 × 106.6
4	R4705 BA(4)	58.3 × 94.6
5	R4705 BA(4)	60.6 × 100.9
6	R4581 C(1)	56.7 × 103.0
7	R4664 GA(1)	53.0 × 93.8
8	R4705 AA(5)	61.9 × 107.6
9	R4705 BA(4)	60.0 × 102.4
10, 11	R4705 BA(4)	39.9 × 111.6
12, 13	R4705 AA(5)	49.6 × 97.3
14, 15	R4664 DA(3)	34.8 × 105.8
	Plate 5	
1	R4705 BG(4)	52.4 × 103.1
2	R4664 BB(5)	54.8 × 98.3
3	R4664 BB(5)	57.5 × 111.4
4, 5	R4705 BG(4)	61.2 × 110.5
6, 7	R4705 AA(5)	60.5 × 97.8
8, 9	R4664 FE(1)	58.5 × 98.7
10, 11	R4664 CD(4)	50.3 × 107.7
12, 13	R4664 CD(4)	55.7 × 112.1
14	R4705 BA(4)	38.7 × 99.5

unit, where present, is the Steel Creek Formation, a poorly sorted sand and clay.

In this paper, age determinations for samples from the Upper Cretaceous of Georgia are made using pollen and dinoflagellate taxa. The chronostratigraphic ranges of these fossils are known on the basis of previous work mainly in the Middle Atlantic States. European stage assignments and ages of Upper Cretaceous formations in New Jersey (fig. 2) are based primarily on calcareous nannofossil correlations, but the relation between calcareous nannofossil zones and European stages is subject to revision. Here, we use the boundary proposals summarized by Burnett (1996) from the Second Symposium on Cretaceous Stage Boundaries, Brussels, 1995.

Of particular importance to our work is the placement of the Campanian-Maastrichtian boundary at the first appearance datum of the ammonite *Pachydiscus neubergicus* (von Hauer) in the Teras Quarry, France. This boundary position is stratigraphically higher (younger) than some previous interpretations of the boundary. When this boundary is correlated using nannofossil and foraminiferal zones, some strata that were previously considered to be Maastrichtian should now be considered to be upper Campanian. For example, the Mount Laurel Formation of New Jersey was considered by some earlier authors (for example, Olsson and others, 1988; Aurisano, 1989) to be lower Maastrichtian. However, the Mount Laurel Formation has been assigned to calcareous nannofossil Zone CC 22 (Self-Trail and Bybell, 1995; Sugarman and others, 1995), and Burnett

Table 3. Coordinates of photographed dinoflagellate and acritarch specimens on Olympus Vanox microscope 201526 at the U.S. Geological Survey, Reston, Virginia.

Figure	Sample R no. (slide no.)	Coordinates
	Plate 6	
1	R4705 BG(3)	32.8 × 100.0
2	R4664 BB(4)	30.1 × 97.8
3	R4705 BF(3)	35.5 × 86.9
4	R4664 BB(4)	26.4 × 96.1
5	R4664 CB(3)	37.0 × 83.5
6	R4705 BF(2)	32.5 × 99.2
7	R4705 BG(3)	29.2 × 72.0
8	R4664 BB(4)	24.2 × 99.7
9	R4664 BB(4)	24.4 × 77.5
10	R4664 CB(4)	20.3 × 105.2
11	R4705 BG(3)	37.1 × 101.5
12	R4705 BF(2)	25.6 × 90.8
13	R4705 BF(2)	34.4 × 69.6
14	R4664 CB(3)	34.8 × 95.9
15	R4705 BF(2)	20.0 × 105.3
16	R4705 BG(3)	31.7 × 108.9
	Plate 7	
1	R4705 BF(2)	32.5 × 84.4
2	R4664 BA(4)	37.1 × 73.6
	Plate 7—Continued	
3	R4664 BA(4)	26.7 × 84.3
4	R4664 BA(4)	30.7 × 94.2
5	R4664 BB(4)	23.3 × 99.6
6	R4705 CB(4)	33.3 × 80.2
7	R4664 CD(3)	22.3 × 106.7
8, 9	R4705 CB(4)	30.2 × 89.0
10	R4664 CA(4)	36.8 × 76.4
11	R4664 BB(4)	36.0 × 108.0
12	R4705 BF(2)	26.1 × 72.0
13	R4705 BG(3)	30.1 × 72.1
14	R4705 BG(3)	36.0 × 103.7
15	R4664 CA(4)	35.8 × 102.0
16	R4664 CA(4)	32.3 × 73.7
17	R4664 CB(3)	32.7 × 100.5
18	R4664 BB(4)	28.7 × 95.9
19	R4836 B(3)	30.3 × 77.4
20	R4664 BB(4)	28.7 × 97.8
21	R4705 CB(4)	32.2 × 81.4

(1996) placed the Campanian-Maastrichtian boundary within the lower part of Zone CC 23; therefore, we agree with Self-Trail and Bybell (1995) and Sugarman and others (1995) in assigning the Mount Laurel Formation to the upper Campanian (fig. 2).

Sugarman and others (1995) provided nannofossil zonal assignments for the Navesink Formation and for the lower part of the Red Bank Sand of New Jersey. Self-Trail and Bybell (1995) gave nannofossil zonal assignments for the Merchantville, Englishtown, Marshalltown, Mount Laurel, and Navesink Formations. Self-Trail and Bybell presented these stage assignments in terms of Perch-Nielsen's (1985) calcareous nannofossil zonation, but Self-Trail (written commun., 1996) has translated her zonal assignments into the zonal and stage scheme of Burnett (1996), which is followed here.

European stage assignments of Upper Cretaceous formations in the Gulf Coast were summarized by Sohl and others (1991) on the basis mainly of mollusk, planktonic foraminiferal, and calcareous nannofossil data. Tschudy (1973, 1975) and Christopher (1982b,c) instead used pollen taxa to correlate these Gulf Coast stratigraphic units with those of the Atlantic Coastal Plain and of Europe.

The standard pollen zonation for the Upper Cretaceous of the Gulf and Atlantic Coastal Plains (fig. 2) has been developed in a series of abstracts and papers, notably those of Doyle (1969), Sirkin (1974), Wolfe (1976), Doyle and Robbins (1977), and Christopher (1977b, 1982c). This zonation was based on material mainly from the Middle Atlantic States. The base of pollen Zone V (fig. 2) occurs in the lowermost part of the Austin Chalk of Texas (Christopher, 1982c), which is Coniacian (Sohl and others, 1991). The top of Zone V is Santonian (Christopher and others, 1997). The South Amboy Fire Clay Member, which forms the upper part of the Raritan Formation in New Jersey, has not been dated by means of marine fossils; therefore, the age determinations of Christopher (1977a), as modified by Christopher (1982c), are used for this member. Aurisano's (1989) suggestion that the South Amboy Fire Clay Member should be reassigned from the Raritan to the Magothy Formation appears to be a good idea, but for purposes of the present paper, the South Amboy Fire Clay Member is retained in the Raritan Formation.

In this paper, age determinations are based on pollen range charts presented by Tschudy (1973, 1975), Wolfe (1976), Christopher (1978, 1979), Frederiksen and Christopher (1978), and Litwin and others (1993), with some occurrence and range data from additional publications (for example, Tschudy, 1970; Christopher and others, 1979; Christopher, 1980). We have preferred to use the better known Atlantic Coastal Plain stratigraphic ranges rather than Gulf Coast ranges. However, it appears that some pollen taxa have somewhat different stratigraphic ranges in the Carolinas and Georgia than they have in the Middle Atlantic States. This regional difference may account for difficulties in making age determinations for some samples in this paper (R.A. Christopher, written commun., 1996). Similar

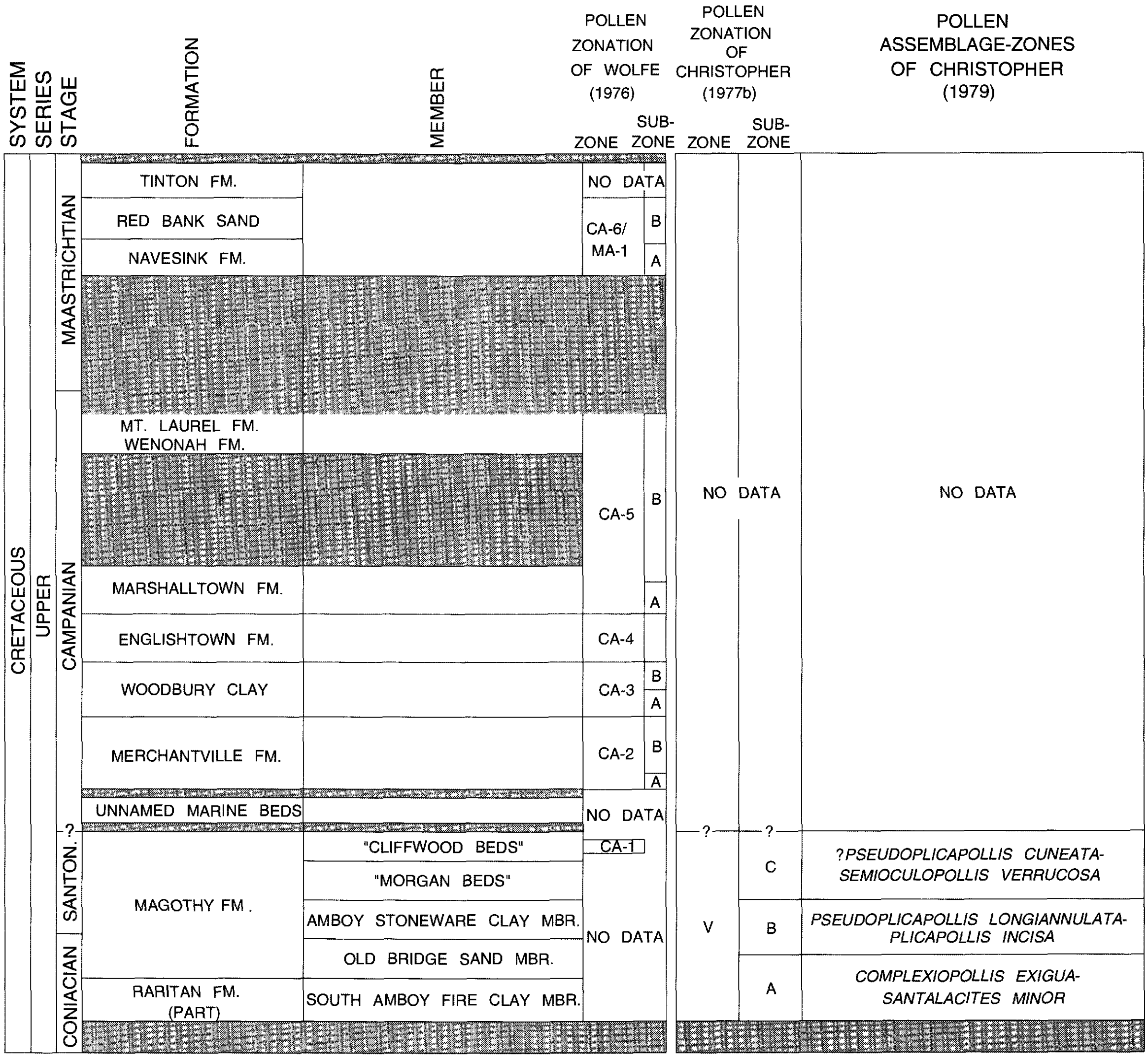

Figure 2. Chart showing European stage assignments of Coniacian to Maastrichtian formations in New Jersey and the main pollen zonations proposed for these formations. Sources of the stage assignments are given in the text. Not shown is the tentative assignment of the unnamed marine beds to Zone CA-2A by Litwin and others (1993). FM., Formation, MBR., Member.

differences in marine coccolith floras between New Jersey and Georgia are reported by Bukry (this volume, chap. D).

Most of the pollen taxa mentioned in this report (table 4) have been illustrated previously in the publications listed, but many of the taxa are also illustrated in this report (plates 1–5).

Relatively little has been published on the dinoflagellates from Upper Cretaceous sediments of the Eastern United States. Early work in Texas (Zaitzeff and Cross, 1971) has been supplemented by recent papers by Srivastava (1991, 1993) and Cretaceous-Tertiary boundary studies by Habib and others (1996). Papers by Habib and Miller (1989) and Lucas-Clark (1992) list some of the dinoflagellates from South Carolina from the same stratigraphic units that are present in the Georgia cores discussed here. The study by Firth (1987) in western Georgia dealt with dinoflagellates near the Cretaceous-Tertiary boundary.

Dinoflagellates from the Atlantic Coastal Plain have been described by several authors, including Koch and Olsson (1977), Whitney (1979), May (1980), and Aurisano (1989). The dinoflagellate succession described by May (1980) from the Mount Laurel Formation in the Atlantic Highlands in New Jersey is of particular relevance. Some of the key dinoflagellate taxa from the present samples are illustrated in plates 6 and 7, and the dinoflagellate and acritarch taxa mentioned in this report are listed in table 5.

Table 4. List of pollen taxa mentioned in this paper with some synonyms.

Taxon	Plate	Figure
Brevicolporites sp.	3	14, 15
Brevicolporites sp. A of Christopher (1978); see CP3F-1	—	—
Casuarinidites sp. A of Frederiksen and Christopher (1978) = *Triatriopollenites rurensis* Pflug & Thomson *in* Thomson and Pflug (1953) of Gray and Groot (1966)	1	14, 17
Casuarinidites sp.	—	—
Complexiopollis abditus Tschudy = NB-1 of Wolfe (1976)	2	11
Complexiopollis exigua Christopher	—	—
Complexiopollis funiculus Tschudy	2	10
Complexiopollis sp. D of Christopher (1979)	—	—
Complexiopollis sp. E of Christopher (1979)	—	—
Complexiopollis sp. H of Christopher (1979)	—	—
Complexiopollis sp. I of Christopher (1979)	—	—
Complexiopollis sp.	2	12
Complexiopollis? sp.	2	17–19
C3A-2 of Wolfe (1976)	—	—
Aff. C3C-1 of Wolfe (1976)	4	7
CP3B-1 of Wolfe (1976)	—	—
CP3B-6 of Wolfe (1976)	—	—
CP3D-1 of Wolfe (1976)	—	—
CP3D-3 of Wolfe (1976) = *Holkopollenites* cf. *H. chemardensis* Fairchild *in* Stover and others (1966) of Christopher (1978)	4 5	3 1–3
CP3E-1 of Wolfe (1976) = ?*Holkopollenites* sp. of Christopher (1978)	4 5	12, 13 4–9
CP3F-1 of Wolfe (1976) in part = *Brevicolporites* sp. A of Christopher (1978)	3 4 4	12, 13 1, 2 4, 5
CP3F-2 of Wolfe (1976) = *Brevicolporites* sp. B of Christopher (1978)	—	—
CP3G-1 of Wolfe (1976)	4	8
Holkopollenites spp.	4 5	14, 15 14
Interporopollenites turgidus Tschudy	2	2
Labrapollis sp. B of Christopher (1979)	—	—
Lanagiopollis cribellatus (Srivastava) Frederiksen = CP3A-3 of Wolfe (1976) = *Tricolporites* sp. C of Christopher (1980)	3	16
Libopollis sp.	—	—
Momipites fragilis Frederiksen & Christopher	—	—
Momipites microfoveolatus (Stanley) Nichols = NK-3 of Wolfe (1976)	1	3
Momipites tenuipolus group of Frederiksen and Christopher (1978) = NK-2 of Wolfe (1976)	1	5
Momipites sp. H of Christopher (1979)	—	—
Momipites sp. I of Christopher (1979)	—	—
Momipites n. sp. 1	1 1	6, 7 10–12
Cf. MPH-1 of Wolfe (1976)	5	10, 11
New genus A of Tschudy (1975)	2	13
New genus D, sp. B of Christopher (1979)	2	21

Table 4. List of pollen taxa mentioned in this paper with some synonyms—Continued.

Taxon	Plate	Figure
New genus D, sp. H of Christopher (1979)	2	20
New genus D, sp. J of Christopher (1979)	3	1
New genus D, sp. L of Christopher (1979)	3	2
N20-2 of R.A. Christopher (unpublished)	3	3–5
N20-12 of R.A. Christopher (unpublished)	1	13
NB-2 of Wolfe (1976) = *Complexiopollis* sp. of Christopher (1978)	—	—
NB-3 of Wolfe (1976)	—	—
Cf. ND-2 of Wolfe (1976)	2	16
NF-1 of Wolfe (1976) = *Trudopollis* sp. A of Christopher (1978)	—	—
NO-3 of Wolfe (1976) = *Betulaceoipollenites* sp. of Christopher (1978)	—	—
NP-1 of Wolfe (1976) = *Triatriopollenites* sp. A of Christopher (1980)	—	—
NP-2 of Wolfe (1976) = *Triatriopollenites* sp. of Christopher (1978) = *Triatriopollenites* sp. B of Christopher (1980)	1	8, 9
Nyssapollenites sp. of Christopher (1982b)	—	—
Nyssapollenites sp.	4	10, 11
Plicapollis sp. A of Christopher (1979)	2	8
Plicapollis sp. K of Christopher (1979)	2	9
Plicatopollis cretacea Frederiksen & Christopher = NN-2 of Wolfe (1976)	—	—
?*Porocolpopollenites* sp. A of Christopher and others (1979)	3	6, 7
Porocolpopollenites n. sp. 1	3	8
Praecursipollis plebius Tschudy	2	14, 15
Proteacidites sp. aff. PR-3 of Wolfe (1976)	—	—
PR-1 of Wolfe (1976) = *Proteacidites* sp. B of Christopher (1978)	1 2	18 1
PR-5 of Wolfe (1976) = *Proteacidites* sp. C of Christopher (1978)	—	—
PR-7 of Wolfe (1976) = *Proteacidites* sp. A of Christopher (1978) = *Proteacidites* sp. G of Christopher (1980)	1	15, 16
Rhombipollis sp.	3	10, 11
Rugubivesiculites sp.	1	1
Santalacites minor Christopher	—	—
Tetracolporate sp.	5	12, 13
Triatriopollenites spp.	1	2, 4
Tricolpites spp.	2	5–7
Tricolporites sp.	4	6, 9
Cf. Triporate type 4 of Christopher (1979)	1	19–21
Trisectoris costatus Tschudy	2	3, 4
Trudopollis sp. cf. *T. meekeri* Newman	3	9

Table 5. List of dinoflagellate and acritarch taxa mentioned in this paper.

Taxon	Plate	Figure
Alisogymnium-Dinogymnium spp. = specimens representing various species of the genera *Alisogymnium* Lentin & Vozzhennikova 1990 and *Dinogymnium* Evitt et al. 1967	6	1, 2
Alterbidinium acutulum (Wilson 1967) Lentin & Williams 1985	6	3
Andalusiella polymorpha (Malloy 1972) Lentin & Williams 1977	6	5
Andalusiella spicata (May 1980) Lentin & Williams 1981	6	4, 6
Cerodinium pannuceum (Stanley 1965) Lentin & Williams 1987	6	7
Cerodinium striatum (Drugg 1967) Lentin & Williams 1987	6	8
Cordosphaeridium fibrospinosum Davey & Williams 1966	6	9
Cribroperidinium Neal & Sarjeant 1962, emend. Helenes 1984 sp.	6	10
Diphyes recurvatum May 1980	6	11
Exochosphaeridium Davey et al. 1966 sp.	6	12
Fromea Cookson & Eisenack 1958, emend. Yun 1981 spp.	6	13, 14
Lejeunecysta Artzner & Dorhofer 1978, emend. Bujak 1980 sp.	7	18
Membranosphaera maastrictica Samoilovitch 1961	6	15
Odontochitina costata Alberti 1961	7	1
Operculodinium Wall 1967 spp.	6	16
Palaeohystrichophora infusorioides Deflandre 1935	7	2, 3
Palaeoperidinium Deflandre 1934, emend. Sarjeant 1967 sp.	7	4
Spiniferites Mantell 1850, emend. Sarjeant 1970 spp.	7	6
Spongodinium delitiense (Ehrenberg 1838) Deflandre 1936	7	7
Tanyosphaeridium xanthiopyxides (Wetzel 1933) Stover & Evitt 1978	7	5
Tricodinium castanea (Deflandre 1935) Clark & Verdier 1967	7	8, 9
Xenascus ceratioides (Deflandre 1937) Lentin & Williams 1973	7	19
Miscellaneous areoligeracean forms	7	15–17, 21
Miscellaneous chorate forms (excluding *Spiniferites* spp.)	7	14
Small peridiniacean forms	7	10–13, 20

MILLHAVEN TEST HOLE

The Millhaven test hole (33X048) was drilled by the U.S. Geological Survey at lat 32°53'25" N., long 81°35'43" W., near Sylvania, Burtons Ferry Landing 7.5-min quadrangle, Screven County, Ga. (fig. 1). The surface elevation is 110 ft above sea level. Sixteen Upper Cretaceous samples were examined for pollen and dinoflagellates from the depth interval of 1,212.0 to 680.8 ft (table 1). Stratigraphic occurrences of angiosperm pollen taxa in the productive samples are shown in figure 3; many of these samples also contained the Cretaceous gymnosperm pollen genus *Rugubivesiculites* Pierce. Taxon occurrences of dinoflagellates in 10 samples are shown in figure 4.

CAPE FEAR FORMATION

No palynological samples were studied from the Cape Fear Formation in the Millhaven core.

MIDDENDORF FORMATION

SUBUNIT 2

Sample R4664 BA, from a 1,212.0-ft depth, is from subunit 2 of the Middendorf Formation. It contains only two useful angiosperm pollen taxa (fig. 3). Both of these range throughout Zone V (fig. 2), which is equivalent to the combined *Complexiopollis exigua-Santalacites minor*, *Pseudoplicapollis longiannulata-Plicapollis incisa*, and ?*Pseudoplicapollis cuneata-Semioculopollis verrucosa* Zones (fig. 2) of Coniacian, Santonian, and earliest Campanian age. The same sample contains rare dinoflagellate cysts of *Palaeohystrichophora infusorioides* Deflandre and other peridiniacean forms, which suggests a marginal marine or very nearshore marine environment.

BLACK CREEK GROUP

SUBUNIT 1

Sample R4664 CA, from a depth of 1,124.3 to 1,124.7 ft in the Millhaven test hole, is from subunit 1 of the Black Creek Group. Pollen taxa occurrences in this sample are shown in figure 5. Six species are not known to range higher, or they barely range higher, than the top of the ?*Pseudoplicapollis cuneata-Semioculopollis verrucosa* Zone. Because of the presence of these taxa, Clarke and others (1996) interpreted this sample as being Santonian in age and as belonging to Zone V (fig. 2). It should be noted that *Praecursipollis plebius* Tschudy apparently has not been reported from the Atlantic Coastal Plain and is known only from a single sample of the Eutaw Formation in western Georgia (Tschudy, 1975). Sohl and others (1991) considered the Eutaw Formation to be middle Coniacian to late (but not latest) Santonian in age in western Georgia. This formation age is used for the age range of *Praecursipollis plebius* Tschudy shown in figure 5 and other range charts of this paper that include this species. A very similar species, *Praecursipollis* sp. A of Christopher (1979), has a range in New Jersey from the base of the *Complexiopollis exigua-Santalacites minor* Zone to the lower part of the ?*Pseudoplicapollis cuneata-Semioculopollis verrucosa* Zone; thus, *Praecursipollis* sp. A has a range virtually identical to the range shown for *Praecursipollis plebius* Tschudy in this paper.

CP3B-1 and CP3B-6 of Wolfe (1976) are known from the uppermost part of the ?*Pseudoplicapollis cuneata-Semioculopollis verrucosa* Zone, but they are not known to coexist with *Complexiopollis exigua* Christopher, *Momipites* sp. I of Christopher (1979), and New genus D, sp. L of Christopher (1979). CP3B-1 and CP3B-6 belong to the *Holkopollenites* complex, which is as yet poorly described and only partly illustrated. This complex is mainly developed in the Campanian and Maastrichtian although it has its range base in the Santonian (Christopher, 1982a).

PR-1 of Wolfe (1976), *Proteacidites* sp. aff. PR-3 of Wolfe (1976), and CP3D-3 of Wolfe (1976) might be contaminants, presumably from drilling mud, or they might have been misidentified. A more likely explanation for the species range pattern in figure 5 is that sample R4664 CA contains a number of reworked taxa from the Coniacian and Coniacian to Santonian, but the sample is probably assignable to mid-Campanian Zone CA-4.

Sample R4664 CA contains rare dinoflagellates of *Palaeohystrichophora infusorioides* Deflandre, other peridiniacean forms, and miscellaneous areoligeracean forms (fig. 4), suggesting a marginal marine or very nearshore marine environment. These dinoflagellate specimens might be reworked. However, this possibility is unlikely because (1) the specimens are fragile and would not withstand reworking while remaining in a fair state of preservation, and (2) formations from which they might be reworked (Cape Fear and Middendorf) are entirely or nearly entirely nonmarine.

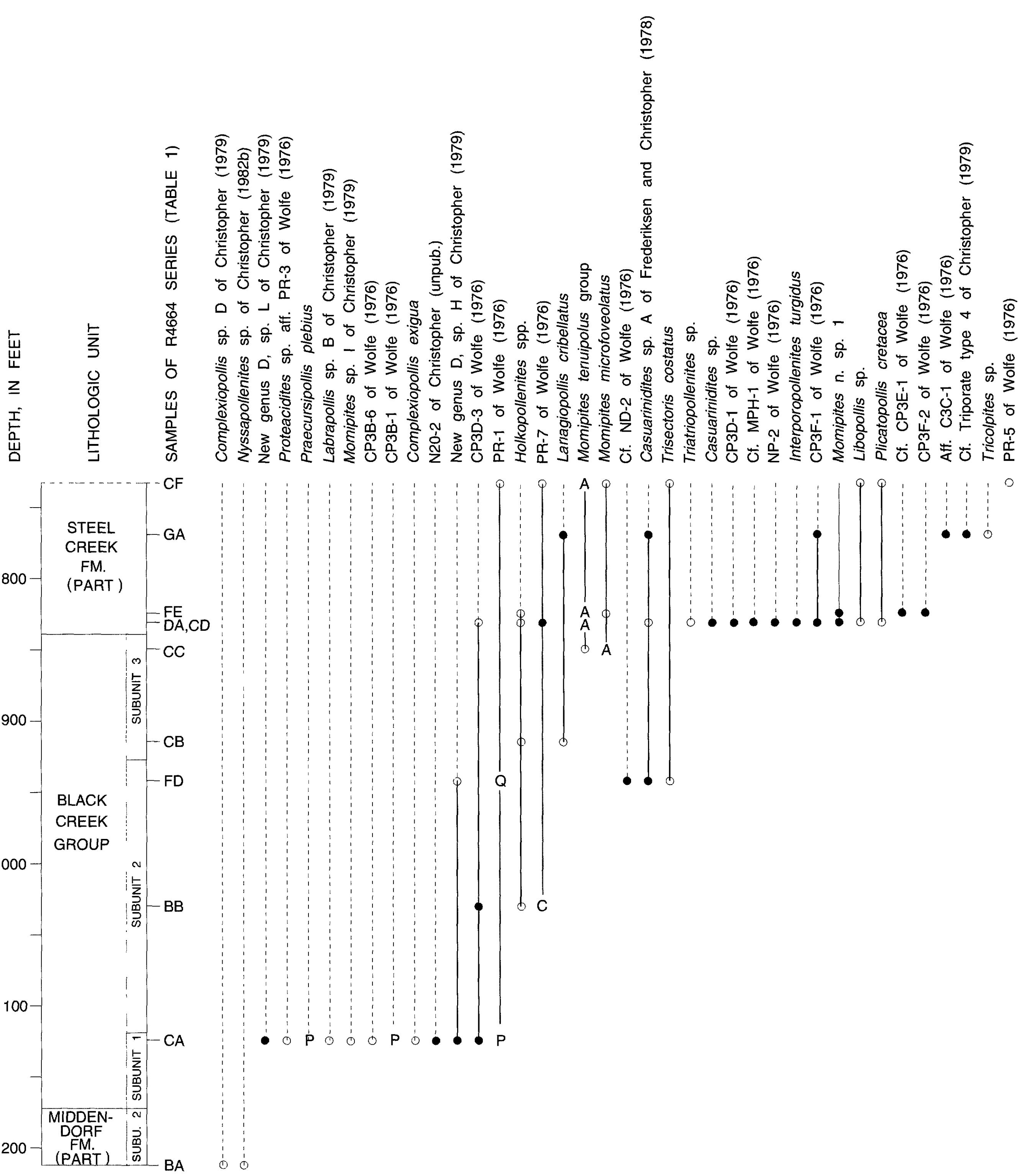

Figure 3. Chart showing pollen taxa occurrences in 11 samples between 1,212.0 and 733.2 ft in the Millhaven core, Screven County, Ga. Solid circles indicate that the identification of the specimens was checked by R.A. Christopher from photomicrographs provided by the senior author; hollow circles indicate that the identification of the specimens was not so checked; A = aff., meaning the specimens observed were similar to the taxon listed but probably belong to a different species; C = cf., meaning that the specimens are similar to and may well belong to the taxon listed; P indicates that the specimens probably belong to the taxon listed; Q indicates that identification of the taxon was questionable, uncertain. Depths are in feet below land surface. FM., Formation.

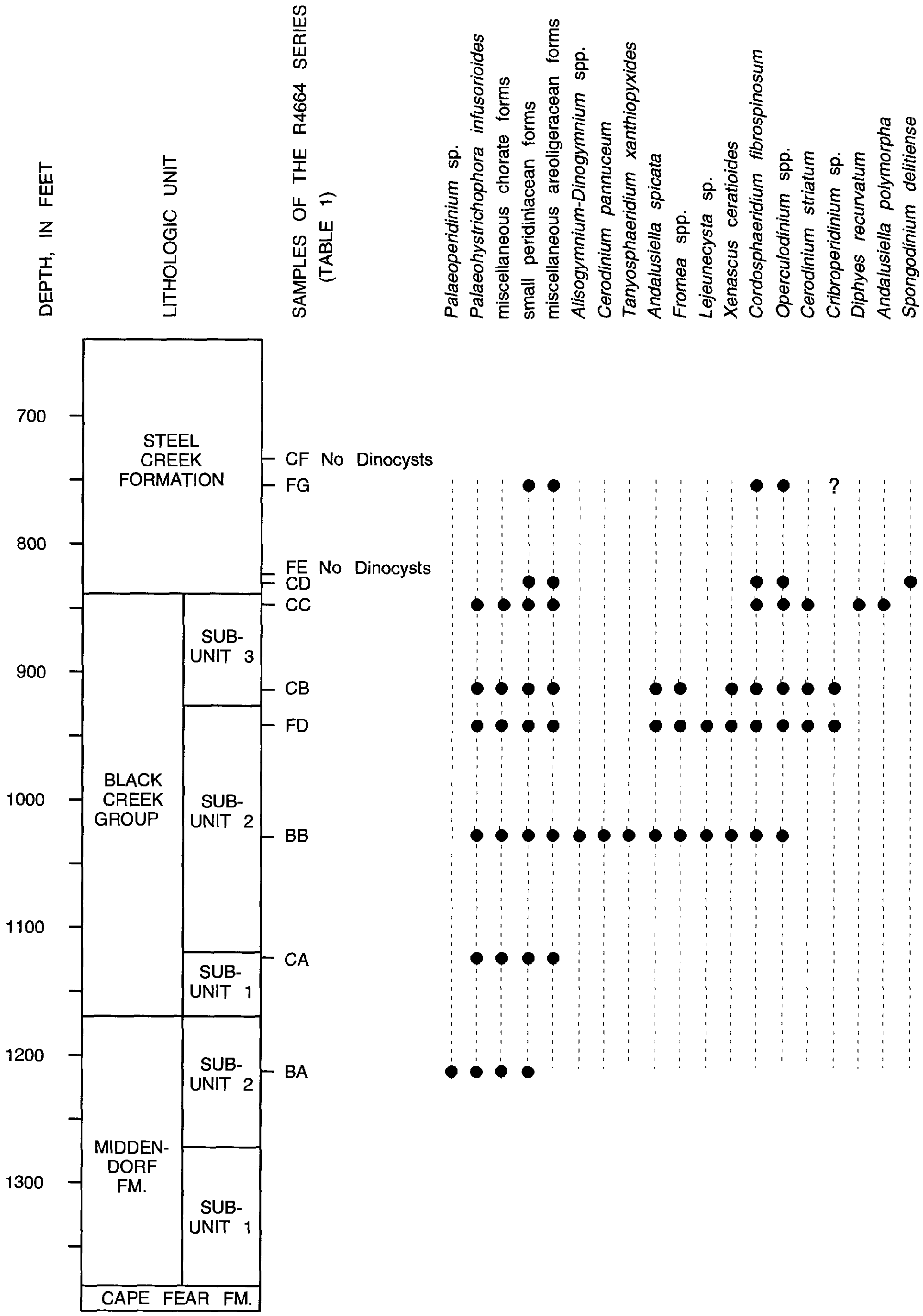

Figure 4. Chart showing dinoflagellate taxa occurrences in 10 samples between 1,212.0 and 680.8 ft in the Millhaven core, Screven County, Ga. Depths are in feet below land surface. FM., Formation.

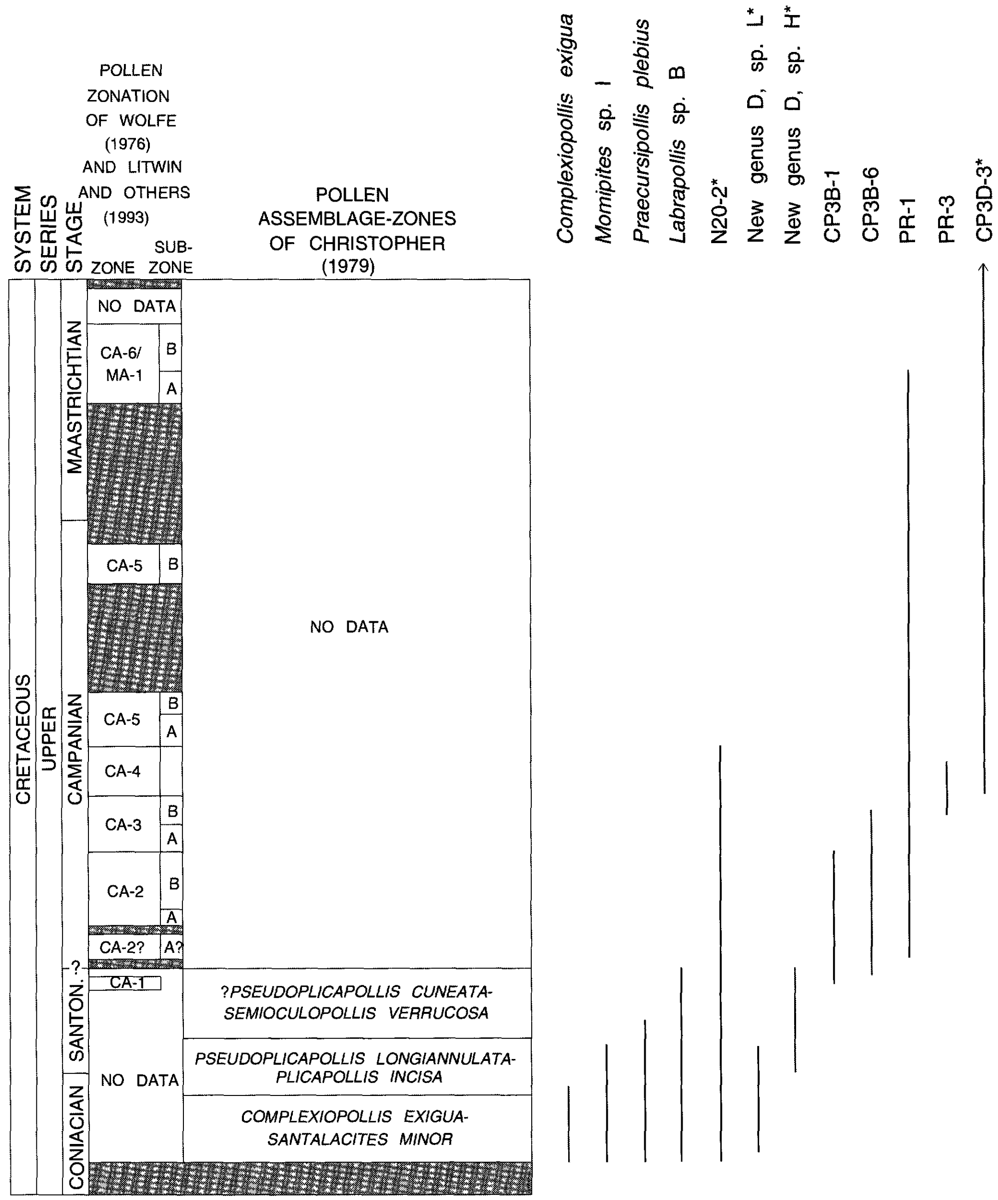

Figure 5. Chart showing known stratigraphic ranges of pollen taxa in sample R4664 CA, subunit 1 of the Black Creek Group, from 1,124.3–1,124.7 ft in the Millhaven core, Screven County, Ga. The known range shown for N20-2 of R.A. Christopher (unpublished) is from Christopher (written commun., 1996). The identification of taxa followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, these taxa are of greater significance than the others. Full names of taxa are in figure 3 and table 4.

SUBUNIT 2

Pollen grains and dinoflagellates were examined from two samples of subunit 2 of the Black Creek Group in the Millhaven core. They are R4664 BB and R4664 FD (figs. 3, 4).

Pollen taxa occurrences in sample R4664 BB, from a 1,029.5-ft depth, are shown in figure 6. The stratigraphic ranges are not very informative except to indicate that the age of the sample is probably late Campanian or Maastrichtian. However, Bukry (this volume, chap. D) reports that on the basis of calcareous nannofossils the interval between 1,077.0 and 968.0 ft is late Campanian (Zone CC 22) in age.

Sample R4664 FD, from a depth of 941.7 to 941.9 ft, contains mainly long-ranging pollen taxa (fig. 7). Interpretation of the stratigraphic ranges is complicated by the fact that the specimen identified as cf. ND-2 only probably belongs to species ND-2 of Wolfe (1976), and the identification of species PR-1 of Wolfe (1976) was even more tenuous. However, like the underlying sample R4664 BB, this sample cannot be older than late Campanian; therefore, the specimen of New genus D, sp. H of Christopher (1979) is reworked or was misidentified, or its range should be extended upward.

Dinoflagellates are moderately abundant and diverse in samples R4664 BB and FD (1,029.5 and 941.7–941.9 ft, respectively; fig. 4). Important species include *Andalusiella spicata* (May) Lentin & Williams, *Cerodinium striatum* (Drugg) Lentin & Williams, *Cerodinium pannuceum* (Stanley) Lentin & Williams, *Palaeohystrichophora infusorioides* Deflandre, and *Xenascus ceratioides* (Deflandre) Lentin & Williams. The assemblage indicates correlation with the Mount Laurel Formation in New Jersey. This is because the first two species have their lowest occurrences in the Mount Laurel Formation and the last three species have their highest occurrences near the top of the Mount Laurel Formation (May, 1980). As previously stated, we consider the Mount Laurel Formation to be upper Campanian. However, late Campanian calcareous nannofossils were only found as high as 968.0 ft (Bukry, this volume, chap. D). Therefore, the possibility cannot be excluded that some of the stratigraphically highest occurrences of diverse dinoflagellate assemblages in the Millhaven core (as well as in the Girard and Thompson Oak cores) might be correlative with the uppermost Campanian part of the Mount Laurel-Navesink unconformity (fig. 2), that is, slightly younger than the preserved Mount Laurel Formation itself.

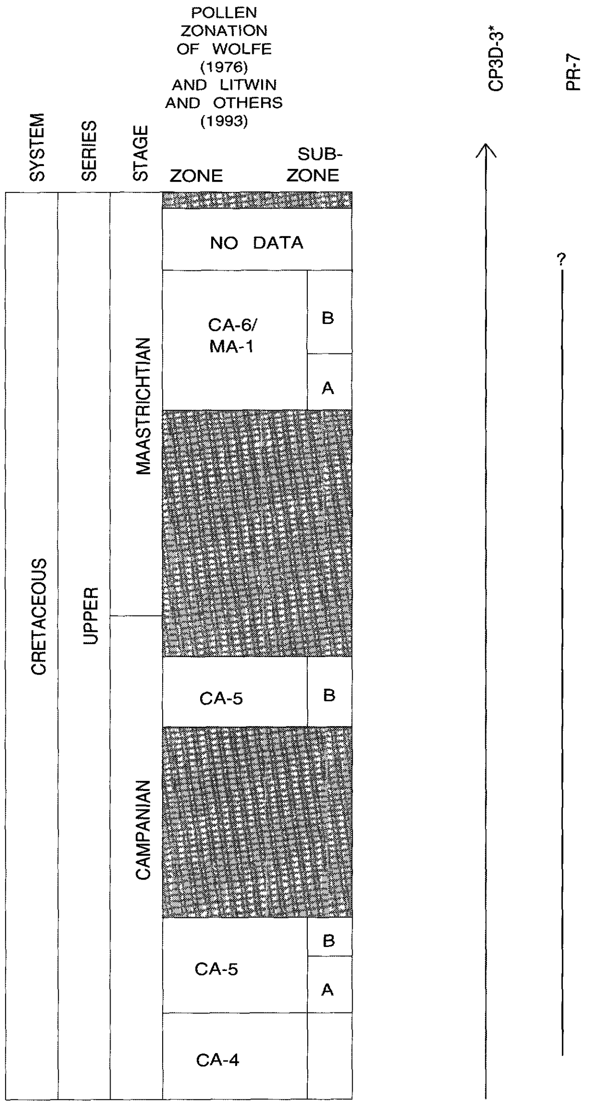

Figure 6. Chart showing known stratigraphic ranges of pollen taxa in sample R4664 BB, subunit 2 of the Black Creek Group, from 1,029.5 ft in the Millhaven core, Screven County, Ga. The identification of the taxon followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, this taxon is of greater significance than the other. Full names of taxa are in figure 3 and table 4. The question mark indicates that the youngest age of the taxon is uncertain.

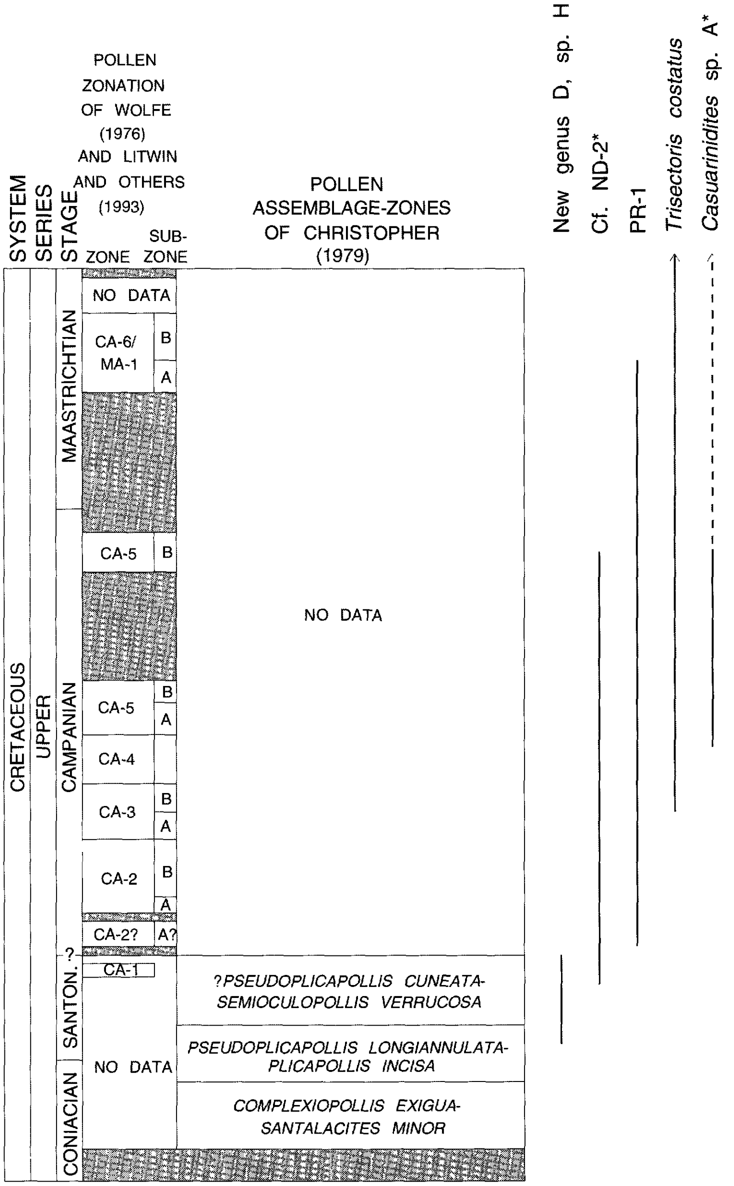

Figure 7. Chart showing known stratigraphic ranges of pollen taxa in sample R4664 FD, subunit 2 of the Black Creek Group, from 941.7–941.9 ft in the Millhaven core, Screven County, Ga. The identification of taxa followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, these taxa are of greater significance than the others. The stratigraphic range shown for species cf. ND-2 is the known range of ND-2 of Wolfe (1976). The identification of species PR-1 of Wolfe (1976) was uncertain. Full names of taxa are in figure 3 and table 4.

SUBUNIT 3

Pollen grains and dinoflagellates were examined from two samples of subunit 3 of the Black Creek Group in the Millhaven core. They are R4664 CB and R4664 CC (figs. 3, 4).

Sample R4664 CB from a depth of 913.8–914.2 ft has only sparse pollen grains that include only a few taxa (fig. 3). The only useful species, *Lanagiopollis cribellatus* (Srivastava) Frederiksen, ranges from mid-Campanian Zone CA-4 into the Paleocene.

Sample R4664 CC, from 849.3–849.6 ft, contains so few (fig. 3) and such long-ranging pollen taxa that little can be said about its age.

The dinoflagellate assemblage in sample R4664 CB of subunit 3 (913.8–914.2 ft; fig. 4) is virtually identical to the assemblage in the sample below (R4664 FD at 941.7–941.9 ft) in subunit 2. Important species include *Andalusiella spicata* (May) Lentin & Williams, *Cerodinium striatum* (Drugg) Lentin & Williams, *Palaeohystrichophora infusorioides* Deflandre, and *Xenascus ceratioides* (Deflandre) Lentin & Williams. Here again, the assemblage is late Campanian, correlative with the Mount Laurel Formation in New Jersey.

Sample R4664 CC (849.3–849.6 ft) has a less diverse assemblage but contains the highest occurrence of *Palaeohystrichophora infusorioides* Deflandre. The highest occurrence of *P. infusorioides* Deflandre marks the top of Koch and Olsson's (1977) *P. infusorioides* Zone, which we now consider to correlate approximately with the Campanian-Maastrichtian boundary.

STEEL CREEK FORMATION

Ten samples of the Steel Creek Formation from the Millhaven test hole were examined for pollen and dinoflagellates. Three samples were barren of both pollen and dinoflagellates (table 1): R4664 FF, CE, and CG. A fourth sample—R4664 GB—contains practically no pollen and only late Paleocene dinoflagellates, which are clearly contaminants from uphole. The six samples providing biostratigraphic information are discussed below.

Figure 8 displays stratigraphic ranges of pollen taxa in three Steel Creek samples from between depths of 830.5 and 824.1 ft in the Millhaven test hole:

Sample	*Depth below land surface, in feet*
R4664 FE	824.1–824.4
R4664 DA	829.5–829.8
R4664 CD	830.3–830.5

These three samples contain many taxa that were not found to range lower in the Millhaven core section. These pollen taxa include several reworked forms from the Santonian and lower Campanian, but the bulk of the evidence points to a Campanian or Maastrichtian age. The apparent presence of CP3E-1 of Wolfe (1976) and cf. MPH-1 of Wolfe (1976) suggests an assignment to Zone CA-5, of middle to late Campanian age. However, the specimen of cf. MPH-1 may have been misidentified or may be reworked, and CP3E-1 might be observed to range up into the early Maastrichtian if strata of that age are found preserved in certain parts of the coastal plain. The critical taxon in these samples is a new species, *Momipites* n. sp. 1 (pl. 1, figs. 6, 7, 10–12), known only from the Maastrichtian (R.A. Christopher, written commun., 1996). However, the species might possibly be determined to range down into the uppermost Campanian if strata of that age are locally found to be preserved. Furthermore, the pollen assemblage in sample R4664 DA includes a specimen of *Interporopollenites turgidus* Tschudy (pl. 2, fig. 2), which apparently has previously been known only from the lower Paleocene (Tschudy, 1975). This specimen may represent contamination from drilling mud, but it appears more likely that this occurrence demonstrates that the species actually ranges, in the form of rare specimens, down into the Upper Cretaceous. If this is so, then the presence of *Interporopollenites turgidus* Tschudy would also suggest that the samples are Maastrichtian. In summary, because reworking and misidentification are more likely than contamination from uphole, samples R4664 CD, DA, and FE are most likely Maastrichtian in age.

Sample R4664 CD, from a depth of 830.3–830.5 ft in the Steel Creek Formation, contains a rather sparse dinoflagellate assemblage. The presence of *Spongodinium delitiense* (Ehrenberg) Deflandre, which has its lowest occurrence in the upper part of the Mount Laurel Formation in New Jersey (May, 1980), indicates that the sample is late Campanian or Maastrichtian.

Sample R4664 FE, from 824.1–824.4 ft, does not contain dinoflagellates; sample R4664 DA, from 829.5–829.8 ft, was not examined for these fossils.

In summary, the Campanian-Maastrichtian boundary in the Millhaven core appears to be between 849.3–849.6 and 830.3–830.5 ft, apparently coinciding with the boundary between the Black Creek Group and the Steel Creek Formation at 839.0 ft. This is because the last occurrence of *Palaeohystrichophora infusorioides* Deflandre is at 849.3–849.6 ft and the species is not known to range higher than the Campanian (as the Campanian-Maastrichtian boundary is defined in Burnett, 1996), and the first appearance of

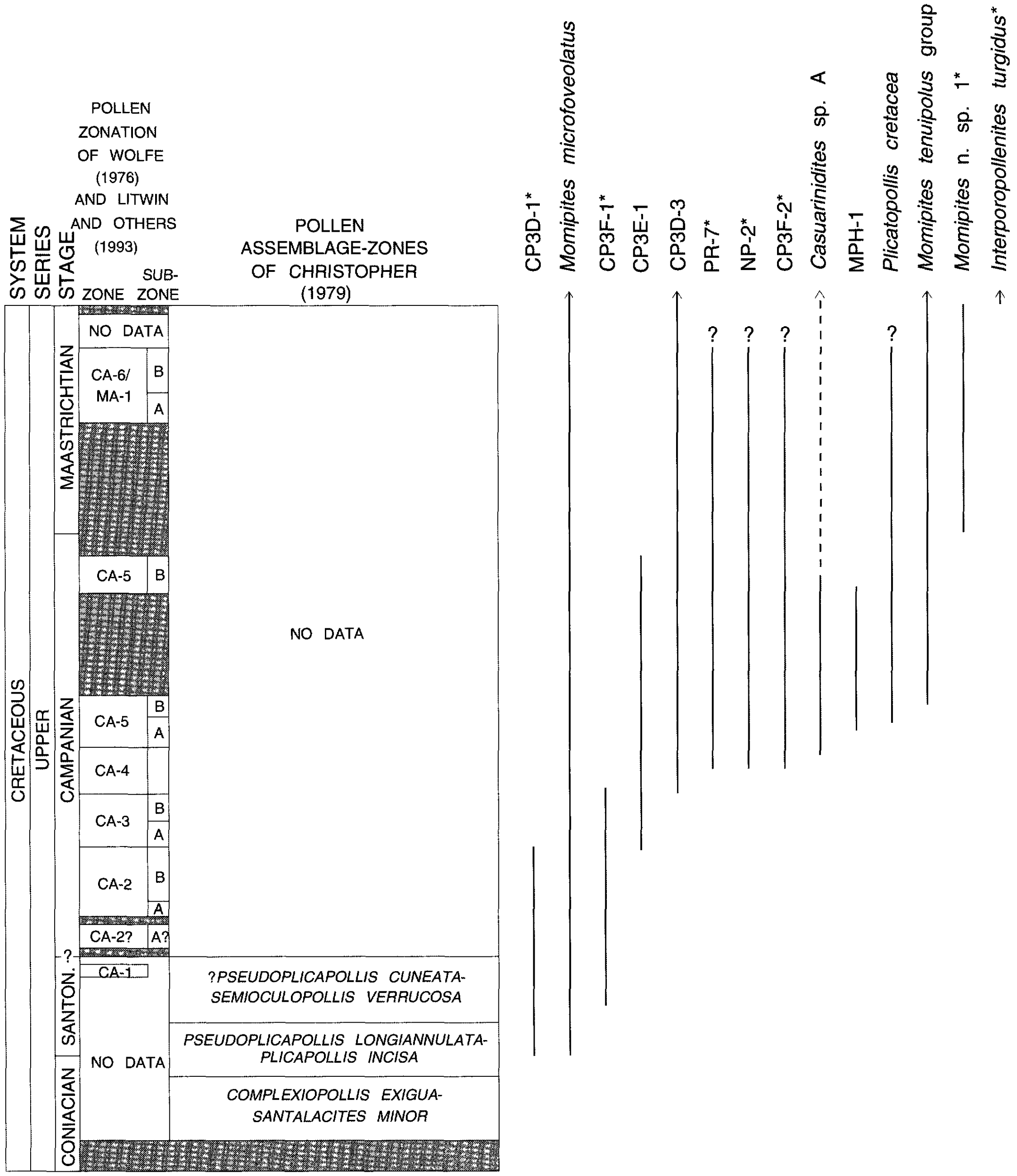

Figure 8. Chart showing known stratigraphic ranges of pollen taxa in three samples (R4664 CD, DA, and FE) from the Steel Creek Formation between 830.5 and 824.1 ft in the Millhaven core, Screven County, Ga. The identification of taxa followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, these taxa are of greater significance than the others. The identification of CP3E-1 of Wolfe (1976) and MPH-1 of Wolfe (1976) was only probable; the range lines show the known stratigraphic ranges of the species themselves. Full names of taxa are in figure 3 and table 4.

Maastrichtian pollen species *Momipites* n. sp. 1 is at 830.3–830.5 ft.

Sample R4664 GA, from a depth of 769.0 to 769.3 ft, contains pollen species CP3F-1 of Wolfe (1976), not thought to range higher than the mid-Campanian, as well as *Casuarinidites* sp. A of Frederiksen and Christopher (1978) and *Lanagiopollis cribellatus* (Srivastava) Frederiksen, which probably range from about the mid-Campanian to near the top or above the top of the Cretaceous (fig. 9). Underlying samples from the Steel Creek Formation are very probably Maastrichtian; therefore, the specimen of CP3F-1 of Wolfe (1976) is presumably reworked. One specimen was found in sample R4664 GA that resembles Triporate type 4 of Christopher (1979), which is known only from one sample from the middle of the Magothy Formation near the Coniacian-Santonian boundary of New Jersey. Either the specimen in the Millhaven core represents a different species, or the species (species group?) actually ranges from the Santonian up to the Maastrichtian, or else the specimen is reworked from older strata. Sample R4664 GA lacks dinoflagellates.

Sample R4664 FG, from a depth of 755.0 to 755.3 ft, does not contain any known Cretaceous pollen grains. Instead, it has the lower Tertiary taxa *Sparganiaceaepollenites* sp., *Plicatopollis triradiatus* (Nichols) Frederiksen & Christopher, and *Momipites-Plicatopollis-Platycaryapollenites* complex of Frederiksen (1979). These specimens no doubt represent contamination of the sample by drilling mud. This sample also contains sparse dinoflagellates (fig. 4) that may be either indigenous (Late Cretaceous), indicating at least a marginally marine environment of deposition, or may be Tertiary specimens representing contamination from uphole.

Sample R4664 CF, from a depth of 733.2 to 733.3 ft, apparently is late Campanian or early Maastrichtian in age according to the ranges of its pollen taxa (fig. 10). Because of the apparent Maastrichtian age of samples lower in the section (fig. 8), this is also probably Maastrichtian. This sample lacked dinoflagellates.

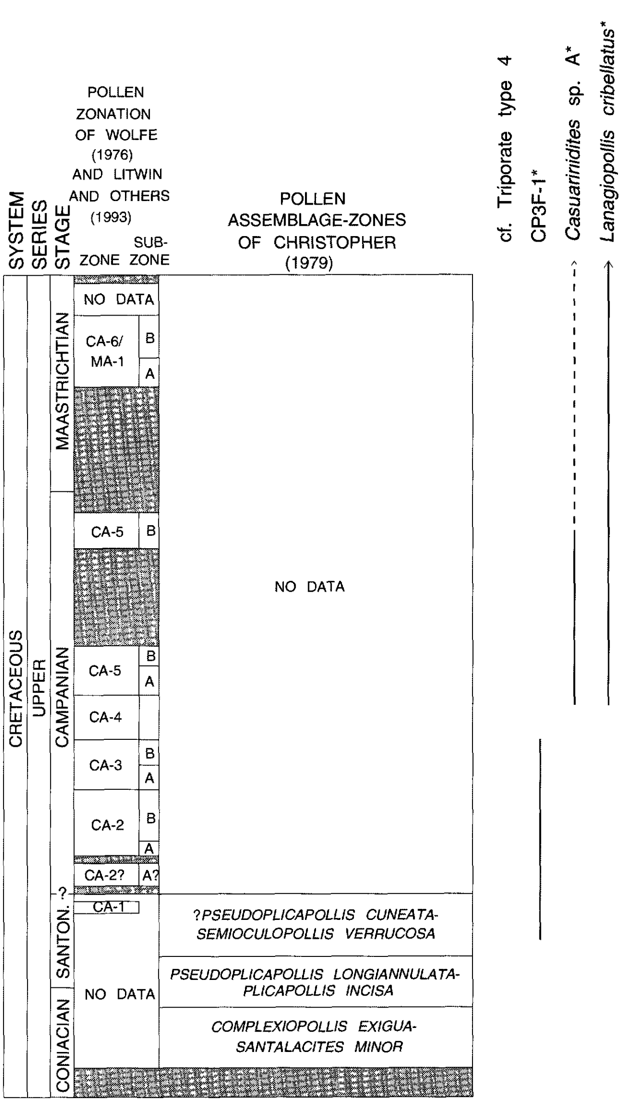

Figure 9. Chart showing known stratigraphic ranges of pollen taxa in sample R4664 GA, Steel Creek Formation, from 769.0–769.3 ft in the Millhaven core, Screven County, Ga. The identification of taxa followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, these taxa are of greater significance than the others. Full names of taxa are in figure 3 and table 4. A range line for C3C-1 of Wolfe (1976) is not shown because the specimen found is only similar to but probably not the same species as C3C-1.

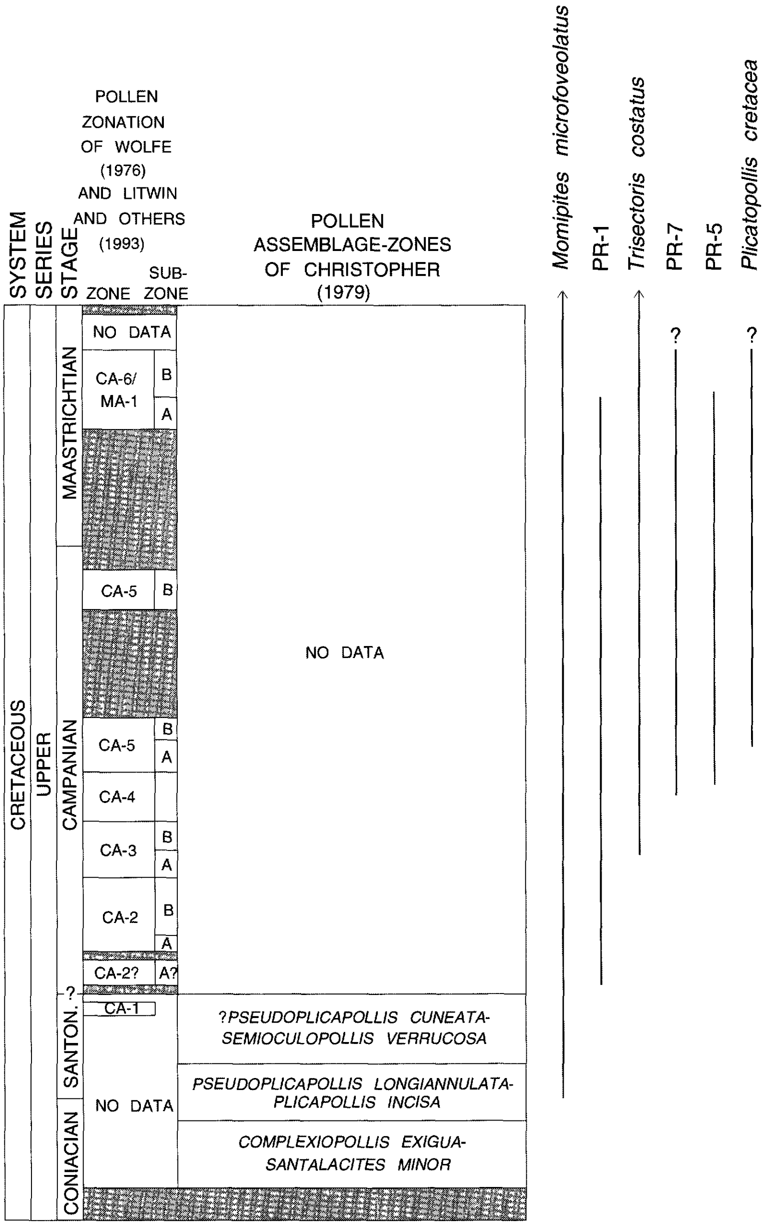

Figure 10. Chart showing known stratigraphic ranges of pollen taxa in sample R4664 CF, Steel Creek Formation, from 733.2–733.3 ft in the Millhaven core, Screven County, Ga. Full names of taxa are in figure 3 and table 4.

GIRARD TEST HOLE

The U.S. Geological Survey drilled the Girard test hole (32Y020) in southern Burke County at the lookout tower on Griffins Landing Road, 2 miles north of the town of Girard, at lat 33°03'54" N., long 81°43'13" W., Girard 7.5-min quadrangle (fig. 1). The surface elevation is 250 ft above sea level. Nineteen Upper Cretaceous samples from this core were examined for palynomorphs (table 1). Three of these were scanned in detail for pollen (fig. 11), and four samples were scanned in detail for dinoflagellates (fig. 12).

CAPE FEAR FORMATION

No palynological samples were studied from the Cape Fear Formation in the Girard core.

MIDDENDORF FORMATION

SUBUNIT 1

Sample R4705 AA, from a depth of 1,138.0 to 1,139.0 ft in the Girard core, is from subunit 1 of the Middendorf Formation. The sample had only four angiosperm pollen taxa of known stratigraphic range, and the ranges of these are spread throughout the Upper Cretaceous (fig. 13). Therefore, the data are ambiguous. This sample did not contain dinoflagellates, and neither did another sample from subunit 1; the second sample was barren of all palynomorphs.

SUBUNIT 2

Sample R4705 BA, from a depth of 1,012.0 to 1,012.3 ft in the Girard core, is from subunit 2 of the Middendorf Formation. The sample is similar to sample R4705 AA in containing pollen taxa apparently having disparate stratigraphic ranges (fig. 14). According to R.A. Christopher (written commun., 1996), the pollen flora of the sample from 1,012.0–1,012.3 ft suggests a latest Santonian(?) or earliest Campanian age on the basis of a pollen correlation with the upper part of the Shepherd Grove Formation of the USGS Clubhouse Crossroads core in Dorchester County, S.C. The sample does not appear to correlate with the middle Santonian Middendorf Formation of the Clubhouse Crossroads core (see Gohn, 1992).

Six samples from the Middendorf Formation (subunit 2) were examined for dinoflagellates (fig. 12), but none contained these fossils; therefore, these samples are assumed to be nonmarine.

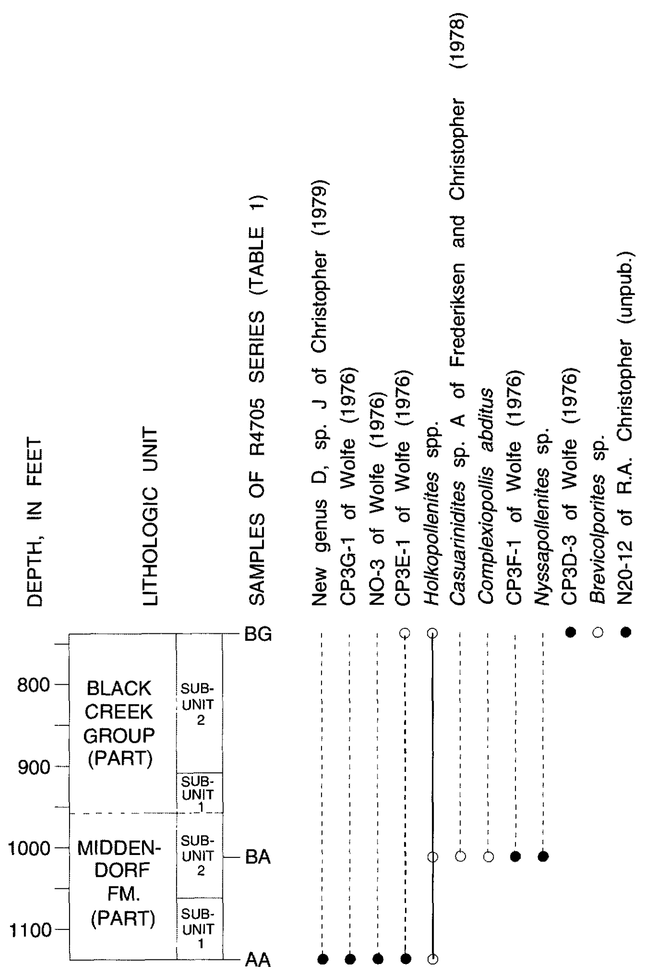

Figure 11. Chart showing pollen taxa occurrences in three samples between 1,139.0 and 738.3 ft in the Girard core, Burke County, Ga. Solid circles indicate that the identification of the specimens was checked by R.A. Christopher from photomicrographs provided by the senior author; hollow circles indicate that the identification of the specimens was not so checked. Depths are in feet below land surface. FM., Formation.

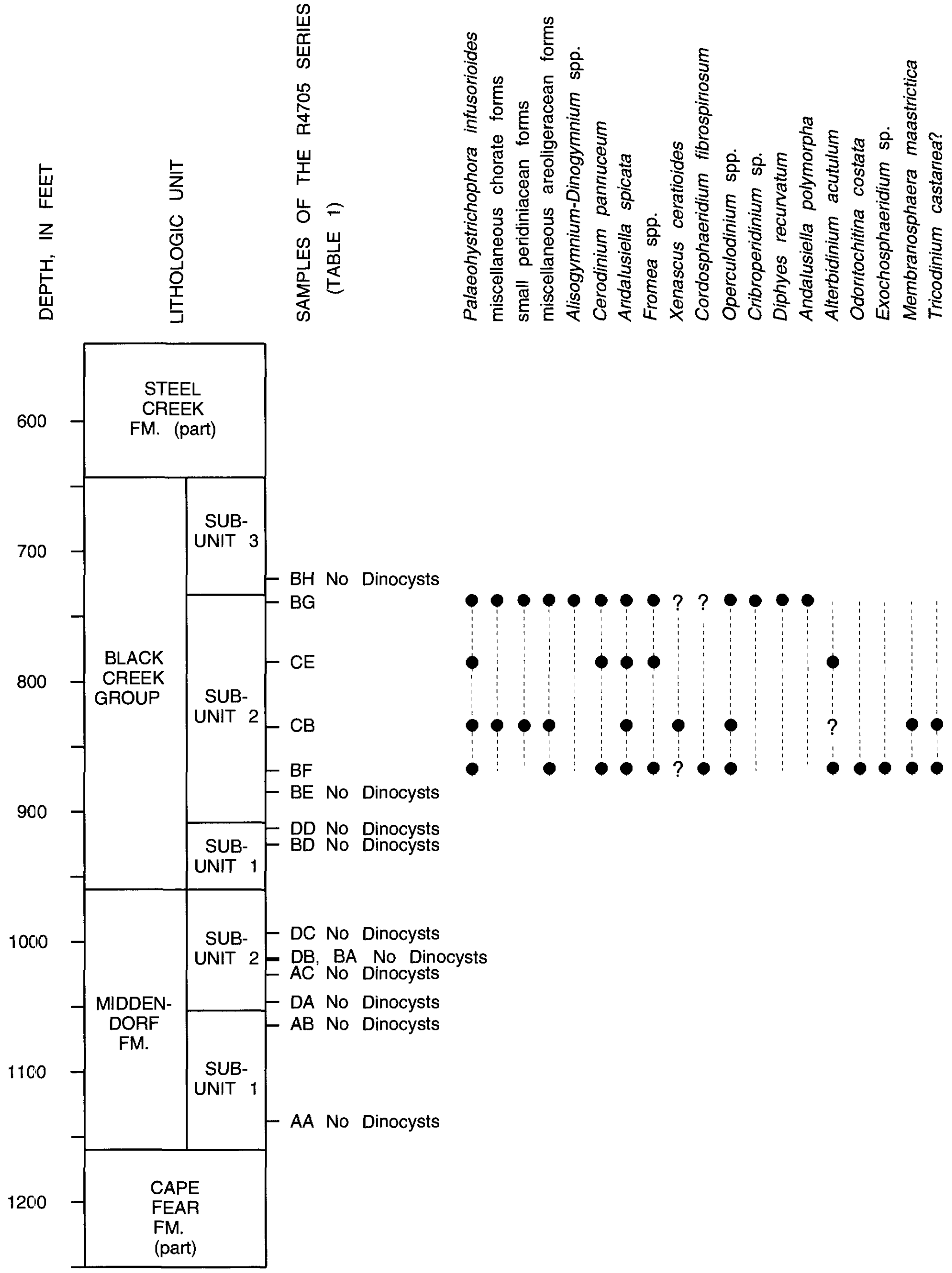

Figure 12. Chart showing dinoflagellate taxa occurrences in 15 samples between 1,139.0 and 720.3 ft in the Girard core, Burke County, Ga. Depths are in feet below land surface. FM., Formation. Four samples were scanned in detail for dinoflagellates. Question marks within range lines indicate uncertainty of identification.

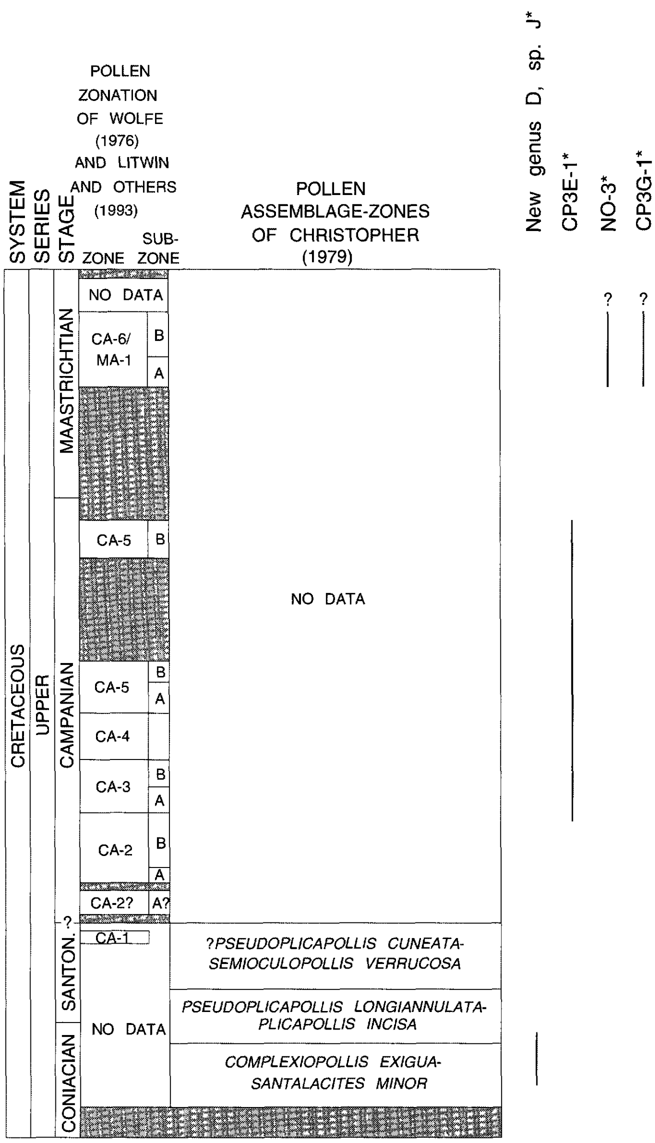

Figure 13. Chart showing known stratigraphic ranges of pollen taxa in sample R4705 AA, subunit 1 of the Middendorf Formation, from 1,138.0–1,139.0 ft in the Girard core, Burke County, Ga. Taxa followed by an asterisk indicate that identification of the specimens was checked by R.A. Christopher from photomicrographs provided by the senior author. Full names of taxa are in figure 11 and table 4. Question marks indicate that the youngest age of the taxon is uncertain.

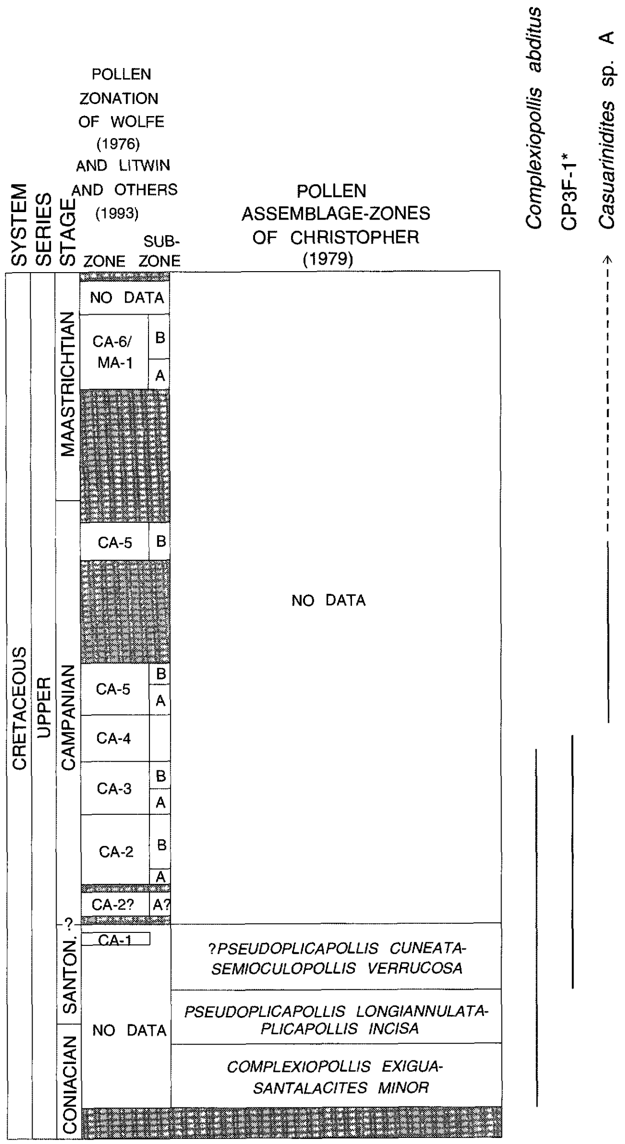

Figure 14. Chart showing known stratigraphic ranges of pollen taxa in sample R4705 BA, subunit 2 of the Middendorf Formation, from 1,012.0–1,012.3 ft in the Girard core, Burke County, Ga. The identification of the taxon followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, this taxon is of greater significance than the others. Full names of taxa are in figure 11 and table 4.

BLACK CREEK GROUP

The lowest marine palynomorphs in the Black Creek Group in the Girard core were found at 868.5–868.7 ft, in subunit 2, and the presence and absence pattern of dinoflagellate occurrences (fig. 12) suggests nonmarine conditions in subunit 1 of the Black Creek Group, then marine conditions in subunit 2, then nonmarine deposition in subunit 3 of the Black Creek. The dinoflagellate-bearing assemblages in the Girard core are not as rich but contain many of the same taxa and are the same age as samples from subunit 2 and the lower part of subunit 3 of the Black Creek Group in the Millhaven core. The taxa found in Black Creek samples from both cores are *Palaeohystrichophora infusorioides* Deflandre, *Xenascus ceratioides* (Deflandre) Lentin & Williams, *Cordosphaeridium fibrospinosum* Davey & Williams, and *Andalusiella spicata* (May) Lentin & Williams. In the Millhaven core, these assemblages came from strata assignable in part to late Campanian calcareous nannofossil Zone CC 22 (Bukry, this volume, chap. D), and the dinoflagellate assemblages were correlated with those from the upper Campanian Mount Laurel Formation of New Jersey.

Most pollen assemblages from the Black Creek of the Girard core are sparse and not age diagnostic. However, sample R4705 BG, from 738.3 to 738.6 ft (subunit 2 of the Black Creek Group), had two useful pollen taxa (fig. 15), and the overlap of the ranges of these taxa suggests a middle to late Campanian age somewhere within Zone CA-4 or Zone CA-5. As noted above, dinoflagellates from this sample suggest a late Campanian age correlative with the upper part of pollen Zone CA-5.

STEEL CREEK FORMATION

No palynological samples were studied from the Steel Creek Formation in the Girard core.

THOMPSON OAK TEST HOLE

The Thompson Oak test hole was drilled by the Georgia Geologic Survey at lat 33°10'42" N., long 81°47'10" W., Shell Bluff Landing 7.5-min quadrangle, Burke County, Ga. (fig. 1). The surface elevation is 240 ft above sea level. Two samples were examined from this core.

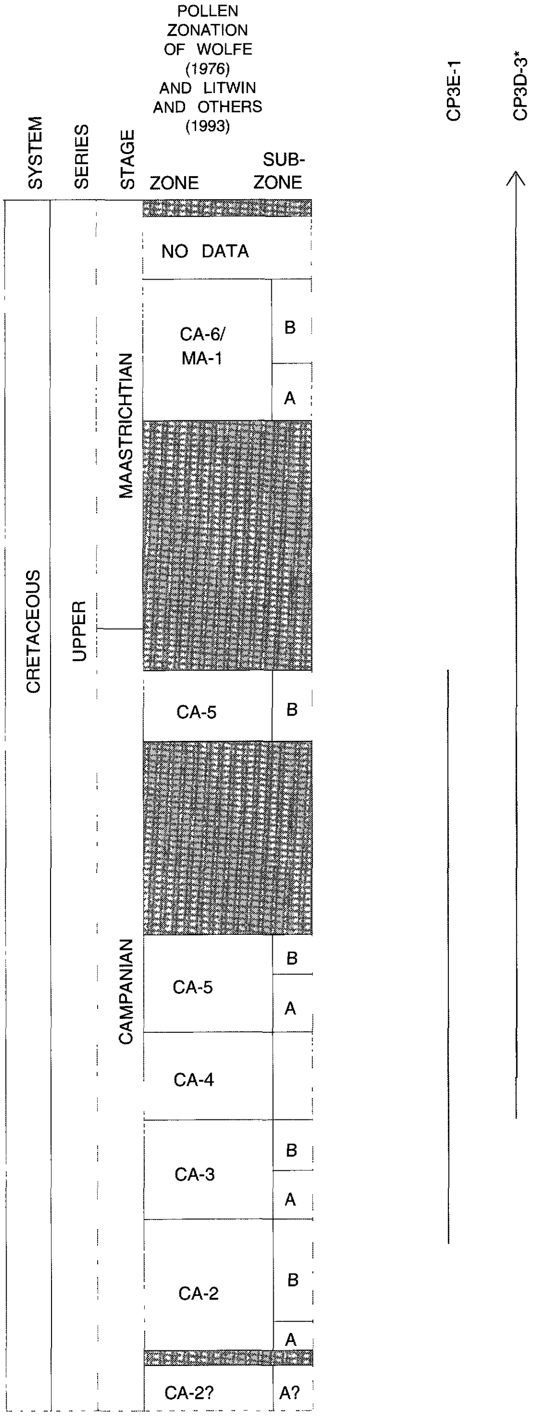

Figure 15. Chart showing known stratigraphic ranges of pollen taxa in sample R4705 BG, subunit 2 of the Black Creek Group, from 738.3–738.6 ft in the Girard core, Burke County, Ga. Not shown is species N20-12 of R.A. Christopher (unpub.), which has a very long stratigraphic range from Zone V (fig. 2) to the Maastrichtian (R.A. Christopher, written commun., 1996). The identification of the taxon followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, this taxon is of greater significance than the other. Full names of taxa are in figure 11 and table 4.

BLACK CREEK GROUP

Two samples from the Black Creek Group in the Thompson Oak core were examined for dinoflagellates. The lower sample (R4836 A, 561.0 ft depth) is from a kaolinitic, lignitic, micaceous sand. It contains only three dinoflagellate specimens that do not appear to be marine. The upper sample (R4836 B, 505.0 ft depth) is from a sandy, micaceous, lignitic kaolin and contains a sparse assemblage similar to that of samples R4664 BB to CB (from subunit 2 and the lowermost part of subunit 3 of the Black Creek Group) in the Millhaven core, that is, *Palaeohystrichophora infusorioides* Deflandre(?), *Xenascus ceratioides* (Deflandre) Lentin & Williams, and *Andalusiella spicata* (May) Lentin & Williams (fig. 16). These dinoflagellate taxa indicate a nearshore marine to normal marine environment of deposition and a late Campanian age.

MILLERS POND TEST HOLE

The Millers Pond test hole was drilled by the Georgia Geologic Survey (Burke 2, GGS-3758) near Shell Bluff Landing on the Savannah River, lat 33°13'48" N., long 81°52'44" W., McBean 7.5-min quadrangle, Burke County, Ga. (fig. 1). The surface elevation is 245 ft above sea level. Clarke and others (1994) provided a lithologic description of the cored section.

Fifteen samples were collected from Cretaceous strata in this core (table 1) from the depth interval of 852.0 to 282.0 ft. Only four contained useful pollen assemblages (fig. 17), and none of the samples contained marine palynomorphs.

CAPE FEAR FORMATION

Christopher and others (1979) examined samples from the Cape Fear Formation of North Carolina and concluded, on the basis of the pollen flora, that the Cape Fear Formation could be assigned to undifferentiated pollen Zone V, which is approximately equivalent to the combined *Complexiopollis exigua-Santalacites minor*, *Pseudoplicapollis longiannulata-Plicapollis incisa*, and ?*Pseudoplicapollis cuneata-Semioculopollis verrucosa* Zones of Coniacian to earliest Campanian age (fig. 2).

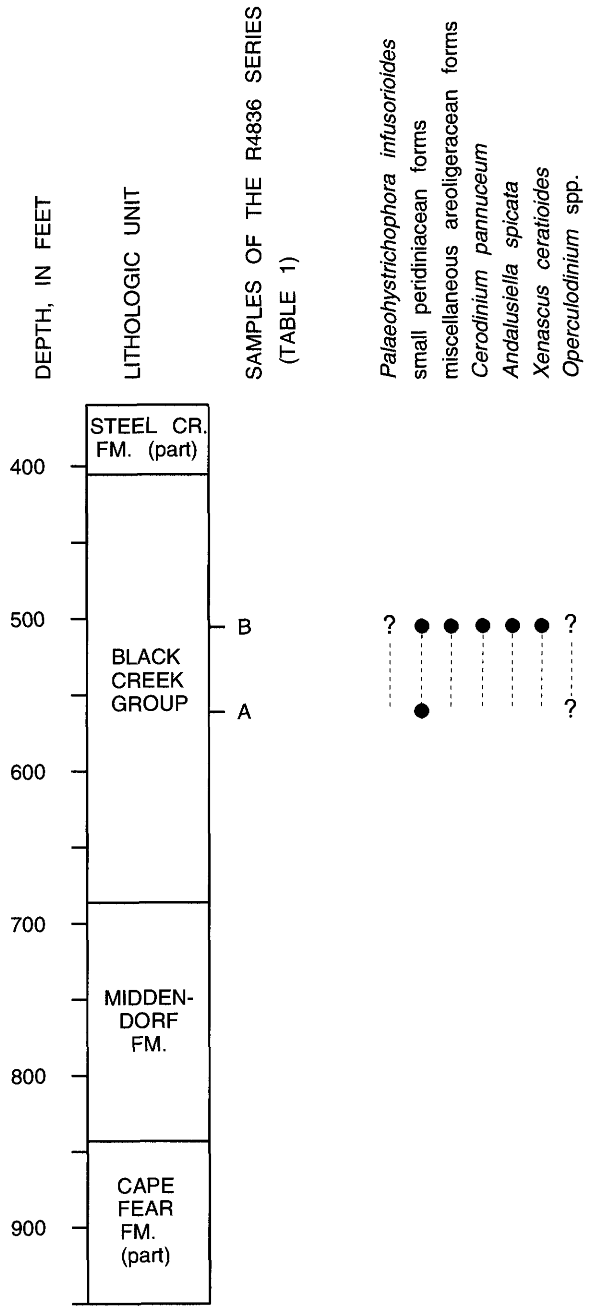

Figure 16. Chart showing dinoflagellate taxa occurrences in two samples from 561.0 and 505.0 ft, respectively (Black Creek Group), in the Thompson Oak core, Burke County, Ga. Depths are in feet below land surface. FM., Formation. Full names of taxa are in table 5.

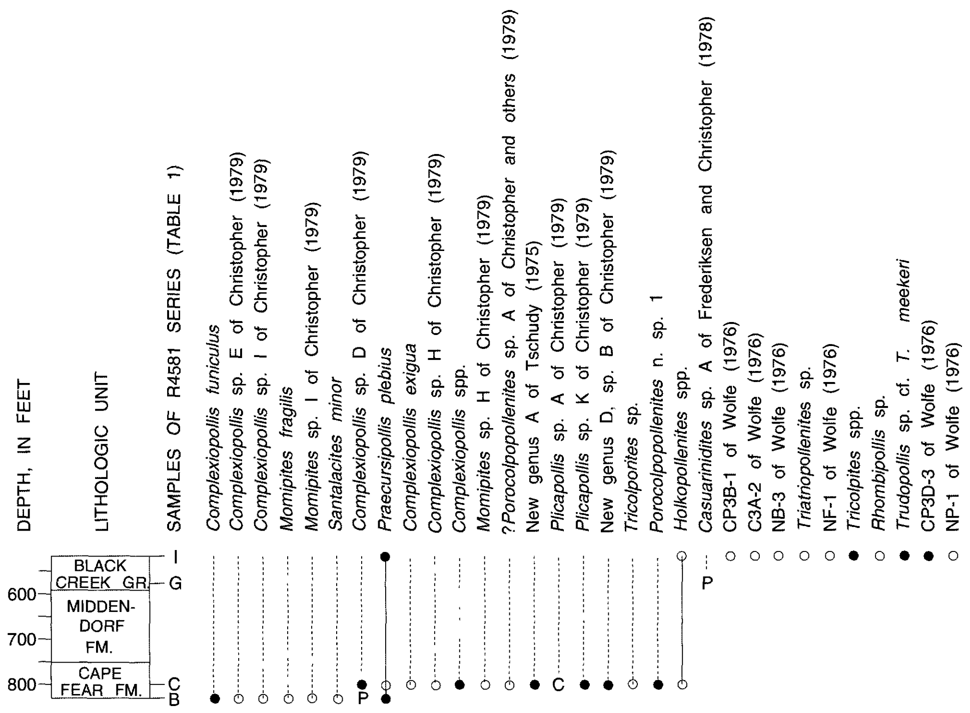

Figure 17. Chart showing pollen taxa occurrences in four samples between 832.0 and 517.0 ft in the Millers Pond core, Burke County, Ga. Solid circles indicate that the identification of the specimens was checked by R.A. Christopher from photomicrographs provided by the senior author; hollow circles indicate that the identification of the specimens was not so checked; C = cf., meaning that the specimens are similar to and may well belong to the taxon listed; P indicates that the specimens probably belong to the taxon listed. Depths are in feet below land surface. GR., Group; FM., Formation.

Sample R4581 B, from a depth of 827.0 to 832.0 ft in the Millers Pond core, contains pollen taxa whose ranges suggest assignment to the combined *Complexiopollis exigua-Santalacites minor*, *Pseudoplicapollis longiannulata-Plicapollis incisa*, and ?*Pseudoplicapollis cuneata-Semioculopollis verrucosa* Zones (figs. 2, 18; the range of *Momipites* sp. I of Christopher (1979) is difficult to evaluate because the identification of this species has not been verified). However, sample R4581 C, from a depth of 797.0 to 802.0 ft, can be narrowed to the *Complexiopollis exigua-Santalacites minor* and *Pseudoplicapollis longiannulata-Plicapollis incisa* Zones (fig. 19) and most likely belongs to the *Complexiopollis exigua-Santalacites minor* Zone of Coniacian age. Therefore, the underlying sample R4581 B would also belong to this zone. The occurrence of New Genus A of Tschudy (1975) is interesting, as it was previously known only from a single sample of the Eutaw Formation in western Georgia (Tschudy, 1975), which was also the case with *Praecursipollis plebius* Tschudy (discussed under sample R4664 CA, Black Creek Group of the Millhaven core). Clarke and others (1994, 1996) and Leeth and others (1996) considered the Eutaw Formation of the eastern Gulf Coast to be correlative with the Middendorf Formation, not with the Cape Fear Formation, of the Southern Atlantic Coastal Plain. As an alternative interpretation, Prowell, Christopher, and others (1985) correlated the Cape Fear Formation with the lower half of the Eutaw Formation, and the Middendorf Formation with the upper half of the Eutaw Formation.

The lack of both marine palynomorphs (dinoflagellates, acritarchs) and microforaminiferal linings in samples R4581 B and R4581 C suggests a nonmarine environment of deposition for the Cape Fear Formation.

Two additional samples from the Cape Fear Formation, from depths of 847.0–852.0 and 778.0 ft, were barren of palynomorphs.

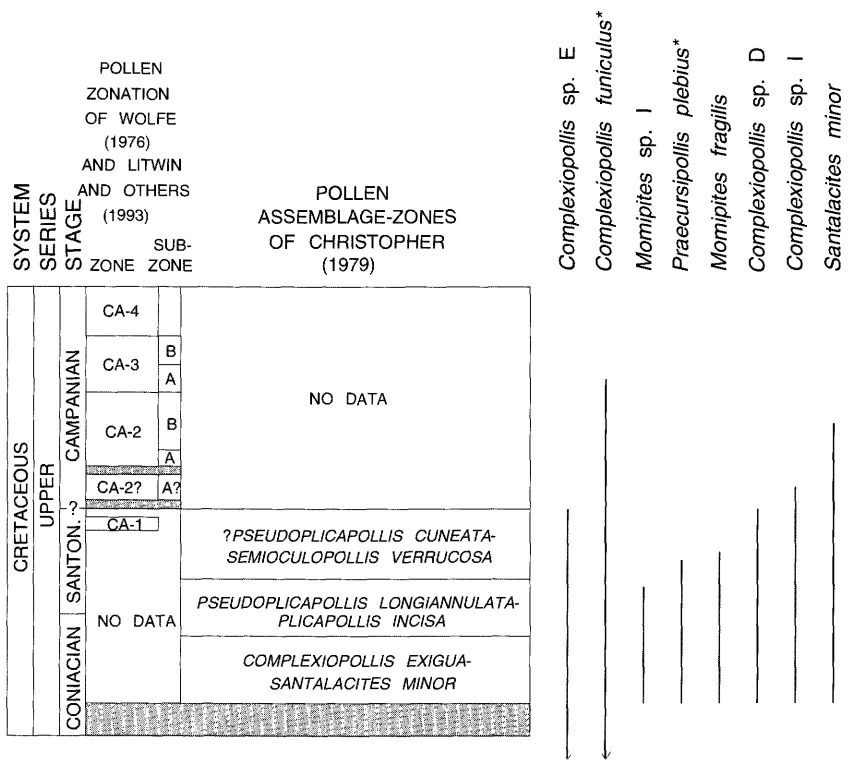

Figure 18. Chart showing known stratigraphic ranges of pollen taxa in sample R4581 B, Cape Fear Formation, from 827.0–832.0 ft in the Millers Pond core, Burke County, Ga. The identification of taxa followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, these taxa are of greater significance than the others. Full names of taxa are in figure 17 and table 4.

MIDDENDORF FORMATION

No productive palynological samples were studied from the Middendorf Formation in the Millers Pond core.

BLACK CREEK GROUP

Sample R4581 G, from 578.0 ft, contained only rare angiosperm pollen grains; the only useful pollen species (whose identification is probably correct) was *Casuarinidites* sp. A of Frederiksen and Christopher (1978). In the Middle Atlantic States, this species has a known range base in the mid-Campanian (see fig. 14). However, sample R4705 BA, from the Middendorf Formation of the Girard core, also contains this species (fig. 14). This Girard sample is thought to be uppermost Santonian or lowermost Campanian, suggesting that *Casuarinidites* sp. A of Frederiksen and Christopher (1978) has its range base near the base of the Campanian. In summary, Millers Pond sample R4581 G may be latest Santonian or earliest Campanian like the Girard sample, or it may be younger.

Sample R4581 I, from 517.0 ft, contains taxa having a great variety of known stratigraphic ranges (fig. 20). *Praecursipollis plebius* Tschudy is probably reworked. If NF-1 and CP3B-1 are reworked or misidentified, the other taxa would suggest a middle to late Campanian age within Zones CA-4 or CA-5. The absence of marine dinoflagellates and microforaminiferal linings in this sample (as in all Cretaceous samples from the Millers Pond core) indicates a nonmarine environment of deposition.

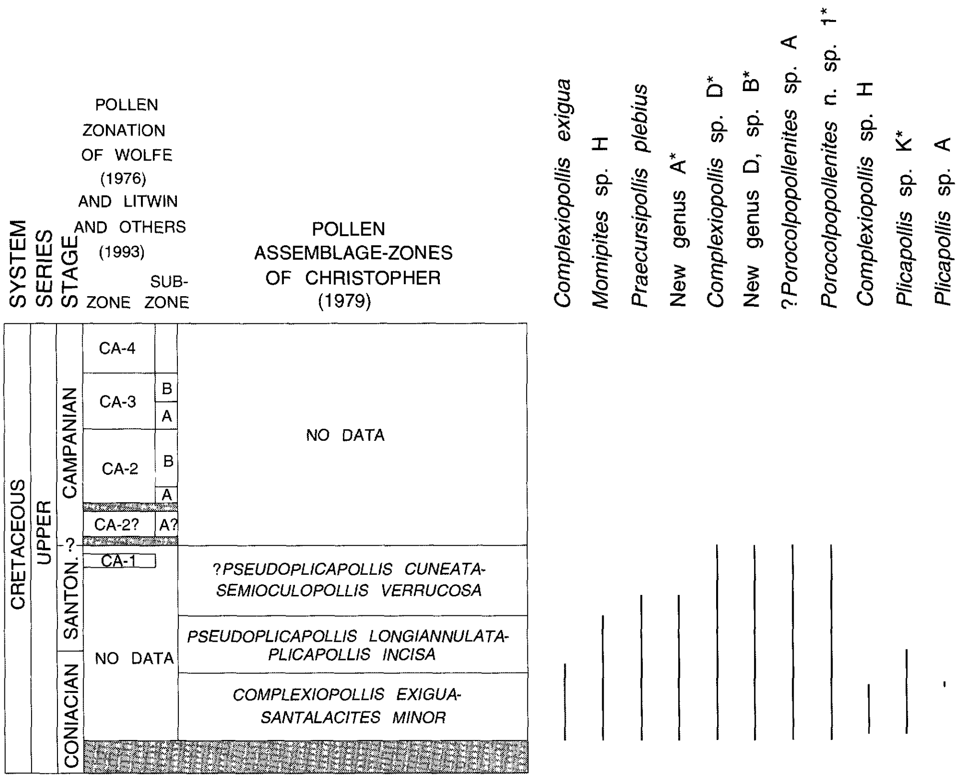

Figure 19. Chart showing known stratigraphic ranges of pollen taxa in sample R4581 C, Cape Fear Formation, from 797.0–802.0 ft in the Millers Pond core, Burke County, Ga. The known range shown for *Porocolpopollenites* n. sp. 1 is from Christopher (written commun., 1996). The identification of taxa followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, these taxa are of greater significance than the others. Full names of taxa are in figure 17 and table 4.

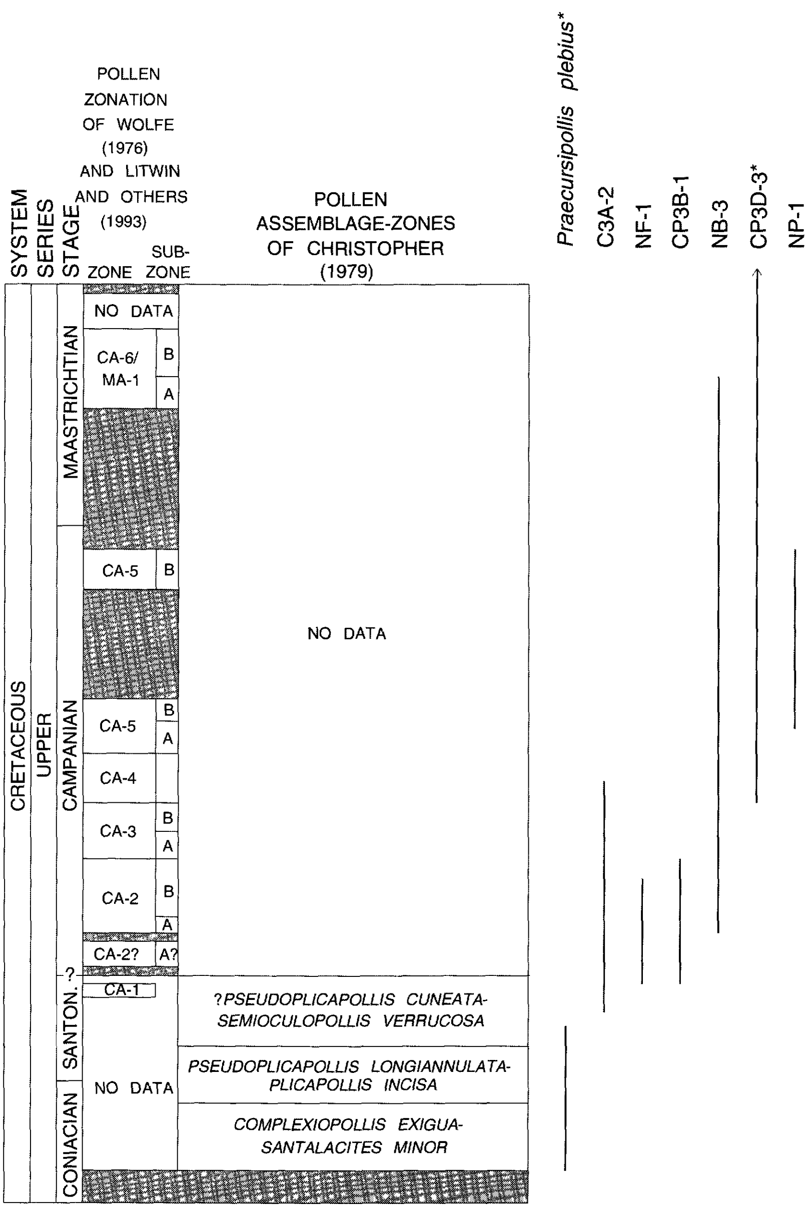

Figure 20. Chart showing known stratigraphic ranges of pollen taxa in sample R4581 I, Black Creek Group, from 517.0 ft in the Millers Pond core, Burke County, Ga. The identification of taxa followed by an asterisk was checked by R.A. Christopher from photomicrographs provided by the senior author; therefore, these taxa are of greater significance than the others. Full names of taxa are in figure 17 and table 4. *Trudopollis* sp. cf. *T. meekeri* is not shown because the stratigraphic range of the species in the eastern United States is unknown.

SUMMARY

Fifty-two Upper Cretaceous samples were examined for palynomorphs from four cores (Millhaven, Girard, Thompson Oak, and Millers Pond) in Screven and Burke Counties, Ga. (table 1). Seventeen of the samples from the Millhaven, Girard, and Millers Pond cores contained biostratigraphically useful angiosperm pollen assemblages.

Two pollen-bearing samples from the Cape Fear Formation were analyzed, both of them from the Millers Pond core. They are Coniacian or early Santonian, most probably Coniacian, in age.

The age of strata mapped as Middendorf Formation varies from place to place in the Carolinas (Christopher and others, 1997). For example, Gohn (1988, 1992), Clarke and others (1994, 1996), and Leeth and others (1996) showed this formation as being confined to the Santonian, whereas Lucas-Clark (1992, p. 81) considered the Middendorf to be "probably Santonian to Campanian in age." Christopher and others (1997) stated that at least some strata assigned to the Middendorf in the area of the Savannah River Site are the same age as the lowermost part of the Black Creek Group (which, according to the present paper, is probably at least in part mid-Campanian).

Three samples that contained angiosperm pollen were obtained from the Middendorf Formation in the present study. A sample from the Millhaven core (subunit 2) appears to be from Zone V of Coniacian and Santonian age. Two samples from the Girard core, from subunits 1 and 2, each contain a seemingly heterogeneous set of taxa whose known occurrences are Coniacian to Santonian, Campanian, or Maastrichtian. The peculiar nature of these two assemblages seems due to some combination of reworking, drilling mud contamination from uphole, species misidentification, and different species ranges in Georgia than in the Middle Atlantic States. However, at least the pollen flora of the sample from subunit 2 suggests a latest Santonian(?) or earliest Campanian age.

One sample from subunit 2 of the Middendorf Formation in the Millhaven core contained marginal marine or very nearshore marine dinoflagellates. Yet, five samples examined from the Middendorf of the Girard core contained pollen but lacked dinoflagellates and thus are probably nonmarine.

Seven pollen-bearing samples were examined in detail from the Black Creek Group, from the Millhaven, Girard, and Millers Pond cores. One sample from near the base of the Black Creek (subunit 1) in the Millhaven core has a pollen assemblage probably assignable to mid-Campanian Zone CA-4 and has marginal marine or very nearshore dinoflagellates. Above this sample in the Millhaven core is a thick sequence of marine Black Creek sediments that contains late Campanian calcareous nannofossils of Zone CC 22 in subunit 2 (Bukry, this volume, chap. D) and abundant late Campanian marine dinoflagellates. Two pollen assemblages from subunit 2 and one from subunit 3 indicate poorly defined mid-Campanian to Maastrichtian ages. The lowest part of subunit 3 of the Black Creek Group in the Millhaven core has the same diverse late Campanian dinoflagellate assemblage as in subunit 2 of the core. However, the uppermost part of subunit 3 has a less diverse dinoflagellate assemblage, which indicates minor marine influence.

One sample from the Black Creek of the Girard core and two samples from the Black Creek of the Millers Pond core contained pollen grains. The Girard assemblage suggests a middle to late Campanian age; one Millers Pond assemblage gave only a poorly defined age, but the other assemblage seems to be mid-Campanian in age. In the Girard core, dinoflagellate presence and absence data indicate nonmarine conditions for subunit 1 and the lowermost part of subunit 2. The data indicate marine conditions for the remainder of subunit 2 and nonmarine conditions during deposition of subunit 3 of the Black Creek Group. The dinoflagellate taxa in subunit 2 indicate a late Campanian age.

Two samples of the Black Creek Group from the Thompson Oak core were examined for dinoflagellates. One sample contained sparse marine dinoflagellates indicating a late Campanian age, and the other lacked dinoflagellates.

Five pollen-bearing samples were analyzed from the Steel Creek Formation, all from the Millhaven core. All of these assemblages appear to be Maastrichtian in age. Two samples from the Steel Creek have dinoflagellates which, if indigenous and not representing contamination from uphole, indicate at least a marginally marine paleoenvironment. The Campanian-Maastrichtian boundary in the Millhaven core can be shown apparently to coincide with the contact between the Black Creek Group and the Steel Creek Formation by using a combination of pollen and dinoflagellate occurrence data.

All Cretaceous samples from the Millers Pond core lacked dinoflagellates.

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PLATES 1–7

PLATE 1

[All specimens are from Screven and Burke Counties, Georgia]

Figure 1. *Rugubivesiculites* sp., Middendorf Formation, subunit 1, Girard core (1,138.0–1,139.0 ft), Burke County.

2. *Triatriopollenites* sp., Steel Creek Formation, Millhaven core (829.5–829.8 ft), Screven County.

3. *Momipites microfoveolatus* (Stanley) Nichols, Steel Creek Formation, Millhaven core (824.1–824.4 ft), Screven County.

4. *Triatriopollenites* sp., Black Creek Group, Millers Pond core (517.0 ft), Burke County.

5. *Momipites tenuipolus* group of Frederiksen and Christopher (1978), Steel Creek Formation, Millhaven core (824.1–824.4 ft), Screven County. This species group is characterized by having a ring of thin exine about one pole. In the present specimen, the ring is triangular in shape, and only two sides of the ring are distinct.

6, 7. *Momipites* n. sp. 1, Steel Creek Formation, Millhaven core (829.5–829.8 ft), Screven County.

8. Aff. NP-2 of Wolfe (1976), Steel Creek Formation, Millhaven core (830.3–830.5 ft), Screven County. In this specimen, the exine is slightly thicker than in NP-2 but thinner than in NP-1.

9. NP-2 of Wolfe (1976), Steel Creek Formation, Millhaven core (829.5–829.8 ft), Screven County.

10–12. *Momipites* n. sp. 1, Steel Creek Formation, Millhaven core (824.1–824.4 ft, 829.5–829.8 ft, and 824.1–824.4 ft, respectively), Screven County.

13. N20-12 of R.A. Christopher (unpublished), Black Creek Group, subunit 2, Girard core (738.3–738.6 ft). Burke County. The pores protrude considerably less than in NO-3 of Wolfe (1976) (R.A. Christopher, written commun., 1996).

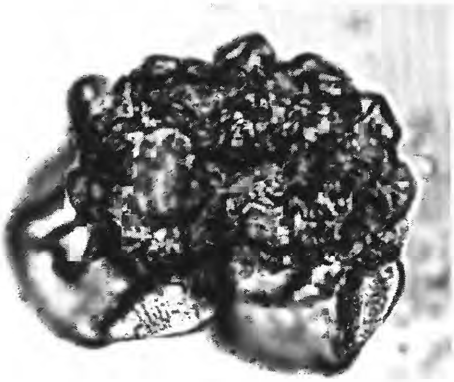
14. *Casuarinidites* sp. A of Frederiksen and Christopher (1978), Black Creek Group, subunit 2, Millhaven core (941.7–941.9 ft), Screven County. Many specimens assigned to this species in the present material have one or two pores offset onto one face of the grain, and in this respect they are very similar to the Tertiary genus *Subtriporopollenites*.

15, 16. PR-7 of Wolfe (1976), Steel Creek Formation, Millhaven core (829.5–829.8 ft), Screven County.

17. *Casuarinidites* sp. A of Frederiksen and Christopher (1978), Steel Creek Formation, Millhaven core (769.0–769.3 ft), Screven County.

18. PR-1 of Wolfe (1976), Black Creek Group, subunit 1, Millhaven core (1,124.3–1,124.7 ft), Screven County.

19–21. Cf. Triporate type 4 of Christopher (1979), Steel Creek Formation, Millhaven core (769.0–769.3 ft), Screven County.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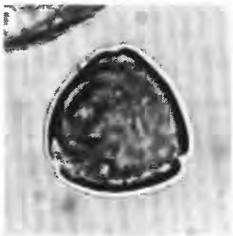
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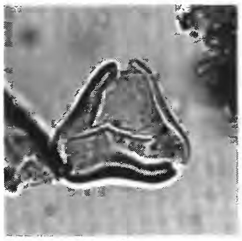
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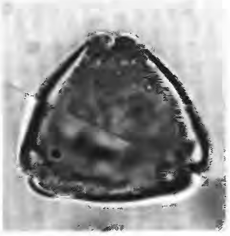
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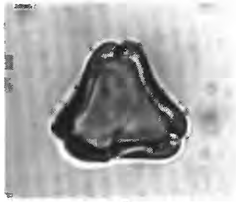
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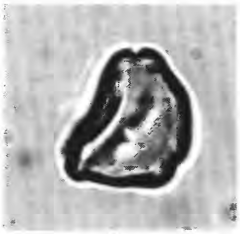
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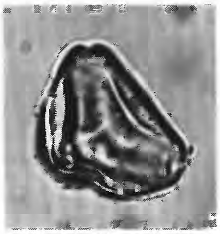
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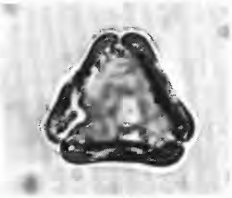
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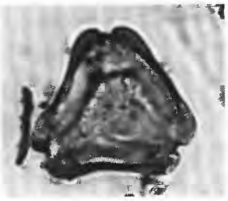
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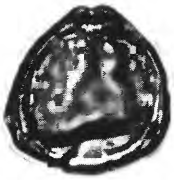
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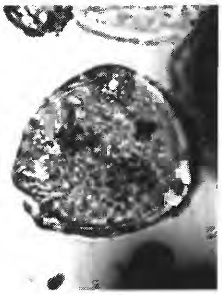
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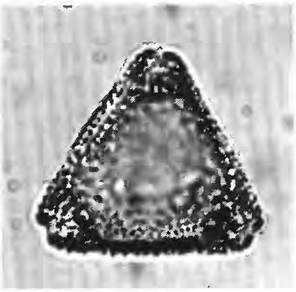
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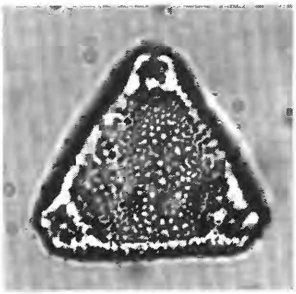
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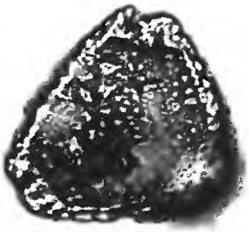
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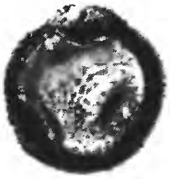
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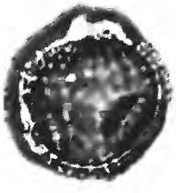
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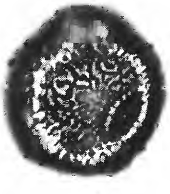
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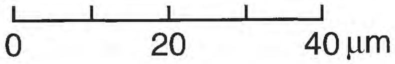


POLLEN

PLATE 2

[All specimens are from Screven and Burke Counties, Georgia]

Figure 1. PR-1 of Wolfe (1976), Black Creek Group, subunit 2, Millhaven core (941.7–941.9 ft), Screven County.

2. *Interporopollenites turgidus* Tschudy, Steel Creek Formation, Millhaven core (829.5–829.8 ft), Screven County.

3, 4. *Trisectoris costatus* Tschudy, Black Creek Group, subunit 2, Millhaven core (941.7–941.9 ft), Screven County.

5. *Tricolpites* sp., Black Creek Group, Millers Pond core (517.0 ft), Burke County.

6, 7. *Tricolpites* sp., Steel Creek Formation, Millhaven core (769.0–769.3 ft), Screven County.

8. Aff. *Plicapollis* sp. A of Christopher (1979), Cape Fear Formation, Millers Pond core (797.0–802.0 ft), Burke County.

9. *Plicapollis* sp. K of Christopher (1979), Cape Fear Formation, Millers Pond core (797.0–802.0 ft), Burke County.

10. *Complexiopollis funiculus* Tschudy, Cape Fear Formation, Millers Pond core (827.0–832.0 ft), Burke County.

11. *Complexiopollis abditus* Tschudy, Middendorf Formation, subunit 2, Girard core (1,012.0–1,012.3 ft), Burke County.

12. *Complexiopollis* sp., Cape Fear Formation, Millers Pond core (797.0–802.0 ft), Burke County.

13. New genus A of Tschudy (1975), Cape Fear Formation, Millers Pond core (797.0–802.0 ft), Burke County.

14. Probably *Praecursipollis plebius* Tschudy, Black Creek Group, subunit 1, Millhaven core (1,124.7–1,124.3 ft), Screven County.

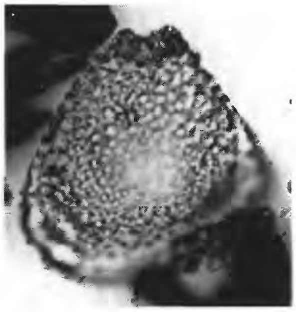
15. *Praecursipollis plebius* Tschudy, Cape Fear Formation, Pond core (827.0–832.0 ft), Burke County. Two sides of the grain have been folded inward.

16. Cf. ND-2 of Wolfe (1976), Black Creek Group, subunit 2, Millhaven core (941.7–941.9 ft), Screven County. Plicae are present but very weak; an interloculum is lacking.

17–19. *Complexiopollis*? sp., Cape Fear Formation, Millers Pond core (827.0–832.0 ft), Burke County.

20. New genus D, sp. H of Christopher (1979), Black Creek Group, subunit 1, Millhaven core (1,124.3–1,124.7 ft), Screven County.

21. New genus D, sp. B of Christopher (1979), Cape Fear Formation, Millers Pond core (797.0–802.0 ft), Burke County.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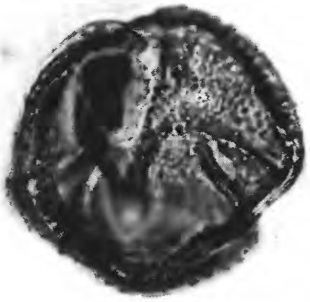
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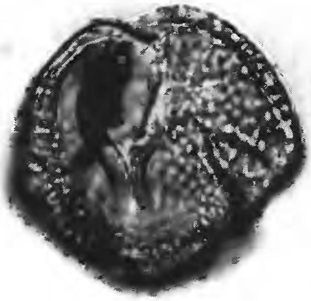
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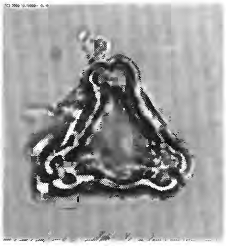
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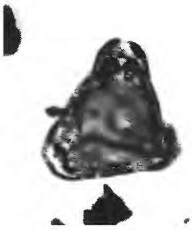
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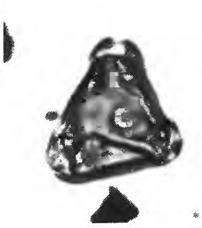
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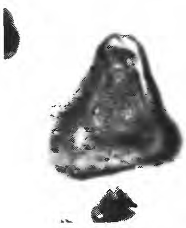
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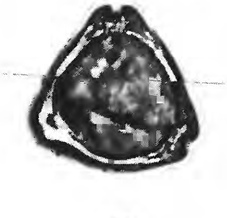
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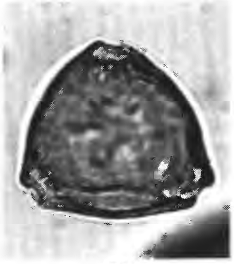
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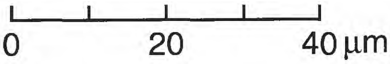


POLLEN

PLATE 3

[All specimens are from Screven and Burke Counties, Georgia]

Figure 1. New genus D, sp. J of Christopher (1979), Middendorf Formation, subunit 1, Girard core (1,138.0–1,139.0 ft), Burke County.

2\. New genus D, sp. L of Christopher (1979), Black Creek Group, subunit 1, Millhaven core (1,124.3–1,124.7 ft), Screven County.

3–5. N20-2 of R.A. Christopher (unpublished), Black Creek Group, subunit 1, Millhaven core (1,124.3–1,124.7 ft), Screven County.

6, 7. ?*Porocolpopollenites* sp. A of Christopher and others (1979), Cape Fear Formation, Millers Pond core (797.0–802.0 ft), Burke County.

8\. *Porocolpopollenites* n. sp. 1, Cape Fear Formation, Millers Pond core (797.0–802.0 ft), Burke County.

9\. *Trudopollis* sp. cf. *T. meekeri* Newman, Black Creek Group, Millers Pond core (517.0 ft), Burke County.

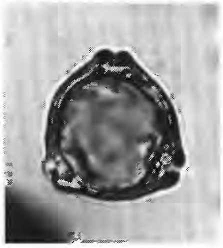
10, 11. *Rhombipollis* sp., Black Creek Group, Millers Pond core (517.0 ft), Burke County.

12\. CP3F-1 of Wolfe (1976), Steel Creek Formation, Millhaven core (769.0–769.3 ft), Screven County. This specimen is similar both to CP3F-1 and to *Brevicolporites* sp. A of Christopher (1978).

13\. CP3F-1 of Wolfe (1976), Steel Creek Formation, Millhaven core (769.0–769.3 ft), Screven County.

14, 15. *Brevicolporites* sp., Black Creek Group, subunit 2, Girard core (738.3–738.6 ft), Burke County.

16\. *Lanagiopollis cribellatus* (Srivastava) Frederiksen, Steel Creek Formation, Millhaven core (769.0–769.3 ft), Screven County.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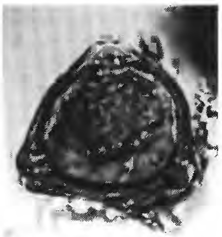
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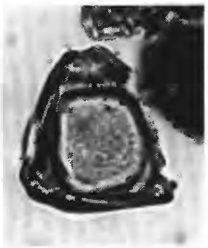
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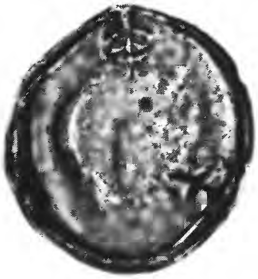
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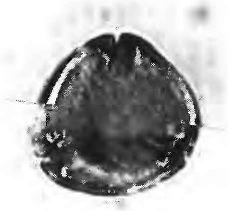
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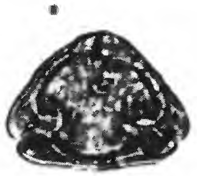
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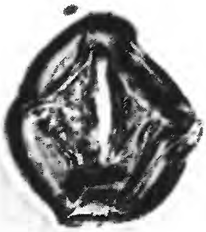
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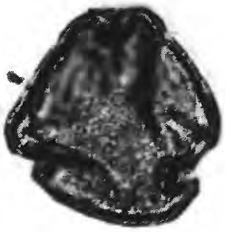
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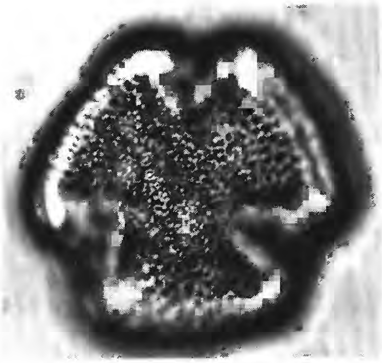
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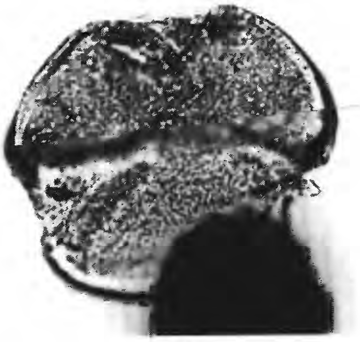
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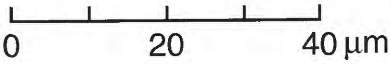

POLLEN

PLATE 4

[All specimens are from Screven and Burke Counties, Georgia]

Figures 1, 2. *Brevicolporites* sp. A of Christopher (1980), Steel Creek Formation, Millhaven core (829.5–829.8 ft), Screven County. *Brevicolporites* sp. A of Christopher (1980) is not exactly the same as *Brevicolporites* sp. A of Christopher (1978) nor as CP3F-1 of Wolfe (1976).

3. CP3D-3 of Wolfe (1976), Black Creek Group, Millers Pond core (517.0 ft), Burke County.

4, 5. *Brevicolporites* sp. A of Christopher (1978), Middendorf Formation, subunit 2, Girard core (1,012.0–1,012.3 ft), Burke County. These specimens seem to differ from CP3F-1 of Wolfe (1976).

6. *Tricolporites* sp., Cape Fear Formation, Millers Pond core (797.0–802.0 ft), Burke County.

7. Aff. C3C-1 of Wolfe (1976), Steel Creek Formation, Millhaven core (769.0–769.3 ft), Screven County.

8. CP3G-1 of Wolfe (1976), Middendorf Formation, subunit 1, Girard core (1,138.0–1,139.0 ft), Burke County.

9. *Tricolporites* sp., Middendorf Formation, subunit 2, Girard core (1,012.0–1,012.3 ft), Burke County.

10, 11. *Nyssapollenites* sp., Middendorf Formation, subunit 2, Girard core (1,012.0–1,012.3 ft), Burke County.

12, 13. CP3E-1 of Wolfe (1976), Middendorf Formation, subunit 1, Girard core (1,138.0–1,139.0 ft), Burke County.

14, 15. *Holkolpollenites* sp., Steel Creek Formation, Millhaven core (829.5–829.8 ft), Screven County.


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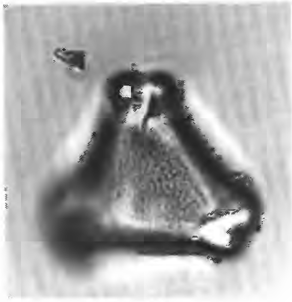
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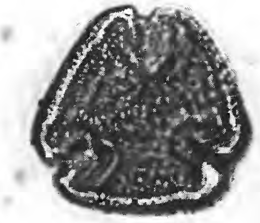
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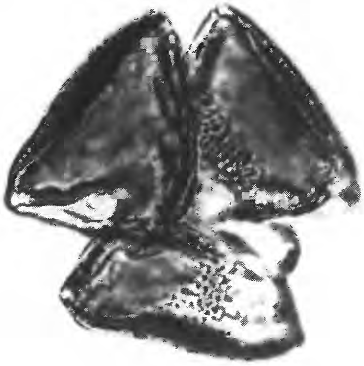
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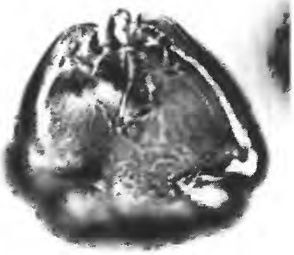
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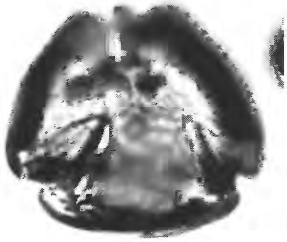
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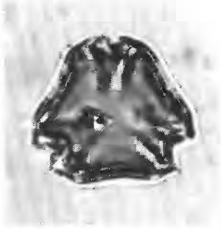
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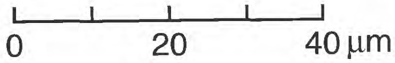


POLLEN

PLATE 5

[All specimens are from Screven and Burke Counties, Georgia]

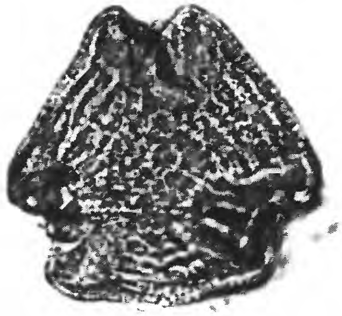
Figures 1–3. CP3D-3 of Wolfe (1976), Black Creek Group, subunit 2. 1, Girard core (738.3–738.6 ft), Burke County; 2, 3, Millhaven core (1,029.5 ft), Screven County.

4–9. CP3E-1 of Wolfe (1976). 4, 5, Black Creek Group, subunit 2, Girard core (738.3–738.6 ft), Burke County; 6, 7, Middendorf Formation, subunit 1, Girard core (1,138.0–1,139.0 ft), Burke County; 8, 9, Steel Creek Formation, Millhaven core (824.1–824.4 ft), Screven County.

10, 11. Cf. MPH-1 of Wolfe (1976), Steel Creek Formation, Millhaven core (830.3–830.5 ft), Screven County. MPH-1 of Wolfe = *Baculostephanocolpites* sp. A of Christopher (1980) has distinct columellae, whereas the present specimen has barely perceptible columellae.

12, 13. Tetracolporate sp., Steel Creek Formation, Millhaven core (830.3–830.5 ft), Screven County.

14. *Holkopollenites* sp., Middendorf Formation, subunit 2, Girard core (1,012.0–1,012.3 ft), Burke County.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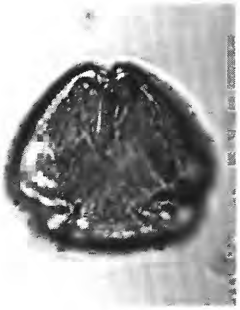
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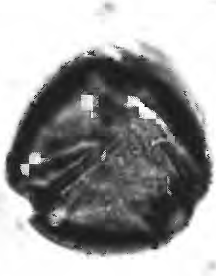
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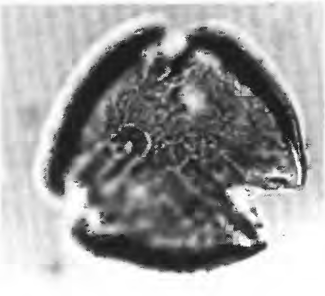
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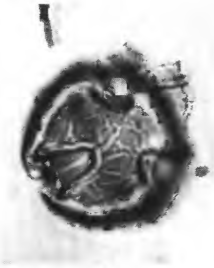
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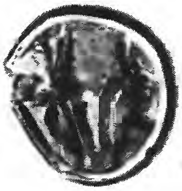
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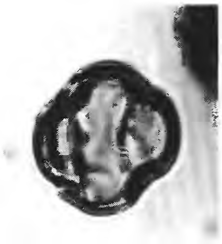
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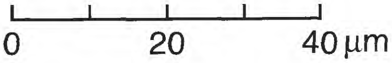

POLLEN

PLATE 6

[Upper scale bar is for specimens at × 400; lower scale bar is for specimens at × 600. All specimens are from the Black Creek Group in Screven and Burke Counties, Georgia]

Figure 1. *Alisogymnium euclaense* (Cookson & Eisenack) Lentin & Vozzhennikova, Black Creek Group, subunit 2, Girard core (738.3–738.6 ft), Burke County; ?ventral view at mid-focus (× 600).

2. *Dinogymnium acuminatum* Evitt et al., Black Creek Group, subunit 2, Millhaven core (1,029.5 ft), Screven County; orientation unknown at high focus (× 600).

3. *Alterbidinium acutulum* (Wilson) Lentin & Williams, Black Creek Group, subunit 2, Girard core (868.5–868.7 ft), Burke County; dorsal view of dorsal surface (× 400).

4. ?*Andalusiella spicata* (May) Lentin & Williams, Black Creek Group, subunit 2, Millhaven core (1,029.5 ft), Screven County; ventral view of dorsal surface (× 400). This form is an end member in a plexus that includes *A. spicata* (May) Lentin & Williams. Considerable variation exists in the surface texture, relative archeopyle size, and horn lengths.

5. *Andalusiella polymorpha* (Malloy) Lentin & Williams, Black Creek Group, subunit 3, Millhaven core (913.8–914.2 ft), Screven County; left lateral view at mid-focus (× 400).

6. *Andalusiella spicata* (May) Lentin & Williams, Black Creek Group, subunit 2, Girard core (868.5–868.7 ft), Burke County; ventral view of dorsal surface (× 400).

7. *Cerodinium pannuceum* (Stanley) Lentin & Williams, Black Creek Group, subunit 2, Girard core (738.3–738.6 ft), Burke County; dorsal view of dorsal surface (× 400).

8. *Cerodinium striatum* (Drugg) Lentin & Williams, Black Creek Group, subunit 2, Millhaven core (1,029.5 ft), Screven County; ventral view at mid-focus (× 400).

9. *Cordosphaeridium fibrospinosum* Davey & Williams, Black Creek Group, subunit 2, Millhaven core (1,029.5 ft) Screven County; left lateral view at mid-focus (× 400).

10. *Cribroperidinium* sp., Black Creek Group, subunit 3, Millhaven core (913.8–914.2), Screven County; ventral view at mid-focus (× 400).

11. *Diphyes recurvatum* May, Black Creek Group, subunit 2, Girard core (738.3–738.6 ft), Burke County; orientation unknown at mid-focus (× 600).

12. *Exochosphaeridium* sp., Black Creek Group, subunit 2, Girard core (868.5–868.7 ft), Burke County; dorsal view of dorsal surface (× 400).

13. *Fromea* sp., Black Creek Group, subunit 2, Girard core (868.5–868.7 ft), Burke County; orientation unknown at low focus (× 400).

14. *Fromea* sp., Black Creek Group, subunit 3, Millhaven core (913.8–914.2 ft), Screven County; orientation unknown at mid-focus (× 400).

15. *Membranosphaera maastrictica* Samoilovitch, Black Creek Group, subunit 2, Girard core (868.5–868.7 ft), Burke County; ventral view at mid-focus (× 600).

16. *Operculodinium* sp., Black Creek Group, subunit 2, Girard core (738.3–738.6 ft), Burke County; left lateral view at mid-focus (× 400).


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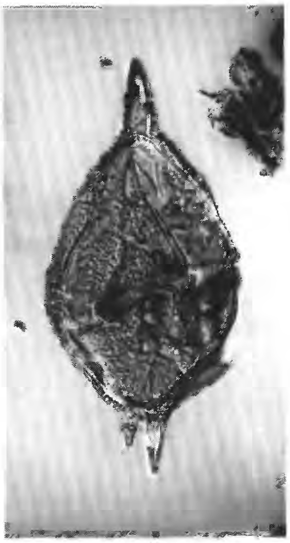
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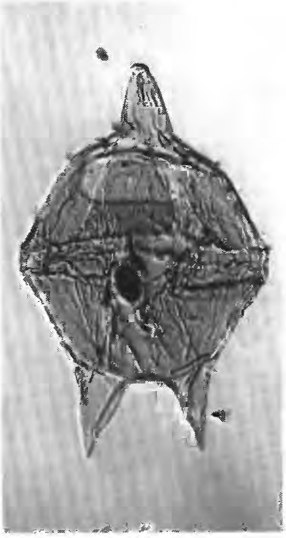
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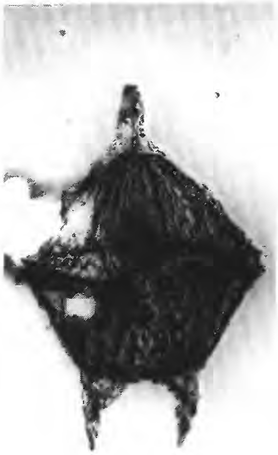
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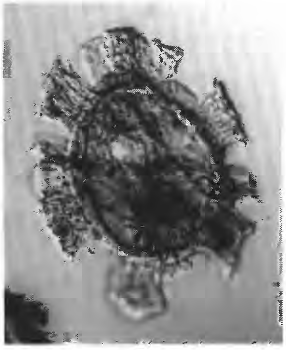
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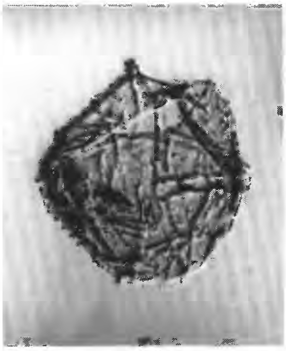
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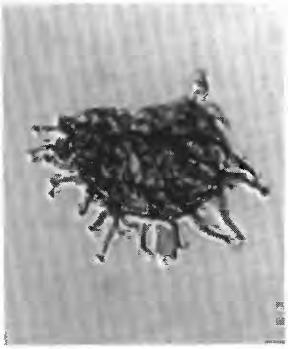
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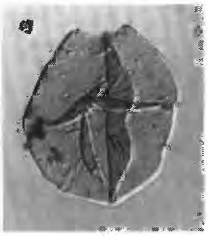
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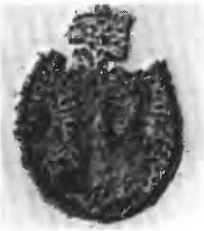
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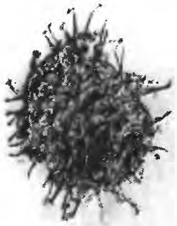
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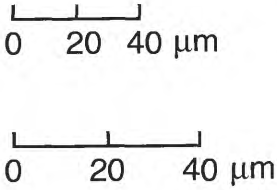


DINOFLAGELLATES AND ACRITARCHS

PLATE 7

[Upper scale bar is for specimens at × 400; lower scale bar is for specimens at × 600. All specimens are from Screven and Burke Counties, Georgia]

Figure 1. *Odontochitina costata* Alberti, Black Creek Group, subunit 2, Girard core (868.5–868.7 ft), Burke County; ventral view at mid-focus (× 400).

2. *Palaeohystrichophora infusorioides* Deflandre, Middendorf Formation, subunit 2, Millhaven core (1,212.0 ft), Screven County; dorsal view of dorsal surface (× 400).

3. *Palaeohystrichophora infusorioides* Deflandre, Middendorf Formation, subunit 2, Millhaven core (1,212.0 ft), Screven County; orientation unknown at mid-focus (× 400).

4. *Palaeoperidinium* sp., Middendorf Formation, subunit 2, Millhaven core (1,212.0 ft), Screven County; ventral view at mid-focus (× 400).

5. *Tanyosphaeridium xanthiopyxides* (Wetzel) Stover & Evitt, Black Creek Group, subunit 2, Millhaven core (1,029.5 ft), Screven County; orientation unknown at mid-focus (× 600).

6. *Spiniferites* sp., Black Creek Group, subunit 2, Girard core (834.6–834.8 ft), Burke County; orientation unknown at high focus (× 400).

7. *Spongodinium delitiense* (Ehrenberg) Deflandre, Steel Creek Formation, Millhaven core (830.3–830.5 ft), Screven County; isolated operculum (× 400).

8, 9. *Tricodinium castanea* (Deflandre) Clark & Verdier, Black Creek Group, subunit 2, Girard core (834.6–834.8 ft), Burke County; ventral views of ventral surface (8) and dorsal surface (9) (both × 400).

10. Small peridiniacean form, Black Creek Group, subunit 1, Millhaven core (1,124.3–1,124.7 ft), Screven County; dorsal view of dorsal surface (× 400).

11. Small peridiniacean form, Black Creek Group, subunit 2, Millhaven core (1,029.5 ft), Screven County; dorsal view of dorsal surface (× 400).

12. Small peridiniacean form, Black Creek Group, subunit 2, Girard core (868.5–868.7 ft), Burke County; dorsal view of dorsal surface (× 400).

13. Small peridiniacean form, Black Creek Group, subunit 2, Girard core (738.3–738.6 ft), Burke County; dorsal view of dorsal surface (× 400).

14. *Hystrichosphaeridium tubiferum* (Ehrenberg) Deflandre, Black Creek Group, subunit 2, Girard core (738.3–738.6 ft), Burke County; orientation unknown at mid-focus (× 400) [included in tables and figures under "miscellaneous chorate forms"].

15. Miscellaneous areoligeracean form, Black Creek Group, subunit 1, Millhaven core (1,124.3–1,124.7 ft), Screven County; dorsal view at mid-focus (× 400).

16. Miscellaneous areoligeracean form, Black Creek Group, subunit 1, Millhaven core (1,124.3–1,124.7 ft), Screven County; ventral view at mid-focus (× 400).

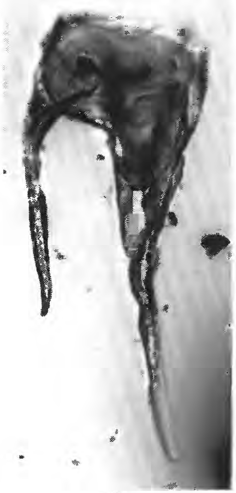
17. Miscellaneous areoligeracean form, Black Creek Group, subunit 3, Millhaven core (913.8–914.2 ft), Screven County; dorsal view of dorsal surface? (× 400).

18. *Lejeunecysta* sp., Black Creek Group, subunit 2, Millhaven core (1,029.5 ft), Screven County; dorsal view of dorsal surface (× 400).

19. *Xenascus ceratioides* (Deflandre) Lentin & Williams, Black Creek Group, Thompson Oak core (505.0 ft), Burke County; dorsal view at mid-focus (× 400).

20. Small peridiniacean form, Black Creek Group, subunit 2, Millhaven core (1,029.5 ft), Screven County; ventral view of ventral surface (× 600).

21. Miscellaneous areoligeracean form, Black Creek Group, subunit 2, Girard core (834.6–834.8 ft), Burke County; dorsal view? at mid-focus (× 400).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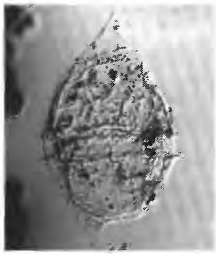
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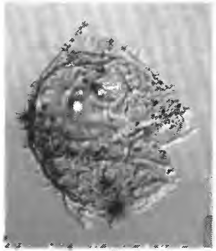
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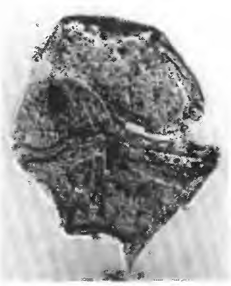
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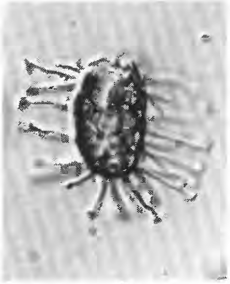
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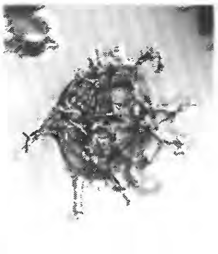
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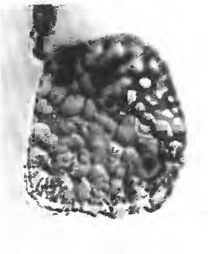
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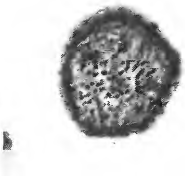
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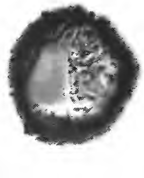
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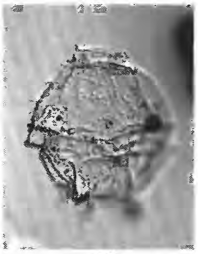
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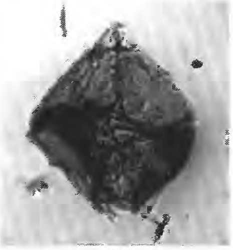
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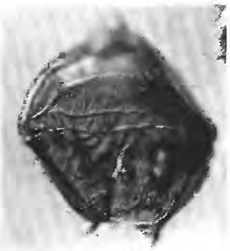
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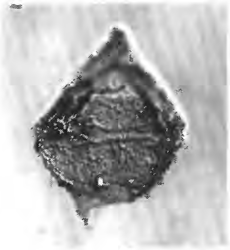
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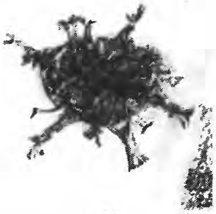
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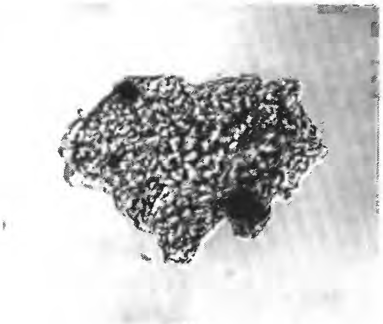
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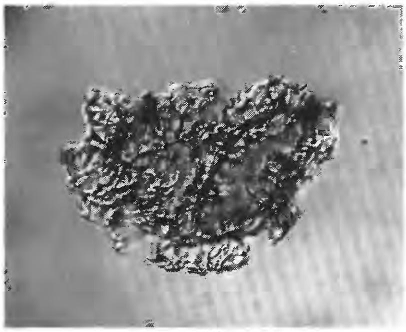
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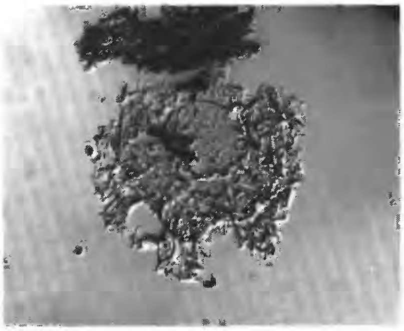
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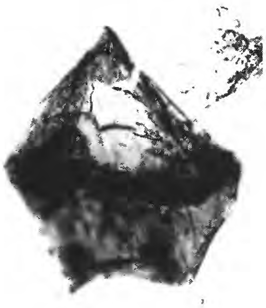
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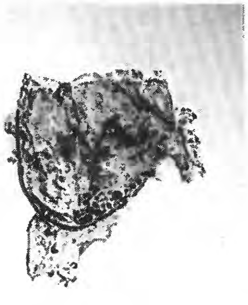
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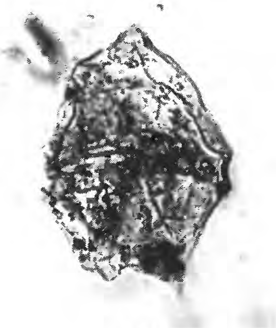
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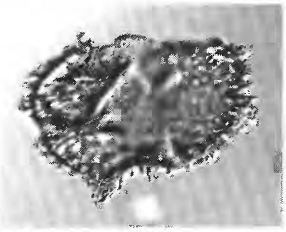
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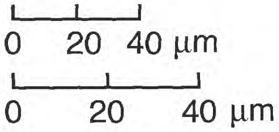

DINOFLAGELLATES

U.S. Department of the Interior
U.S. Geological Survey

Late Campanian (Zone CC 22) Coccoliths from the Millhaven Core, Screven County, Georgia

By David Bukry

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1603–D

Prepared in cooperation with the
U.S. Department of Energy and the
Georgia Geologic Survey

GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Edited by Lucy E. Edwards

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Late Campanian (Zone CC 22) Coccoliths from the Millhaven Core, Screven County, Georgia

By David Bukry

ABSTRACT

Coccolith floras from the Millhaven core in Screven County, Georgia, from depths of 1,077 to 968 feet, belong to late Campanian Zone CC 22. The co-occurrence of zonal guide species *Quadrum trifidum* (Stradner) Prins & Perch-Nielsen and *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen permits direct correlation with the paleomagnetically dated Point Loma Formation in California. *Q. trifidum* (Stradner) Prins & Perch-Nielsen, a warm-water taxon, is consistently present in the Georgia and California sections but is missing from the late Campanian floras that occur in the northern Atlantic Coastal Plain in New Jersey.

INTRODUCTION

Four core samples were examined for coccolith content from the U.S. Geological Survey Millhaven test hole (lat 32°53'25" N., long 81°35'43" W.), which is located in Screven County, Ga. (fig. 1). These samples were studied to supplement biostratigraphic dating of the Cretaceous marine sediments in the core interval from the 1,099 to 927 ft. This Cretaceous interval is considered to be part of the Black Creek Group, which ranges in age from middle to late Campanian in the Millhaven core (Falls and Prowell, this volume, chap. A; Edwards and others, this volume, chap. B). Samples studied for this report represent all but the lowest 20 ft of the Black Creek Group subunit 2 of Falls and Prowell (this volume, chap. A). Comparative coccolith samples from New Jersey and California Cretaceous strata also were used in this study. The Californian floras have been published previously by Bukry and Kennedy (1969) and Bukry (1993, 1994). Coccoliths identified from the Millhaven core are listed in table 1, and all taxa considered in this report are listed in table 2.

ACKNOWLEDGMENTS

I thank Gregory S. Gohn and Lucy E. Edwards (U.S. Geological Survey) for providing samples and supporting information about the Georgia research. I thank Kevin Purcell (USGS) for doing special sample preparations for general matrix and coherent rock chips for each sample and for processing the text. Special appreciation goes to Peter J. Sugarman (New Jersey Geological Survey) and Norman F. Sohl and James Owens (U.S. Geological Survey, both deceased) for providing New Jersey core and outcrop samples as an extension of our joint studies from 1989 to 1994. Michael P. Kennedy (California Division of Mines and Geology), George W. Moore (U.S. Geological Survey), Annika Sanfilippo (University of California, San Diego/ Scripps Institution of Oceanography), and Thomas A. Deméré (San Diego Natural History Museum) helped me to collect the California core and outcrop samples.

MATERIAL AND METHODS

Samples from the Millhaven core and outcrop samples from New Jersey and California were prepared for light-microscope examination (magnifications × 600 and × 1560) using the technique described in Bukry and Kennedy (1969). Zonal assignments are based on Perch-Nielsen (1985, p. 342), and stage assignments are based on Sissingh (1977) and Burnett and others (1992).

GEORGIA COCCOLITHS

Coccoliths from the Millhaven core (table 1) are slightly etched and common to abundant. Floras have moderate to high species diversity (number of species (n)=15 to 30). The most common species are dissolution-resistant *Micula decussata* Vekshina and *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen. Other stratigraphic guide spe-

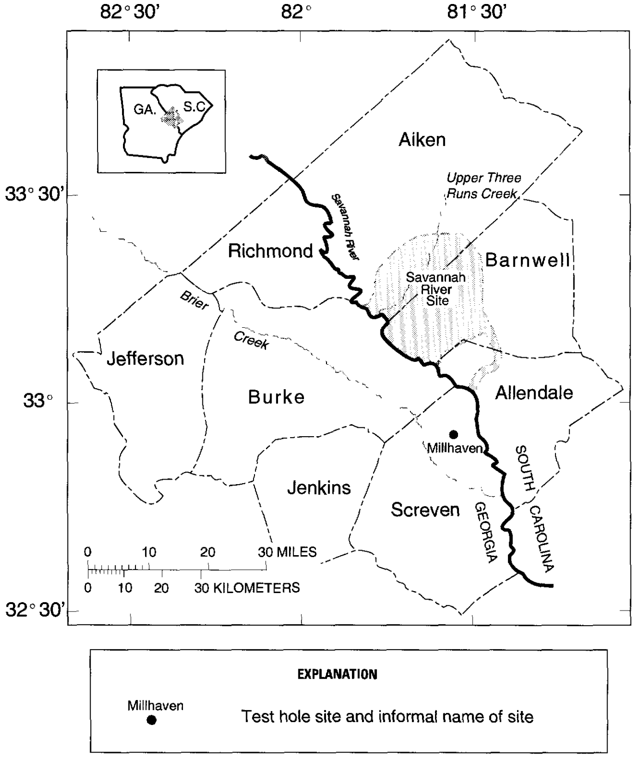

Figure 1. Index map showing the Savannah River Site and the location of the Millhaven test hole in Screven County, Georgia.

cies such as *Broinsonia parca* (Stradner) Bukry, *Calculites obscurus* (Deflandre) Prins & Sissingh, *Ceratolithoides aculeus* (Stradner) Prins & Sissingh, *Quadrum trifidum* (Stradner) Prins & Perch-Nielsen, and *R. levis* Prins & Sissingh are present in smaller numbers. All four of the closely spaced floras (1,077, 1,021.5, 971, and 968 ft) contain both *Q. trifidum* (Stradner) Prins & Perch-Nielsen and *R. anthophorus* (Deflandre) Perch-Nielsen, which together define late Campanian Zone CC 22. *Reinhardtites levis* Prins & Sissingh, which has been designated a guide species for upper Subzone CC 22b, occurs only rarely in the bottom and top samples. It is missing in the most diverse (*n*=30) sample at 1,021.5 ft. In the sample taken at 971 ft, only two specimens of *Reinhardtites* sp. cf. *R. levis* Prins & Sissingh were identified. Evidence from floras in California and Israel suggests that *R. levis* Prins & Sissingh has a longer range in CC 21 and CC 22 at middle latitudes (Bukry, 1994; Eshet and Moshkovitz, 1995). The best coccolith assignment for all four Georgia floras from the Millhaven core is late Campanian Zone CC 22.

NEW JERSEY COCCOLITHS

Outcrop and core samples from the Upper Cretaceous Mount Laurel Formation in New Jersey contain coccolith floras assigned to Subzone CC 22b (Sugarman and others, 1995). This late Campanian correlation is based on the identifications of key coccolith species *Broinsonia parca* (Stradner) Bukry, *Calculites obscurus* (Deflandre) Prins & Sissingh, *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen, *R. levis* Prins & Sissingh, and *Tranolithus phacelosus* Stover. The warm-water biostratigraphic guide species *Quadrum trifidum* (Stradner) Prins & Perch-Nielsen and *Quadrum sissinghii* Perch-Nielsen are missing from New Jersey floras (Bukry, 1990).

The absence of *Quadrum trifidum* (Stradner) Prins & Perch-Nielsen in New Jersey floras may be attributed to its general global distribution pattern and local ecological conditions. Roth (1978) described *Q. trifidum* (Stradner) Prins & Perch-Nielsen as a temperature-sensitive, warm-water species. Thierstein (1981, fig. 21) demonstrated maximum abundances within approximately 30 degrees latitude of the paleoequator for *Q. trifidum* (Stradner) Prins & Perch-Nielsen. Doeven (1983) used this information to suggest that in Canadian Atlantic well sites, the top range of *Q. trifidum* (Stradner) Prins & Perch-Nielsen might be depressed as a result of decreased paleotemperatures. Further, he reported only rare abundances at Canadian sites. Similarly, Burnett and others (1992) reported only sporadic occurrences of *Q. trifidum* (Stradner) Prins & Perch-Nielsen in sections from Germany and Poland. This occurrence pattern contrasts with the rare to common but consistent occurrences in California (Bukry, 1993, 1994) and the consistent presence in the Georgia core samples studied here.

Similar consistent occurrences were cited in Israel (Moshkovitz, 1984), supporting warm-water affinities for *Quadrum trifidum* (Stradner) Prins & Perch-Nielsen. The late Campanian Mount Laurel Formation floras from New Jersey lack *Q. trifidum* (Stradner) Prins & Perch-Nielsen but were assigned to Zone CC 22 or Subzone CC 22b based on the co-occurrence of other taxa, principally *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen and *R. levis* Prins & Sissingh. The highest occurrence of *R. anthophorus* (Deflandre) Perch-Nielsen defines the top of Zone CC 22 in the late Campanian. In cooler water floras, the co-occurrence of *R. levis* Prins & Sissingh with *R. anthophorus* (Deflandre) Perch-Nielsen is considered a useful indicator for Subzone CC 22b (Perch-Nielsen, 1985, p. 347).

COMPARISON OF CAMPANIAN COCCOLITH FLORAS IN THE ATLANTIC COASTAL PLAIN AND CALIFORNIA

The Point Loma Formation in San Diego County, Calif., contains the same key coccolith species in late Campanian Zone CC 22 that occur in the Georgia floras. The consistent occurrence of *Quadrum trifidum* (Stradner) Prins & Perch-Nielsen in the Georgia floras matches the pattern in Point Loma core hole DH–1 where it occurs in 30 of 31 coccolith-bearing samples from CC 22 (Bukry, 1993). Both

Table 1. U.S. Geological Survey Millhaven core coccolith checklist.

Coccolith	Sample depth, in feet			
	1,077	1,021.5	971	968
Arkhangelskiella cymbiformis	X	X	X	--
Biscutum sp.	--	X	--	--
Broinsonia parca parca	X	X	--	X
Broinsonia parca constricta	X	X	--	--
Calculites obscurus	--	X	X	--
Ceratolithoides aculeus	X	X	X	X
Chiastozygus amphipons	--	X	--	--
Chiastozygus sp.	X	--	X	X
Coronocyclus sp.	--	X	--	--
Cretarhabdus crenulatus	X	X	X	X
Cribrosphaera ehrenbergii	X	X	--	X
Eiffellithus eximius	--	--	X	--
Eiffellithus turriseiffelii	X	--	X	--
Gartnerago concavum	--	X	--	--
Gartnerago costatum	--	X	--	X
Kamptnerius magnificus	X	X	X	--
Lithraphidites carniolensis	--	X	--	--
Lucianorhabdus cayeuxii	--	X	X	--
Lucianorhabdus maleformis	--	X	--	--
Microrhabdulus decoratus	--	X	--	X
Micula concava	--	--	--	X
Micula decussata	X	X	X	X
Parhabdolithus embergeri	X	X	X	X
Prediscosphaera cretacea	X	X	X	X
Prediscosphaera spinosa	--	--	--	X
Quadrum sissinghii	X	X	--	--
Quadrum trifidum	X	X	X	X
Reinhardtites anthophorus	X	X	X	X
Reinhardtites levis	X	--	--	X
Reinhardtites sp. cf. *R. levis*	--	--	X	--
Rucinolithus sp.	--	X	--	--
Tranolithus phacelosus	--	X	--	--
Vagalapilla octoradiata	X	X	--	--
Watznaueria barnesae	X	X	X	--
Watznaueria biporta	X	X	X	--
Zygodiscus bicrescenticus	X	X	X	--
Zygodiscus spiralis	--	X	--	--

sites are part of a warm-water regime, but the Point Loma flora lacks *Calculites obscurus* (Deflandre) Prins & Sissingh, *Kamptnerius magnificus* Deflandre, *Lucianorhabdus cayeuxii* Deflandre, and *Tranolithus phacelosus* Stover. These absences reflect deep-water deposition for the Point Loma core strata. In shallower water strata of the Point Loma Formation in Carlsbad, Calif., some *C. obscurus* (Deflandre) Prins & Sissingh and *L. cayeuxii* Deflandre were recorded (Bukry, 1994).

At La Jolla, Calif., floras assigned to CC 22b occur in a 280-ft stratigraphic section that has been assigned to magnetochronostratigraphic Chron 33n (Bannon and others, 1989, fig. 3) in the late Campanian (Bannon and others, 1989; Bukry, 1994). The key La Jolla coccoliths in the Chron 33n portion of Subzone CC 22b include *Broinsonia parca* (Stradner) Bukry, *Q. trifidum* (Stradner) Prins & Perch-Nielsen, *Q. sissinghii* Perch-Nielsen, *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen, and *R. levis* Prins & Sissingh, which enable direct correlation of late Campanian paleomagnetic Chron 33n with the four Georgia floras assigned to the Black Creek Group. The disappearance of *R. anthophorus* (Deflandre) Perch-Nielsen in Europe predates

Table 2. Coccolith taxa considered in this report.

Arkhangelskiella cymbiformis Vekshina
Broinsonia parca (Stradner) Bukry
Broinsonia parca constricta Hattner et al.
Calculites obscurus (Deflandre) Prins & Sissingh *in* Sissingh
Ceratolithoides aculeus (Stradner) Prins & Sissingh *in* Sissingh
Chiastozygus amphipons (Bramlette & Martini) Gartner
Cretarhabdus crenulatus Bramlette & Martini
Cribrosphaera ehrenbergii Arkhangelsky
Eiffellithus eximius (Stover) Perch-Nielsen
Eiffellithus turriseiffelii (Deflandre) Reinhardt
Gartnerago concavum (Gartner) Bukry
Gartnerago costatum (Gartner) Bukry
Kamptnerius magnificus Deflandre
Lithraphidites carniolensis Deflandre
Lucianorhabdus cayeuxii Deflandre
Lucianorhabdus maleformis Reinhardt
Microrhabdulus decoratus Deflandre
Micula concava (Stradner *in* Martini and Stradner) Verbeek
Micula decussata Vekshina
Parhabdolithus embergeri (Noël) Stradner
Prediscosphaera cretacea (Arkhangelsky) Gartner
Prediscosphaera spinosa (Bramlette & Martini) Gartner
Quadrum sissinghii Perch-Nielsen
Quadrum trifidum (Stradner) Prins & Perch-Nielsen *in* Manivit
Reinhardtites anthophorus (Deflandre) Perch-Nielsen
Reinhardtites levis Prins & Sissingh
Tranolithus phacelosus Stover
Vagalapilla octoradiata (Gorka) Bukry
Watznaueria barnesae (Black) Perch-Nielsen
Watznaueria biporta Bukry
Zygodiscus bicrescenticus (Stover) Bukry
Zygodiscus spiralis Bramlette & Martini

the appearance of the cephalopod *Belemnella lanceolata* (basal Maastrichtian) (Burnett and others, 1992) and helps to confirm the late Campanian age for the correlated CC 22b coccolith floras on the Atlantic and Pacific coasts.

CONCLUSIONS

Millhaven core samples from 1,077 to 968 ft contain late Campanian Zone CC 22 coccolith floras identified by key taxa *Quadrum trifidum* (Stradner) Prins & Perch-Nielsen and *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen. The consistent presence of *Q. trifidum* (Stradner) Prins & Perch-Nielsen indicates a warm-water regime similar to coeval California floras and unlike cooler water New Jersey floras. Coccolith species permit direct long-range correlation for Georgia floras to paleomagnetic Chron 33n in California and standard European upper Campanian reference sections.

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Ostracode Biostratigraphy of Upper Campanian (Cretaceous) Marine Sediments from the Millhaven Core, Screven County, Georgia

By Gregory S. Gohn

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1603–E

Prepared in cooperation with the
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GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

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PLATE

[Plate follows References Cited]

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TABLE

GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Ostracode Biostratigraphy of Upper Campanian (Cretaceous) Marine Sediments from the Millhaven Core, Screven County, Georgia

By Gregory S. Gohn

ABSTRACT

The Cretaceous section in the Millhaven core from Screven County, Georgia, contains calcareous, fine-grained marine deposits in part of the interval assigned to the Black Creek Group. These calcareous deposits and associated overlying and underlying deposits between depths of 1,119 and 927 ft are designated informally as Black Creek subunit 2 by Falls and Prowell (this volume, chap. A).

Two informally named ostracode assemblages are present in Black Creek subunit 2 between depths of 1,043 and 975 ft: an older *Haplocytheridea everetti* assemblage and a younger *Haplocytheridea sarectaensis* assemblage. The presence of *Escharacytheridea pinochii* (Jennings) in the lowest studied sample and the presence of *Fissocarinocythere pidgeoni* (Berry) in higher samples indicate a late Campanian to Maastrichtian age for the interval between 1,043 and 1,015 ft. This age is compatible with the late Campanian age assigned to the calcareous part of Black Creek subunit 2 by Bukry (this volume, chap. D; calcareous nannofossil Zone CC 22). Both ostracode assemblages are strongly dominated by various species of *Haplocytheridea* and related genera that suggest inner-neritic paleoenvironments of deposition for the sediments of Black Creek subunit 2.

The total range of the ostracode *Haplocytheridea sarectaensis* Brown is within the upper parts of intervals assigned to calcareous nannofossil Zone CC 22 in the Millhaven section and in previously studied test holes in central South Carolina. The top of Zone CC 22 is slightly older than the Campanian-Maastrichtian Stage boundary as defined by J.A. Burnett and others (1992, Newsletters on Stratigraphy, v. 27, p. 157–172). Hence the highest occurrence of *H. sarectaensis* Brown approximates this stage boundary in eastern Georgia and central South Carolina. Sections in central South Carolina containing *H. sarectaensis* Brown and calcareous nannofossil Zone CC 22 are within the Donoho Creek Formation of the Black Creek Group.

INTRODUCTION

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy (USDOE) and the Georgia Geologic Survey of the Georgia Department of Natural Resources, conducted a study of ground-water flow and ground-water quality in the area of eastern Georgia that is adjacent to the USDOE Savannah River Site in South Carolina (fig. 1). This study addressed concerns by the State of Georgia regarding the potential for movement of ground water containing radionuclides or other contaminants from the Savannah River Site into Georgia through coastal plain aquifers passing beneath the Savannah River (Clarke, 1992, 1995).

A principal component of the study was the hydrologic and geologic analysis of test hole clusters drilled in the coastal plain sediments of Burke and Screven Counties, Ga. (fig. 1). The hydrologic studies at the cluster sites included determinations of hydraulic properties, pressure heads, and water quality for multiple aquifers (Clarke and others, 1994, 1996; Leeth and others, 1996). The geologic studies included lithologic, paleontologic, and stratigraphic analyses of the Cretaceous and Cenozoic sediments in continuously cored sections at each site. These geologic analyses were conducted to determine the physical characteristics, distributions, and correlations of the several aquifers and confining units. This report discusses the ostracode biostratigraphy, inferred depositional paleoenvironments, and regional correlation of Cretaceous calcareous marine sediments present in the Millhaven test hole in northern Screven County, Ga. (fig. 1).

The Millhaven stratigraphic test hole was completed by a USGS drill crew in February 1992 to a depth of

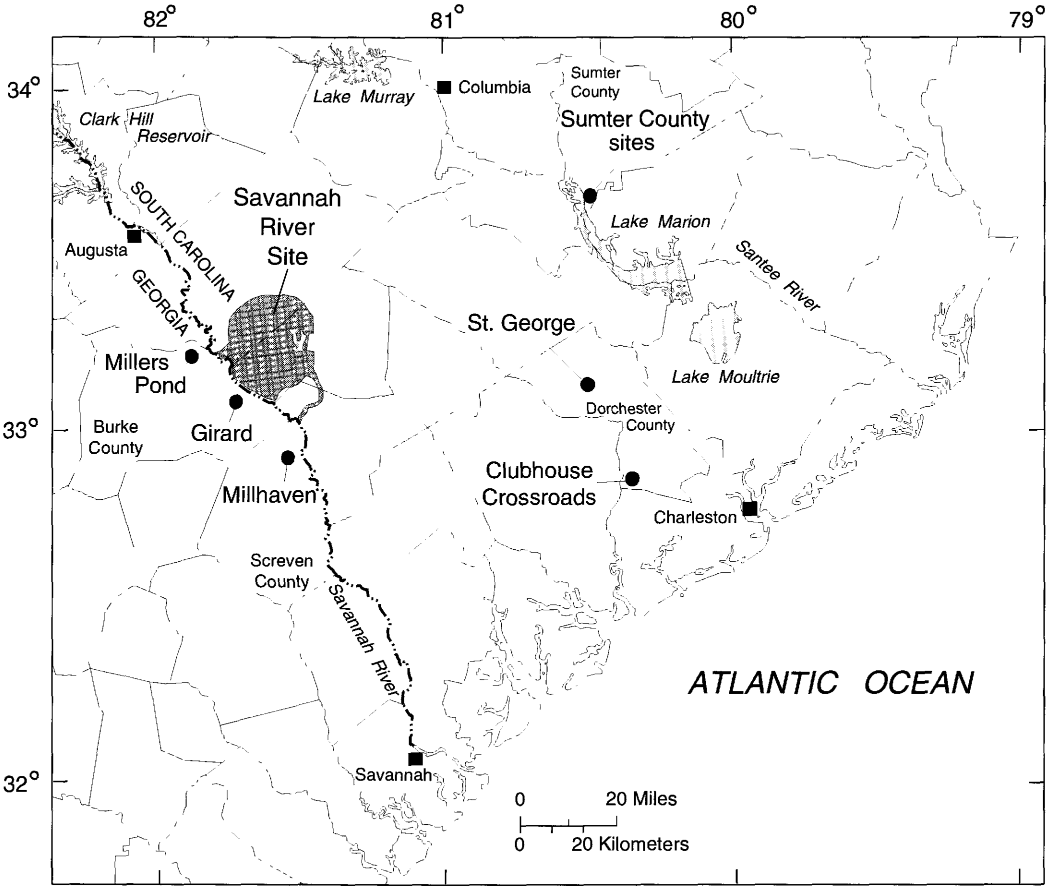

Figure 1. Location of the Millhaven test hole in Georgia and additional test holes in Georgia and South Carolina.

1,452 ft where the hole bottomed in the Upper Cretaceous Cape Fear Formation. This testhole is located in the Burtons Ferry Landing 7.5-minute quadrangle in northern Screven County at latitude 32°53'25" N., longitude 81°35'43" W. (fig. 1). Ground elevation at the drill site is +110 ft. The lithologies and stratigraphy of the Millhaven section are discussed by Clarke and others (1996) and Falls and Prowell (this volume, chap. A).

Depths measured to specific horizons in the Millhaven core typically are 5 to 7 ft deeper than the depths measured to the corresponding positions on the geophysical logs. In this report, and throughout this volume, core depths are used as the primary depth reference for samples and stratigraphic features. On figure 2, the geophysical logs for the Millhaven test hole have been shifted graphically (down 5 ft) to produce a closer correspondence between log depths and core depths.

ACKNOWLEDGMENTS

The site description of the Millhaven core by W. Fred Falls (USGS) was an important guide to this study of the Millhaven Cretaceous section. USGS Volunteer-for-Science Xenedee Bradley assisted in the preparation of the ostracode samples from the Millhaven core. I thank Jean M. Self-Trail (USGS) for discussions of Cretaceous calcareous nannofossils in the South Carolina cores. Reviews by Harry Dowsett (USGS), Raymond Christopher (Clemson University), and Lucy Edwards (USGS) substantially improved the manuscript.

CAMPANIAN MARINE DEPOSITS IN THE MILLHAVEN CORE

PHYSICAL STRATIGRAPHY

Upper Cretaceous sediments are present in the Millhaven core between its base and a depth of 642 ft (fig. 2) (Falls and others, 1997; Falls and Prowell, this volume, chap. A; Edwards and others, this volume, chap. B). Falls and Prowell (this volume, chap. A) assign the interval between 1,172 and 839 ft to the Black Creek Group, which they divide into informal lithologic subunits 1, 2, and 3

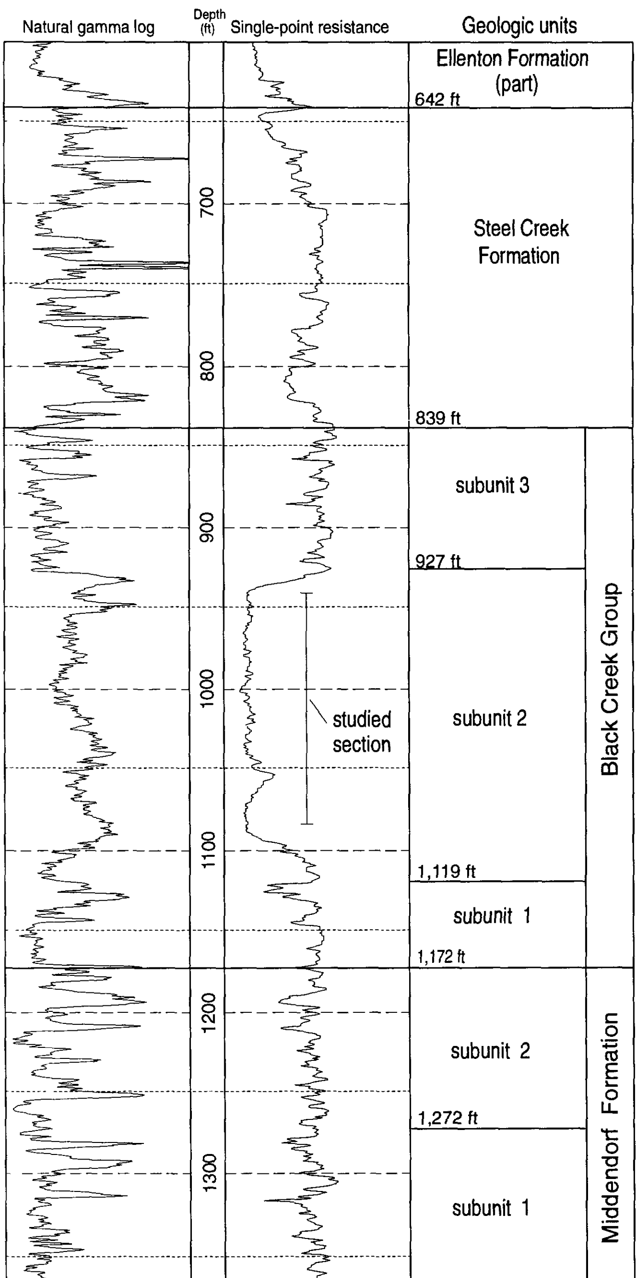

Figure 2. Geophysical logs and geologic units of the Cretaceous section in the Millhaven core to a depth of 1,452 feet. The stratigraphic position of Black Creek subunit 2, which was studied for this report, is indicated. The lithostratigraphy is from Falls and Prowell (this volume, chap. A). The geophysical logs have been shifted graphically to produce a correspondence between core depths and log depths for stratigraphic horizons.

(from base to top). Black Creek subunit 2 (1,119 to 927 ft) contains the only calcareous Cretaceous sediments in the Millhaven core. The calcareous section is present between 1,085 and 940 ft in the core.

From its basal contact at 1,119 ft to 1,085 ft, Black Creek subunit 2 consists of noncalcareous, slightly to moderately muddy, fine to medium, and medium to very coarse sand. This section of sand is broadly gradational upward into calcareous fine-grained deposits that are more typical of the unit. The grain size of the sand fraction and the sand/(clay+silt) ratio decrease upward in this basal interval.

Above 1,085 ft, Black Creek subunit 2 consists of sparingly calcareous to moderately calcareous, bioturbated, muddy, very fine to fine sand and similar appearing sandy and silty clay. Calcareous macrofossils, microfossils, and nannofossils are present from 1,085 to 965 ft in subunit 2. Molds of pelecypods, locally with traces of preserved calcium carbonate, are present above 965 to about 940 ft. An interval of slightly muddy, calcareous, very fine to fine sand is present from 1,063 to 1,051 ft. This sand has gradational contacts with underlying and overlying muddier sections. At the top of Black Creek subunit 2, its typically fine-grained deposits grade upward into moderately well-sorted, highly micaceous, very fine to fine sand (934 to 927 ft).

The dark, bioturbated, fine-grained sediments of Black Creek subunit 2 in the Millhaven core readily correlate with sections of similar fine-grained marine sediments that are included in the Black Creek Formation or Black Creek Group in wells throughout the Savannah River area (Logan and Euler, 1989; Fallaw and others, 1992a,b; Fallaw and Price, 1992, 1995; Falls and Prowell, this volume, chap. A). Despite their lithologic similarity to Black Creek subunit 2 at Millhaven, few of the correlative Black Creek marine sections have retained their calcareous fossils, probably owing to ground-water dissolution of the calcium carbonate.

OSTRACODE BIOSTRATIGRAPHY

OSTRACODE SAMPLES

Twenty-one ostracode samples were collected from the calcareous part of Black Creek subunit 2 in the Millhaven core between depths of 1,082.7 and 940.0 ft. Of these, three samples at the top of the section (965.5, 956.0, and 940.0 ft) did not produce a reaction when treated with dilute hydrochloric acid and were assumed to be noncalcareous; these samples were not processed.

The eighteen remaining samples were processed using standard microfossil techniques. Samples weighing approximately 150 g were soaked in deionized water and sieved. Ostracode valves and carapaces were picked from the fine, medium, and coarse sand fractions and placed on standard micropaleontology slides for sorting and identification.

Table 1. Cretaceous ostracodes from the Black Creek Group in the Millhaven core, Screven County, Georgia.

[Samples are reported as depths (in ft) below the surface]

	Haplocytheridea everetti assemblage				*Haplocytheridea sarectaensis* assemblage										
Species	1,043	1,038	1,033	1,029	1,021	1,015	1,010	1,005	1,000	995	989	985	975	Totals	% of Total
Haplocytheridea sp. aff. *H. everetti* (Berry)	0	0	0	0	222	253	11	44	15	31	0	57	0	633	42.9%
Haplocytheridea sarectaensis Brown	0	0	0	0	30	24	8	3	0	4	1	109	16	195	13.2%
Haplocytheridea renfroensis Crane	166	13	1	0	0	0	0	0	0	0	0	0	0	180	12.2%
Haplocytheridea everetti (Berry)	30	21	63	5	0	0	0	0	0	0	0	0	0	119	8.1%
Antibythocypris minuta (Berry)	0	0	0	0	87	28	1	0	0	0	0	0	0	116	7.9%
Cytherella spp.	72	13	7	1	3	0	0	0	0	0	0	0	0	96	6.5%
Brachycythere ovata (Berry)	16	4	0	0	3	0	0	0	0	0	0	0	0	23	1.6%
Eocytheropteron straillis Brown	0	0	0	0	8	12	0	0	0	0	0	3	0	23	1.6%
Loxoconcha spp.	2	4	9	0	6	0	0	0	0	0	0	0	0	21	1.4%
Brachycythere rhomboidalis (Berry)	0	0	0	0	16	4	0	0	0	0	0	0	0	20	1.4%
Escharacytheridea pinochii (Jennings)	16	0	0	0	0	0	0	0	0	0	0	0	0	16	1.1%
Curfsina communis (Israelsky)	5	0	1	0	4	0	0	0	0	0	0	0	0	10	0.7%
Brachycythere spp.	0	0	0	1	2	2	0	0	0	0	0	0	0	5	0.3%
Fissocarinocythere pidgeoni (Berry)	1	0	0	0	2	2	0	0	0	0	0	0	0	5	0.3%
Orthonotacythere hannai (Israelsky)	5	0	0	0	0	0	0	0	0	0	0	0	0	5	0.3%
Cytheropteron(?) sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0.1%
Orthonotacythere sulcata Brown	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0.1%
Antibythocypris fabaformis (Berry)	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0.1%
Cytherelloidea sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.1%
Paracypris(?) sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0.1%
Totals	315	56	82	7	383	326	20	47	15	35	1	171	16	1,474	100.0%

Five samples at the bottom of the section (1,082.7, 1,077.0, 1,067.5, 1,061.5, and 1,051.5 ft) did not yield ostracodes upon processing. Planktonic foraminifers and mollusk fragments also are absent from these five samples; however, they do contain very sparse assemblages of calcareous benthic foraminifers, dominantly *Lenticulina* spp. The other thirteen samples produced very small to moderately large numbers of ostracode valves (table 1). These productive samples also contain mollusk fragments and calcareous and agglutinated benthic foraminifers. Variable abundances of planktonic foraminifers are present in some of these samples with heterohelicid genera dominating over globotruncanid genera except at 1,021 and 1,015 ft where heterohelicids were not seen.

OSTRACODE ASSEMBLAGES

Two ostracode assemblages are present in Black Creek subunit 2 (table 1). The strong dominance of three taxa in each assemblage and the absence or near absence of these dominant forms in the other assemblage permit definition of the assemblages by inspection.

The lower assemblage, informally named the *Haplocytheridea everetti* (Berry) assemblage, is present in the four samples between the depths of 1,043 and 1,029 ft. The upper assemblage, informally named the *Haplocytheridea sarectaensis* Brown assemblage, is present in the nine samples between the depths of 1,021 and 975 ft.

The *Haplocytheridea everetti* (Berry) assemblage is dominated by the widely distributed species *Haplocytheridea renfroensis* Crane and *Haplocytheridea everetti* (Berry) as well as undescribed species of the genus *Cytherella* (table 1). These three taxa constitute about 85 percent of the recovered valves in this assemblage. *Brachycythere ovata* (Berry), *Escharacytheridea pinochii* (Jennings), and typically crushed or fragmented specimens of *Loxoconcha* spp. are the only other moderately common forms. Sparse described forms include *Curfsina communis* (Israelsky), *Orthonotacythere hannai* (Israelsky), *Orthonotacythere sulcata* Brown, *Antibythocypris fabaformis* (Berry), and *Fissocarinocythere pidgeon*i (Berry).

The *Haplocytheridea sarectaensis* Brown assemblage is dominated by *Haplocytheridea sarectaensis* Brown, *Antibythocypris minuta* (Berry), and an undescribed species assigned to *Haplocytheridea* sp. aff. *H. everetti* (Berry) (table 1). Together, these three species constitute about 93 percent of the assemblage. Sparse described forms include *Eocytheropteron straillis* Brown, *Brachycythere rhomboidalis* (Berry), *Brachycythere ovata* (Berry), *Curfsina communis* (Israelsky), and *Fissocarinocythere pidgeoni* (Berry).

BIOSTRATIGRAPHY AND AGE

Most of the described species in both Black Creek ostracode assemblages are long-ranging middle Campanian to Maastrichtian species or late Campanian to Maastrichtian species (Crane, 1965; Hazel and Brouwers, 1982; Gohn, 1995). These long-ranging species include *Antibythocypris fabaformis* (Berry), *Antibythocypris minuta* (Berry), *Brachycythere ovata* (Berry), *Brachycythere rhomboidalis* (Berry), *Haplocytheridea everetti* (Berry), *Haplocytheridea renfroensis* Crane, *Curfsina communis* (Israelsky) and *Orthonotacythere hannai* (Israelsky).

Two of the described ostracode species in Black Creek subunit 2 can be used to place this section in the regional ostracode zonation of Hazel and Brouwers (1982), as modified by Pitakpaivan and Hazel (1994) (fig. 3). The presence of *Escharacytheridea pinochii* (Jennings) in the lowest studied sample (table 1), coupled with the presence of *Fissocarinocythere pidgeoni* (Berry) in higher samples, indicates placement of at least part of the studied section (1,043 to 1,015 ft) within the late Campanian to early Maastrichtian chronozones of the *Escharacytheridea pinochii* (Jennings) Interval Zone and (or) the *Platycosta lixula* (Crane) Interval Zone. This late Campanian to early Maastrichtian age is compatible with the late Campanian age assigned to the calcareous part of Black Creek subunit 2 at Millhaven by Bukry (this volume, chap. D) on the basis of calcareous nannofossils.

PALEOENVIRONMENTS

Species of the genera *Haplocytheridea* (Stephenson) and *Antibythocypris* (Jennings) tend to dominate the terrigenous inner-neritic deposits of the Atlantic and Gulf of Mexico Coastal Plains (Hazel and Brouwers, 1982; Puckett, 1996). Conversely, ornate trachyleberid forms and smooth-valved forms (except cytherellids) are more common in deeper water chalk and glauconite deposits and tend to be rare in shallow-marine deposits. In the *Haplocytheridea everetti* assemblage (table 1), *Haplocytheridea* specimens constitute about two-thirds of the recovered valves, and an inner-neritic paleoenvironment is inferred from this assemblage.

Similarly, in the *Haplocytheridea sarectaensis* Brown assemblage, the abundance of *Haplocytheridea* specimens and *Antibythocypris minuta* (Berry) in moderately diverse subassemblages at 1,021 and 1,015 ft suggests an inner-neritic paleoenvironment. The abundance of two *Haplocytheridea* species in the higher samples representing this assemblage and the paucity of other taxa suggest possible environmental restrictions during sedimentation in an inner-neritic paleoenvironment, perhaps a low-oxygen water column.

DISCUSSION

The relatively little-studied ostracode species *Haplocytheridea sarectaensis* Brown holds potential as a local biostratigraphic marker. Known occurrences of this species in eastern Georgia and South Carolina are limited to the

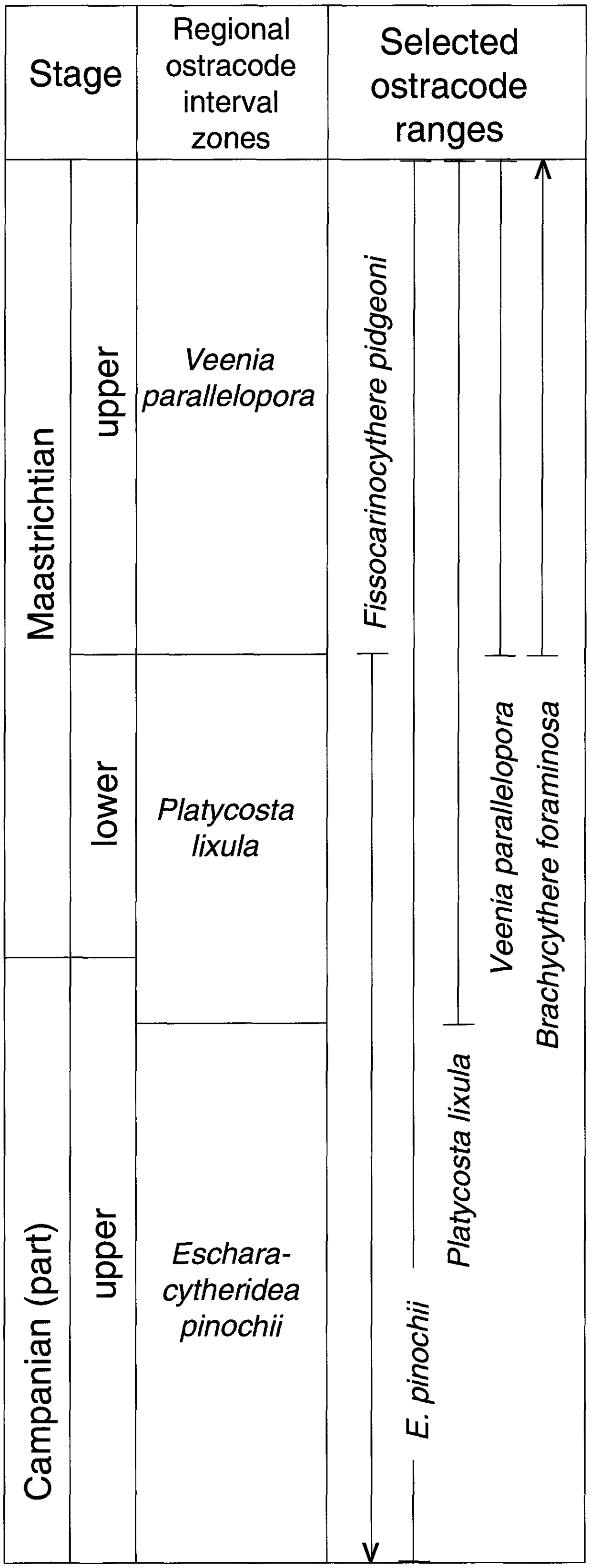

Figure 3. Ostracode interval zones and associated ostracode datums. The ostracode interval zones are from Hazel and Brouwers (1982) as modified by Pitakpaivan and Hazel (1994).

upper part of calcareous nannofossil Zone CC 22. *Haplocytheridea sarectaensis* Brown is present in the interval assigned to Zone CC 22 in the Millhaven core (Bukry, this volume, chap. D) and in the USGS-St. George core in northern Dorchester County, central South Carolina (Self-Trail and Gohn, 1996; for locations, see fig. 1 of this chapter). I also have recorded *H. sarectaensis* Brown at 923 to 898 ft in the USGS-Clubhouse Crossroads No. 1 core in southern Dorchester County, which is in a section representing calcareous nannofossil zone CC 22 (data in Hattner and Wise, 1980; J.M. Self-Trail, USGS, 1995, written commun.). In addition, some specimens from Sumter County, S.C., cores (fig. 1) that I previously assigned to *Haplocytheridea wilmingtonensis* Brown (*in* Prowell, 1993, p. 43) are assigned here to *H. sarectaensis* Brown. These occurrences of *H. sarectaensis* Brown in the Sumter County cores also are within calcareous nannofossil Zone CC 22 (J.M. Self-Trail, USGS, 1995, written commun.).

Burnett and others (1992), Bukry (1994; this volume, chap. D), and Burnett (1996) place the Campanian-Maastrichtian Stage boundary within calcareous nannofossil Subzone CC 23a shortly above the extinction level of *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen at the top of Zone CC 22. Therefore, the upper part of calcareous nannofossil Zone CC 22 is very late Campanian, but not latest Campanian, in age. In eastern Georgia and South Carolina, the highest occurrence of *Haplocytheridea sarectaensis* Brown approximates the top of Zone CC 22 and, hence, approximates the position of the Campanian-Maastrichtian boundary.

The sections in central South Carolina containing *Haplocytheridea sarectaensis* Brown and calcareous nannofossil Zone CC 22 are assigned to the upper part of the Donoho Creek Formation of the Black Creek Group by Gohn (1992), Prowell (1993), and Self-Trail and Gohn (1996). Black Creek subunit 2 in the Millhaven core, therefore, occupies the same biostratigraphic position as the upper part of the Donoho Creek Formation in central South Carolina; it is also generally similar lithologically to the South Carolina Donoho Creek sections. As yet, however, Black Creek subunit 2 at Millhaven has not been traced lithologically through intervening drill holes to the central South Carolina sections. Although the Donoho Creek Formation is the uppermost formation in the Black Creek Group in central South Carolina (Gohn, 1992; Self-Trail and Gohn, 1996), the equivalent section is overlain by a substantial thickness of sediments assigned to the Black Creek subunit 3 in the Millhaven core (fig. 2) (Falls and Prowell, this volume, chap. A; Frederiksen and others, this volume, chap. C).

TAXONOMIC NOTES ON OSTRACODES

Most of the described ostracode species listed in table 1 are common, widespread forms that are adequately illustrated in the literature. Except for a few selected taxa, these common species are not illustrated in this report; however, synonymies are provided as a guide to my concepts of these taxa. Brouwers and Hazel (1978) discussed many of the species listed in these notes; their detailed synonymies provide the bases for many of the synonymies used here. Undescribed species listed in table 1 are represented by small numbers of valves and are not treated in these notes; the several species representing the smooth-valved genus *Cytherella* Jones also are not treated. Listed stratigraphic ranges are from Hazel and Brouwers (1982) unless otherwise stated.

ANTIBYTHOCYPRIS FABAFORMIS (BERRY, 1925)

Cytherella fabaformis Berry, 1925, p. 487, fig. 13.

Cytheridea fabaformis (Berry, 1925). Alexander, 1929, p. 76, pl. 5, fig. 18.

Haplocytheridea? fabaformis (Berry, 1925). Schmidt, 1948, p. 426, pl. 62, fig. 23, text-fig. 2e; Howe and Laurencich, 1958, p. 350, text-fig.; Benson and Tatro, 1964, p. 16, pl. 3, fig. 13; Crane, 1965, p. 199, pl. 1, fig. 11*A*, *B*; Van Nieuwenhuise and Kanes, 1976, pl. 3, fig. *B*.

Cytheridea (Haplocytheridea) fabaformis (Berry, 1925). Brown, 1957, p. 17, pl. 2, figs. 7, 8; Brown, 1958, p. 58, pl. 5, fig. 7.

Antibythocypris fabaformis (Berry, 1925). Brouwers and Hazel, 1978, p. 25, pl. 2, fig. 8; pl. 3, figs. 1–3; pl. 10, fig. 5; Hazel and Brouwers, 1982, p. 181, pl. 5, fig. 3; Gohn, 1995, pl. II, fig. 9.

Cythere ulrichi Berry, 1925, p. 483, fig. 3.

Stratigraphic range.—Middle Campanian through Maastrichtian.

ANTIBYTHOCYPRIS MINUTA (BERRY, 1925)

Plate 1, figure 3

Cytherideis minutus Berry, 1925, p. 487, fig. 12.

Cytherideis minuta Berry, 1925. Howe and Laurencich, 1958, p. 286.

Antibythocypris minuta (Berry, 1925). Brouwers and Hazel, 1978, p. 25, pl. 3, figs. 4–7; pl. 10, fig. 6; Hazel and Brouwers, 1982, p. 184, pl. 4, fig. 2; pl. 5, fig. 13; Gohn, 1995, pl. II, fig. 11.

Haplocytheridea? ulrichi (Berry, 1925). Schmidt, 1948, p. 426, pl. 62, figs. 18, 19; Howe and Laurencich, 1958, p. 358, text-fig.; Crane, 1965, p. 200, pl. 1, fig. 9*A*, *B*.

Cytheridea (Haplocytheridea) ulrichi (Berry, 1925). Brown, 1957, p. 18, pl. 2, figs. 4, 5; Brown, 1958, p. 58, pl. 5, fig. 6.

Haplocytheridea? macropora (Alexander, 1929). Schmidt, 1948, p. 425, pl. 62, fig. 24; Van Nieuwenhuise and Kanes, 1976, pl. 4, fig. *A*.

Remarks.—*Cythere ulrichi* Berry, 1925, is the female dimorph of *Antibythocypris fabaformis* (Berry, 1925). The similar species *Antibythocypris macropora* (Alexander, 1929) is common in the Gulf of Mexico Coastal Plain but is rare in the Atlantic Coastal Plain. *Antibythocypris minuta* typically occurs in inner-neritic muddy sands in South Carolina sections of the Black Creek Group and Peedee Formation (Self-Trail and Gohn, 1996).

Stratigraphic range.—Middle Campanian through Maastrichtian.

BRACHYCYTHERE OVATA (BERRY, 1925)

Cythereis ovatus Berry, 1925, p. 484, fig. 15.

Cythere ovata (Berry, 1925). Alexander, 1929, p. 87, pl. VII, figs. 10, 13.

Brachycythere ovata (Berry, 1925). Skinner, 1956, p. 190, pl. II, fig. 3*A*–*C*; Howe and Laurencich, 1958, p. 89, text-figs.; Benson and Tatro, 1964, p. 19, pl. 4, figs. 11–13, text-fig. 6; Crane, 1965, p. 210, pl. 4, fig. 1*A*, *B*; Brouwers and Hazel, 1978, pl. 7, figs. 5–7, pl. 11, fig. 4; Hazel and Brouwers, 1982, p. 185, pl. 4, fig. 12; Pitakpaivan and Hazel, 1994, fig. 3-(2); Gohn, 1995, pl. II, fig. 2.

Brachycythere ovata vecarina Crane, 1965, p. 210, pl. 4, fig. 3*A*, *B*.

Cytheropteron sp. A, Israelsky, 1929, p. 7, pl. IA, fig. 1*A*, *C*.

Stratigraphic range.—Upper Campanian through Maastrichtian.

BRACHYCYTHERE RHOMBOIDALIS (BERRY, 1925)

Cythere rhomboidalis Berry, 1925, p. 481, figs. 1, 2.

Cythere rhomboidalis Berry, 1925. Alexander, 1929, p. 86, pl. VII, figs. 1, 2.

Brachycythere rhomboidalis (Berry, 1925). Schmidt, 1948, p. 414, pl. 62, figs. 8–10; Butler and Jones, 1957, p. 28, pl. 3, fig. 2*A*, *B*; Brown, 1957, p. 11, pl. 4, figs. 5, 8–10; Brown, 1958, p. 61, pl. 2, fig. 9; Howe and Laurencich, 1958, p. 90, text-figs.; Benson and Tatro, 1964, p. 19, pl. 5, figs. 16–18, text-fig. 7; Crane, 1965, p. 209, pl. 4, fig. 7; Van Nieuwenhuise and Kanes, 1976, pl. 2, fig. *C*; Brouwers and Hazel, 1978, pl. 7, fig. 8; pl. 8, figs. 1–3; pl. 11, fig. 5; Smith, 1978, p. 551, pl. 4, figs. 4–6, 10; Hazel and Brouwers, 1982, p. 189, pl. 4, fig. 6; Pitakpaivan and Hazel, 1994, fig. 3-(3); Gohn, 1995, pl. II, fig. 1.

Brachycythere jerseyensis Jennings, 1936, p. 48, pl. 6, fig. 14*A*, *B*.

Remarks.—Specimens assigned to *Pterygocythere pinguita* Crane,1965 by Crane (1965) and Smith (1978) probably represent *Brachycythere rhomboidalis* (Berry, 1925).

Stratigraphic range.—Upper Campanian through Maastrichtian.

CURFSINA COMMUNIS (ISRAELSKY, 1929)

Cythereis communis Israelsky, 1929, p. 14, pl. 3*A*, figs. 9–13.

Cythereis communis Israelsky, 1929. Alexander, 1929, p. 101, pl. IX, fig. 18; Jennings, 1936, p. 52, pl. 7, fig. 3; Schmidt, 1948, p. 419, pl. 61, figs. 11–13; Skinner, 1956, p. 196, pl. III, fig. 7*A*–*E*; Butler and Jones, 1957, p. 35, pl. 3, fig. 6; Howe and Laurencich, 1958, p. 189, text-fig; Crane, 1965, p. 221, pl. 6, fig. 12; Van Nieuwenhuise and Kanes, 1976, pl. 2, figs. *A*, *B*; Brouwers and Hazel, 1978, pl. 5, figs. 7–9; pl. 10, fig. 8; Smith, 1978, p. 554, pl. 5, figs. 20–23.

Trachyleberis communis (Israelsky, 1929). Brown, 1957, p. 14, pl. 3, figs. 10, 11; Brown, 1958, p. 63, pl. 4, fig. 5.

Trachyleberis? *communis* (Israelsky, 1929). Benson and Tatro, 1964, p. 22, pl. 5, figs. 13–15, text-fig. 10.

Curfsina communis (Israelsky, 1929). Hazel and Brouwers, 1982, p. 180, pl. 1, fig. 12; Pitakpaivan and Hazel, 1994, fig. 3-(4); Gohn, 1995, pl. I, fig. 5.

Paracythereis semilenis Schmidt, 1948, p. 418, pl. 61, fig. 14.

Remarks.—*Paracythereis semilenis* Schmidt, 1948, is a molt of *Curfsina communis* (Israelsky, 1929).

Stratigraphic range.—Middle Campanian through Maastrichtian.

EOCYTHEROPTERON STRAILLIS BROWN, 1957

Plate 1, figure 6

Cytheropteron (Eocytheropteron) straillis Brown, 1957, p. 20, pl. 6, figs. 14, 15.

Cytheropteron (Eocytheropteron) straillis Brown, 1957. Brown, 1958, p. 60, pl. 7, fig. 14.

Stratigraphic range.—Upper Campanian-Maastrichtian (data in Brown, 1957; this report).

ESCHARACYTHERIDEA PINOCHII (JENNINGS, 1936)

Plate 1, figure 5

Cytheridea pinochii Jennings, 1936, p. 58, pl. 7, fig. 9.

Haplocytheridea? *pinochii* (Jennings, 1936). Howe and Laurencich, 1958, p. 356, text-fig.

Escharacytheridea pinochii (Jennings, 1936). Hazel and Brouwers, 1982, p. 185, pl. 5, fig. 9; pl. 6, fig. 13; Gohn, 1995, pl. III, fig. 1; Puckett, 1995, p. 25, pl. 1, figs. 13, 14.

Remarks.—Marker species for the base of the *Escharacytheridea pinochii* Interval Zone of Hazel and Brouwers (1982).

Stratigraphic range.—Upper Campanian and Maastrichtian.

FISSOCARINOCYTHERE PIDGEONI (BERRY, 1925)

Cytheridea pidgeoni Berry, 1925, p. 485, figs. 7, 8.

Cythereis pidgeoni (Berry, 1925). Schmidt, 1948, p. 421, pl. 62, figs. 2–6; Howe and Laurencich, 1958, p. 223, text-figs.; Crane, 1965, p. 216, pl. 5, fig. 10*A*, *B*; Van Nieuwenhuise and Kanes, 1976, p. 87, pl. 4, fig. *B*.

Trachyleberis pidgeoni (Berry, 1925). Brown, 1957, p. 14, pl. 7, figs. 26, 27; Brown, 1958, p. 63, pl. 4, fig. 3; Benson and Tatro, 1964, p. 22, pl. 5, figs. 1–3, text-fig. 11.

Fissocarinocythere pidgeoni (Berry, 1925). Brouwers and Hazel, 1978, p. 40, pl. 7, figs. 1–4; pl. 11, fig. 3; Hazel and Brouwers, 1982, p. 185, pl. 1, fig. 14.

"Archicythereis" cf. *Cythereis pidgeoni* (Berry, 1925). Schmidt, 1948, p. 417, pl. 62, fig. 1.

Remarks.—*"Archicythereis"* cf. *Cythereis pidgeoni* (Berry, 1925) of Schmidt (1948) is a molt of *Fissocarinocythere pidgeoni* (Berry, 1925). Marker species for the top of the *Platycosta lixula* Interval Zone of Pitakpaivan and Hazel (1994).

Stratigraphic range.—Upper Campanian and lower Maastrichtian (Hazel and Brouwers, 1982; Pitakpaivan and Hazel, 1994).

HAPLOCYTHERIDEA EVERETTI (BERRY, 1925)

Cytheridea everetti Berry, 1925, p. 486, fig. 9.

Cytheridea everetti Berry, 1925. Alexander, 1929, p. 74, pl. 5, figs. 9, 10.

Haplocytheridea? *everetti* (Berry, 1925). Howe and Laurencich, 1958, p. 350, text-fig.

Haplocytheridea everetti (Berry, 1925). Brouwers and Hazel, 1978, p. 17, pl. 1, figs. 4, 6, 7, 9; pl. 10, fig. 3; Smith, 1978, p. 550, pl. 2, fig. 18; Hazel and Brouwers, 1982, p. 181, pl. 5, fig. 8; Puckett, 1992, pl. 2, fig. 14.

Cytheridea monmouthensis Berry, 1925, p. 486, fig. 10.

Cytheridea (Haplocytheridea) monmouthensis (Berry, 1925). Brown, 1957, p. 19, pl. 2, fig. 6; Brown, 1958, p. 58, pl. 5, fig. 11.

Haplocytheridea monmouthensis (Berry, 1925). Benson and Tatro, 1964, p. 16, pl. 6, figs. 17, 21, 23.

Cytheridea truncatus Berry, 1925, p. 485, fig. 6.

Haplocytheridea plummeri (Alexander, 1929). Schmidt, 1948, p. 425, pl. 62, figs. 27–29.

Cytheridea (Haplocytheridea) plummeri Alexander, 1929. Brown, 1957, p. 18, pl. 2, figs. 9–11.

Cytheridea (Haplocytheridea) punctura (Schmidt, 1948). Brown, 1957, p. 19, pl. 2, figs. 26–28; Brown, 1958, pl. 5, fig. 11.

Remarks.—*Cytheridea truncatus* Berry, 1925 is a juvenile of *Haplocytheridea everetti* (Berry, 1925).

Stratigraphic range.—Middle Campanian through Maastrichtian.

HAPLOCYTHERIDEA RENFROENSIS CRANE, 1965

Haplocytheridea? *renfroensis* Crane, 1965, p. 201, pl. 2, fig. 1*A*, *B*.

Haplocytheridea renfroensis Crane, 1965. Brouwers and Hazel, 1978, p. 18, pl. 1, fig. 8; pl. 2, figs. 1, 2; pl. 10, fig. 4; Hazel and Brouwers, 1982, p. 189, pl. 4, fig. 17; pl. 5, fig. 11; Pitakpaivan and Hazel, 1994, fig. 5-(4).

Cytheridea monmouthensis Berry, 1925. Alexander, 1929, p. 74, pl. 5, figs. 11–14.

Haplocytheridea monmouthensis (Berry, 1925). Swain, 1952, p. 79, pl. 18, fig. 19; Howe and Laurencich, 1958, p. 355, text-fig.

Haplocytheridea? sp. cf. *H. monmouthensis* (Berry, 1925). Crane, 1965, p. 200, pl. 1, fig. 12*A*, *B*.

Haplocytheridea? *monmouthensis* (Berry, 1925). Smith, 1978, p. 550, pl. 2, figs. 14–16.

Haplocytheridea pinochii (Jennings, 1936). Schmidt, 1948, p. 427, pl. 61, figs. 25, 26.

Cytheridea plummeri Alexander, 1929. Skinner, 1956, p. 197, pl. 4, fig. 2*A*, *D*.

Haplocytheridea? *plummeri* (Alexander, 1929). Butler and Jones, 1957, p. 16, pl. 4, fig. 9; Benson and Tatro, 1964, p. 16, pl. 3, figs. 25–27.

Stratigraphic range.—Middle Campanian through Maastrichtian.

HAPLOCYTHERIDEA SARECTAENSIS BROWN, 1957

Plate 1, figures 1, 2

Cytheridea (Haplocytheridea) sarectaensis, Brown, 1957, p. 17, pl. 7, figs. 1–3.

Description.—Sexual dimorphism is pronounced. Females have a rounded subtriangular outline and are flattened ventrally; the dorsal margin is broadly convex and slightly angled in front of mid-length; the ventral margin is straight in right valves, slightly sinuous in left. Males have elongate-subquadrate outlines; the dorsal margin is very broadly convex; the ventral margin is straight in right valves, slightly sinuous in left. The central three-quarters of the lateral surface has prominent smooth, low, subvertical ridges that alternate with pitted subvertical furrows. The longest furrow is slightly in front of the mid-length and is convex toward the anterior; the marginal areas of the lateral surfaces are smooth. A low node is present near the posterior-ventral termination in right valves. An indistinct, vertically elongate node near the anterior margin causes the lateral surface to descend steeply to the slanting anterior margin; this node is most pronounced in right valves. The valves have a narrow duplicature and a shallow anterior vestibule. The valves have a holomerodont hinge, the anterior hinge element is distinctly larger than the posterior element, and the medial element is narrow. Muscle scars are not discerned.

Measurements.—Below are measurements (in millimeters) of 16 female and 6 male specimens:

	Number	Average	Observed range
Female:			
Length	16	0.63	0.58–0.67
Height	16	0.36	0.33–0.45
Male:			
Length	6	0.75	0.72–0.78
Height	6	0.40	0.37–0.43

Comparisons.—The smaller size, pronounced dimorphism, and vertical ridges and furrows of *Haplocytheridea sarectaensis* Brown readily distinguish this species from *Haplocytheridea everetti* (Berry) and *Haplocytheridea renfroensis* Crane.

Remarks.—As noted by Brown (1957), this species closely resembles early Tertiary species that were later assigned by Hazel (1968) to the genus *Phractocytheridea* Sutton and Williams. In fact, Hazel (1968, p. 131) included *Haplocytheridea sarectaensis* Brown in *Phractocytheridea* Sutton and Williams. However, the Millhaven specimens appear to lack the strong shelf at the bottom of the anterior socket (left-valve hinge) that was deemed characteristic of *Phractocytheridea* Sutton and Williams by Hazel (1968). Therefore, this species is left in *Haplocytheridea* Stephenson in this report. At least one of the specimens assigned to *Phractocytheridea* cf. *P. sarectaensis* (Brown, 1957) by Puckett (1996, pl. 2, fig. 4) represents the related, more rugose species *Haplocytheridea wilmingtonensis* Brown.

Stratigraphic range.—Upper Campanian (data in Brown, 1957; Self-Trail and Gohn, 1996; Gohn, this report).

HAPLOCYTHERIDEA SP. AFF. *HAPLOCYTHERIDEA EVERETTI* (BERRY, 1925)

Plate 1, figure 4

Description.—Valves are moderate sized and subtriangular; males are slightly longer than females. The dorsal margin is slightly angled in females; the ventral margin is sinuous in left valves and straight in right valves. The anterior margin is broadly rounded and denticulate; denticles are more abundant on the right valve; the posterior margin is rounded and extended. The posterior fifth of the ventral margin is denticulate in the right valve. Node-like thickenings of the left valve occur at the center of the anterior margin and at the posterior termination; this thickening is most pronounced in females. The central two-thirds of the lateral surface has moderate-sized pits; two short, smooth vertical ridges at the center are separated and flanked by shallow, pitted furrows. In right valves, the lateral surface descends at a steep angle to the anterior margin, producing a blunt anterior termination. The anterior vestibule is shallow; the hinge is holomerodont.

Stratigraphic range.—Middle and upper Campanian (Gohn, this report; G. Gohn, unpub. data).

ORTHONOTACYTHERE HANNAI (ISRAELSKY, 1929)

Cytheridea? *hannai* Israelsky, 1929, p. 12, pl. 2A, fig. 10*A*, *B*.

Cytheropteron hannai (Israelsky, 1929). Alexander, 1929, p. 105, pl. IX, fig. 16.

Orthonotacythere hannai (Israelsky, 1929). Alexander, 1933, p. 200, pl. 25, fig. 1*A*–*C*; pl. 26, fig. 6*A*, *B*; pl. 27, fig. 14*A*, *B*; Skinner, 1956, p. 202, pl. IV, fig. 9*A*, *B*; Butler and Jones, 1957, p. 21, pl. 4, fig. 2; Brown, 1957, p. 24, pl. 6, figs. 3–5; Brown, 1958, p. 67, pl. 4, fig. 13; Howe and Laurencich, 1958, p. 436, text-figs.; Crane, 1965, p. 207, pl. 8, fig. 24; Brouwers and Hazel, 1978, pl. 9, fig. 4; Smith, 1978, p. 551, pl. 3, fig. 13; Hazel and Brouwers, 1982, p. 184, pl. 3, fig. 6; Pitakpaivan and Hazel, 1994, fig. 5-(8).

Orthonotacythere (Orthonotacythere) hannai (Israelsky, 1929). Benson and Tatro, 1964, p. 27, pl. 6, figs. 6, 7.

Stratigraphic range.—Upper Campanian and Maastrichtian (Crane, 1965; Puckett, 1996).

ORTHONOTACYTHERE SULCATA BROWN, 1957

Orthonotacythere sulcata Brown, 1957, p. 23, pl. 6, figs. 6–8.

Orthonotacythere sulcata Brown, 1957. Brown, 1958, p. 68, pl. 4, fig. 14.

Remarks.—This species may be equivalent to *Orthonotacythere scrobiculata* Alexander (Alexander, 1934).

Stratigraphic range.—Campanian (data in Brown, 1957, 1958; Self-Trail and Gohn, 1996).

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PLATE 1

PLATE 1

[All specimens are selected Cretaceous ostracodes from the Black Creek Group in the Millhaven core from Screven County, Georgia]

Figure 1. *Haplocytheridea sarectaensis* Brown, 985 ft, exterior view of female right valve (× 90).
2. *Haplocytheridea sarectaensis* Brown, 985 ft, exterior view of male left valve (× 68).
3. *Antibythocypris minuta* (Berry), 1,021 ft, exterior view of male left valve (× 73).
4. *Haplocytheridea* sp. aff. *Haplocytheridea everetti* (Berry), 1,021 ft, exterior view of female left valve (× 75).
5. *Escharacytheridea pinochii* (Jennings), 1,043 ft, exterior view of right side of female carapace (× 91).
6. *Eocytheropteron straillis* Brown, 1,015 ft, exterior view of female(?) left valve (× 66).

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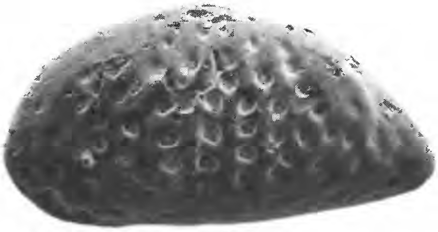

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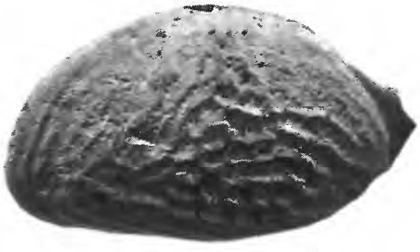

6

OSTRACODES

U.S. Department of the Interior
U.S. Geological Survey

Calcareous Nannofossil Biostratigraphy of Cenozoic Sediments from the Millhaven Core, Screven County, Georgia

By Laurel M. Bybell

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1603–F

Prepared in cooperation with the
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Georgia Geologic Survey

GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Edited by Lucy E. Edwards

CONTENTS

PLATE

[Plate follows References Cited]

FIGURES

GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Calcareous Nannofossil Biostratigraphy of Cenozoic Sediments from the Millhaven Core, Screven County, Georgia

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ABSTRACT

Calcareous nannofossils were examined from the Cenozoic portion of the Millhaven core that was drilled by the U.S. Geological Survey in Screven County, Georgia. Calcareous nannofossil Zones NP 4, NP 5, and NP 8 are present in the Paleocene Ellenton Formation; calcareous nannofossils were not examined from the overlying noncalcareous Snapp Formation; Zone NP 14 is present in the overlying middle Eocene Congaree Formation; Zone NP 15 occurs in the Warley Hill Formation; Zone NP 17 occurs in the upper middle Eocene Santee Limestone; and Zone 19/20 and probably Zone 21 occur in the upper Eocene and possibly lower Oligocene Barnwell unit. A few samples were examined from the Ellenton Formation in the core from the nearby Girard test hole and the Santee Limestone in the Millers Pond core. These samples could add no more precise information concerning the age of these two formations.

INTRODUCTION

PURPOSE AND SCOPE

In this study, calcareous nannofossils were examined from 68 samples from the Cenozoic portion of the Millhaven core in order to establish a biostratigraphic framework that could be used to understand better the groundwater flow in the aquifers in the region near the Savannah River Site. I anticipated that calcareous nannofossils would not be useful in dating the more updip Girard and Millers Pond test holes, but I examined a few select samples in order to test this hypothesis. Falls and Prowell (this volume, chap. A) describe the lithology and physical stratigraphy of the Cretaceous and Cenozoic sediments recovered in the cores.

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Donald Queen, Eugene Cobbs, and Eugene Cobbs III, of the U.S. Geological Survey (USGS), drilled the Millhaven corehole, and I thank them for their diligent efforts in obtaining good core recovery. I thank Jean M. Self-Trail (USGS) and Amanda Chapman (USGS) for their preparation of the calcareous nannofossil samples and their excellent illustrations. I also thank Jean M. Self-Trail and Raymond A. Christopher (Clemson University) for their thoughtful reviews of the manuscript.

MATERIAL AND METHODS

The Millhaven test hole (33X048) was drilled in Screven County, Ga., in late 1991 and early 1992 as part of a cooperative effort among the U.S. Geological Survey, the U.S. Department of Energy, and the Georgia Geologic Survey of the Georgia Department of Natural Resources. The test hole is located at lat 32°53'25" N. and long 81°35'43" W. (fig. 1). The drill site is located at an altitude of 110 ft, and the test hole was drilled to a depth of 1,452 ft. The hole was continuously cored, and the cores are temporarily stored at the U.S. Geological Survey in Reston, Va.

Sixty-eight samples between the depths of 639.6 and 59.8 ft in the Millhaven core were examined for their calcareous nannofossil content (fig. 2). Two samples were examined from the Girard core (32Y020), which was drilled by the U.S. Geological Survey in 1992 in southern Burke County, Ga., at the lookout tower on Griffins Landing Road, 2 miles north of the town of Girard at lat 33°03'54" N. and long 81°43'13" W. (fig. 1). Three samples were examined

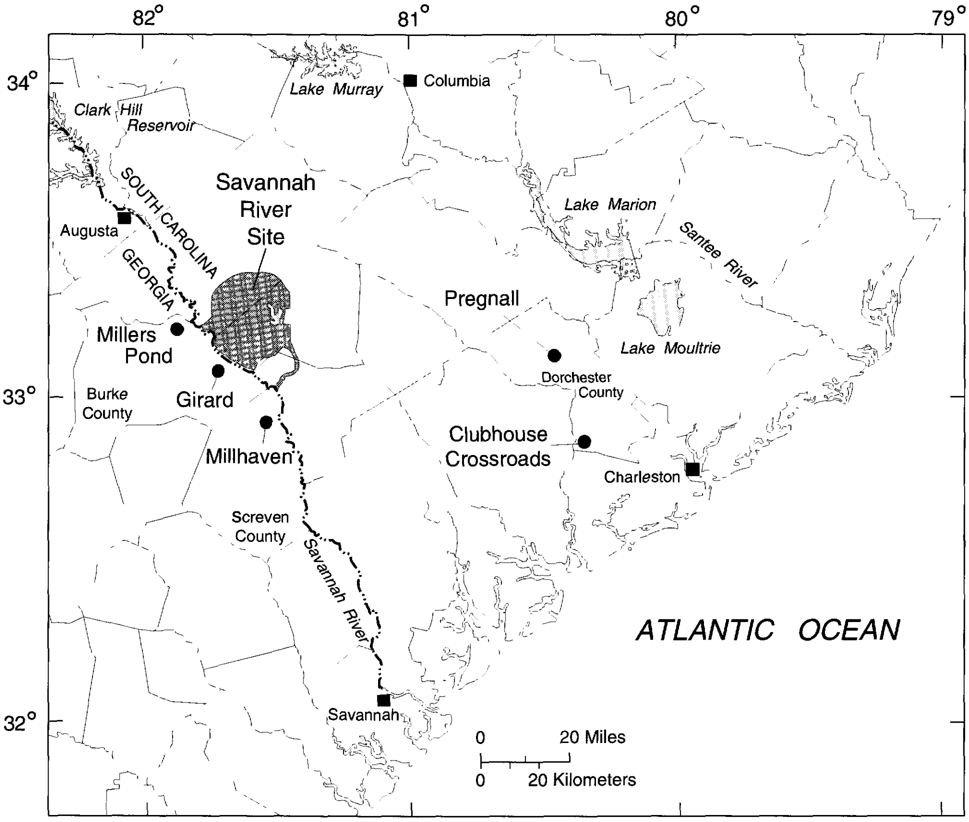

Figure 1. Location of the Millhaven, Girard, and Millers Pond test holes in Georgia and additional test holes in South Carolina.

from the Millers Pond core (GGS–3758, Burke 2), which was drilled by the Georgia Geologic Survey in 1991 in northern Burke County, Ga., 2 miles west of the Savannah River and 16 miles south of Augusta at lat 33°13'48" N. and long 81°52'44" W. (fig. 1). Comparisons are made with calcareous nannofossil data obtained from the Clubhouse Crossroads core No. 1 (Hazel and others, 1977) and the Pregnall core (Edwards and others, 1997), both located in Dorchester County, S.C.

Calcareous nannofossil samples were extracted from the central portion of core-segment surfaces (freshly broken where possible) at approximately 2- to 10-ft intervals. 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 author's laboratory at the U.S. Geological Survey in Reston, Va. A timed settling procedure was used to obtain the optimum sediment-size fraction. For this procedure, a small amount of sample was placed in a beaker, stirred, and settled through 2 cm of water. The first settling time was 1 minute to remove the coarse material, and the second settling time was 10 minutes to remove the fine clay fraction. Smear slides then were prepared from the remaining 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.

Initially, all samples were examined by using a Zeiss Photomicroscope III. A few samples, which were thought to have the best preservation and the highest abundances of calcareous nannofossils, were scanned by using a JEOL 35 scanning electron microscope (SEM). Photomicrographs of several of the best preserved specimens are presented on plate 1.

BIOSTRATIGRAPHIC ZONATION

In this study, the biostratigraphic zonation of the Cenozoic strata is based primarily on the calcareous nannofossil zonation of Martini (1971) and secondarily on the zonation of Bukry (1973, 1978) and Okada and Bukry (1980). The calcareous nannofossil assemblages usually were sufficient in numbers of specimens, diversity of taxa, and preservational state in the Millhaven strata to allow placement of most samples within one specific calcareous nannofossil zone (fig. 3).

Text continues on p. F8.

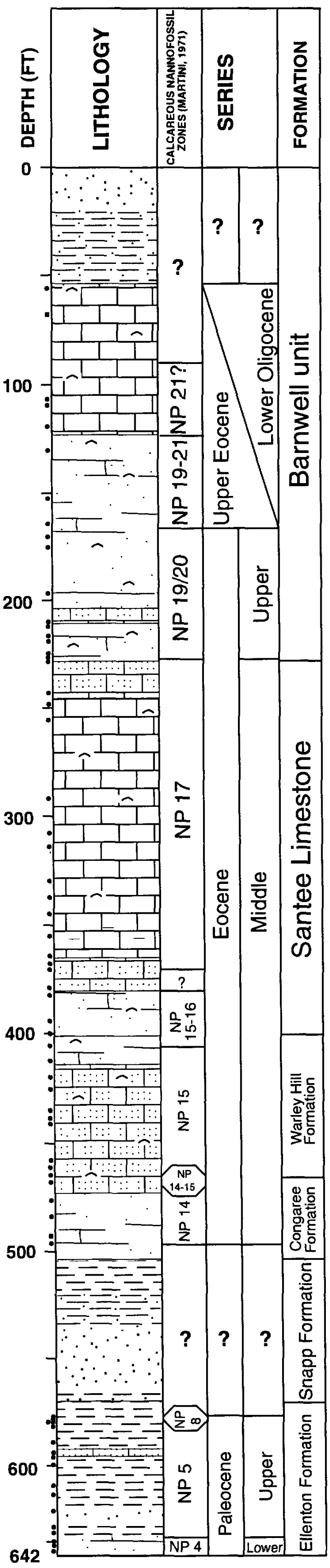

Figure 2. Calcareous nannofossil biostratigraphic zonation of Cenozoic intervals in the Millhaven core from Georgia. Lithology and formations from Falls and Prowell (this volume, chap. A).

Species	Ellenton Formation																	Congaree Fm.					Warley Hill Formation									
	Early Paleocene			Late Paleocene														Middle Eocene														
NP Zone	NP 4	NP 4	NP 4	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 8	NP 8	NP 14	NP 14	NP 14	NP 14	NP 14/15	NP 14/15	NP 15	NP 15	NP 15	NP 15	NP 15	NP 15	NP 15	NP 15	NP 15/16
Depth (ft)	639.6	636.8	635.4	631.3	628.7	621.2	613.1	609.8	599.1	595.6	593.7	589.0	581.0	579.5	579.2	578.0	577.2	497.4	495.5	481.5	473.5	465.5	462.0	458.1	456.0	443.3	442.5	435.5	426.5	420.5	413.0	404.0
Blackites creber	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	.	.	.	.	.	.	.	.	.
Blackites scabrosus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	.	.	.	.	.	.	.	x	.
Blackites spinosus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Blackites tenuis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	.	.	x	.	.	.	.	.	.	x
Braarudosphaera bigelowii	.	.	.	.	x	.	x	.	.	.	x	.	x	x	x	x	.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Braarudosphaera discula	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.
Braarudosphaera stylifer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.
Campylosphaera dela	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	x	.	x	x	x	.	.	x	x	x	x
Cepekiella lumina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	.	.	x	.	.	.	.	.	x	x	.
Chiasmolithus bidens	.	.	.	x	x	x	x	.	x	.	x	.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	.	.	.	.	x	x
Chiasmolithus sp. aff. *C. bidens*	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chiasmolithus consuetus s.l.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chiasmolithus eograndis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chiasmolithus expansus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.
Chiasmolithus gigas	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	x	.	x	.	.	.	x	x	.
Chiasmolithus grandis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	x	.	x	x	.	x	.	x	x
Chiasmolithus oamaruensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chiasmolithus spp. small unsplit	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	x	x	x	.	x	x	x	x	x	x	x	x	x
Chiphragmalithus acanthodes	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
Coccolithus eopelagicus	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	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
Cribrocentrum reticulatum	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cruciolithus spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.
Cruciplacolithus primus	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cruciplacolithus staurion	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.
Cruciplacolithus tenuis	.	.	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cruciplacolithus spp.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	x	x	.	.	x	.	x	.	.	.	.	.	.	.	.	.	.	.
Cyclagelosphaera prima	x	.	.	x	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cyclococcolithus formosus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cyclococcolithus protoannulus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	x	.	.	.	.	.	.
Cyclococcolithus spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	x	.	.	.	x	.	.	.	.	.	x	x	x
Dictyococcites bisectus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dictyococcites scrippsae	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Discoaster barbadiensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	x	x	x	.	x	x	.	.	x	x	x	x	x
Discoaster distinctus/deflandrei	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	x	.	.	.	.	.	.
Discoaster kuepperi	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.
Discoaster sp. aff. *D. kuepperi*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	x	x	.	.	.	.	.	.
Discoaster limbatus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Discoaster lodoensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	1	1	.	.	.	1	.	.	.	.	.	.	.	.
Discoaster mirus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Discoaster saipanensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	x	.	x	.	.	.	.	x	.
Discoaster sublodoensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	x	x	.	.	.	.	.	.	.	.	.	.	.	.
Discoaster tanii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Discoaster woodringii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ellipsolithus distichus	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ellipsolithus lajollaensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.
Ellipsolithus macellus	x	.	.	.	.	.	.	.	.	.	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ericsonia obruta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.
Ericsonia subpertusa	x	x	x	x	x	x	x	.	.	.	x	.	x	x	x	x	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.
Fasciculithus tympaniformis	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Fasciculithus spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Goniolithus fluckigeri	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hayella situliformis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Helicosphaera bramlettei	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Helicosphaera compacta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Helicosphaera intermedia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Helicosphaera lophota	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	.	.	x	x	.	.	.	.	.	x	.
Helicosphaera reticulata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Figure 3. Calcareous nannofossil occurrence chart for Cenozoic deposits in the Millhaven core from Georgia. The following symbols are used. Abundance: A, abundant or greater than 10 specimens per field of view at × 500; C, common or 1 to 10 specimens per field of view at × 500; F, frequent or 1 specimen per 1 to 10 fields of view at × 500; R, rare or 1 specimen in greater than 10 fields of view at × 500; B, barren of calcareous nannofossils. Preservation: F, fair; P, poor; T, terrible. Other symbols: 1,2,3, only one, two, or three specimens observed in entire sample; C, contaminated specimen from elsewhere; ?, possible occurrence.

Santee Limestone																	Barnwell unit																			
Middle Eocene																		Late Eocene									Late Eocene/ Early Oligocene									
NP 15/16	NP 15/16	NP 15/16	?	?	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19–21	NP 19–21	NP 19–21	NP 21–?	NP 21–?	NP 21?	NP 21?	?	?	
400.0	396.0	379.8	375.0	370.9	368.0	365.0	355.0	346.0	338.0	331.0	313.5	307.0	290.8	256.3	248.0	242.5	227.5	225.9	223.8	219.0	216.5	212.2	210.0	195.0	176.0	168.5	160.0	151.0	131.0	118.0	105.0	103.5	95.0	65.3	59.8	Species
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*Blackites creber*
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x	x	.	.	.	x	x	x	.	.	.	.	.	.	.	.	.	x	x	x	x	x	x	.	x	x	.	.	.	.	.	x	x	x	.	.	*Braarudosphaera bigelowii*
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x	x	x	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*Campylosphaera dela*
x	x	x	.	.	.	x	x	.	.	.	.	.	.	.	.	.	x	x	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	*Cepekiella lumina*
x	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	*Chiasmolithus bidens*
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x	x	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	x	.	.	*Chiasmolithus* spp. small unsplit
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x	.	.	.	.	x	x	.	.	.	.	x	.	.	.	.	.	x	x	x	.	.	x	.	x	.	x	.	.	.	.	.	.	x	.	.	*Coccolithus eopelagicus*
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	.	.	*Coccolithus pelagicus*
.	.	.	.	.	x	x	x	x	.	x	x	x	.	x	.	.	x	x	x	x	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	*Cribrocentrum reticulatum*
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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	.	.	*Cyclococcolithus formosus*
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x	x	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*Cyclococcolithus* spp.
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.	.	.	.	.	.	x	x	.	.	x	.	.	.	.	.	.	x	x	.	x	x	x	x	x	.	.	.	.	.	.	x	x	x	.	.	*Dictyococcites scrippsae*
x	.	.	.	.	x	x	.	.	.	x	.	.	.	.	.	.	x	x	x	.	x	x	.	2	x	x	.	.	.	.	.	.	.	.	.	*Discoaster barbadiensis*
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Figure 3. Continued.

	Ellenton Formation[1]																	Congaree Fm.					Warley Hill Formation									
	Early Paleocene			Late Paleocene														Middle Eocene														
NP Zone	NP 4	NP 4	NP 4	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 5	NP 8	NP 8	NP 14	NP 14	NP 14	NP 14	NP 14/15	NP 14/15	NP15	NP15	NP 15	NP 15	NP 15	NP 15	NP 15	NP 15	NP 15/16
Species / Depth (ft)	639.6	636.8	635.4	631.3	628.7	621.2	613.1	609.8	599.1	595.6	593.7	589.0	581.0	579.5	579.2	578.0	577.2	497.4	495.5	481.5	473.5	465.5	462.0	458.1	456.0	443.3	442.5	435.5	426.5	420.5	413.0	404.0
Helicosphaera seminulum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	.	x	.	.	x	.	.	.	.	x
Heliolithus riedelii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Isthmolithus recurvus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lanternithus minutus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Lithostromation operosum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.
Lithostromation simplex	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.
Lophodolithus mochlophorus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	.	.	x	.	.	.	.	.	.	.	.
Lophodolithus nascens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.
Markalius apertus	x	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Markalius inversus	.	.	x	.	.	.	.	.	.	.	x	.	.	.	x	.	.	.	.	x	.	.	.	x	.	x	.	.	.	.	.	x
Micrantholithus aequalis	.	.	.	.	.	.	.	.	.	.	.	.	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Micrantholithus crenulatus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	x	.	x	x	x	x	.	x	.	x	.
Micrantholithus fornicatus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Micrantholithus pinguis	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Neochiastozygus concinnus	x	.	x	x	x	.	x	.	.	.	.	.	.	.	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Neococcolithes dubius	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Neococcolithes sp. aff. *N. protenus*	.	.	.	.	x	.	.	.	.	.	x	.	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Neococcolithes spp.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	x	.	.	.	.	.	x	.	x	x	x	.	x	x	x
Pedinocyclus larvalis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	x	.	.
Pemma basquense	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pemma papillatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pemma rotundum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.
Pemma stradneri	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x
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Placozygus sigmoides	x	.	x	x	x	.	x	.	.	.	x	.	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pontosphaera multipora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	x	.	.	.	.	.	.	.	.	.	.	.
Pontosphaera punctosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.
Pontosphaera wechesensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.
Pontosphaera spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	x	.	x	.	.	x	x	.	.	.	x	.	x
Prinsius spp.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pseudotriquetrorhabdulus inversus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	x	x	.	.	.	.	x	x	.
Reticulofenestra daviesii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	x	.	.	.	.	.	.	x	.
Reticulofenestra floridana	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	x	x	x	x	x	x	x	.	.	x	x	x	x
Reticulofenestra hillae	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Reticulofenestra umblicus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Reticulofenestra sp. aff. *R. umbilicus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	x	.	x	.	x	.	.	x	x	x	x
Reticulofenestra spp. small	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	.	x	.	.	.	x	x	.	x	x	x	.
Rhabdosphaera inflata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Sphenolithus anarrhopus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.
Sphenolithus capricornutus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.
Sphenolithus moriformis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	.	x	x	x	.	x	x	x	x	.	x	.
Sphenolithus obtusus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.
Sphenolithus pseudoradians	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sphenolithus radians	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	.	.	.	.	.	.	.	.	.
Thoracosphaera spp.	.	x	.	x	x	x	x	x	x	.	.	.	x	.	.	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Toweius pertusus	x	.	x	x	x	.	x	.	.	.	x	.	x	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Toweius selandianus	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Transversopontis fimbriatus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.
Transversopontis pulcher	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	x	.	.	x	x	x	x	.	x	x	x
Transversopontis pulcheroides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	x	x	x	.	.	.	.	.	.	x	x
Transversopontis pulchriporus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Transversopontis zigzag	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.
Zygrhablithus bijugatus	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	x	x	x	x	x	x	x	.	x	x	x	x
placoliths	.	.	.	.	.	.	.	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cretaceous forms	x	.	x	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	x	x	.	.	.	.	.	.	.	.	.	.	.
Abundance	F	R	F	F	F	R	F	R	R	R	F	B	R	F	F	F	F-	F	R	F	C	F	F	C	F	C	C	C	F	C	F	F
Preservation	P	T	F	P	P	P	P	P	P	P	P		P	F	F	F	F	F	P	F	F	P	P	P	P	P	P	P	F	F	P	F

[1] The Snapp Formation was cored above the Ellenton Formation from 504 to 570 ft; the Snapp did not yield any calcareous nannofossil samples.

Figure 3. Calcareous nannofossil occurrence chart for Cenozoic deposits in the Millhaven core from Georgia. The following symbols are used. Abundance: A, abundant or greater than 10 specimens per field of view at × 500; C, common or 1 to 10 specimens per field of view at × 500; F, frequent or 1 specimen per 1 to 10 fields of view at × 500; R, rare or 1 specimen in greater than 10 fields of view at × 500; B, barren of calcareous nannofossils. Preservation: F, fair; P, poor; T, terrible. Other symbols: 1,2,3, only one, two, or three specimens observed in entire sample; C, contaminated specimen from elsewhere; ?, possible occurrence—Continued.

Santee Limestone																	Barnwell unit																			
Middle Eocene																		Late Eocene									Late Eocene/ Early Oligocene									
NP 15/16	NP 15/16	NP 15/16	?	?	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 17	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19/20	NP 19–21	NP 19–21	NP 19–21	NP 21–?	NP 21–?	NP 21?	NP 21?	?	?	
400.0	396.0	379.8	375.0	370.9	368.0	365.0	355.0	346.0	338.0	331.0	313.5	307.0	290.8	256.3	248.0	242.5	227.5	225.9	223.8	219.0	216.5	212.2	210.0	195.0	176.0	168.5	160.0	151.0	131.0	118.0	105.0	103.5	95.0	65.3	59.8	Species
x	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*Helicosphaera seminulum*
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x	.	.	.	.	x	x	.	.	.	.	.	x	x	.	.	.	x	x	x	x	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	*Markalius inversus*
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.	.	.	.	.	x	x	x	.	.	.	.	.	.	x	.	.	x	.	.	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	*Reticulofenestra daviesii*
x	.	x	.	x	x	x	x	x	.	x	x	x	x	x	.	.	x	x	x	x	x	x	x	x	x	.	.	.	.	.	.	.	.	.	.	*Reticulofenestra floridana*
.	.	.	.	.	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	x	x	x	.	.	.	.	.	x	x	x	.	.	*Reticulofenestra umblicus*
x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*Reticulofenestra* sp. aff. *R. umbilicus*
x	.	.	.	.	x	x	.	.	.	x	x	.	x	.	x	.	x	.	.	x	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	*Reticulofenestra* spp. *small*
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x	.	x	.	.	x	x	x	x	.	.	.	.	.	.	.	.	x	x	x	x	x	x	.	x	x	.	.	.	.	.	.	.	x	.	.	*Sphenolithus moriformis*
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x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*Sphenolithus radians*
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.	.	.	.	.	x	x	.	.	.	.	.	.	.	.	.	.	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*Transversopontis pulcheroides*
.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*Transversopontis pulchriporus*
.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	*Transversopontis zigzag*
x	x	x	.	.	x	x	x	x	.	x	x	x	x	.	.	.	x	x	x	x	x	x	x	x	x	x	.	.	.	.	.	x	x	.	.	*Zygrhablithus bijugatus*
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	placoliths
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C	F	F	B	R	F	C	F	F	R	F	C	F	F	F	F	B	F	A	C	C	F	C	C	C	F	R	B	R	B	R	F	F	C	B	B	Abundance
P	P	P		P	P	F	P	P	P	P	P	P	P	P	P		F	F	F	P	P	F	P	P	P	P		P		P	P	P	P			Preservation

Figure 3. Continued.

The following calcareous nannofossil species can be used to date sediments of early Paleocene to early Oligocene age. Many, but not all, of these species are present in the Millhaven core. A FAD indicates a first appearance datum, and a LAD indicates a last appearance datum. Zonal markers for the Martini NP zones are indicated with an asterisk (*), and a pound sign (#) indicates a zonal marker for the Bukry CP zones. The author has found the remaining species to be biostratigraphically useful in the Gulf of Mexico and Atlantic Coastal Plains (Bybell, 1982; Bybell and Gibson, 1985; Poore and Bybell, 1988; Self-Trail and Bybell, 1995).

LAD *#_Reticulofenestra umbilicus_ (Levin) Martini & Ritzkowski—top of Zone NP 22, top of Subzone CP 16c, early Oligocene

LAD *_Cyclococcolithus formosus_ Kamptner—top of Zone NP 21, early Oligocene

LAD _Isthmolithus recurvus_ Deflandre—within Zone NP 21

LAD *#_Discoaster saipanensis_ Bramlette & Riedel—top of Zone NP 19/20, top of Subzone CP 15b, late Eocene

LAD #_Discoaster barbadiensis_ Tan Sin Hok—top of Zone NP 19/20, top of Subzone CP 15b, late Eocene; actually has its LAD slightly below the LAD of _D. saipanensis_

LAD _Cribrocentrum reticulatum_ (Gartner & Smith) Perch-Nielsen—very near top of Zone NP 19/20, late Eocene

FAD *_Isthmolithus recurvus_ Deflandre—base of Zone NP 19/20, late Eocene

FAD *#_Chiasmolithus oamaruensis_ (Deflandre) Hay et al.—base of Zone NP 18, base of Subzone CP 15a, late Eocene

FAD _Helicosphaera compacta_ Bramlette & Wilcoxon—within the uppermost part of Zone NP 16; can be used to approximate the Zone NP 16/17 boundary.

LAD *#_Chiasmolithus bidens_ (Bramlette & Sullivan) Hay & Mohler/_Chiasmolithus solitus_ (Bramlette & Sullivan) Hay et al.—top of Zone NP 16, middle Eocene

FAD _Cribrocentrum reticulatum_ (Gartner & Smith) Perch-Nielsen—within Zone NP 16, middle Eocene

FAD _Dictyococcites bisectus_ (Hay et al.) Bukry & Percival—within Zone NP 16, middle Eocene

FAD _Dictyococcites scrippsae_ Bukry & Percival—within Zone NP 16, middle Eocene

FAD #_Reticulofenestra umbilicus_ (Levin) Martini & Ritzkowski—large forms first appear near base of Zone NP 16, base of Subzone CP 14a, middle Eocene

LAD *_Rhabdosphaera gladius_ Locker—top of Zone NP 15, middle Eocene

FAD *#_Nannotetrina fulgens_ (Stradner) Achuthan & Stradner—base of Zone NP 15, base of Subzone CP 13a, middle Eocene, the genus _Nannotetrina_ first appears very near the Zone NP 14/15 boundary

LAD #_Rhabdosphaera inflata_ Bramlette & Sullivan—top of Zone NP 14, base of Subzone CP 12b, middle Eocene

FAD #_Rhabdosphaera inflata_ Bramlette & Sullivan—middle of Zone NP 14, top of Subzone CP 12b, middle Eocene

FAD *#_Discoaster sublodoensis_ Bramlette & Sullivan—base of Zone NP 14, base of Subzone CP 12a, early Eocene

LAD *_Rhomboaster orthostylus_ (Shamrai) Bybell & Self-Trail—top of Zone NP 12, early Eocene

FAD _Helicosphaera lophota_ (Bramlette & Sullivan) Locker—near top of Zone NP 12; has been used to approximate the Zone NP 12/NP 13 boundary, early Eocene

FAD _Helicosphaera seminulum_ Bramlette & Sullivan—middle of Zone NP 12, early Eocene

FAD *_Discoaster lodoensis_ Bramlette & Riedel—base of Zone NP 12, early Eocene

LAD *#_Rhomboaster contortus_ (Stradner) Bybell & Self-Trail—top of Zone NP 10, top of Subzone CP 9a, early Eocene

FAD *_Rhomboaster bramlettei_ (Brönnimann & Stradner) Bybell & Self-Trail—base of Zone NP 10, early Eocene

FAD *#_Discoaster multiradiatus_ Bramlette & Riedel—base of Zone NP 9, base of Subzone CP 8a, late Paleocene

FAD *_Heliolithus riedelii_ Bramlette & Sullivan—base of Zone NP 8, late Paleocene

FAD *#_Discoaster mohleri_ Bukry & Percival—base of Zone NP 7, base of Zone CP 6, late Paleocene

FAD *#_Heliolithus kleinpellii_ Sullivan—base of Zone NP 6, base of Zone CP 5, late Paleocene

FAD _Heliolithus cantabriae_ Perch-Nielsen—within upper part of Zone NP 5, late Paleocene

FAD _Chiasmolithus bidens_ (Bramlette & Sullivan) Hay & Mohler—within Zone NP 5, late Paleocene

FAD *#_Fasciculithus tympaniformis_ Hay & Mohler—base of Zone NP 5, base of Zone CP 4, late Paleocene

FAD _Chiasmolithus_ sp. aff. _C. bidens_ (Bramlette & Sullivan) Hay & Mohler—within Zone NP 4

FAD _Toweius pertusus_ (Sullivan) Romein—within Zone NP 4

FAD _Ellipsolithus distichus_ (Bramlette & Sullivan) Sullivan—near base of Zone NP 4, early Paleocene

FAD	*#*Ellipsolithus macellus* (Bramlette & Sullivan) Sullivan—base of Zone NP 4, base of Zone CP 3, early Paleocene
FAD	*#*Chiasmolithus danicus* (Brotzen) Hay & Mohler—base of Zone NP 3, base of Zone CP 2, early Paleocene
FAD	*#*Cruciplacolithus tenuis* (Stradner) Hay & Mohler—base of Zone NP 2, base of Subzone CP 1b, early Paleocene

Calcareous nannofossil contamination normally is confined to occasional reworked specimens of Cretaceous species. However, at 639.6 ft in the Millhaven core, there is a significant amount of downhole contamination of middle Eocene calcareous nannofossil specimens into a highly porous middle Paleocene sample. This is presumed to be the result of injection into open spaces of material from farther up in the corehole via drilling fluid. Contamination of Eocene pollen also was observed in this interval (see Frederiksen, this volume, chap. H). Two samples in the Pregnall core in Dorchester County, S.C., also are contaminated with middle Eocene calcareous nannofossils (Edwards and others, 1997), but there the contamination occurs in porous upper Paleocene limestone rather than in the middle Paleocene section. The possibility for this type of contamination is always present when dealing with cores, but careful sampling procedures and awareness that contamination is possible can reduce significantly the chances for biostratigraphic dating errors.

MILLHAVEN CORE

ELLENTON FORMATION, LOWER AND UPPER PALEOCENE, ZONES NP 4, NP 5, AND NP 8

Sediments in the interval from 642 to 570 ft in the Millhaven core are placed in the Ellenton Formation (Falls and Prowell, this volume, chap. A). Seventeen samples from 639.6 to 577.2 ft in this unit were examined for their calcareous nannofossil content (fig. 3).

Three samples from 639.6, 636.8, and 635.4 ft are placed in Zone NP 4 because of the presence of *Ellipsolithus macellus* (Bramlette & Sullivan) Sullivan (FAD defines the base of Zone NP 4) and *Chiasmolithus* sp. aff. *C. bidens* (Bramlette & Sullivan) Hay & Mohler, which occurs only within Zone NP 4, and the absence of species indicative of Zone NP 5. The central X-shaped structure of *C.* sp. aff. *C. bidens* closely resembles that of *Chiasmolithus bidens* (Bramlette & Sullivan) Sullivan, except that the X is unsplit. Perch-Nielsen (1985) contains a discussion of split versus unsplit terminology for the genus *Chiasmolithus*. Lower Zone NP 4 is placed in the early Paleocene, and upper Zone NP 4 is placed in the late Paleocene (Berggren and others, 1985, 1995). Calcareous nannofossils cannot be used to determine whether the samples from the Millhaven core are in the lower or upper part of Zone NP 4. However, dinoflagellates (Edwards, this volume, chap. G) and foraminifers (Gibson, this volume, chap. I) clearly place this interval within the early Paleocene. For example, the planktonic foraminifer *Globoconusa daubjergensis* (Brönnimann), which occurs at 636.8 ft, never occurs in material younger than the lower Paleocene (Gibson, this volume, chap. I).

The 12 samples from 631.3 to 579.2 ft are placed within the lower part of Zone NP 5 (late Paleocene) by the presence of *Chiasmolithus bidens* (Bramlette & Sullivan) Hay & Mohler (FAD within Zone NP 5) and the absence of both *Heliolithus cantabriae* Perch-Nielsen (FAD in upper half of Zone NP 5) and *Heliolithus kleinpellii* Sullivan (FAD defines the base of Zone NP 6). *Fasciculithus tympaniformis* Hay & Mohler (FAD defines the base of Zone NP 5) is rare in the Millhaven core and could not be used as a reliable biostratigraphic indicator. An unconformity within the Ellenton Formation comprises the upper part of Zone NP 4.

Two samples from 578.0 and 577.2 ft are placed in the late Paleocene Zone NP 8 on the basis of the presence of *Heliolithus riedelii* Bramlette & Sullivan (FAD defines the base of Zone NP 8) and the absence of *Discoaster multiradiatus* Bramlette & Riedel (FAD defines the base of Zone NP 9). An unconformity in the Ellenton spans the upper part of Zone 5 and Zones NP 6–7. No calcareous nannofossil samples were collected from the upper 7 ft of the Ellenton Formation. It is unknown whether there might be material of Zone NP 9 age (uppermost Paleocene) in this interval. Zone NP 9 is present in Dorchester County, S.C., both in the Pregnall core (Edwards and others, 1997) and in the Clubhouse Crossroads No. 1 core (Hazel and others, 1977).

SNAPP FORMATION

Calcareous nannofossils were not examined from the noncalcareous Snapp Formation, which extends between 570 and 504 ft in the core. See Frederiksen (this volume, chap. H) for a discussion of the pollen from the Snapp Formation.

CONGAREE FORMATION, MIDDLE EOCENE, ZONE NP 14 AND POSSIBLY ZONE NP 15

Five samples were examined from the Congaree Formation, which extends from 504 to 462 ft in the Millhaven core (fig. 3). Four samples from 497.4, 495.5, 481.5, and 473.5 ft can be placed in Zone NP 14 by the presence of *Discoaster sublodoensis* Bramlette & Sullivan (FAD defines the base of Zone NP 14) at 497.4, 495.5, and 481.5 ft; the presence of *Rhabdosphaera inflata* Bramlette & Sullivan (only occurs in the upper part of Zone NP 14) at 473.5 ft; and the absence of the genus *Nannotetrina* (FAD at the base of Zone NP 15) in this material. *Discoaster saipanensis* Bramlette & Riedel (early forms of this species first appear in Zone NP 14), *Lanternithus minutus* Stradner (first appears in the upper part of Zone NP 14), and *Lithostromation operosum* (Deflandre) Bybell and *Lithostromation simplex* (Klumpp) Bybell (both first appear in Zone NP 14) are present in this interval. The sample at 473.5 ft, which is definitely in the upper part of Zone NP 14 because of the presence of *Rhabdosphaera inflata* Bramlette & Sullivan, is middle Eocene in age. The absence of *R. inflata* Bramlette & Sullivan in the lower three samples could indicate that these samples are from the lower part of Zone NP 14 (upper part of the early Eocene) or, more probably, the absence is the result of poor calcareous nannofossil assemblages in these samples. The sample from 465.5 ft contains no diagnostic species and could be in either Zone NP 14 or Zone NP 15.

WARLEY HILL FORMATION, MIDDLE EOCENE, ZONE NP 15 AND POSSIBLY ZONE NP 16

Ten samples were examined from the Warley Hill Formation, which extends from 462 to 401 ft in the Millhaven core (fig. 3). The lowest sample from 462.0 ft can be dated no closer than either Zone NP 14 or Zone NP 15. Eight samples from 458.1 to 413.0 ft are placed in Zone NP 15 because of the presence of *Chiasmolithus gigas* (Bramlette & Sullivan) Hay et al. (FAD and LAD in Zone NP 15) in this interval and because large specimens of *Reticulofenestra umbilicus* (Levin) Martini & Ritzkowski (FAD near the base of Zone NP 16) are not present. The sample from 404.0 ft can be no older than Zone NP 15 because it overlies sediments of this age and can be no younger than Zone NP 16 because it contains *Chiasmolithus bidens* (Bramlette & Sullivan) Hay & Mohler/*Chiasmolithus solitus* (Bramlette & Sullivan) Hay et al. (LAD defines the top of Zone NP 16).

SANTEE LIMESTONE, MIDDLE EOCENE, ZONE NP 17 AND POSSIBLY ZONES NP 15 OR NP 16

Seventeen samples were examined from the Santee Limestone, which extends from 401 to 228 ft in the Millhaven core (fig. 3). The deepest three samples from 400.0 to 379.8 ft tentatively are placed in Zones NP 15 or NP 16 because they contain *Chiasmolithus bidens* (Bramlette & Sullivan) Hay & Mohler/*Chiasmolithus solitus* (Bramlette & Sullivan) Hay et al. (LAD defines the top of Zone NP 16) and overlie samples of Zone NP 15 age. The sample from 375.0 ft is barren of calcareous nannofossils, and the sample from 370.9 ft contains only rare nondiagnostic species.

At 368.0 ft, the sample does contain frequent calcareous nannofossils and a moderate assemblage with 21 species present. The absence of *Chiasmolithus bidens* (Bramlette & Sullivan) Hay & Mohler/*Chiasmolithus solitus* (Bramlette & Sullivan) Hay et al. is considered to be significant, and this sample is placed in Zone NP 17. The 11 samples in the interval from 365.0 to 242.5 ft also are placed in Zone NP 17 because of the absence of *Chiasmolithus bidens* (Bramlette & Sullivan) Hay & Mohler/*Chiasmolithus solitus* (Bramlette & Sullivan) Hay et al. (LAD at the top of Zone NP 16) and the presence of *Helicosphaera compacta* Bramlette & Wilcoxon (FAD very near the top of Zone NP 16), *Reticulofenestra umbilicus* (Levin) Martini & Ritzkowski, *Cribrocentrum reticulatum* (Gartner & Smith) Perch-Nielsen, *Dictyococcites bisectus* (Hay et al.) Bukry & Percival, and *Dictyococcites scrippsae* Bukry & Percival (FAD's in Zone NP 16).

BARNWELL UNIT, UPPER EOCENE AND POSSIBLY LOWER OLIGOCENE, ZONES NP 19/20–21

Nineteen samples were examined from the Barnwell unit between 227.5 and 59.8 ft in the Millhaven test hole. The lowest calcareous nannofossil sample from the Barnwell unit at 227.5 ft tentatively has been placed in the middle Eocene Zone NP 17 because it overlies material of Zone NP 17 age but contains no species indicative of a younger age. The fact that the rest of the Barnwell unit is in the late Eocene (Zone NP 19/20 or younger) indicates that this sample most likely is also of late Eocene age, and the age discrepancy is the result of the absence of diagnostic late Eocene species in the sample. The author has observed similar discrepancies near formational contacts elsewhere in the Gulf of Mexico and Atlantic Coastal Plains.

The nine samples that were examined from 225.9 to 168.5 ft are placed in Zone NP 19/20 because of the presence of *Isthmolithus recurvus* Deflandre (FAD defines the base of Zone NP 19/20), *Discoaster saipanensis* Bramlette & Riedel (LAD defines the top of Zone NP 19/20), *Discoaster barbadiensis* Tan Sin Hok, and *Cribrocentrum reticulatum* (Gartner & Smith) Perch-Nielsen (LAD's very near the top of Zone NP 19/20). The three samples from 160.0, 151.0, and 131.0 ft can be dated no more accurately than Zone NP 19/20 or Zone NP 21. This is because the samples from 160.0 and 131.0 ft are barren of calcareous nannofossils and the sample at 151.0 ft contains only rare and poorly preserved specimens.

Four samples at 118.0, 105.0, 103.5, and 95.0 ft questionably are placed in Zone NP 21. All four samples contain *Isthmolithus recurvus* Deflandre (FAD at the base of Zone NP 19/20 and LAD in Zone NP 21) and *Cyclococcolithus formosus* Kamptner (LAD defines the top of Zone NP 21). Also, all four samples do not have *Discoaster barbadiensis*

Tan Sin Hok, *Discoaster saipanensis* Bramlette & Riedel, or *Cribrocentrum reticulatum* (Gartner & Smith) Perch-Nielsen (LAD's near or at the top of Zone NP 20). However, the absence of all but one specimen of the genus *Discoaster* in this interval could possibly indicate that *Discoaster barbadiensis* Tan Sin Hok and *Discoaster saipanensis* Bramlette & Riedel are absent for other than evolutionary reasons. There is a possibility that this material is still in Zone NP 19/20. The Eocene/Oligocene boundary occurs within Zone NP 21 (Berggren and others, 1985, 1995). So if this interval in the Millhaven core is in Zone NP 21, it could be either late Eocene or early Oligocene in age.

The two samples from 65.3 and 59.8 ft are barren of calcareous nannofossils. Two samples from 65.5 and 59.6 ft were examined by Jonathan R. Bryan of Okaloosa-Walton Community College in Niceville, Fla., for their larger foraminifers, which indicate either a latest Eocene or an earliest Oligocene age, with the Oligocene being more likely.

GIRARD CORE

Two samples were examined from the Ellenton Formation in the Girard core (fig. 1) at 521.0 and 514.0 ft. Both samples were barren of calcareous nannofossils.

MILLERS POND CORE

Three samples were examined from the Santee Limestone in the Millers Pond core (fig. 1). Species from the lowest sample at 148 ft, which contained rare calcareous nannofossils with poor preservation, are as follows:

Braarudosphaera bigelowii (Gran & Braarud) Deflandre
Helicosphaera lophota (Bramlette & Sullivan) Locker
Reticulofenestra sp.

Species from the middle sample at 120 ft, which contained frequent calcareous nannofossils with poor preservation, are as follows:

Campylosphaera dela (Bramlette & Sullivan) Hay & Mohler
Coccolithus pelagicus (Wallich) Schiller
Cyclococcolithus formosus Kamptner
Ericsonia obruta Perch-Nielsen
Neococcolithes sp.
Pemma papillatum Martini
Pontosphaera multipora (Kamptner) Roth
Reticulofenestra daviesii (Haq) Haq
Reticulofenestra floridana (Roth & Hay) Theodoridis
Reticulofenestra umbilicus (Levin) Martini & Ritzkowski
Rhabdosphaera sp.
Sphenolithus moriformis (Brönnimann & Stradner) Bramlette & Wilcoxon
Transversopontis pulcher (Deflandre) Perch-Nielsen
Transversopontis pulcheroides (Sullivan) Báldi-Beke
Transversopontis zigzag Roth & Hay
Zygrhablithus bijugatus (Deflandre) Deflandre

The age of the sample at 120 ft is middle to late Eocene, and unfortunately cannot be constrained any closer than Zones NP 16 to NP 21. The highest sample at 82 ft was barren of calcareous nannofossils.

LIST OF CALCAREOUS NANNOFOSSIL SPECIES MENTIONED IN THIS PAPER

[Selected well-preserved specimens from the Millhaven core are shown in plate 1 as indicated below]

Blackites creber (Deflandre *in* Deflandre and Fert, 1954) Stradner & Edwards 1968
Blackites scabrosus (Deflandre *in* Deflandre and Fert, 1954) Roth 1970 (this paper, pl. 1, fig. 8)
Blackites spinosus (Deflandre & Fert 1954) Hay & Towe 1962
Blackites tenuis (Bramlette & Sullivan 1961) Sherwood 1974
Braarudosphaera bigelowii (Gran & Braarud 1935) Deflandre 1947
Braarudosphaera discula Bramlette & Riedel 1954
Braarudosphaera stylifer Troelsen & Quadros 1971
Campylosphaera dela (Bramlette & Sullivan 1961) Hay & Mohler 1967
Cepekiella lumina (Sullivan 1965) Bybell 1975
Chiasmolithus bidens (Bramlette & Sullivan 1961) Hay & Mohler 1967
Chiasmolithus consuetus (Bramlette & Sullivan 1961) Hay & Mohler 1967
Chiasmolithus danicus (Brotzen 1959) Hay & Mohler 1967
Chiasmolithus eograndis Perch-Nielsen 1971
Chiasmolithus expansus (Bramlette & Sullivan 1961) Hay et al. 1966
Chiasmolithus gigas (Bramlette & Sullivan 1961) Hay et al. 1966
Chiasmolithus grandis (Bramlette & Riedel 1954) Hay et al. 1966
Chiasmolithus oamaruensis (Deflandre *in* Deflandre and Fert, 1954) Hay et al. 1966
Chiasmolithus solitus (Bramlette & Sullivan 1961) Hay et al. 1966
Chiphragmalithus acanthodes Bramlette & Sullivan 1961
Coccolithus eopelagicus (Bramlette & Riedel 1954) Bramlette & Sullivan 1961
Coccolithus pelagicus (Wallich 1877) Schiller 1930 (this paper, pl. 1, figs. 1, 11)
Cribrocentrum reticulatum (Gartner & Smith 1967) Perch-Nielsen 1971
Cruciplacolithus primus Perch-Nielsen 1977

Cruciplacolithus staurion (Bramlette & Sullivan 1961) Gartner 1971
Cruciplacolithus tenuis (Stradner 1961) Hay & Mohler *in* Hay and others (1967)
Cyclagelosphaera prima (Bukry 1969) Bybell & Self-Trail 1995
Cyclococcolithus formosus Kamptner 1963
Cyclococcolithus protoannulus (Gartner 1971) Haq & Lohmann 1976
Dictyococcites bisectus (Hay et al. 1966) Bukry & Percival 1971
Dictyococcites scrippsae Bukry & Percival 1971
Discoaster barbadiensis Tan Sin Hok 1927 (this paper, pl. 1, fig. 2)
Discoaster deflandrei Bramlette & Riedel 1954 (this paper, pl. 1, fig. 6)
Discoaster distinctus Martini 1958
Discoaster kuepperi Stradner 1959
Discoaster limbatus Bramlette & Sullivan 1961
Discoaster lodoensis Bramlette & Riedel 1954
Discoaster mirus Deflandre *in* Deflandre and Fert (1954)
Discoaster mohleri Bukry & Percival 1971
Discoaster multiradiatus Bramlette & Riedel 1954
Discoaster saipanensis Bramlette & Riedel 1954
Discoaster sublodoensis Bramlette & Sullivan 1961 (this paper, pl. 1, fig. 3)
Discoaster tanii Bramlette & Riedel 1954
Discoaster woodringii Bramlette & Riedel 1954
Ellipsolithus distichus (Bramlette & Sullivan 1961) Sullivan 1964
Ellipsolithus lajollaensis Bukry & Percival 1971
Ellipsolithus macellus (Bramlette & Sullivan 1961) Sullivan 1964
Ericsonia obruta Perch-Nielsen 1971
Ericsonia subpertusa Hay & Mohler 1967 (this paper, pl. 1, fig. 10)
Fasciculithus tympaniformis Hay & Mohler *in* Hay and others (1967)
Goniolithus fluckigeri Deflandre 1957
Hayella situliformis Gartner 1969
Helicosphaera bramlettei (Müller 1970) Jafar & Martini 1975
Helicosphaera compacta Bramlette & Wilcoxon 1967
Helicosphaera intermedia Martini 1965
Helicosphaera lophota (Bramlette & Sullivan 1961) Locker 1973 (this paper, pl. 1, fig. 7)
Helicosphaera reticulata Bramlette & Wilcoxon 1967
Helicosphaera seminulum Bramlette & Sullivan 1961
Heliolithus cantabriae Perch-Nielsen 1971
Heliolithus kleinpellii Sullivan 1964
Heliolithus riedelii Bramlette & Sullivan 1961
Isthmolithus recurvus Deflandre *in* Deflandre and Fert (1954)
Lanternithus minutus Stradner 1962
Lithostromation operosum (Deflandre *in* Deflandre and Fert, 1954) Bybell 1975
Lithostromation simplex (Klumpp 1953) Bybell 1975
Lophodolithus mochlophorus Deflandre *in* Deflandre and Fert (1954)
Lophodolithus nascens Bramlette & Sullivan 1961
Markalius apertus Perch-Nielsen 1979
Markalius inversus (Deflandre *in* Deflandre and Fert, 1954) Bramlette & Martini 1964
Micrantholithus aequalis Sullivan 1964
Micrantholithus crenulatus Bramlette & Sullivan 1961
Micrantholithus fornicatus Martini 1961
Micrantholithus pinguis Bramlette & Sullivan 1961
Nannotetrina fulgens (Stradner 1960) Achuthan & Stradner 1969
Neochiastozygus concinnus (Martini 1961) Perch-Nielsen 1971
Neococcolithes dubius (Deflandre *in* Deflandre and Fert, 1954) Black 1967
Neococcolithes protenus (Bramlette & Sullivan 1961) Black 1967
Pedinocyclus larvalis Bukry & Bramlette 1971
Pemma basquense (Martini 1959) Bybell & Gartner 1972
Pemma papillatum Martini 1959
Pemma rotundum Klumpp 1953
Pemma stradneri (Chang 1969) Perch-Nielsen 1971
Placozygus sigmoides (Deflandre *in* Deflandre and Fert, 1954) Black 1967 (this paper, pl. 1, fig. 9)
Pontosphaera multipora (Kamptner ex Deflandre 1959) Roth 1970
Pontosphaera punctosa (Bramlette & Sullivan 1961) Perch-Nielsen 1984
Pontosphaera wechesensis (Bukry & Percival 1971) Aubry 1986
Pseudotriquetrorhabdulus inversus (Bukry & Bramlette 1969) Wise *in* Wise and Constans (1976)
Reticulofenestra daviesii (Haq 1968) Haq 1971
Reticulofenestra floridana (Roth & Hay *in* Hay and others, 1967) Theodoridis 1984 (this paper, pl. 1, fig. 4)
Reticulofenestra hillae Bukry & Percival 1971
Reticulofenestra umbilicus (Levin 1965) Martini & Ritzkowski 1968
Rhabdosphaera gladius Locker 1967
Rhabdosphaera inflata Bramlette & Sullivan 1961
Rhomboaster bramlettei (Brönnimann & Stradner 1960) Bybell & Self-Trail 1995
Rhomboaster contortus (Stradner 1958) Bybell & Self-Trail 1995
Rhomboaster orthostylus (Shamrai 1963) Bybell & Self-Trail 1995
Sphenolithus anarrhopus Bukry & Bramlette 1969
Sphenolithus capricornutus Bukry & Percival 1971
Sphenolithus moriformis (Brönnimann & Stradner 1960) Bramlette & Wilcoxon 1967
Sphenolithus obtusus Bukry 1971

Sphenolithus pseudoradians Bramlette & Wilcoxon 1967

Sphenolithus radians Deflandre *in* Grassé (1952)

Toweius pertusus (Sullivan 1965) Romein 1979

Toweius selandianus Perch-Nielsen 1979 (this paper, pl. 1, fig. 12)

Transversopontis fimbriatus (Bramlette & Sullivan 1961) Locker 1968

Transversopontis pulcher (Deflandre *in* Deflandre and Fert, 1954) Perch-Nielsen 1967

Transversopontis pulcheroides (Sullivan 1964) Báldi-Beke 1971 (this paper, pl. 1, fig. 5)

Transversopontis pulchriporus (Reinhardt 1967) Sherwood 1974

Transversopontis zigzag Roth & Hay *in* Hay and others, 1967

Zygrhablithus bijugatus (Deflandre *in* Deflandre and Fert, 1954) Deflandre 1959

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PLATE 1

PLATE 1

[All specimens are from the Millhaven core, from Screven County, Georgia. Sample depths are given in feet below the surface. Specimen diameters are given in micrometers (µm). Designation of the calcareous nannofossil zone of Martini (1971) is shown in the upper right corner of each photomicrograph]

Figure 1. Coccosphere of *Coccolithus pelagicus* (Wallich) Schiller, Zone NP 14, Congaree Formation (481.5 ft) (diameter, 8.6 µm).

2. *Discoaster barbadiensis* Tan Sin Hok, Zone NP 14, Congaree Formation (481.5 ft), side 1 (diameter, 13.6 µm).

3. *Discoaster sublodoensis* Bramlette & Sullivan, Zone NP 14, Congaree Formation (481.5 ft), side 1 (diameter, 11.0 µm).

4. *Reticulofenestra floridana* (Roth & Hay) Theodoridis, Zone NP 14, Congaree Formation (481.5 ft), distal view (length, 7.4 µm).

5. *Transversopontis pulcheroides* (Sullivan) Báldi-Beke, Zone NP 14, Congaree Formation (481.5 ft), distal view (length, 4.1 µm).

6. *Discoaster deflandrei* Bramlette & Riedel, Zone NP 14, Congaree Formation (481.5 ft), side 1 (diameter, 12.3 µm).

7. *Helicosphaera lophota* (Bramlette & Sullivan) Locker, Zone NP 14, Congaree Formation (481.5 ft), proximal view (length, 10.6 µm).

8. *Blackites scabrosus* (Deflandre) Roth, Zone NP 14, Congaree Formation (481.5 ft), distal view (diameter, 4.6 µm).

9. *Placozygus sigmoides* (Deflandre) Black, Zone NP 5, Ellenton Formation (593.7 ft), proximal view (length, 7.4 µm).

10. *Ericsonia subpertusa* Hay & Mohler, Zone NP 5, Ellenton Formation (593.7 ft), distal view (length, 3.7 µm).

11. *Coccolithus pelagicus* (Wallich) Schiller, Zone NP 5, Ellenton Formation (593.7 ft), distal view (length, 4.8 µm).

12. *Toweius selandianus* Perch-Nielsen, Zone NP 5, Ellenton Formation (593.7 ft), distal view (length, 7.4 µm).

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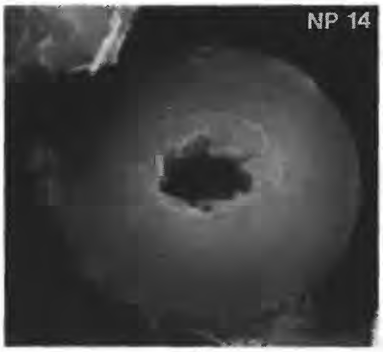

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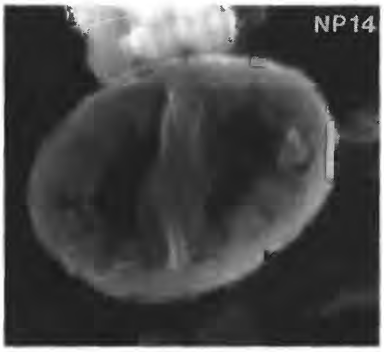

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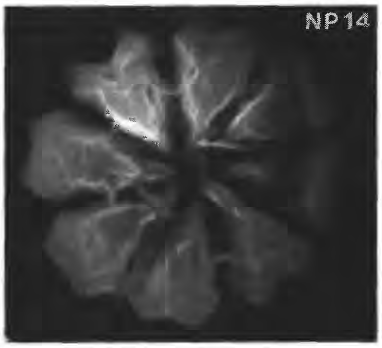

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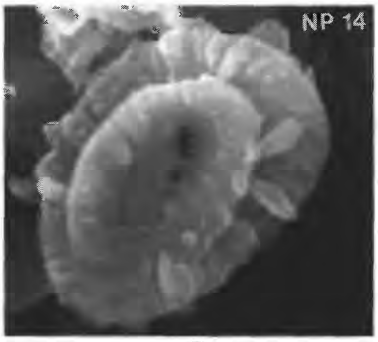

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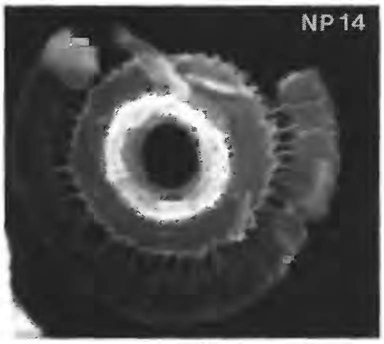

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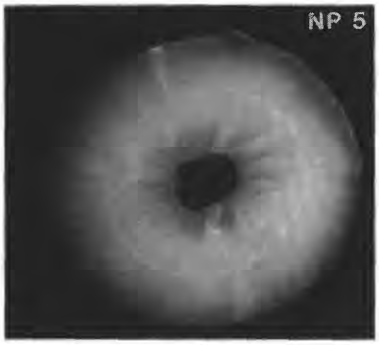

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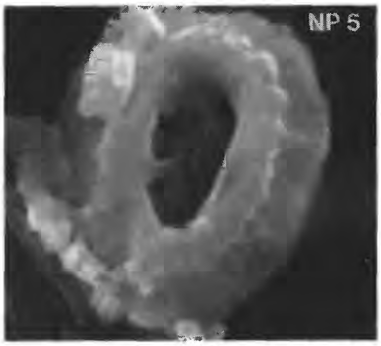

12

COCCOLITHUS, DISCOASTER, RETICULOFENESTRA, TRANSVERSOPONTIS, HELICOSPHAERA,
BLACKITES, PLACOZYGUS, ERICSONIA, AND *TOWEIUS*

U.S. Department of the Interior
U.S. Geological Survey

Dinocyst Biostratigraphy of Tertiary Sediments from Five Cores from Screven and Burke Counties, Georgia

By Lucy E. Edwards

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1603–G

Prepared in cooperation with the
U.S. Department of Energy and the
Georgia Geologic Survey

GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Edited by Lucy E. Edwards

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[Plates follow References Cited]

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GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Dinocyst Biostratigraphy of Tertiary Sediments from Five Cores from Screven and Burke Counties, Georgia

By Lucy E. Edwards

ABSTRACT

Dinoflagellate cysts and acritarchs from five cores in Burke and Screven Counties in Georgia reveal a complex pattern of deposition and erosion. Paleocene sediments in the Ellenton Formation include two separate assemblages. The older one is of early Paleocene age (Danian, Midwayan) and contains *Carpatella cornuta* Grigorovich; the younger assemblage contains *Phelodinium* sp. of Edwards (1989, U.S. Geological Survey Professional Paper 1489–C) and is of late Paleocene age (Selandian and Thanetian, Midwayan and Sabinian). *Andalusiella* sp. aff. *A. polymorpha* of Edwards (1980, Geological Society of America Field Trip Guidebooks, v. 2, p. 424–427) and *Isabelidinium viborgense* sensu Kurita and McIntyre (1995, Palynology, v. 19, p. 119–136) may be found just below and in the lower part of the upper assemblage.

The Snapp Formation is present in varying thicknesses in four of the five cores. Rare dinocysts are present but are not age diagnostic. The Fourmile Branch Formation is early Eocene and is recognized only in the Thompson Oak core where the Snapp Formation is absent and in the Girard core. Early Eocene dinocysts are conspicuously missing from the Millhaven, Millers Pond, and McBean cores.

Lower middle Eocene sediments of the Congaree Formation containing *Pentadinium favatum* Edwards are present in all cores. The highest occurrence of *Turbiosphaera* cf. *T. galatea* and the lowest occurrence of *Glaphyrocysta* cf. *G.*? *vicina* may mark an important level near the calcareous nannofossil Zone NP 14/NP 15 boundary. Sediments containing both *P. favatum* Edwards and *Pentadinium goniferum* Edwards are found only in the Millhaven core, where they are assigned to calcareous nannofossil Zone NP 15 and to the Warley Hill Formation.

Upper middle Eocene sediments are present in the Santee Limestone in all cores. The lowest occurrences of *Cordosphaeridium cantharellus* (Brosius) Gocht, *Cyclopsiella vieta* Drugg & Loeblich, and *Dapsilidinium pseudocolligerum* (Stover) Bujak et al. are found in the Santee Limestone, and *Hystrichosphaeropsis* Deflandre n. sp. A, *Pentadinium* Gerlach n. sp. D, and *Pentadinium polypodum* Edwards are apparently restricted to the Santee Limestone. Specimens of species of the genus *Wetzeliella* are present in a few Santee samples but are not common.

Dinocyst recovery is variable in sediments of the Barnwell unit. In the Millhaven core, *Batiacasphaera baculata* Drugg, *Batiacasphaera compta* Drugg, and *Cordosphaeridium funiculatum* Morgenroth indicate a late Eocene age.

Core-to-core correlations based on the dinocyst assemblages show striking variations in units and thicknesses. The oldest Paleocene sediments are thickest in the updip direction. Of the five cores studied, none contains all three of the Fourmile Branch, Congaree, and Warley Hill Formations. Erosion by a paleo-Savannah River may have allowed selective infilling during later transgressions and selective preservation of the stratigraphic units.

INTRODUCTION

The Savannah River Site (SRS) in Aiken, Barnwell, and Allendale Counties, S.C., has manufactured, disposed of, and stored a variety of hazardous materials since the early 1950's. The U.S. Geological Survey, in cooperation with the U.S. Department of Energy and the Georgia Geologic Survey of the Georgia Department of Natural Resources, is conducting a study of the subsurface geology, hydrology, and water quality in the vicinity of the SRS. The goal of the study is to understand the actual and possible future ground-water flow in the aquifers of the area. This paper focuses on the Tertiary dinocyst biostratigraphy in Burke and Screven Counties in Georgia, directly across the Savannah River from the SRS (fig. 1).

Dinoflagellates are microscopic algae with a complex life cycle that may include an encysted stage. Chemically resistant dinoflagellate cysts (dinocysts) are abundant and well-preserved fossils in many of the Tertiary sediments in

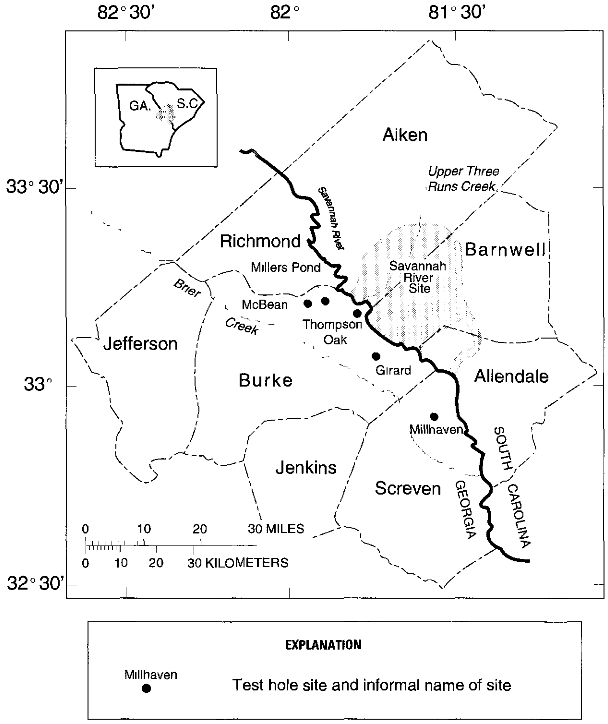

Figure 1. Index map showing the Savannah River Site and locations of stratigraphic test holes in the study area.

Burke and Screven Counties in Georgia. These rapidly evolving and distinctive fossils produce a detailed biostratigraphic framework for the area. Two distinctive, chemically resistant microfossils of uncertain origin (acritarchs) are also included in this study.

PREVIOUS WORK

Relatively little has been published on the dinoflagellate biostratigraphy of the southeastern United States. Early taxonomic works by Drugg and Loeblich (1967) and Drugg (1970) laid the foundation for later studies. Much of the biostratigraphic information used for correlation with classic Alabama localities is contained in Edwards (1977), and key species were named and documented in Edwards (1982). A preliminary report on the biostratigraphy of the Chattahoochee area in Alabama and Georgia was given in Edwards (1980). Prowell, Christopher, and others (1985) and Prowell, Edwards, and Frederiksen (1985) used dinocysts to help correlate units in the subsurface of Georgia and South Carolina and to help document the ages of stratigraphic units. Firth (1987) documented the dinocyst stratigraphy across the Cretaceous/Tertiary boundary in western Georgia.

More recently, brief papers by Edwards (1992) and Lucas-Clark (1992) have focused on the dinocysts of the SRS and surrounding areas. Clarke and others (1994, 1996) and Leeth and others (1996) described the geologic and hydrologic data from three of the cores that are used in the present study. Recent papers by Kurita and McIntyre (1995) on the Paleocene of Manitoba, Canada, and by Edwards (1996) on the Eocene of Virginia and Maryland, U.S., show many forms similar to those encountered here.

ACKNOWLEDGMENTS

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MATERIAL AND METHODS

This study is based on the dinocysts from five cores in east-central Georgia (fig. 1). They are discussed in order from most basinward (downdip) to most inshore (updip):

- The Millhaven test hole (33X048) was drilled by the U.S. Geological Survey in 1991–92 in northern Screven County at lat 32°53'25" N., long 81°35'43" W. Surface elevation is 110 ft above sea level.
- The Girard test hole (32Y020) was drilled by the U.S. Geological Survey in 1992 in southern Burke County at the lookout tower on Griffins Landing Road. The test hole is located 2 miles north of the town of Girard at lat 33°03'54" N., long 81°43'13" W. Surface elevation is 250 ft above sea level.
- The Thompson Oak test hole (GGS–3794, TR92–6, Burke 12) was drilled by the Georgia Geologic Survey in 1993 in northeastern Burke County. The test hole is located 21 miles south of Augusta just above the flood plain of the Savannah River at lat 33°10'42" N., long 81°47'10" W. Surface elevation is 240 ft above sea level.
- The Millers Pond test hole (GGS–3758, Burke 2) was drilled by the Georgia Geologic Survey in 1991 in northern Burke County. The test hole is located 2 miles west of the Savannah River and 16 miles south of Augusta, at lat 33°13'48" N., long 81°52'44" W. Surface elevation is 245 ft above sea level.
- The McBean test hole (GGS–3757, Burke 5) was drilled by the Georgia Geologic Survey in 1991 in northern Burke County. The test hole is located on the north shoulder of Collins Road, 1.1 miles east of

the intersection of GA 56 and Collins Road at lat 33°13'38" N., long 81°55'50" W. Surface elevation is 297 ft above sea level.

Core samples were selected on the basis of favorable lithology and providing biostratigraphic coverage. Samples were assigned U.S. Geological Survey paleobotanical numbers by locality and letter designations by depth. Table 1 provides a convenient summary of these. The depth range includes the thickness of the sample as well as the uncertainty of the core recovery; sample depths recorded only to the nearest foot have a least 1 ft of uncertainty in recovery.

Samples were cleaned and scraped and treated with hydrochloric and hydrofluoric acids. The samples were oxidized using nitric acid, stained with Bismark brown, sieved at 20 micrometers, and mounted in glycerin jelly for light-microscope observation. All slides are stored at the U.S. Geological Survey, Reston, Va.

Coordinates for dinoflagellate specimens are given for Olympus Vanox microscope 201526 at the U.S. Geological Survey, Reston, Va. On this microscope, the coordinates for the center point of a standard 25.4×76.2-millimeter slide are 27.5 and 112.7 for the vertical and horizontal axes. The vertical coordinates increase as the stage is moved up, and the horizontal coordinates increase as the slide is moved from left to right. Slide numbers and microscope coordinates of photographed specimens are listed in table 2.

Taxonomy follows Williams and others (1998). Full taxonomic citations for all forms in the text and figures are found in "Taxonomic Notes." In contrast to Williams and others (1998), however, I do not recognize the genus *Tityrosphaeridium* Sarjeant as separate and distinct from the genus *Cordosphaeridium* Eisenack, because both appear to possess cingular processes. Except for the distinctive species that are listed separately, the highly variable plexus that contains members of the genera *Adnatosphaeridium, Areoligera*, and *Glaphyrocysta* was considered to be a single taxonomic entity (miscellaneous areoligeraceae, pl. 4, figs. 13, 14).

LITHOSTRATIGRAPHIC FRAMEWORK

Details of the lithostratigraphy are given by Falls and Prowell (this volume, chap. A). They recognize seven Tertiary units, and their terminology and correlations are followed here. However, the individual components of their "Fourmile Branch/Congaree/Warley Hill unit" are discussed separately. The Ellenton Formation is the lowest Tertiary unit and consists of calcareous and noncalcareous sand and clay that is locally glauconitic. It is overlain by the Snapp Formation, a distinctive unlithified sand and overlying white kaolin. The Fourmile Branch Formation is recognized only in the Girard and Thompson Oak cores, where it consists of layers of clay and poorly sorted sand. The Congaree Formation consists of interbedded sand, marl, and limestone in downdip cores and sand with or without sandy carbonate in more updip cores. The Warley Hill Formation is found only in the Millhaven core and is primarily a carbonate sand. The Santee Limestone is predominantly a carbonate that includes beds of calcareous sand and clay. The Barnwell unit is a mixed lithologic package of sandy limestone, marl, clay, and sand. The Ellenton and Snapp Formations are Paleocene; the Fourmile Branch Formation, Congaree Formation, Warley Hill Formation, Santee Limestone, and Barnwell unit are Eocene (Edwards and others, this volume, chap. B).

DINOCYSTS FROM THE MILLHAVEN CORE

Thirty-three samples were examined for dinocysts in the Tertiary sediments in the Millhaven core, and all but six contained dinocysts. The occurrences of dinocyst taxa in this core are shown in figure 2.

ELLENTON FORMATION (642–570 ft)

Dinocysts in the Paleocene Ellenton Formation in the Millhaven core were studied from eight samples from 639.5–571 ft depth (table 1). The lowest sample (R4664 GC, at 639.5 ft) contains *Areoligera volata* Drugg, *Carpatella cornuta* Grigorovich (pl. 1, fig. 10), *Spinidinium densispinatum* Stanley, *Spinidinium pulchrum* (Benson) Lentin & Williams, and *Tenua* sp. cf. *T. formosa* of Kurita and McIntyre (1995). *Carpatella cornuta* Grigorovich has not been reported from sediments younger than early Paleocene (Danian). Ellenton samples below 635.4 ft have been assigned to calcareous nannofossil Zone NP 4 (Bybell, this volume, chap. F). The early-late Paleocene boundary is within Zone NP 4 (Berggren and others, 1995); the presence of *C. cornuta* Grigorovich indicates that these sediments are from the early Paleocene part of the zone.

The next higher sample (R4664 CH, at 632–632.2 ft) is dominated by small peridiniaceans such as *Senegalinium microgranulatum* (Stanley) Stover & Evitt and contains other forms such as *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant and *Hafniasphaera septata* (Cookson & Eisenack) Hansen, *Andalusiella* sp. aff. *A. polymorpha* of Edwards (1980), and *Deflandrea* cf. *D. diebelii* of Drugg (1967). The remaining Ellenton samples contain similar assemblages that include *Damassadinium californicum* (Drugg) Fensome et al. (pl. 2, fig. 3), *Phelodinium* sp. of Edwards (1989) (lowest occurrence in R4664 GD, at 620.8 ft), and *Deflandrea delineata* Cookson & Eisenack (lowest occurrence in R4664 A, at 589 ft, pl. 5, 5.5). *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant and *Fibradinium annetorpense* Morgenroth are present in the highest sample (R4664 D, at 571 ft). Most of the Ellenton has been

Table 1. Samples studied by core with U.S. Geological Survey paleobotanical numbers (R numbers), depth below surface, and geologic unit.

[Fourmile, Fourmile Branch Formation; T/F, discussed in text and figures]

R number	Depth (ft)	Unit	Notes
Millhaven core			
R4664 AV	105	Barnwell	Barren.
R4664 AU	118	Barnwell	1 dinocyst.
R4664 AT	195	Barnwell	1 dinocyst.
R4664 AS	205	Barnwell	T/F
R4664 AR	210	Barnwell	T/F
R4664 AQ	216.5	Barnwell	T/F
R4664 AP	227.5	Barnwell	T/F
R4664 AO	237.5	Santee	Barren.
R4664 AN	242.5	Santee	Barren.
R4664 AL	260	Santee	Barren.
R4664 AI	293	Santee	T/F
R4664 AG	313.5	Santee	T/F
R4664 AC	346	Santee	T/F
R4664 Y	375	Santee	T/F
R4664 X	396	Santee	Barren.
R4664 V	413	Warley Hill	T/F
R4664 R	442	Warley Hill	T/F
R4664 O	466	Congaree	T/F
R4664 N	473.5	Congaree	T/F
R4664 L	483.5	Congaree	T/F
R4664 K	490	Congaree	T/F
R4664 J	495.5	Congaree	T/F
R4664 I	498.5	Congaree	T/F
R4664 F	527	Snapp	Barren.
R4664 E	564–565	Snapp	T/F
R4664 D	571	Ellenton	T/F
R4664 C	577	Ellenton	T/F
R4664 B	581	Ellenton	T/F
R4664 A	589	Ellenton	T/F
R4664 GE	599.5	Ellenton	T/F
R4664 GD	620.8	Ellenton	T/F
R4664 CH	632–632.2	Ellenton	T/F
R4664 GC	639.5	Ellenton	T/F
Girard core			
R4705 L	64.1–64.3	Barnwell	Barren.
R4705 K	103.6–103.8	Barnwell	Barren.
R4705 J	146.6–146.8	Barnwell	T/F
R4705 I	211.1–211.3	Barnwell	T/F
R4705 H	257.8–258	Santee	T/F
R4705 G	321.4–321.6	Santee	T/F
R4705 F	322.3–322.5	Santee	T/F
R4705 AF	327.3–327.5	Congaree	T/F
Girard core—Continued			
R4705 E	362–362.3	Congaree	T/F
R4705 CF	415	Fourmile	T/F
R4705 AE	415.2–415.5	Fourmile	T/F
R4705 D	484.1–484.3	Ellenton	T/F
R4705 C	514–514.3	Ellenton	T/F
R4705 AD	517.9–518.1	Ellenton	T/F
R4705 B	521–521.2	Ellenton	T/F
R4705 A	532.5–532.7	Ellenton	T/F
Thompson Oak core			
R4836 R	138	Santee	T/F
R4836 Q	154	Santee	T/F
R4836 P	164	Santee	T/F
R4836 O	172	Santee	T/F
R4836 N	174	Santee	T/F
R4836 M	181.5	Santee	T/F
R4836 L	183	Congaree	T/F
R4836 K	192	Congaree	T/F
R4836 J	194	Congaree	T/F
R4836 I	210	Congaree	T/F
R4836 H	231.5	Congaree	T/F
R4836 G	245	Congaree	T/F
R4836 F	255	Fourmile	T/F
R4836 E	269	Fourmile	T/F
R4836 D	281	Ellenton	T/F
R4836 C	302	Ellenton	T/F
Millers Pond core			
R4581 Y	72–77	Barnwell	Barren.
R4581 X	82–83	Santee	Barren.
R4581 W	120	Santee	T/F
R4581 V	124	Santee	T/F
R4581 U	148	Santee	T/F
R4581 T	155	Santee	T/F
R4581 S	165	Congaree	T/F
R4581 R	237–242	Ellenton	T/F
R4581 Q	252–257	Ellenton	T/F
McBean core			
R4663 G	181	Santee	T/F
R4663 F	210	Congaree	T/F
R4663 E	243	Snapp	No dinocysts.
R4663 D	264	Snapp	T/F
R4663 C	276	Ellenton	T/F
R4663 B	294	Ellenton	T/F

Table 2. Slide numbers and microscope coordinates of photographed specimens.

[The slide designations show the sample number (table 1) followed by the slide number in parentheses. Coordinates are given for Olympus Vanox microscope 201526 at the U.S. Geological Survey, Reston, Va.]

Figure	Slide	Coordinates
	Plate 1	
1	R4664 K (1)	31.1×83.0
2	R4664 O (3)	20.2×93.2
3	R4705 E (2)	33.5×74.5
4	R4705 D (2)	18.7×80.3
5	R4581 Q (4)	22.6×81.2
6	R4664 R (4)	27.6×98.4
7	R4664 AS (1)	30.7×86.0
8, 9	R4664 AS (1)	30.2×81.4
10	R4664 GC (1)	20.4×97.0
11	R4664 AS (1)	33.7×78.6
12, 13	R4664 K (1)	28.2×79.1
14	R4664 AC (3)	29.8×81.4
15	R4705 I (3)	35.6×90.6
16	R4664 O (3)	34.3×89.4
17	R4664 AC (3)	27.3×103.4
18	R4705 I (3)	26.9×94.4
	Plate 2	
1, 2	R4663 B (4)	34.5×93.8
3	R4664 A (3)	22.1×71.8
4	R4664 AS (1)	30.9×86.7
5	R4664 O (3)	19.4×103.8
6	R4664 AQ (2)	37.5×80.7
7	R4705 E (2)	21.1×75.0
8	R4664 A (3)	19.4×97.7
9	R4664 AR (1)	37.2×84.5
10–12	R4664 O (3)	34.3×76.4
13	R4705 E (2)	30.4×75.6
14	R4836 K (3)	26.0×71.1
15	R4705 G (3)	30.4×89.0
	Plate 3	
1	R4836 F (2)	30.0×76.0
2, 3	R4836 R (3)	22.6×79.6
4	R4663 G (3)	33.2×94.2
5	R4663 G (3)	21.9×77.1
6	R4664 AC (3)	34.7×84.7
7–9	R4836 R (3)	17.8×75.3
10	R4705 AD (2)	26.9×101.6
11	R4836 E (3)	19.2×89.6
12	R4705 I (3)	28.9×86.7
13	R4836 N (4)	35.0×107.8
14	R4664 O (3)	34.8×85.1
15	R4664 N (2)	30.8×86.6
16	R4664 AC (3)	35.7×71.7
17	R4664 AR (1)	36.5×101.9
18	R4664 AR (1)	26.4×94.9
19–21	R4836 P (1)	24.1×108.0
	Plate 4	
1	R4664 AI (4)	33.3×76.5
2	R4664 AI (4)	21.4×74.8
3	R4836 K (3)	28.4×97.0
4	R4664 AC (3)	31.4×103.8
5	R4664 AC (3)	24.3×72.3
6	R4705 I (3)	24.0×75.3
7	R4705 AD (2)	33.7×76.4
8	R4705 G (3)	24.9×90.4
9	R4664 AR (1)	35.7×104.9
10, 11	R4705 AD (2)	33.6×76.3
12	R4664 K (1)	30.3×78.0
13	R4664 K (1)	31.9×87.1
14	R4581 R (4)	36.1×91.1
	Plate 5	
1	R4581 R (1)	23.2×74.6
2	R4663 C (4)	21.1×93.5
3	R4581 R (1)	26.0×73.0
4	R4836 D (3)	22.4×75.2
5	R4664 A (3)	23.5×92.3
6	R4705 AD (2)	27.2×95.5
7	R4705 CF (1)	32.6×72.4
8	R4705 B (3)	30.5×107.9
9	R4664 AS (1)	24.6×78.8
10	R4836 D (3)	18.2×74.6
11	R4664 AQ (2)	37.4×98.2
12	R4705 E (2)	17.9×80.4
13	R4664 A (3)	23.7×82.8
14	R4663 C (4)	33.4×95.2
15	R4664 AQ (2)	32.3×86.3
16, 17	R4664 O (3)	26.0×95.7
18	R4664 V (4)	18.9×81.0
	Plate 6	
1	R4705 E (2)	29.8×95.6
2	R4664 AG (4)	34.6×69.6
3	R4705 I (3)	23.0×91.7
4	R4664 V (4)	18.3×78.9
5	R4581 R (1)	28.8×104.8
6, 10	R4836 C (3)	32.4×80.8
7	R4664 K (1)	35.1×91.8
8	R4705 B (3)	28.9×94.8
9	R4664 AQ (2)	22.0×74.4
11	R4664 L (1)	26.9×83.5
12	R4581 V (4)	18.3×79.0
13	R4664 D (4)	35.3×92.6
14	R4664 E (4)	18.9×72.1
15	R4663 C (4)	31.4×91.4
16	R4581 R (1)	22.7×73.5
17	R4664 AS (1)	25.3×86.8
18	R4664 D (4)	29.0×81.0

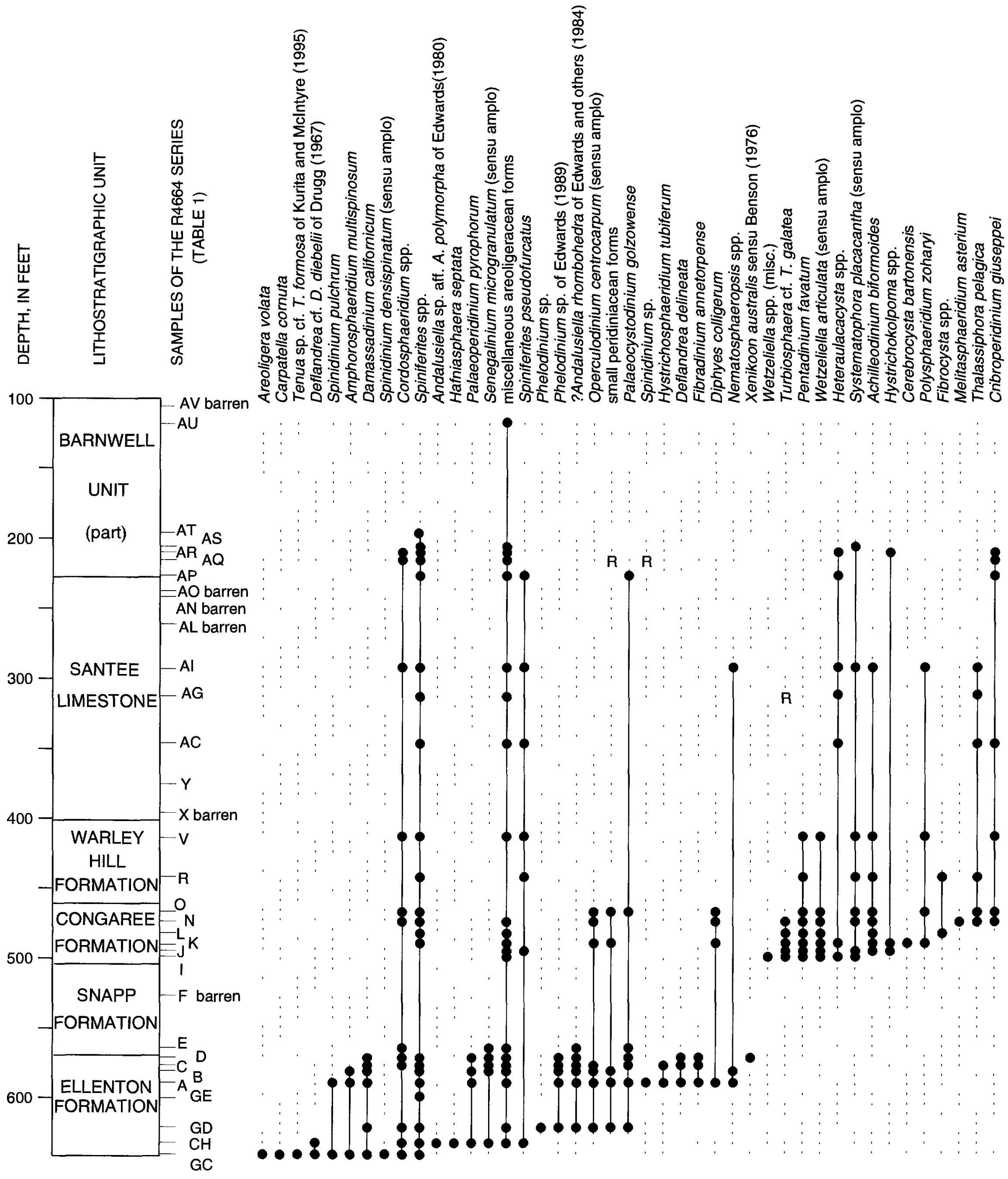

Figure 2. Range and occurrence chart of dinocysts and acritarchs in the Millhaven core. Lithostratigraphy from Falls and Prowell (this volume, chap. A). R=reworked; cf=compares with; ?=questionably identified; 1=single specimen.

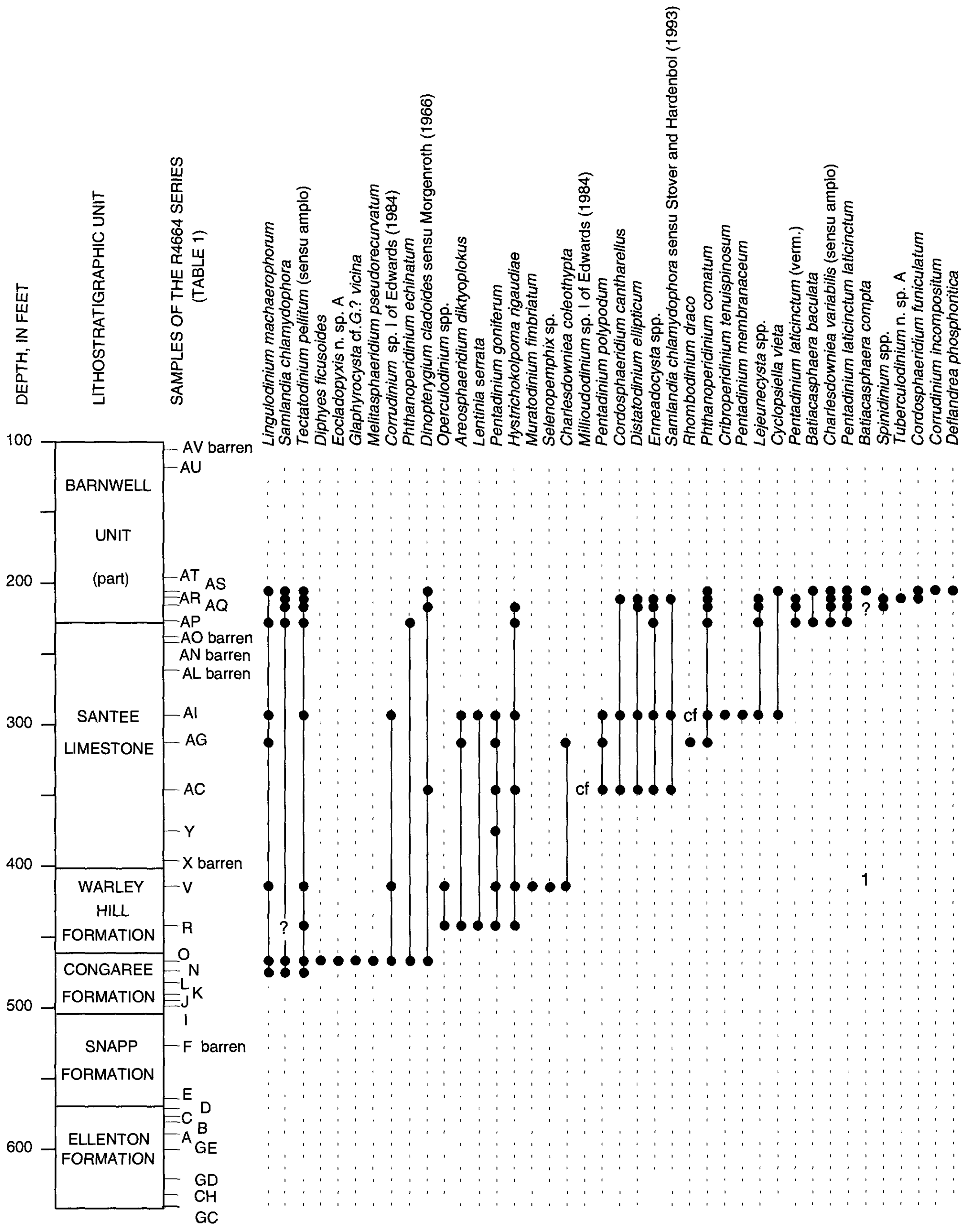

Figure 2. Continued.

assigned to the early late Paleocene calcareous nannofossil Zone NP 5, but the uppermost part of the Ellenton (above 578 ft) has been placed in the middle late Paleocene Zone NP 8 (Bybell, this volume, chap. F).

SNAPP FORMATION (570–504 ft)

A single sample in the Snapp Formation (R4664 E, at 564–565 ft) produced rare, small peridiniacean dinocysts (pl. 6, fig. 14), as well as miscellaneous areoligeracean forms and *Cordosphaeridium* Eisenack sp. This Snapp Formation sample remains undated paleontologically. In this sample, the Snapp is at least marginally marine, unless all specimens are reworked. A higher sample (R4664 F, at 527 ft) did not contain dinocysts.

FOURMILE BRANCH FORMATION (NOT PRESENT)

The Fourmile Branch Formation is not present in the Millhaven core. Sediments containing marine middle Eocene dinocysts directly overlie the Snapp Formation.

CONGAREE FORMATION (504–462 ft)

The dinocyst assemblages in six samples in the Congaree Formation from 498.5–466 ft were studied. All contain *Pentadinum favatum* Edwards (pl. 3, fig. 15). The lower five samples (R4664 I, J, K, L, and N) contain *Turbiosphaera* cf. *T. galatea* (pl. 4, fig. 12), which is reported from the upper part of the Tallahatta Formation in Alabama (Edwards, 1977) and unit E3 of Prowell, Christopher, and others (1985). The absence of *Hafniasphaera goodmanii* Edwards suggests that these samples are of middle Eocene age, rather than early Eocene age, and that lower Eocene sediments are not present in this core. The calcareous nannofossils in these lower samples are assigned to Zone NP 14 (Bybell, this volume, chap. F).

The assemblage at 466 ft (R4664 O) contains the lowest occurrence *Glaphyrocysta* cf. *G.*? *vicina* (pl. 2, figs. 10–12) and appears to be correlative with the lowest part of the Lisbon Formation in Alabama (Edwards, unpub. data). This level could be assigned to either calcareous nannofossil Zone NP 14 or NP 15 (Bybell, this volume, chap. F).

WARLEY HILL FORMATION (462–401 ft)

Both *Pentadinium favatum* Edwards and *Pentadinium goniferum* Edwards are present in the samples of the Warley Hill Formation at 442 and 413 ft (R4664 R and V). These species overlap in a thin interval within the lower, but not lowest, part of the Lisbon Formation in Alabama, which has been dated as NP 15 or NP 16 (Wrenn, 1996). It is assigned to NP 15 in the Millhaven core. The dinocyst assemblages in these samples correspond to those reported in part of the unit E4 of Prowell, Christopher, and others (1985).

SANTEE LIMESTONE (401–228 ft)

Eight samples were examined for dinocysts within the Santee Limestone; four of these are barren. One sample (R4664 Y, at 375 ft) contained only two specimens, both of *Pentadinium goniferum* Edwards. The three remaining samples (R4664 AC, at 346 ft; R4664 AG, at 313.5 ft; and R4664 AI, at 293 ft) produced well-preserved, diverse dinocysts that include *Cordosphaeridium cantharellus* (Brosius) Gocht (pl. 1, fig. 14), *Distatodinium ellipticum* (Cookson) Eaton, *P. goniferum* Edwards (pl. 3, fig. 16), *Pentadinium polypodum* Edwards (pl. 4, fig. 2), *Rhombodinium draco* Gocht (pl. 6, fig. 2), *Samlandia chlamydophora* Eisenack sensu Stover and Hardenbol (1993) (pl. 4, fig. 4), and *Areosphaeridium diktyoplokum* (Klumpp) Eaton. This assemblage is typical of the late middle Eocene and suggests correlation with the upper part of the Lisbon Formation or the Gosport Sand in Alabama. Three samples higher in the Santee (R4664 AL, at 260 ft; R4664 AN, at 242.5 ft; and R4664 AO, at 237.5 ft), as well as one near its base (R4664 X, at 396 ft), are barren. Santee sediments above 368 ft in the Millhaven core have been assigned to late middle Eocene calcareous nannofossil Zone NP 17 (Bybell, this volume, chap. F).

BARNWELL UNIT (228–0 ft)

Seven samples from the Barnwell unit were examined for dinocysts; four were productive, and three are barren or contain only a single specimen.

Samples from the Barnwell unit are above the highest appearance of *P. goniferum* Edwards and are most likely of late Eocene age. The basal Barnwell sample (R4664 AP, at 227.5 ft) contains the lowest occurrence of *Charlesdowniea variabilis* (Bujak) Lentin & Vozzhennikova and *Batiacasphaera baculata* Drugg (pl. 1, fig. 7). Higher samples (R4664 AR, at 210 ft, and R4664 AS, at 205 ft) contain *B. baculata* Drugg or *Batiacasphaera compta* Drugg (pl. 1, figs. 8–9) or both, which suggest correlation with the upper Eocene Yazoo Clay in Alabama, and *Cordosphaeridium funiculatum* Morgenroth (pl. 1, fig. 11), which is found in the Gosport Sand and Moodys Branch Formation (upper middle Eocene) in Alabama and the Parkers Ferry and Harleyville Formations (lower part of the Cooper Group, upper Eocene) in South Carolina (Edwards, 1977; unpub. data). Three samples above 205 ft are barren or nearly so (R4664 AT, AU, AV, at 195, 118 and 105 ft, respectively). Barnwell sediments in the Millhaven core have been assigned to calcareous nannofossil Zones NP 17 and 19/20–21(?) (Bybell, this volume, chap. F).

DINOCYSTS FROM THE GIRARD CORE

Sixteen samples were taken for dinocysts in the Tertiary sediments from the Girard core and all but two contained dinocysts. The occurrences of dinocyst taxa in this core are shown in figure 3.

ELLENTON FORMATION (542–481 ft)

Dinocysts in the Paleocene Ellenton Formation in the Girard core were studied from five samples from 532.7 to 484.1 ft. As in the Millhaven core, both early Paleocene and late Paleocene assemblages were recorded.

The lowest sample (R4705 A, at 532.5–532.7 ft) contains a nondiagnostic dinoflora consisting of small peridiniacean cysts, *Spiniferites* Mantell spp., and a few specimens of the areoligeracean group. The next higher samples (R4705 B, at 521.0–521.2 and R4705 AD, at 517.9–518.1) contain early Paleocene (Danian, Midwayan) dinocysts, including *Carpatella cornuta* Grigorovich, *Tenua* sp. cf. *T. formosa* of Kurita and McIntyre (1995) (pl. 4, fig. 7), *Tectatodinium rugulatum* (Hansen) McMinn (pl. 4, figs. 10, 11) and *Deflandrea* n. sp. aff. *D. truncata* Stover (pl. 5, fig. 8). This assemblage is also dominated by small peridiniacean cysts. The sample R4705 C (at 514.0–514.3 ft) contains a rather sparse dinoflora that includes a fragment questionably identified as *C. cornuta* Grigorovich. The sample R4705 D (at 484.1–484.3 ft) contains a typical late Paleocene (Selandian, late Midwayan) dinoflora, which is also dominated by small peridiniacean cysts and contains *Damassadinium californicum* (Drugg) Fensome et al. and *Phelodinium* sp. of Edwards (1989).

SNAPP FORMATION (481–423 ft)

No samples were taken from the sand and clay of the Snapp Formation in the Girard core.

FOURMILE BRANCH FORMATION (423–390 ft)

Two samples were studied within the Fourmile Branch Formation. The age of these samples is Eocene. However, attempts to determine whether they are early or middle Eocene were inconclusive. In the lower sample (R4705 AE, at 415.2–415.5 ft), *Homotryblium tenuispinosum* Davey & Williams is tentatively identified. A nearby repeat sample (R4705 CF, at 415 ft) recovered a single specimen of *Dracodinium varielongitudum* (Williams & Downie) Costa & Downie (pl. 5, fig. 7).

CONGAREE FORMATION (390–325 ft)

Two samples were studied within the Congaree Formation. The lower sample (R4705 E, at 362–362.3 ft) contains a variety of middle Eocene dinocysts that suggest correlation with the lower part of the Lisbon Formation in Alabama. Important species include *Pentadinium favatum* Edwards, *Corrudinium* sp. I of Edwards (1984), *Phthanoperidinium echinatum* Eaton, *Pseudorhombodinium lisbonense* Wrenn (pl. 6, fig. 1), *Samlandia chlamydophora* Eisenack, *Wetzeliella articulata* Eisenack, *Glaphyrocysta* cf. *G.? vicina* (pl. 2, fig. 13), and *Eocladopyxis* Morgenroth n. sp. A (pl. 2, fig. 7). The higher Congaree sample (R4705 AF, at 327.3–327.5 ft) contains a similar dinocyst assemblage.

WARLEY HILL FORMATION (NOT PRESENT)

No samples containing both *P. favatum* Edwards and *P. goniferum* Edwards were found. Sediments correlative with the Warley Hill in the Millhaven core apparently are not present in the Girard core.

SANTEE LIMESTONE (325–250 ft)

Three samples were examined from the Santee Limestone in the Girard core. The lowest Santee sample (R4705 F, at 322.3–322.5 ft) contains a very sparse and relatively nondiagnostic dinocyst assemblage. It does, however, contain the middle Eocene species *Pentadinium goniferum* Edwards. The sample a foot higher (R4705 G, at 321.4–321.6 ft) contains the lowest occurrence of *Cordosphaeridium cantharellus* (Brosius) Gocht. The sample at 257.8–258 ft (R4705 H) contains a well-preserved, diverse dinocyst assemblage that includes *Pentadinium polypodum* Edwards, *Samlandia chlamydophora* Eisenack sensu Stover and Hardenbol (1993), and *Enneadocysta* spp. These and other species present are characteristic of upper middle Eocene sediments correlative with the upper Lisbon Formation and the Gosport Sand (Edwards, 1977; unpub. data) and with unit E5 of Prowell, Christopher, and others (1985).

BARNWELL UNIT (250–0 ft)

Four samples from the Barnwell unit were studied from the Girard core. Sample R4705 I (at 211.1–211.3 ft) contains the species *Rhombodinium perforatum* (Jan du Chêne & Châteauneuf) Lentin & Williams (pl. 6, fig. 3), *Charlesdowniea variabilis* (Bujak) Lentin & Vozzhennikova, and *Corrudinium incompositum* (Drugg) Stover & Evitt (pl. 1, fig. 15). These species suggest a late middle or late Eocene age. The sample R4705 J (at 146.6–146.8 ft) contains a very sparse and nondiagnostic dinocyst

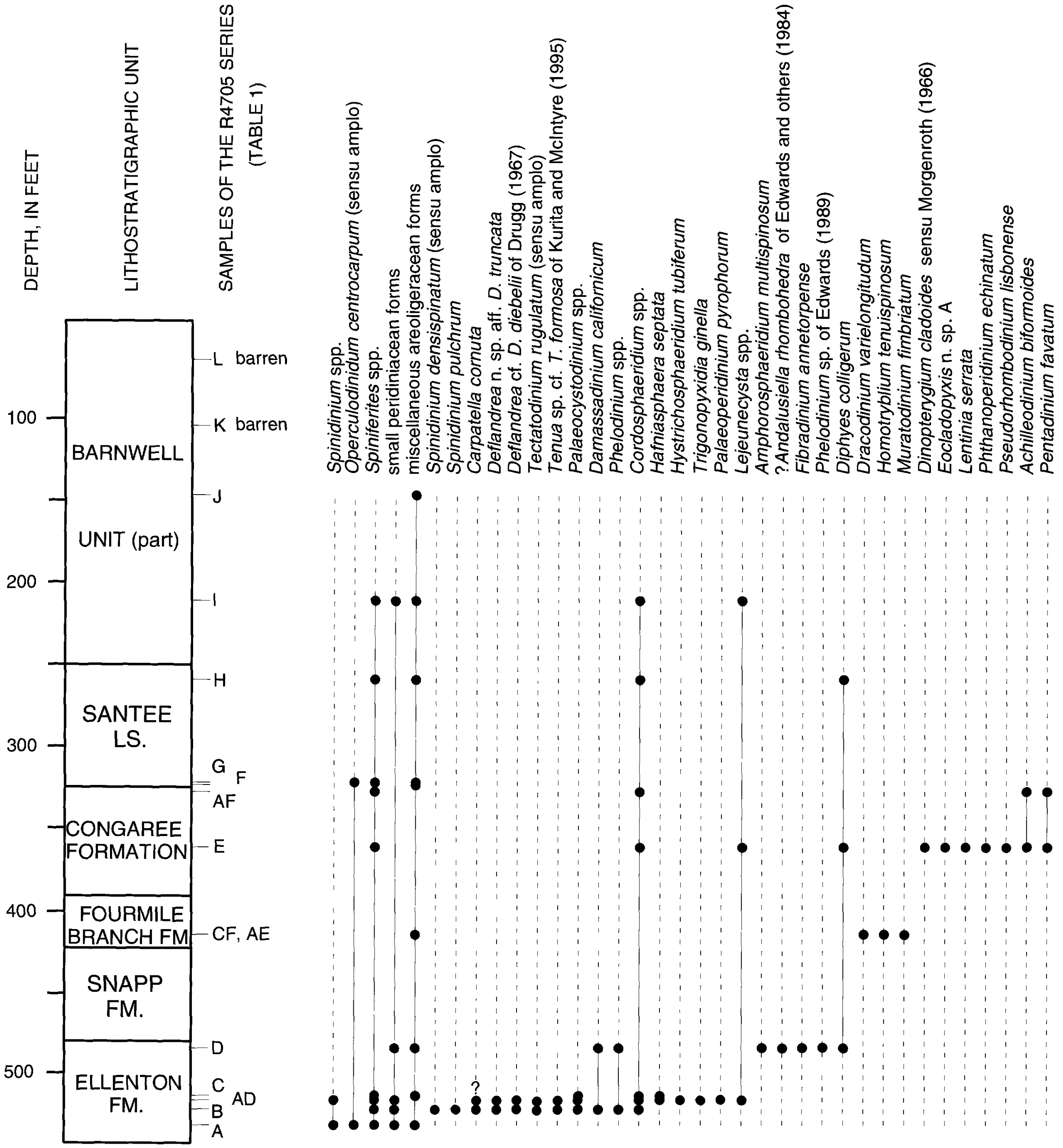

Figure 3. Range and occurrence chart of dinocysts and acritarchs in the Girard core. Lithostratigraphy from Falls and Prowell (this volume, chap. A). cf=compares with; ?=questionably identified.

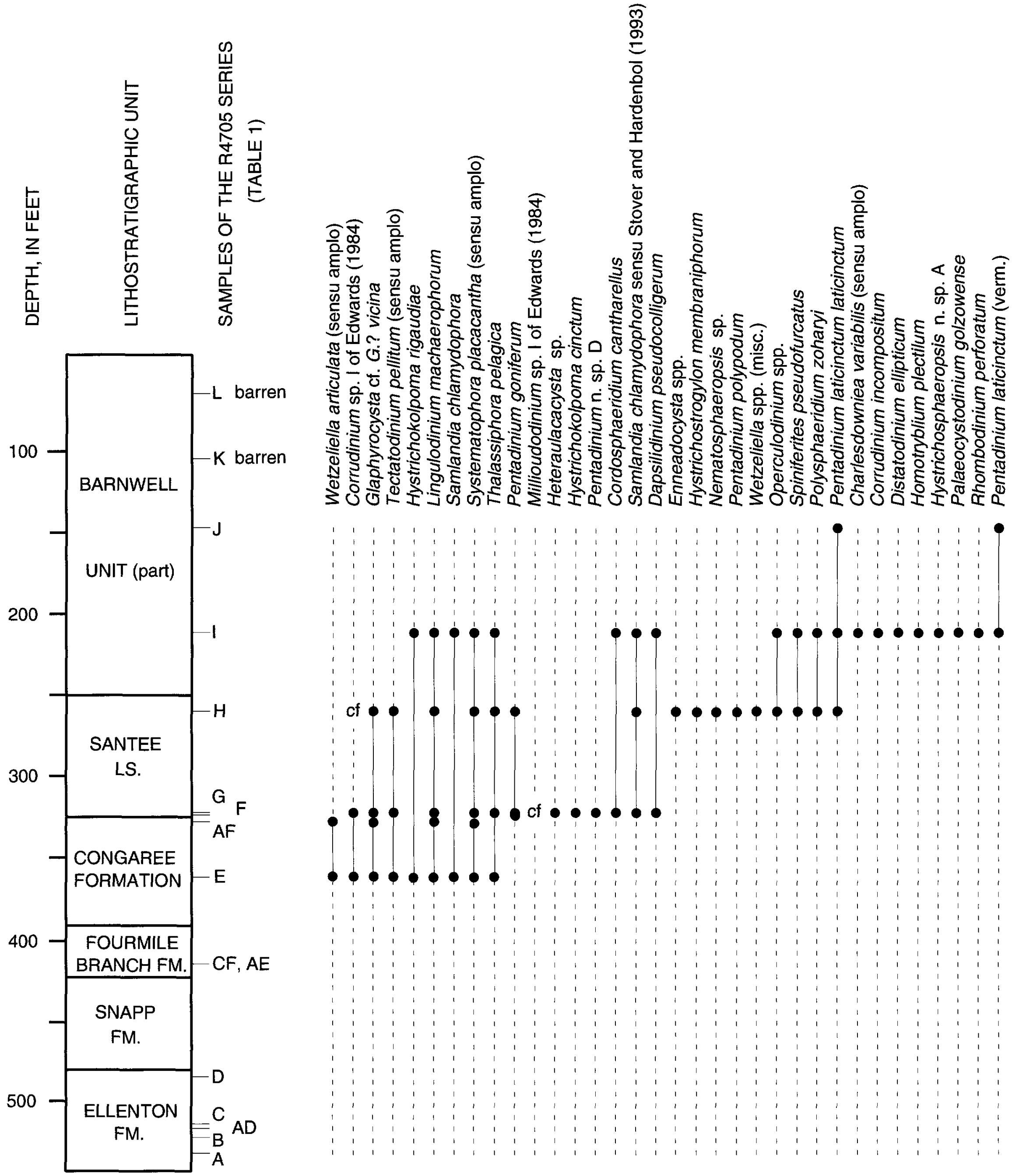

Figure 3. Continued.

assemblage. Samples R4705 K and L (at 103.6–103.8 and 64.1–64.3 ft) are barren of dinocysts.

DINOCYSTS FROM THE THOMPSON OAK CORE

Sixteen samples were taken for dinocysts in the Tertiary sediments of the Thompson Oak core, and all contained dinocysts. The occurrences of dinocyst taxa in the Thompson Oak core are shown in figure 4.

ELLENTON FORMATION (324–274 ft)

Dinocysts in the Ellenton from the Thompson Oak core were studied from two samples. Both are Paleocene (Danian or Selandian, Midwayan). The lower sample (R4836 C, at 302 ft) is dominated by *Areoligera volata* Drugg and small peridiniaceans. Important species present include *Tectatodinium rugulatum* (Hansen) McMinn, *Damassadinium californicum* (Drugg) Fensome et al., *Tenua* sp. cf. *T. formosa* of Kurita and McIntyre (1995), and *Deflandrea* n. sp. aff. *D. truncata* Stover. The sample lacks *Carpatella cornuta* Grigorovich but contains other species recorded in the early Paleocene samples from the Millhaven, Girard, and Millers Pond cores. The upper sample (R4836 D, at 281 ft) is dominated by small peridiniaceans and contains *Andalusiella* sp. aff. *A. polymorpha* of Edwards (1980) (pl. 5, fig. 4) and *Phelodinium* sp. of Edwards (1989). It is of late Paleocene age (Selandian).

SNAPP FORMATION (NOT PRESENT)

The Snapp Formation is not present in the Thompson Oak core. Sediments containing marine Eocene dinocysts directly overlie marine Paleocene sediments.

FOURMILE BRANCH FORMATION (274–251 ft)

Two samples from 269 and 245 ft contain early Eocene dinocysts, including *Hafniasphaera goodmanii* Edwards (pl. 3, fig. 1), primitive forms of *Pentadinium favatum* Edwards, and *Wetzeliella articulata* Eisenack. The lowest of these contains *Homotryblium abbreviatum* Eaton (pl. 3, fig. 11). These assemblages are likely to be of early Eocene age.

CONGAREE FORMATION (251–182 ft)

Six samples in the Congaree from the Thompson Oak core were studied for dinocysts. The lowest sample (R4836 G from 245 ft) contains the highest occurrence of *Hafniasphaera goodmanii* Edwards. Five samples from 231.5–183.5 ft all contain dinofloras that are roughly correlative with the upper part of the Tallahatta Formation and the lower part of the Lisbon Formation in Alabama. Sample R4836 H (at 231.5 ft) is more likely correlative with the upper part of the Tallahatta because it contains *Turbiosphaera* cf. *T. galatea*. The three samples from 194–183 ft (R4836 J, K, and L) are more likely correlative with the lower part of the Lisbon because they contain *Glaphyrocysta* cf. *G.? vicina* (pl. 2, fig. 14). Sample R4836 I (at 210 ft) does not contain sufficient diagnostic taxa.

WARLEY HILL FORMATION (NOT PRESENT)

The Warley Hill Formation is not present in the Thompson Oak core.

SANTEE LIMESTONE (182–130 ft)

Six samples of the Santee Limestone were studied from the Thompson Oak core. The five samples from 181.5–154 ft depth contain a distinctive dinocyst assemblage that includes *Pentadinum goniferum* Edwards, *Pentadinium* Gerlach n. sp. D (pl. 3, figs. 19–21), *Enneadocysta* Stover & Williams spp., *Heteraulacacysta porosa* Bujak, and *Hystrichostrogylon membraniphorum* Agelopoulos (pl. 3, fig. 13). These forms indicate an age in the later part of the middle Eocene and correlation with the upper part of the Lisbon Formation, the Gosport Sand, or the Moodys Branch Formation in the Gulf Coast. The highest Santee Limestone sample (R4836 R, at 138 ft) contains the lowest occurrence of *Cordosphaeridium cantharellus* (Brosius) Gocht.

BARNWELL UNIT (130–0 ft)

Sediments of the Barnwell unit in the Thompson Oak core were not sampled in this study.

DINOCYSTS FROM THE MILLERS POND CORE

Nine samples were taken in Tertiary sediments of the Millers Pond core; seven contained dinocysts, and the uppermost two samples are barren. The occurrences of dinocyst taxa in this core are shown in figure 5.

ELLENTON FORMATION (284–232 ft)

Dinocysts in the Ellenton Formation from the Millers Pond core were studied from two samples (R4581 Q, at 252–257 ft; R4581 R, at 237–242 ft). Both contain dinocyst assemblages of Paleocene age (Danian or Selandian, Midwayan). The lower sample contains *Areoligera volata* Drugg (pl. 1, fig. 5), *Carpatella cornuta* Grigorovich, *Spini-*

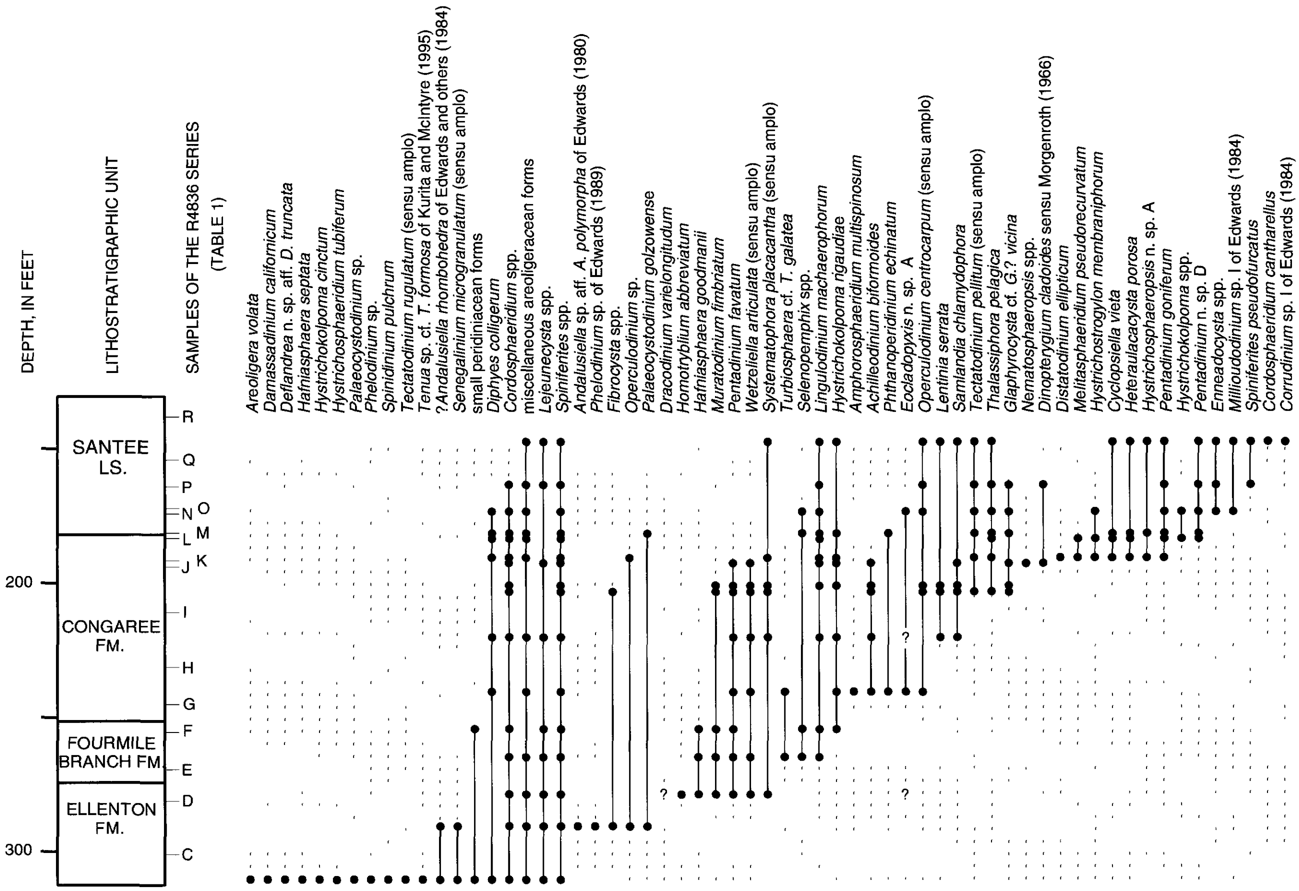

Figure 4. Range and occurrence chart of dinocysts and acritarchs in the Thompson Oak core. Lithostratigraphy from Falls and Prowell (this volume, chap. A). ?=questionably identified.

dinium densispinatum Stanley, *Spinidinium pulchrum* (Benson) Lentin & Williams, *Tectatodinium rugulatum* (Hansen) McMinn, and *Tenua* sp. cf. *T. formosa* of Kurita and McIntyre (1995). *C. cornuta* has not been reported from sediments younger than early Paleocene. This sample contains early Paleocene pollen (Frederiksen, this volume, chap. H).

The upper sample in the Ellenton contains a distinctive assemblage including *Andalusiella* sp. aff. *A. polymorpha* of Edwards (1980) (pl. 5, fig. 3), *Deflandrea* cf. *D. diebelii* of Drugg (1967), *Senegalinium microgranulatum* (Stanley) Stover & Evitt (pl. 6, fig. 5), *Isabelidinium viborgense* sensu Kurita and McIntyre (1995), and *Damassadinium californicum* (Drugg) Fensome et al. The species in this upper sample were reported together in the Porters Creek Clay in Alabama (Edwards, 1980). However, the assemblage could perhaps range into slightly younger sediments, because the Naheola Formation was not included in the 1980 study. Kurita and McIntyre (1995) used the lowest occurrence of *I. viborgense* Heilmann-Clausen to mark the base of the Selandian (earliest late Paleocene) in Manitoba, Canada.

SNAPP FORMATION (232–165 ft)

The interval from 232 to 165 ft in the core consisted of coarse sand and thoroughly oxidized kaolinitic clay and was not sampled for dinocysts.

FOURMILE BRANCH FORMATION (NOT PRESENT)

The Fourmile Branch Formation is not present in the Millers Pond core. There is no evidence of early Eocene marine deposition in this core.

CONGAREE FORMATION (165–156 ft)

Directly above the oxidized clays of the Snapp Formation is a 9-ft-thick unit of silty sand. A sample just above the base (R4581 S, at 165 ft) contains a dinocyst assemblage that includes *Diphyes colligerum* (Deflandre & Cookson) Cookson, *Phthanoperidinium echinatum* Eaton, *Polysphaeridium zoharyi* (Rossignol) Bujak et al., somewhat primitive

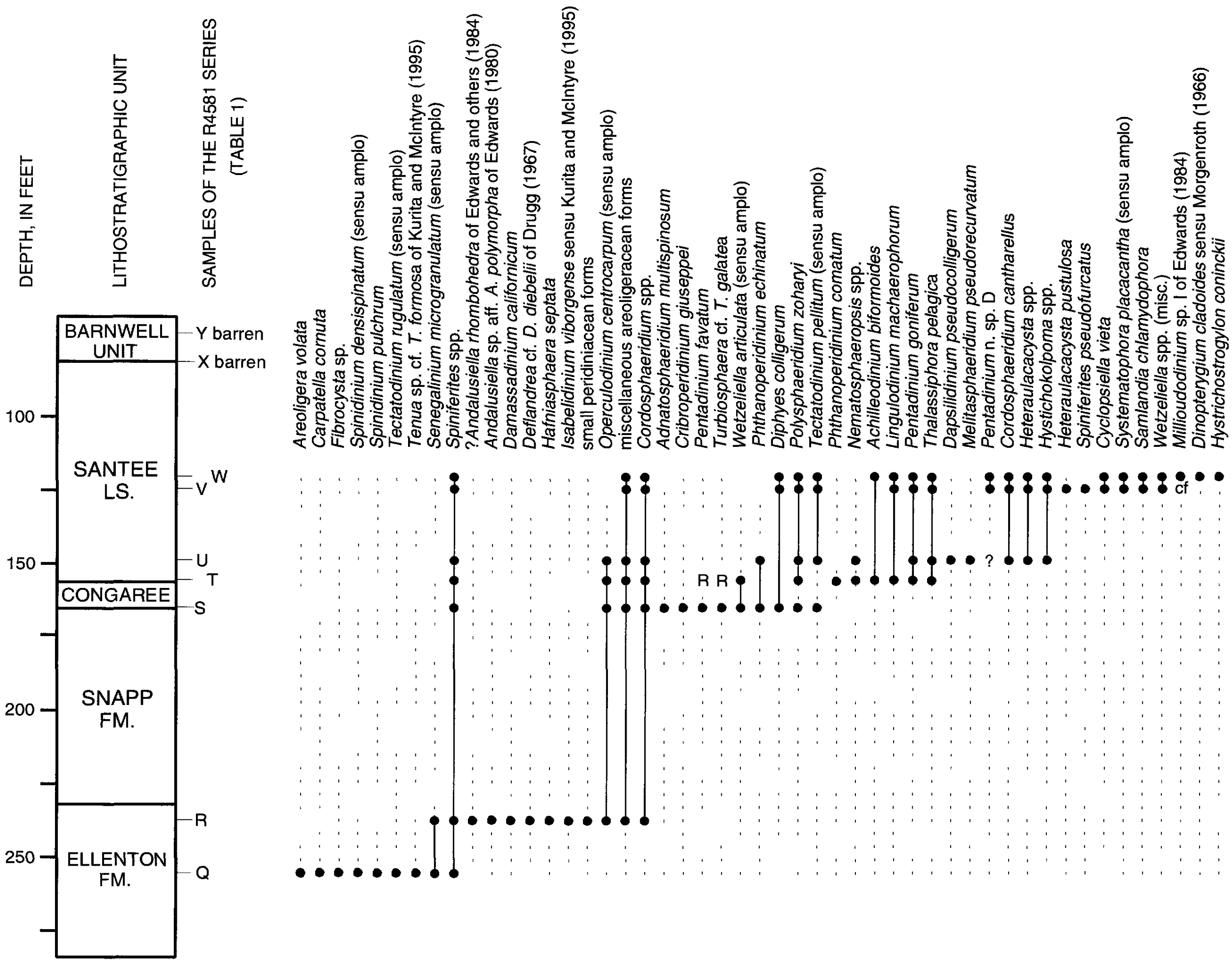

Figure 5. Range and occurrence chart of dinocysts and acritarchs in the Millers Pond core. Lithostratigraphy from Falls and Prowell (this volume, chap. A). R=reworked; cf=compares with; ?=questionably identified.

forms of *Pentadinium favatum* Edwards, *Turbiosphaera* cf. *T. galatea*, and *Wetzeliella articulata* Eisenack. This assemblage correlates with that recorded from the upper part of the Tallahatta Formation in Alabama, which is in the lower part of the middle Eocene.

WARLEY HILL FORMATION (NOT PRESENT)

The Warley Hill Formation is not present in the Millers Pond core.

SANTEE LIMESTONE (156–82 ft)

Five samples from the Santee Limestone were studied from the Millers Pond core. The lowest sample (R4581 T, at 155 ft) contains a diverse dinocyst assemblage including *Achilleodinium biformoides* (Eisenack) Eaton and *Pentadinium goniferum* Edwards, and single specimens of *Pentadinium favatum* Edwards and *Turbiosphaera* cf. *T. galatea*. This assemblage could represent the interval of overlap of the ranges of *P. favatum* Edwards and *P. goniferum* Edwards, or it could represent a lag deposit at the base of the overlying unit. Because *P. favatum* Edwards and *Turbiosphaera* cf. *T. galatea* are each represented by one poorly preserved specimen, and because *Turbiosphaera* cf. *T. galatea* and *P. goniferum* Edwards do not overlap in other cores, the interpretation of this sample as a lag deposit appears more likely.

Three samples (R4581 U, V, W, at 148, 124, and 120 ft) contain diverse and abundant dinocyst assemblages including *Pentadinium goniferum* Edwards, *Pentadinium* Gerlach n. sp. D, *Samlandia chlamydophora* Eisenack, *Hystrichostrogylon coninckii* Heilmann-Clausen, *Cordosphaeridium cantharellus* (Brosius) Gocht, and *Dapsilidinium pseudocolligerum* (Stover) Bujak et al. This is a late middle Eocene assemblage, correlative with the upper part of the Lisbon Formation, Gosport Sand, or Moodys Branch Formation in Alabama. The uppermost

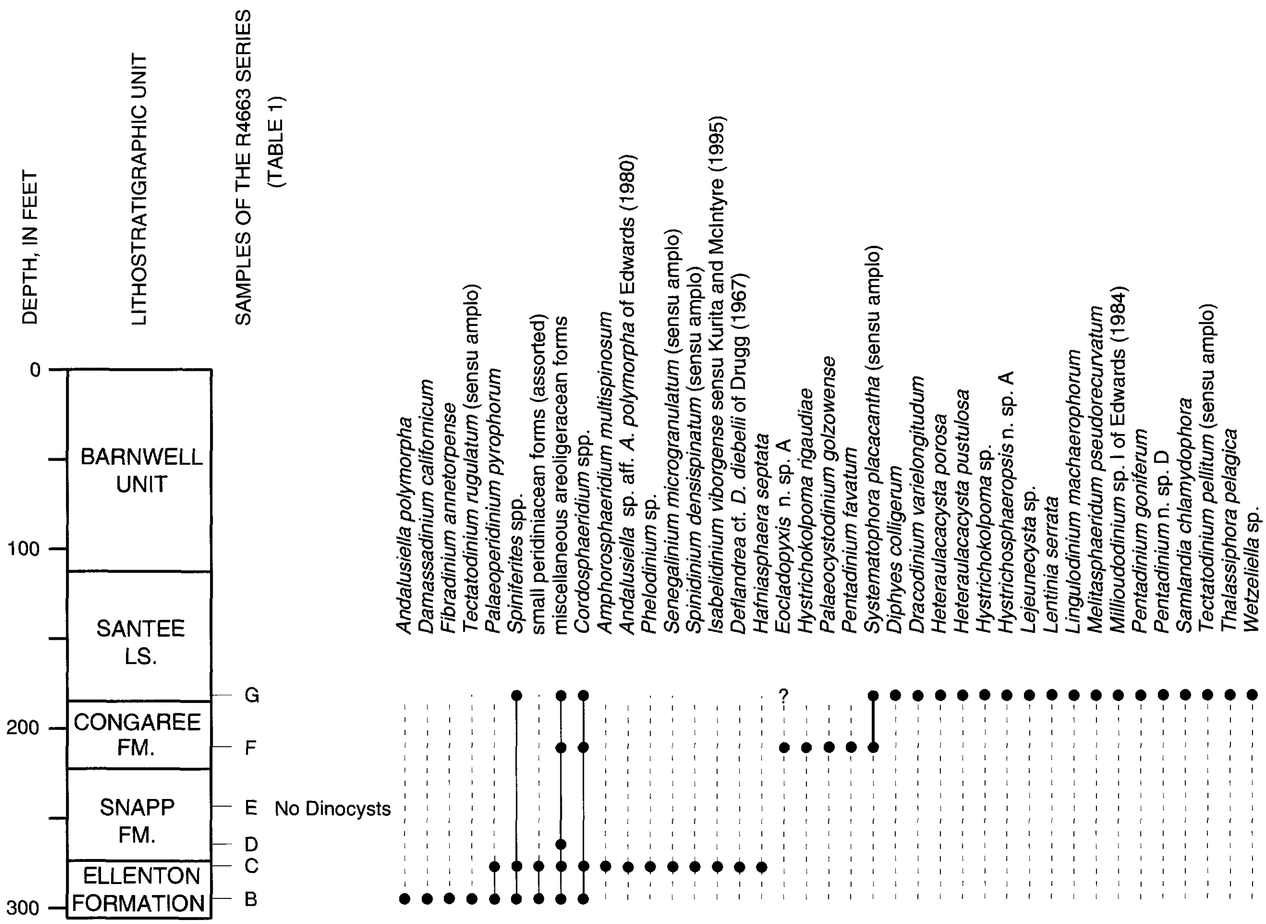

Figure 6. Range and occurrence chart of dinocysts and acritarchs in the McBean core. Lithostratigraphy from Falls and Prowell (this volume, chap. A). ?=questionably identified.

sample in the Santee Limestone (R4581 X, at 82–83 ft) is barren of dinocysts.

BARNWELL UNIT (82–0 ft)

Barnwell unit sediments were examined for dinocysts in a single sample at 72–77 ft in the Millers Pond core. The sample proved barren.

DINOCYSTS FROM THE MCBEAN CORE

Six samples were taken in Tertiary sediments of the McBean core; five contained dinocysts and one yielded only pollen. The occurrences of dinocyst taxa in this core are shown in figure 6.

ELLENTON FORMATION (305–272 ft)

Two samples from the Ellenton Formation in the McBean core yielded Paleocene (Danian or Selandian, Midwayan) dinocyst assemblages. The lower sample (R4663 B, at 294 ft) includes *Damassadinium californicum* (Drugg) Fensome et al. (pl. 2, figs. 1–2), *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant, and *Tectatodinium rugulatum* (Hansen) McMinn. The upper sample (R4663 C, at 276 ft) includes *Andalusiella* sp. aff. *A. polymorpha* of Edwards (1980), *Deflandrea* cf. *D. diebelii* of Drugg (1967), *Hafniasphaera septata* (Cookson & Eisenack) Hansen, *Isabelidinium viborgense* sensu Kurita and McIntyre (1995) (pl. 5, fig. 2), and *P. pyrophorum* (Ehrenberg) Sarjeant. The lower sample is likely to be early Paleocene, as indicated by the presence of *T. rugulatum* (Hansen) McMinn. The upper sample is late Paleocene (Selandian, Midwayan) because of the presence of *I. viborgense* sensu Kurita and McIntyre (1995).

SNAPP FORMATION (272–222 ft)

A single fragmental specimen of the areoligeraceae group was recovered from the sample of the Snapp Formation at 264 ft (R4663 D) in the McBean core. A second sample (R4663 E, at 243 ft) yielded no dinocysts.

FOURMILE BRANCH FORMATION (NOT PRESENT)

The Fourmile Branch Formation is not recognized in the McBean core.

CONGAREE FORMATION (222–186 ft)

A single sample of the Congaree Formation in the McBean core (R4663 F, at 210 ft) contains the early middle Eocene species *Eocladopyxis* Morgenroth n. sp. A and *Pentadinium favatum* Edwards, and long-ranging species.

WARLEY HILL FORMATION (NOT PRESENT)

The Warley Hill Formation is not recognized in the McBean core.

SANTEE LIMESTONE (186–112 ft)

A single sample of the Santee Limestone in the McBean core (R4663 G, at 181 ft) yielded a diverse middle Eocene dinocyst assemblage. *Heteraulacacysta porosa* Bujak, *Heteraulacacyata pustulosa* Jan du Chêne & Adediran (pl. 3, fig. 5), *Pentadinium goniferum* Edwards, and *Samlandia chlamydophora* Eisenack are present. The assemblage resembles that in the Santee Limestone in the Thompson Oak core.

BARNWELL UNIT (112–0 ft)

Sediments of the Barnwell unit from the McBean core were not sampled in this study.

DISCUSSION

Paleocene sediments in the cores studied include two separate assemblages. The older one is early Paleocene (Danian, Midwayan) and contains *Carpatella cornuta* Grigorovich, *Spinidinium pulchrum* (Benson) Lentin & Williams (pl. 6, figs. 6, 10), *Tectatodinium rugulatum* (Hansen) McMinn, and *Tenua* sp. cf. *T. formosa* of Kurita and McIntyre (1995). This assemblage is assigned to calcareous nannofossil Zone NP 4 in the Millhaven core. The younger assemblage contains *Phelodinium* sp. of Edwards (1989) (pl. 5, fig. 10) and is assigned to calcareous nannofossil Zones NP 5 and NP 8 in the Millhaven core (Bybell, this volume, chap. F). Both assemblages contain *Damassadinium californicum* (Drugg) Fensome et al., *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant, and *Deflandrea* cf. *D. diebelii* of Drugg (1967) (pl. 5, fig. 6) and may be dominated by small peridiniaceans (pl. 6, figs. 13, 15, 16). *Andalusiella* sp. aff. *A. polymorpha* of Edwards (1980) and *Isabelidinium viborgense* sensu Kurita and McIntyre (1995) may be found just below, and in the lower part of, the upper assemblage. Kurita and McIntyre (1995) used the lowest occurrence of *I. viborgense* Heilmann-Clausen to approximate the early-late Paleocene (Danian-Selandian) boundary in Manitoba, Canada. In the Millhaven core, the uppermost Ellenton sample has been placed in calcareous nannofossil Zone NP 8 (Bybell, this volume, chap. F) although the dinocyst assemblage is not noticeably different from assemblages in the samples below it.

The Snapp Formation is present in varying thicknesses in four of the five cores. It is conspicuously absent in the Thompson Oak core, and an upper kaolinitic part is not present in the McBean core. Because the Snapp Formation is present in the most updip cores, it was probably also present in the Thompson Oak area originally but subsequently removed. Marginal marine or marine dinocysts are found in two samples of the lower part of the Snapp Formation in the Millhaven and McBean cores. However, the assemblages are not age diagnostic and could perhaps be reworked from the Ellenton.

Lower Eocene sediments are identified in the Fourmile Branch Formation in the Thompson Oak core on the basis of *Hafniasphaera goodmanii* Edwards and primitive forms of *Pentadinium favatum* Edwards. *Homotryblium abbreviatum* Eaton is also present. Sediments in the Fourmile Branch in the Girard core contain *Dracodinium varielongitudum* (Williams & Downie) Costa & Downie and *Homotryblium tenuispinosum* Davey & Williams and may be of early Eocene age. Early Eocene dinocysts are conspicuously missing from the Millhaven, Millers Pond, and McBean cores.

Middle Eocene Congaree sediments correlative with the uppermost part of the Tallahatta Formation and the lower part of the Lisbon Formation are present in all cores. Samples contain diverse dinocyst assemblages, which include *Achilleodinium biformoides* (Eisenack) Eaton (pl. 1, figs. 1–3), *Diphyes colligerum* (Deflandre & Cookson) Cookson, *Eocladopyxis* Morgenroth n. sp. A, *Glaphyrocysta* cf. *G.*? *vicina*, *Phthanoperidinium echinatum* Eaton (pl. 5, figs. 16, 17), *Pentadinium favatum* Edwards, *Samlandia chlamydophora* Eisenack (pl. 4, fig. 3), *Turbiosphaera* cf. *T. galatea*, *Wetzeliella articulata* Eisenack (pl. 6, figs. 7, 11), and many areoligeracean forms. The highest occurrence of *Turbiosphaera* cf. *T. galatea* and the lowest occurrence of *Glaphyrocysta* cf. *G.*? *vicina* may mark an important level, correlative with the Tallahatta Formation-Lisbon Formation boundary in Alabama and the E3-E4 boundary (of Prowell, Christopher, and others, 1985) in Georgia. Calcareous nannofossils in the Millhaven core indicate that this boundary is near the NP 14/NP 15 boundary.

Sediments containing both *Pentadinium favatum* Edwards and *Pentadinium goniferum* Edwards are found only in the Millhaven core. It is here they are assigned to the Warley Hill Formation (Falls and Prowell, this volume, chap. A) and to calcareous nannofossil Zone NP 15 (Bybell, this volume, chap. F).

Middle Eocene sediments correlative with the upper part of the Lisbon Formation and the Gosport Sand in Alabama are present in the Santee Limestone in all cores. Assemblages vary from quite diverse to poorly preserved and nondiagnostic. *Pentadinium goniferum* Edwards is present in every sample. The lowest occurrences of *Cordosphaeridium cantharellus* (Brosius) Gocht, *Cyclopsiella vieta* Drugg & Loeblich, and *Dapsilidinium pseudocolligerum* (Stover) Bujak et al. (pl. 1, fig. 18) are found in the Santee Limestone. *Hystrichosphaeropsis* Deflandre n. sp. A (pl. 3, figs.7–9), *Pentadinium* Gerlach n. sp. D, and *Pentadinium polypodum* Edwards are apparently restricted to the Santee Limestone. *Enneadocysta* spp., various species of *Heteraulacacysta,* and a wide variety of areoligeracean forms are present in the more diverse samples. Species of *Wetzeliella* (pl. 6, fig. 12) are present in a few samples but are not common.

In the Millhaven and Girard cores, the lowest samples in the Santee Limestone are barren or nearly so. In the Millhaven core, the sample at 346 ft contains the lowest occurrences of *Cordosphaeridium cantharellus* (Brosius) Gocht, *Pentadinium polypodum* Edwards, and *Samlandia chlamydophora* Eisenack sensu Stover and Hardenbol (1993). Here, the lowest occurrence of *Cordosphaeridium cantharellus* (Brosius) Gocht approximates the base of calcareous nannofossil Zone NP 17 (Bybell, this volume, chap. F). In the Girard core, the lowest occurrence of *Cordosphaeridium cantharellus* (Brosius) Gocht is just above the base of the Santee Limestone.

Dinocyst recovery is spotty in sediments of the Barnwell unit. In the Millhaven core, samples contain *Batiacasphaera baculata* Drugg, *Batiacasphaera compta* Drugg, and *Cordosphaeridium funiculatum* Morgenroth, which indicate a late Eocene age. In the Girard core, *Rhombodinium perforatum* (Jan du Chêne & Châteauneuf) Lentin & Williams is diagnostic. Both cores contain *Charlesdowniea variabilis* (Bujak) Lentin & Vozzhennikova (pl. 5, fig. 11). In the remaining cores, samples were not taken in Barnwell sediments, except one sample, which was barren (table 1).

Figure 7 shows core-to-core correlations suggested by the dinocyst assemblages. Lower Paleocene sediments are present in all cores, but these may be thicker in the updip cores (McBean, Millers Pond, and Thompson Oak) than in the most downdip core (Millhaven). The younger part of the Ellenton is thinnest in the updip cores.

The Snapp Formation is missing from the Thompson Oak core and truncated in the McBean core. The Fourmile Branch Formation is recognized only in the Girard and Thompson Oak cores. In the Thompson Oak core, the absence of the Snapp corresponds with the presence of the Fourmile Branch and a thickened Congaree relative to other cores.

The Congaree Formation is middle Eocene. It contains two recognizable dinocyst assemblages, which are equivalent to those found in the upper part of the Tallahatta Formation and the lower part of the Lisbon Formation in Alabama. The Warley Hill Formation is recognized only in the most basinward core (Millhaven).

The Tertiary units in the Burke and Screven County cores studied here show a much more complex history than was anticipated. In these generally shallow marine sediments, local patterns of erosion and deposition are important. A paleo-Savannah River may have wholly or partially eroded units such as the Snapp Formation to allow selective infilling, or selective preservation of more widespread infilling, during later transgressions.

TAXONOMIC NOTES

The species present are listed in Williams and others (1998) and their taxonomic history is not repeated here. Brief synonymies are provided for dinocysts that are presented in open or informal nomenclature. Higher level taxonomy is taken from Fensome and others (1993). Taxa are presented alphabetically by order. For convenience, dates are provided with the authors' names for formal taxa; the works these represent are not included in the references here but may be found in Williams and others (1998). Table 2 provides the slide locations of all figured specimens.

Division DINOFLAGELLATA (Butschli 1885) Fensome et al. 1993

Subdivision DINOKARYOTA Fensome et al. 1993

Class DINOPHYCEAE Pascher 1914

Subclass PERIDINIPHYCIDAE Fensome et al. 1993

Order GONYAULACALES Taylor 1980

ACHILLEODINIUM BIFORMOIDES (EISENACK 1954) EATON 1976

Plate 1, figures 1–3

Remarks.—Both relatively smooth forms and those with striate processes are included.

AMPHOROSPHAERIDIUM? MULTISPINOSUM (DAVEY & WILLIAMS 1966) SARJEANT 1981

Plate 1, figure 4

AREOLIGERA VOLATA DRUGG 1967

Plate 1, figure 5

AREOSPHAERIDIUM DIKTYOPLOKUM (KLUMPP 1953) EATON 1971

Plate 1, figure 6

BATIACASPHAERA BACULATA DRUGG 1970

Plate 1, figure 7

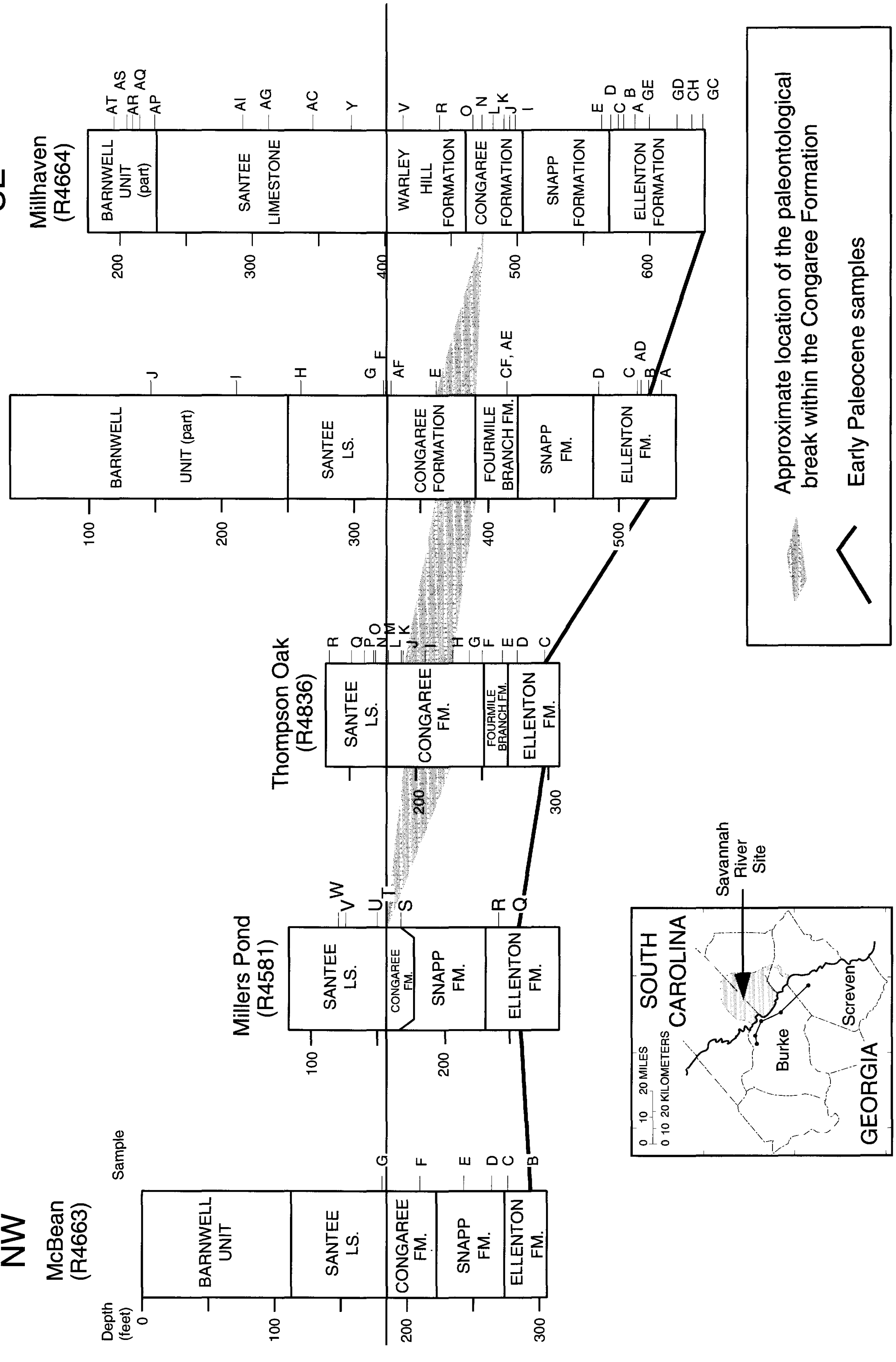

Figure 7. Correlation diagram by dinocyst assemblages for the five Georgia cores. Datum is the base of the Santee Limestone.

BATIACASPHAERA COMPTA DRUGG 1970

Plate 1, figures 8, 9

CARPATELLA CORNUTA GRIGOROVICH 1969

Plate 1, figure 10

CEREBROCYSTA BARTONENSIS BUJAK 1980

Plate 1, figures 12, 13

CORDOSPHAERIDIUM CANTHARELLUS (BROSIUS 1963) GOCHT 1969

Plate 1, figure 14

Remarks.—*Cordosphaeridium* Eisenack 1963 is considered here to be the senior taxonomic synonym of *Tityrosphaeridium* Sarjeant 1981. The holotype of *Cordosphaeridium inodes* (Klumpp 1953) Eisenack 1963 clearly shows cingular processes in the illustration by Sarjeant (1981, text-fig. 1).

CORDOSPHAERIDIUM FUNICULATUM MORGENROTH 1966

Plate 1, figure 11

CORDOSPHAERIDIUM EISENACK 1963 SPP.

Remarks.—The species *Cordosphaeridium fibrospinosum* Davey & Williams 1966, *Cordosphaeridium gracile* (Eisenack 1954) Davey & Williams 1966, *Cordosphaeridium inodes* (Klumpp 1953) Eisenack 1963, and forms between these endmembers are not differentiated in this study.

CORRUDINIUM INCOMPOSITUM (DRUGG 1970) STOVER & EVITT 1978

Plate 1, figure 15

CORRUDINIUM SP. I OF EDWARDS (1984)

Plate 1, figure 16

Corrudinium sp. I. Edwards, 1984, pl. 2, fig. 1.

Remarks.—Some forms are transitional to *Cerebrocysta bartonensis* Bujak 1980.

CRIBROPERIDINIUM GIUSEPPEI (MORGENROTH 1966) HELENES 1984

Plate 1, figure 17

CRIBROPERIDINIUM TENUITABULATUM (GERLACH 1961) HELENES 1984

DAMASSADINIUM CALIFORNICUM (DRUGG 1967) FENSOME ET AL. 1993

Plate 2, figures 1–3

Remarks.—Both typical and elongate forms are included.

DAPSILIDINIUM PSEUDOCOLLIGERUM (STOVER 1977) BUJAK ET AL. 1980

Plate 1, figure 18

DINOPTERYGIUM CLADOIDES SENSU MORGENROTH 1966

Plate 2, figure 4

Dinopterygium cladoides Deflandre. Morgenroth, 1966, pl. 2, fig. 11.
Heteraulacacysta sp. Damassa and others, 1990, fig. 5E, F.
Dinopterygium sp. Stover and Hardenbol, 1993, pl. 12, fig. 83.

DIPHYES COLLIGERUM (DEFLANDRE & COOKSON 1955) COOKSON 1965

DIPHYES FICUSOIDES ISLAM 1983

Plate 2, figure 5

DISTATODINIUM ELLIPTICUM (COOKSON 1965) EATON 1976

Plate 2, figure 9

ENNEADOCYSTA STOVER & WILLIAMS 1995 SPP.

Plate 2, figure 6

Remarks.—Various species of the genus are included.

EOCLADOPYXIS MORGENROTH 1966 N. SP. A

Plate 2, figure 7

Remarks.—The processes resemble those of *Polysphaeridium zoharyi* (Rossignol 1962) Bujak et al. 1980, but the separation of the individual paraplates requires placement in the genus *Eocladopyxis* Morgenroth 1966.

FIBRADINIUM ANNETORPENSE MORGENROTH 1968

Plate 2, figure 8

FIBROCYSTA STOVER & EVITT 1978 SPP.

Remarks.—Various species of the genus are included.

GLAPHYROCYSTA CF. *G.? VICINA* (EATON 1976) STOVER & EVITT 1978

Plate 2, figures 10–15

Remarks.—This form is highly variable in the degree of development of the marginal flanges. It resembles *Membranophoridium aspinatum* Gerlach 1961 in overall appearance, but it is smaller, has less pronounced dorso-ventral compression, and has less prominent flanges. It resembles and may be transitional with *Membranophoridium bilobatum* Michoux 1985, which has narrower flanges and no development of pericoels other than along the margins. It is closest to *Glaphyrocysta*? *vicina* (Eaton 1976) Stover & Evitt 1978. However, the paracingulum may be more pronounced, and the details of the dorsal and ventral surfaces may warrant separation.

HAFNIASPHAERA GOODMANII EDWARDS 1982

Plate 3, figure 1

Remarks.—The illustrated specimen, like most specimens seen, is actually transitional with primitive forms of *Pentadinium favatum* Edwards.

HAFNIASPHAERA SEPTATA (COOKSON & EISENACK 1967) HANSEN 1977

Plate 3, figure 10

HETERAULACACYSTA POROSA BUJAK 1980

Plate 3, figures 2, 3

HETERAULACACYSTA PUSTULOSA JAN DU CHÊNE & ADEDIRAN 1985

Plate 3, figure 5

HETERAULACACYSTA DRUGG & LOEBLICH 1967 SPP.

Plate 3, figure 6

Remarks.—The species *Heteraulacacysta campanula* Drugg & Loeblich 1967 and *Heteraulacacysta*? *leptalea* Eaton 1976 and poorly preserved specimens of the genus that are unattributable to species are placed here.

HOMOTRYBLIUM ABBREVIATUM EATON 1976

Plate 3, figure 11

HOMOTRYBLIUM PLECTILUM DRUGG & LOEBLICH 1967

Plate 3, figure 12

HOMOTRYBLIUM TENUISPINOSUM DAVEY & WILLIAMS 1966

HYSTRICHOKOLPOMA CINCTUM KLUMPP 1953

HYSTRICHOKOLPOMA RIGAUDIAE DEFLANDRE & COOKSON 1955

HYSTRICHOKOLPOMA DEFLANDRE 1935 SPP.

Remarks.—Various species of the genus are included.

HYSTRICHOSPHAERIDIUM TUBIFERUM (EHRENBERG 1838) DEFLANDRE 1937

HYSTRICHOSPHAEROPSIS DEFLANDRE 1935 N. SP. A

Plate 3, figures 7–9

Remarks.—This small, distinctive form has relatively high septa that are finely serrate distally.

HYSTRICHOSTROGYLON CONINCKII HEILMANN-CLAUSEN 1985

HYSTRICHOSTROGYLON MEMBRANIPHORUM AGELOPOULOUS 1964

Plate 3, figure 13

LINGULODINIUM MACHAEROPHORUM (DEFLANDRE & COOKSON 1955) WALL 1967

MELITASPHAERIDIUM ASTERIUM (EATON 1976) BUJAK ET AL. 1980

MELITASPHAERIDIUM PSEUDORECURVATUM (MORGENROTH 1966) BUJAK ET AL. 1980

MILLIOUDODINIUM SP. I OF EDWARDS (1984)

Plate 3, figure 4

Millioudodinium sp. I. Edwards, 1984, pl. 2, fig. 2.
Cribroperidinium sp. 2. Damassa and others, 1990, fig. 4C.
Cribroperidinium sp. 2. Firth, 1996, pl. 5, figs. 7, 8.

Remarks.—The honeycomb pattern in the intraplate areas is distinctive. This form now correctly belongs in the genus *Cribroperidinium* Neale & Sarjeant 1962, emend. Helenes 1984.

MURATODINIUM FIMBRIATUM (COOKSON & EISENACK 1967) DRUGG 1970

NEMATOSPHAEROPSIS DEFLANDRE & COOKSON 1955 SPP.

Remarks.—Various species of the genus are included.

OPERCULODINIUM CENTROCARPUM (DEFLANDRE & COOKSON 1955) WALL 1967

Plate 3, figure 14

Remarks.—The species name is used in the broad sense.

OPERCULODINIUM WALL 1967 SPP.

Remarks.—Various species of the genus are included.

PENTADINIUM FAVATUM EDWARDS 1982

Plate 3, figure 15

PENTADINIUM GONIFERUM EDWARDS 1982

Plate 3, figure 16

PENTADINIUM LATICINCTUM GERLACH 1961 SUBSP. *LATICINCTUM*

Plate 3, figure 17

PENTADINIUM LATICINCTUM GERLACH 1961 (VERM.)

Plate 3, figure 18

Pentadinium laticinctum subsp. *granulatum.* Edwards, 1982, pl. 4, figs. 10, 11.
Pentadinium laticinctum (vermicular) Gerlach. Edwards, 1984, pl. 2, fig. 4.

Remarks.—Specimens of *P. laticinctum* Gerlach 1961 with a vermicular surface are separated from *P. laticinctum* Gerlach 1961 subsp. *laticinctum.* The vermicular surface differs from the granular surface of *Pentadinium laticinctum* subsp. *granulatum* Gocht 1969.

PENTADINIUM MEMBRANACEUM (EISENACK 1965) STOVER & EVITT 1978

Plate 4, figure 1

PENTADINIUM POLYPODUM EDWARDS 1982

Plate 4, figure 2

PENTADINIUM GERLACH 1961 N. SP. D

Plate 3, figures 19–21

Remarks.—In this undescribed form of *Pentadinium* Gerlach 1961, the periphragm in the paracingular region is separated from the endophragm only along the ventral side; the wall layers are appressed laterally and dorsally. The wall surface is smooth.

POLYSPHAERIDIUM ZOHARYI (ROSSIGNOL 1962) BUJAK ET AL. 1980

ROTTNESTIA BORUSSICA (EISENACK 1954) COOKSON & EISENACK 1961

SAMLANDIA CHLAMYDOPHORA EISENACK 1954

Plate 4, figure 3

SAMLANDIA CHLAMYDOPHORA EISENACK SENSU STOVER AND HARDENBOL (1993)

Plate 4, figure 4

Samlandia chlamydophora Eisenack 1954. Stover and Hardenbol, 1993, pl. 8, fig. 54 a,b.

Remarks.—This form has considerably more differentiation into separate penetabular process complexes than does the type of *S. chlamydophora* Eisenack 1954.

SPINIFERITES PSEUDOFURCATUS (KLUMPP 1953) SARJEANT 1970

Plate 4, figure 5

SPINIFERITES MANTELL 1850 SPP.

Remarks.—Various species of the genus are included.

SYSTEMATOPHORA PLACACANTHA (DEFLANDRE & COOKSON 1955) DAVEY ET AL. 1969

Plate 4, figure 6

Remarks.—The species name is used in the broad sense. The process complexes are highly variable.

TECTATODINIUM PELLITUM WALL 1967

Plate 4, figure 8

Remarks.—The species name is used in the broad sense. The wall thickness is highly variable. Although some specimens are assignable to *Tectatodinium grande* Williams et al. 1993, they are clearly only endmembers in a spectrum.

TECTATODINIUM RUGULATUM (HANSEN 1977) MCMINN 1988

Plate 4, figures 10, 11

Remarks.—The species name is used in the broad sense. The wall is thicker than the wall in the type specimen.

TENUA SP. CF. *T. FORMOSA* OF KURITA AND MCINTYRE (1995)

Plate 4, figure 7

Tenua sp. cf. *T. formosa* (Mao & Norris 1988) Lentin & Williams 1993. Kurita and McIntyre, 1995, p. 134, pl. 2, fig. 15.

Remarks.—Like the specimens reported by Kurita and McIntyre (1995), the specimens in the Georgia cores lack well-defined paratabulation. This form was encountered in three cores in the lowest samples from the Ellenton Formation. In four of the five samples, *Carpatella cornuta* Grigorovich was also present.

THALASSIPHORA PELAGICA (EISENACK 1954) EISENACK & GOCHT 1960

TRIGONOPYXIDIA GINELLA (COOKSON & EISENACK 1960) DOWNIE & SARJEANT 1965

TUBERCULODINIUM WALL 1967 N. SP. A

Plate 4, figure 9

Remarks.—Only a few specimens of this form were encountered. It has a broad flange and faintly developed tubercules. The multiplate antapical archeopyle clearly indicates its affinity with *Tuberculodinium* Wall 1967.

TURBIOSPHAERA CF. *T. GALATEA* EATON 1976

Plate 4, figure 12

?*Lanternosphaeridium lanosum* Morgenroth 1966. Drugg and Stover, 1975, pl. 5, fig. 2.

Remarks.—The Georgia form resembles *Turbiosphaera galatea* Eaton 1976, but the intratabular processes are not as well developed and may form a more or less continuous membrane that represents the postcingular and antapical areas. The endocyst may have a distinct apical boss. It is more elongate than *L. lanosum* Morgenroth sensu Drugg and Stover (1975).

MISCELLANEOUS AREOLIGERACEAN FORMS

Plate 4, figures 13, 14

Remarks.—This category is used for the highly variable plexus that contains members of the genera *Adnatosphaeridium, Areoligera*, and *Glaphyrocysta*, except for the distinctive species listed separately.

Order PERIDINIALES Haeckel 1894

ANDALUSIELLA POLYMORPHA (MALLOY 1972) LENTIN & WILLIAMS 1977

Remarks.—Broad forms with two distinct antapical horns were seen.

ANDALUSIELLA SP. AFF. *A. POLYMORPHA* OF EDWARDS (1980)

Plate 5, figures 3, 4

Andalusiella sp. aff. *A. polymorpha* (Malloy 1972) Lentin & Williams 1977. Edwards, 1980, p. 9, fig. 1.

Andalusiella australinum (Cookson 1965) Lentin & Williams 1977. Kurita and McIntyre (1995), pl. 1, fig. 12.

Remarks.—The two antapical horns are fused proximally. At one-third to one-half of the total length of the longer horn, they separate.

?*ANDALUSIELLA RHOMBOHEDRA* OF EDWARDS AND OTHERS (1984)

Plate 5, figure 1

?*Andalusiella rhombohedra* (Benson) Stover & Evitt. Edwards and others, 1984, pl. 2, fig. 5.

Remarks.—This small, distinctive form could perhaps represent the endocyst only.

CHARLESDOWNIEA COLEOTHRYPTA (WILLIAMS & DOWNIE 1966) LENTIN & VOZZHENNIKOVA 1989

CHARLESDOWNIEA VARIABILIS (BUJAK 1980) LENTIN & VOZZHENNIKOVA 1989

Plate 5, figure 11

Remarks.—The species name is used in the broad sense.

DEFLANDREA DELINEATA COOKSON & EISENACK 1965

Plate 5, figure 5

Deflandrea cf. *D. dartmooria* Cookson & Eisenack 1965. Edwards and others, 1984, pl. 1, fig. 7.

Deflandrea cf. *D. dartmooria* of Edwards and others (1984). Edwards, 1989, pl. 1, fig. 6.

Remarks.—This form lacks the broad shoulders characteristic of *Cerodinium dartmoorium* (Cookson & Eisenack 1965) Lentin & Williams 1987.

DEFLANDREA PHOSPHORITICA EISENACK 1938

Plate 5, figure 9

DEFLANDREA N. SP. AFF. *D. TRUNCATA* STOVER

Plate 5, figure 8

Remarks.—The specimen shown in plate 5, figure 8 is a rather large, circumcavate form with a granulate endocyst. This form is relatively rare in the Georgia cores studied, but it may be stratigraphically important.

DEFLANDREA CF. *D. DIEBELII* ALBERTI OF DRUGG (1967)

Plate 5, figure 6

Deflandrea cf. *D. diebelii* Alberti 1959. Drugg, 1967, p. 16–17, pl. 2, fig. 6.

Deflandrea sp. cf. *D. diebelii* sensu Drugg 1967. Edwards, 1980, pl. 9, fig. 4.

Cerodinium speciosum (Alberti 1959) Lentin & Williams 1987. Kurita and McIntyre, 1995, pl. 1, fig. 1.

Remarks.—The periphragm is almost smooth (lacking striations or spinules).

DRACODINIUM VARIELONGITUDUM (WILLIAMS & DOWNIE 1966) COSTA & DOWNIE 1979

Plate 5, figure 7

ISABELIDINIUM VIBORGENSE SENSU KURITA AND MCINTYRE (1995)

Plate 5, figure 2

Peridiniacean cyst sp. C. Edwards, 1980, pl. 9, fig. 11.

Peridiniacean cyst sp. C of Edwards (1980). Edwards, 1989, pl. 1, fig. 12.

Isabelidinium viborgense Heilmann-Clausen 1985. Kurita and McIntyre, 1995, p. 131, pl. 1, figs. 9, 10.

Remarks.—The specimens in the Georgia cores, like the ones described by Kurita and McIntyre (1995), lack the additional openings on the pericyst that are found in the type material of Heilmann-Clausen (1985).

LEJEUNECYSTA ARTZNER & DÖRHÖFER 1978 SPP.

Remarks.—Various species of the genus are included.

LENTINIA SERRATA BUJAK 1980

Plate 5, figure 12

PALAEOCYSTODINIUM GOLZOWENSE ALBERTI 1961

PALAEOCYSTODINIUM ALBERTI 1961 SPP.

Remarks.—Specimens of the genus *Palaeocystodinium* Alberti in the Georgia cores were not assigned to species if the endocyst was clearly wider than the endocyst in specimens assigned to *Palaeocystodinium golzowense* Alberti.

PALAEOPERIDINIUM PYROPHORUM (EHRENBERG 1838) SARJEANT 1967

Plate 5, figure 13

PHELODINIUM SP. OF EDWARDS (1989)

Plate 5, figure 10

Phelodinium sp. Edwards, 1989, pl. 1, fig. 9.

Phelodinium magnificum sensu lato, Edwards, 1996, pl. 1, fig. 12.

Remarks.—*Phelodinium* sp. of Edwards (1989) has an elongated outline and straight sides on the epicyst; that is, the epicystal shape is neither convex nor concave in the terminology of Bujak and Davies (1983). This morphotype is restricted to the upper Paleocene in Virginia (Edwards, 1989, 1996) and the Georgia cores.

PHELODINIUM STOVER & EVITT 1978 SPP.

Plate 5, figure 14

Remarks.—Specimens from the Georgia cores assigned to *Phelodinium* Stover & Evitt spp. are of miscellaneous forms, probably several different species, that broadly are similar to *Phelodinium magnificum* (Stanley) Stover & Evitt sensu stricto.

PHTHANOPERIDINIUM COMATUM (MORGENROTH 1966) EISENACK & KJELLSTROM 1972

Plate 5, figure 15

PHTHANOPERIDINIUM ECHINATUM EATON 1976

Plate 5, figures 16, 17

PSEUDORHOMBODINIUM LISBONENSE WRENN 1996

Plate 6, figure 1

RHOMBODINIUM DRACO GOCHT 1955

Plate 6, figure 2

RHOMBODINIUM PERFORATUM (JAN DU CHÊNE & CHÂTEAUNEUF 1975) LENTIN & WILLIAMS 1977

Plate 6, figure 3

SELENOPEMPHIX NEPHROIDES BENEDEK 1972

Plate 5, figure 18

SELENOPEMPHIX BENEDEK 1972 SPP.

Plate 6, figure 4

Remarks.—Various species of the genus were seen.

SENEGALINIUM MICROGRANULATUM (STANLEY 1965) STOVER & EVITT 1978

Plate 6, figure 5

Remarks.—This species name is used in the broad sense.

SPINIDINIUM DENSISPINATUM STANLEY 1965

Plate 6, figure 8

Remarks.—This species name is used in the broad sense.

SPINIDINIUM PULCHRUM (BENSON 1976) LENTIN & WILLIAMS 1977

Plate 6, figures 6, 10

SPINIDINIUM COOKSON & EISENACK 1962 SPP.

Plate 6, figure 9

Remarks.—Specimens from the Georgia cores assigned to *Spinidinium* Cookson & Eisenack spp. are miscellaneous forms that do not clearly fall into the endmember morphotypes of recognized species. The illustrated specimen, recovered from the upper Eocene Barnwell unit, is probably reworked.

WETZELIELLA ARTICULATA EISENACK 1938

Plate 6, figures 7, 11

Remarks.—The species name is used in the broad sense.

WETZELIELLA EISENACK 1938 SPP.

Plate 6, figure 12

Remarks.—Specimens from the Georgia cores assigned to *Wetzeliella* Eisenack spp. are miscellaneous forms; many of the specimens are poorly preserved.

SMALL PERIDINIACEAN FORMS

Plate 6, figures 13–16

Remarks.—The category "small peridiniacean forms" was used for specimens in the Georgia cores that belong to miscellaneous species of the Family Peridiniaceae Ehrenberg 1831. They belong to several genera including *Alterbidinium* Lentin & Williams 1985, *Lentinia* Bujak 1980, *Senegalinium* Jain & Millepied 1973, and *Spinidinium* Cookson & Eisenack 1962. The category includes poorly preserved specimens and specimens that do not fall into the endmember morphotypes of recognized species.

ACRITARCHS

CYCLOPSIELLA VIETA DRUGG & LOEBLICH 1967

Plate 6, figure 17

XENIKOON AUSTRALIS SENSU BENSON (1976)

Plate 6, figure 18

Xenikoon australis Cookson & Eisenack. Benson, 1976, p. 28, pl. 14, fig. 11.

Xenikoon australis Cookson & Eisenack. Edwards and others, 1984, pl. 1, fig. 6.

Incertae sedis 1. Heilmann-Clausen, 1985, p. 26, text-fig. 11; pl. 15, figs. 7–10.

Xenikoon australis sensu Edwards and others, 1984. Edwards, 1989, pl. 1, fig. 4.

Remarks.—As Heilmann-Clausen (1985) pointed out, this form lacks tabulation and an observable archeopyle.

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PLATES 1–6

PLATE 1

[Upper scale bar is for specimens at × 400; lower scale bar is for specimens at × 600. All specimens are from Screven and Burke Counties, Georgia]

Figure 1. *Achilleodinium biformoides* (Eisenack) Eaton, Millhaven core (490 ft), Congaree Formation, Screven County, Ga., latero-dorsal view at high focus (× 400).

2. *Achilleodinium biformoides* (Eisenack) Eaton, Millhaven core (466 ft), Congaree Formation, Screven County, Ga., right-lateral view (× 400).

3. *Achilleodinium biformoides* (Eisenack) Eaton, Girard core (362–362.3 ft), Congaree Formation, Burke County, Ga., ventral view of dorsal surface (× 400).

4. *Amphorosphaeridium*? *multispinosum* (Davey & Williams) Sarjeant, Girard core (484.1–484.3 ft), Ellenton Formation, Burke County, Ga., orientation uncertain, optical section (× 400).

5. *Areoligera volata* Drugg, Millers Pond core (252–257 ft), Ellenton Formation, Burke County, Ga., dorsal view of dorsal surface (× 400).

6. *Areosphaeridium diktyoplokum* (Klumpp) Eaton, Millhaven core (442 ft), Warley Hill Formation, Screven County, Ga., orientation uncertain, upper focus (× 400).

7. *Batiacasphaera baculata* Drugg, Millhaven core (205 ft), Barnwell unit, Screven County, Ga., orientation uncertain, upper focus (× 400).

8, 9. *Batiacasphaera compta* Drugg, Millhaven core (205 ft), Barnwell unit, Screven County, Ga., orientation uncertain; 8, upper focus; 9, slightly lower focus (× 400).

10. *Carpatella cornuta* Grigorovich, Millhaven core (639.5 ft), Ellenton Formation, Screven County, Ga., ventral view of ventral surface, broken specimen (× 400).

11. *Cordosphaeridium funiculatum* Morgenroth, Millhaven core (205 ft), Barnwell unit, Screven County, Ga., orientation uncertain, upper focus, fragment (× 400).

12, 13. *Cerebrocysta bartonensis* Bujak, Millhaven core (490 ft), Congaree Formation, Screven County, Ga., antapical views; 12, antapex; 13, apex (× 400).

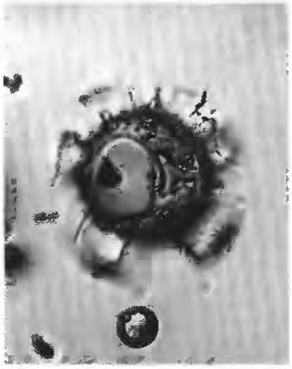
14. *Cordosphaeridium cantharellus* (Brosius), Gocht, Millhaven core (346 ft) Santee Limestone, Screven County, Ga., orientation uncertain, upper focus (× 400).

15. *Corrudinium incompositum* (Drugg) Stover & Evitt, Girard core (211.1–211.3 ft), Barnwell unit, Burke County, Ga., right-lateral view (× 600).

16. *Corrudinium* sp. I of Edwards (1984), Millhaven core (466 ft), Congaree Formation, Screven County, Ga., orientation uncertain, upper focus (× 400).

17. *Cribroperidinium giuseppei* (Morgenroth) Helenes, Millhaven core (346 ft) Santee Limestone, Screven County, Ga., dorsal view of dorsal surface (× 400).

18. *Dapsilidinium pseudocolligerum* (Stover) Bujak et al., Girard core (211.1–211.3 ft), Barnwell unit, Burke County, Ga., orientation uncertain, upper focus (× 400).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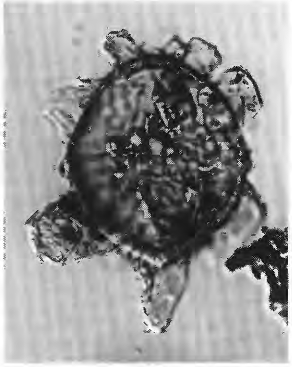
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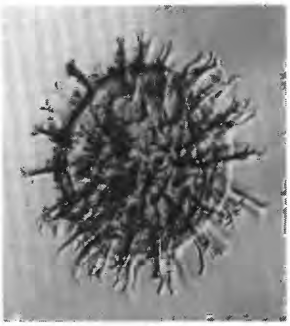
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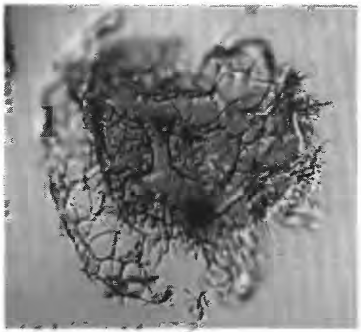
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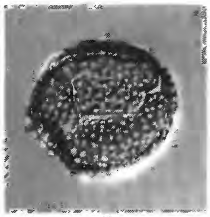
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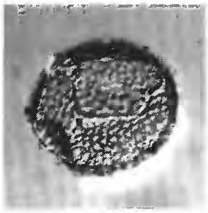
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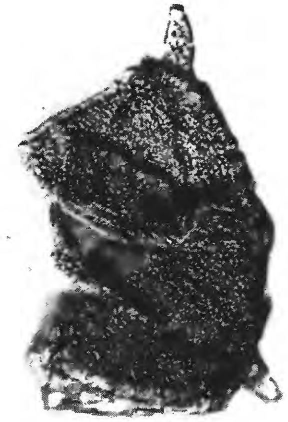
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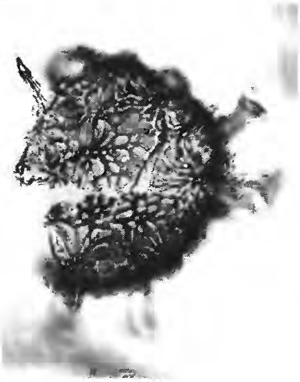
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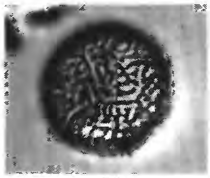
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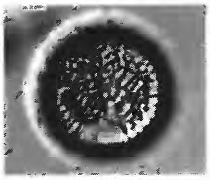
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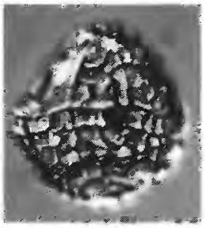
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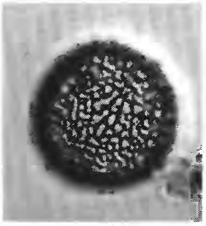
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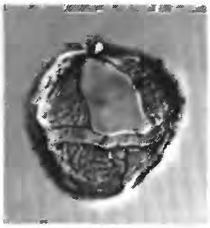
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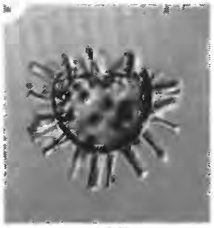
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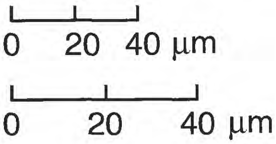


ACHILLEODINIUM, AMPHOROSPHAERIDIUM, AREOLIGERA, AREOSPHAERIDIUM, BATIACASPHAERA, CARPATELLA, CORDOSPHAERIDIUM, CEREBROCYSTA, CORRUDINIUM, CRIBROPERIDINIUM, AND *DAPSILIDINIUM*

PLATE 2

[Upper scale bar is for specimens at × 400; lower scale bar is for specimens at × 600. All specimens are from Screven and Burke Counties, Georgia]

Figures 1, 2. *Damassadinium californicum* (Drugg) Fensome et al., McBean core (294 ft), Ellenton Formation, Burke County, Ga., right-lateral views; 1, upper focus; 2, lower focus (× 400).

3. *Damassadinium californicum* (Drugg) Fensome et al., Millhaven core (589 ft), Ellenton Formation, Screven County, Ga., right-lateral view, upper focus (× 400).

4. *Dinopterygium cladoides* sensu Morgenroth (1966), Millhaven core (205 ft), Barnwell unit, Screven County, Ga., interior view of epicyst (× 400).

5. *Diphyes ficusoides* Islam, Millhaven core (466 ft), Congaree Formation, Screven County, Ga., ventral? view at midfocus (× 400).

6. *Enneadocysta* Stover & Williams sp., Millhaven core (216.5 ft), Barnwell unit, Screven County, Ga., orientation uncertain, midfocus (× 400).

7. *Eocladopyxis* Morgenroth n. sp. A, Girard core (362–362.3 ft), Congaree Formation, Burke County, Ga., interior view of hypocyst (× 400).

8. *Fibradinium annetorpense* Morgenroth, Millhaven core (589 ft), Ellenton Formation, Screven County, Ga., right-lateral view, upper focus (× 600).

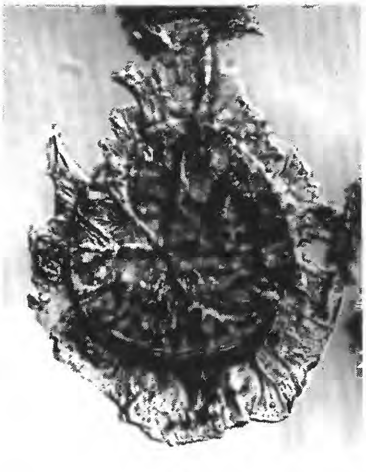
9. *Distatodinium ellipticum* (Cookson) Eaton, Millhaven core (210 ft), Barnwell unit, Screven County, Ga., orientation uncertain, midfocus (× 400)

10–12. *Glaphyrocysta* cf. *G.*? *vicina* (Eaton) Stover & Evitt, Millhaven core (466 ft), Congaree Formation, Screven County, Ga., dorsal views; 10, dorsal surface; 11, optical section; 12, ventral surface (× 400).

13. *Glaphyrocysta* cf. *G.*? *vicina* (Eaton) Stover & Evitt, Girard core (362–362.3 ft), Congaree Formation, Burke County, Ga., ventral view of ventral surface (× 400).

14. *Glaphyrocysta* cf. *G.*? *vicina* (Eaton) Stover & Evitt, Thompson Oak core (192 ft), Congaree Formation, Burke County, Ga., dorsal view of dorsal surface (× 400).

15. *Glaphyrocysta* cf. *G.*? *vicina* (Eaton) Stover & Evitt, Girard core (321.4–321.6 ft), Santee Limestone, Burke County, Ga., ventral view of ventral surface (× 400).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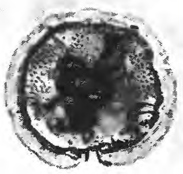
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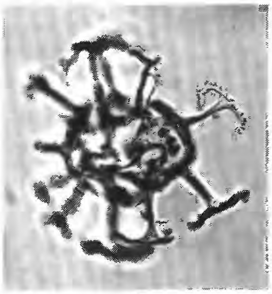
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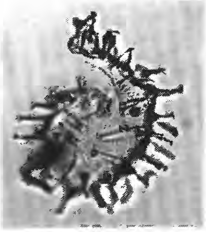
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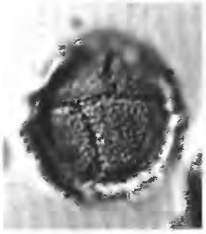
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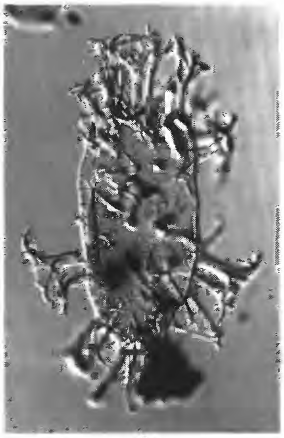
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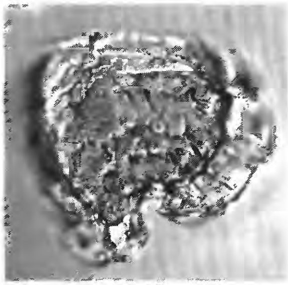
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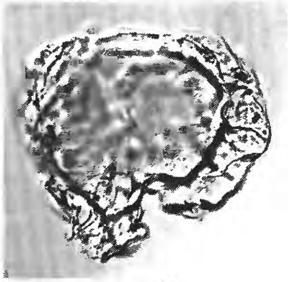
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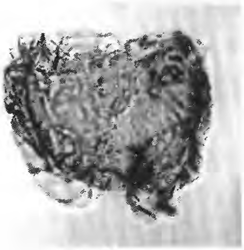
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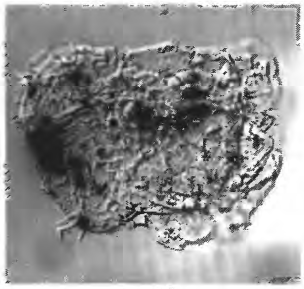
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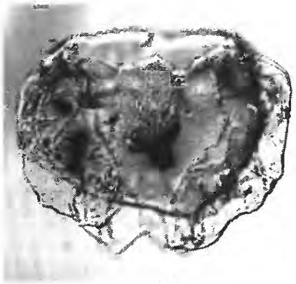
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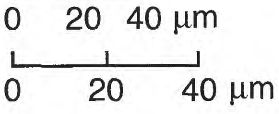


DAMASSADINIUM, DINOPTERYGIUM CLADOIDES SENSU MORGENROTH (1966), *DIPHYES, ENNEADOCYSTA, EOCLADOPYXIS, FIBRADINIUM, DISTATODINIUM,* AND *GLAPHYROCYSTA*

PLATE 3

[All specimens are from Screven and Burke Counties, Georgia]

Figure 1. *Hafniasphaera goodmanii* Edwards, Thompson Oak core (255 ft), Fourmile Branch Formation, Burke County, Ga., dorsal view of dorsal surface (× 400).

2, 3. *Heteraulacacysta porosa* Bujak, Thompson Oak core (138 ft), Santee Limestone, Burke County, Ga., antapical views; 2, antapex; 3, optical section (× 400).

4. *Millioudodinium* sp. I of Edwards (1984), McBean core (181 ft), Santee Limestone, Burke County, Ga., left-lateral view, upper focus (× 400).

5. *Heteraulacacysta pustulosa* Jan du Chêne & Adediran, McBean core (181 ft), Santee Limestone, Burke County, Ga., interior view of hypocyst (× 400).

6. *Heteraulacacysta* Drugg & Loeblich sp., Millhaven core (346 ft), Santee Limestone, Screven County, Ga., apical view, midfocus (× 400).

7–9. *Hystrichosphaeropsis* Deflandre n. sp. A, Thompson Oak core (138 ft), Santee Limestone, Burke County, Ga., dorsal views; 7, dorsal surface; 8, optical section; 9, ventral surface (× 400).

10. *Hafniasphaera septata* (Cookson & Eisenack) Hansen, Girard core (517.9–518.1 ft), Ellenton Formation, Burke County, Ga., orientation uncertain, upper focus (× 400).

11. *Homotryblium abbreviatum* Eaton, Thompson Oak core (269 ft), Fourmile Branch Formation, Burke County, Ga., oblique exterior view of hypocyst (× 400).

12. *Homotryblium plectilum* Drugg & Loeblich, Girard core (211.1–211.3 ft), Barnwell unit, Burke County, Ga., exterior view of hypocyst (× 400).

13. *Hystrichostrogylon membraniphorum* Agelopoulous, Thompson Oak core (174 ft), Santee Limestone, Burke County, Ga., orientation uncertain, midfocus (× 400).

14. *Operculodinium centrocarpum* (Deflandre & Cookson) Wall, Millhaven core (466 ft), Congaree Formation, Screven County, Ga., dorsal view of dorsal surface (× 400).

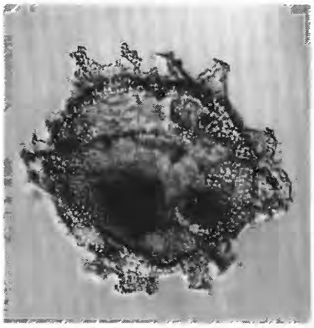
15. *Pentadinium favatum* Edwards, Millhaven core (473.5 ft), Congaree Formation, Screven County, Ga., dorsal view of dorsal surface (× 400).

16. *Pentadinium goniferum* Edwards, Millhaven core (346 ft), Santee Limestone, Screven County, Ga., dorsal view of dorsal surface (× 400).

17. *Pentadinium laticinctum* Gerlach subsp. *laticinctum*, Millhaven core (210 ft), Barnwell unit, Screven County, Ga., oblique left-lateral view, upper focus (× 400).

18. *Pentadinium laticinctum* Gerlach (verm.) Millhaven core (210 ft), Barnwell unit, Screven County, Ga., oblique right-lateral view, upper focus (× 400).

19–21. *Pentadinium* Gerlach n. sp. D, Thompson Oak core (164 ft), Santee Limestone, Burke County, Ga., apical views; 19, apex; 20, optical section; 21, antapex (× 400).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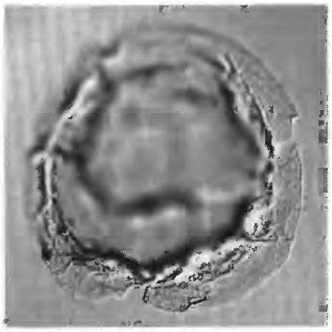
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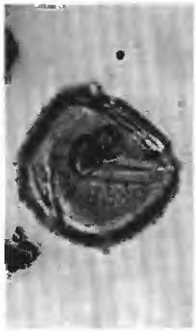
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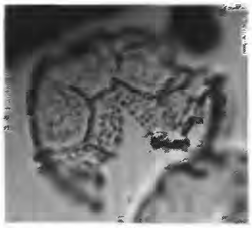
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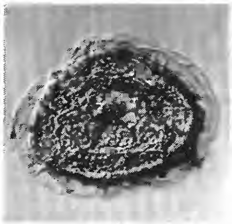
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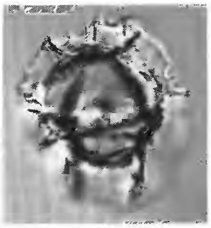
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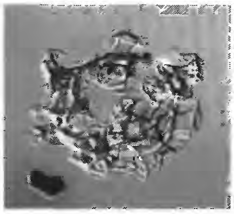
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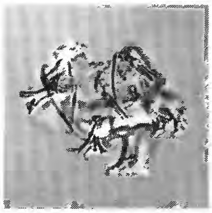
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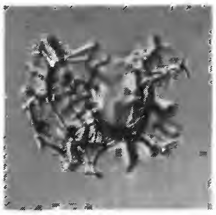
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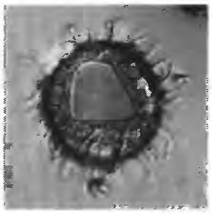
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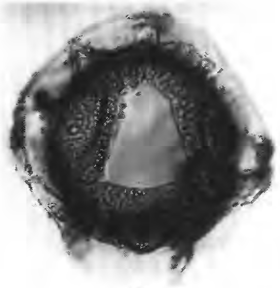
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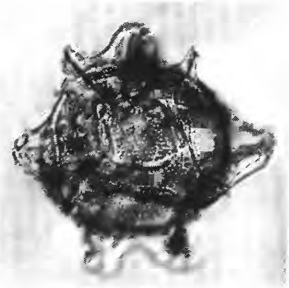
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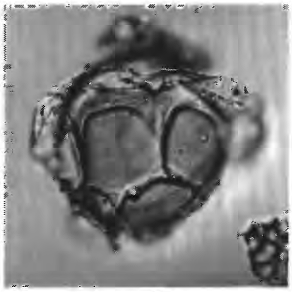
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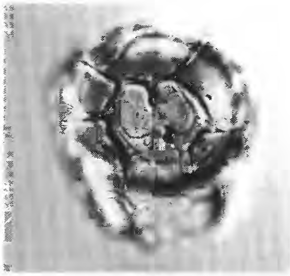
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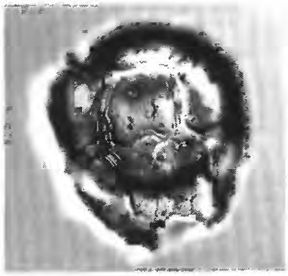
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HAFNIASPHAERA, HETERAULACACYSTA, MILLIOUDODINIUM, HYSTRICHOSPHAEROPSIS, HOMOTRYBLIUM, HYSTRICHOSTROGYLON, OPERCULODINIUM, AND *PENTADINIUM*

PLATE 4

[All specimens are from Screven and Burke Counties, Georgia]

Figure 1. *Pentadinium membranaceum* (Eisenack) Stover & Evitt, Millhaven core (293 ft), Santee Limestone, Screven County, Ga., ventral view of dorsal surface (× 400).

2. *Pentadinium polypodum* Edwards, Millhaven core (293 ft), Santee Limestone, Screven County, Ga., left-lateral view, upper focus (× 400).

3. *Samlandia chlamydophora* Eisenack, Thompson Oak core (192 ft), Congaree Formation, Burke County, Ga., dorsal view, midfocus (× 400).

4. *Samlandia chlamydophora* Eisenack sensu Stover and Hardenbol (1993), Millhaven core (346 ft), Santee Limestone, Screven County, Ga., ventral view of ventral surface (× 400).

5. *Spiniferites pseudofurcatus* (Klumpp) Sarjeant, Millhaven core (346 ft), Santee Limestone, Screven County, Ga., right-lateral view, upper focus (× 400).

6. *Systematophora placacantha* (Deflandre & Cookson) Davey et al., Girard core (211.1–211.3 ft), Barnwell unit, Burke County, Ga., apical view, upper focus (× 400).

7. *Tenua* sp. cf. *T. formosa* of Kurita and McIntyre (1995), Girard core (517.9–518.1 ft), Ellenton Formation, Burke County, Ga., orientation uncertain, upper focus (× 400).

8. *Tectatodinium pellitum* Wall, Girard core (321.4–321.6 ft), Santee Limestone, Burke County, Ga., dorsal view of dorsal surface (× 400).

9. *Tuberculodinium* Wall n. sp. A, Millhaven core (210 ft), Barnwell unit, Screven County, Ga., antapical view of antapex (× 400).

10, 11. *Tectatodinium rugulatum* (Hansen) McMinn, Girard core (517.9–518.1 ft), Ellenton Formation, Burke County, Ga., ventral views; 10, ventral surface; 11, dorsal surface (× 400).

12. *Turbiosphaera* cf. *T. galatea* Eaton, Millhaven core (490 ft), Congaree Formation, Screven County, Ga., ventral view, midfocus (× 400).

13. Miscellaneous areoligeracean form, Millhaven core (490 ft), Congaree Formation, Screven County, Ga., dorsal view, midfocus (× 400).

14. Miscellaneous areoligeracean form, Millers Pond core (237–242 ft), Ellenton Formation, Burke County, Ga., dorsal view of dorsal surface (× 400).


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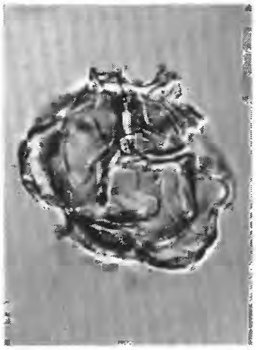
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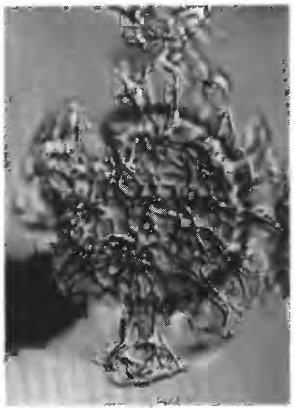
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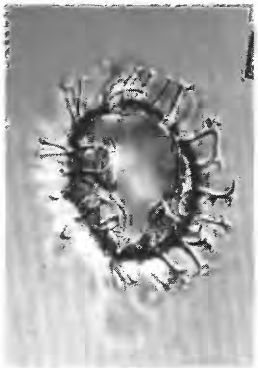
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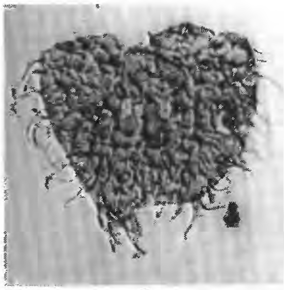
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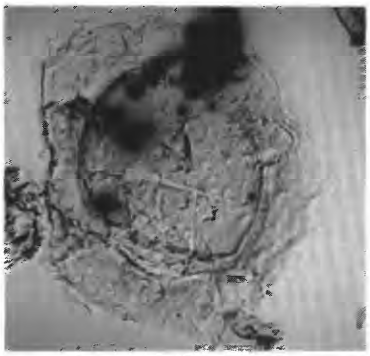
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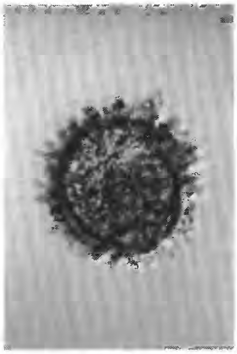
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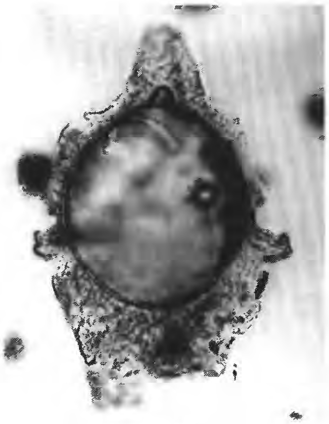
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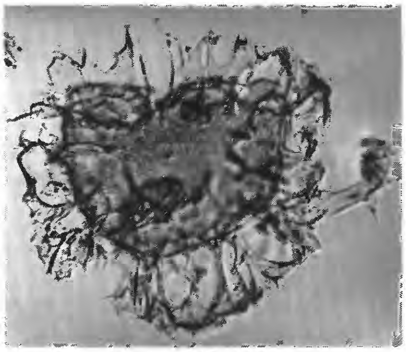
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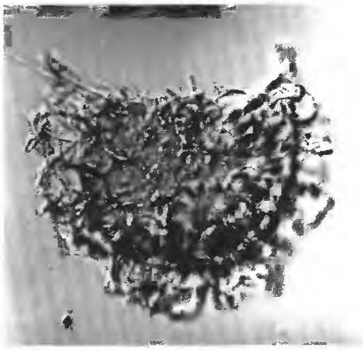
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0 20 40 µm

PENTADINIUM, SAMLANDIA, SPINIFERITES, SYSTEMATOPHORA, TENUA, TECTATODINIUM, TUBERCULODINIUM, TURBIOSPHAERA, AND MISCELLANEOUS AREOLIGERACEAN FORMS

PLATE 5

[Upper scale bar is for specimens at × 300; middle scale bar is for specimens at × 400; lower scale bar is for specimens at × 600. All specimens are from Screven and Burke Counties, Georgia]

Figure 1. ?*Andalusiella rhombohedra* of Edwards and others (1984), Millers Pond core (237–242 ft), Ellenton Formation, Burke County, Ga., dorsal view of dorsal surface (× 400).

2. *Isabelidinium viborgense* sensu Kurita and McIntyre (1995), McBean core (276 ft), Ellenton Formation, Burke County, Ga., dorsal view of dorsal surface (× 400).

3. *Andalusiella* sp. aff. *A. polymorpha* of Edwards (1980), Millers Pond core (237–242 ft), Ellenton Formation, Burke County, Ga., mostly dorsal view of dorsal surface (× 300).

4. *Andalusiella* sp. aff. *A. polymorpha* of Edwards (1980), Thompson Oak core (281 ft), Ellenton Formation, Burke County, Ga., left-lateral view at midfocus (× 300).

5. *Deflandrea delineata* Cookson & Eisenack, Millhaven core (589 ft), Ellenton Formation, Screven County, Ga., ventral view of ventral surface (× 400).

6. *Deflandrea* cf. *D. diebelii* Alberti of Drugg (1967), Girard core (517.9–518.1 ft), Ellenton Formation, Burke County, Ga., orientation uncertain, midfocus (× 400).

7. *Dracodinium varielongitudum* (Williams & Downie) Costa & Downie, Girard core (415 ft), Fourmile Branch Formation, Burke County, Ga., ventral view of dorsal surface (× 400).

8. *Deflandrea* n. sp. aff. *D. truncata* Stover, Girard core (521–521.2 ft), Ellenton Formation, Burke County, Ga., ventral view at midfocus (× 400).

9. *Deflandrea phosphoritica* Eisenack, Millhaven core (205 ft), Barnwell unit, Screven County, Ga., dorsal view of dorsal surface (× 400).

10. *Phelodinium* sp. of Edwards (1989), Thompson Oak core (281 ft), Ellenton Formation, Burke County, Ga., ventral view of dorsal surface (× 400).

11. *Charlesdowniea variabilis* (Bujak) Lentin & Vozzhennikova, Millhaven core (216.5 ft), Barnwell unit, Screven County, Ga., dorsal view of dorsal surface (× 400).

12. *Lentinia serrata* Bujak, Girard core (362–362.3 ft), Congaree Formation, Burke County, Ga., ventral view at midfocus (× 400).

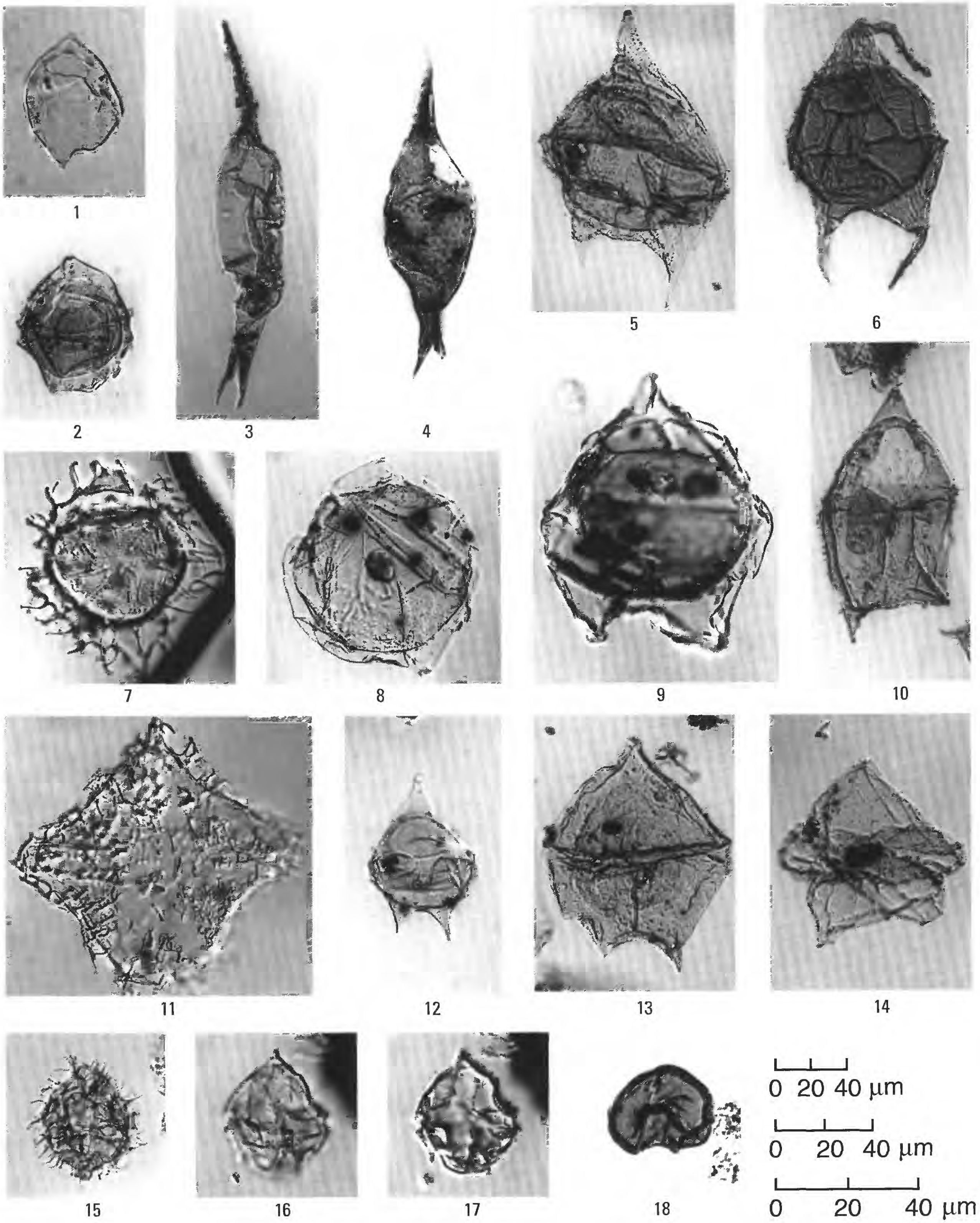
13. *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant, Millhaven core (589 ft), Ellenton Formation, Screven County, Ga., ventral view of dorsal surface (× 400).

14. *Phelodinium* Stover & Evitt sp., McBean core (276 ft), Ellenton Formation, Burke County, Ga., orientation uncertain, upper focus (× 400).

15. *Phthanoperidinium comatum* (Morgenroth) Eisenack & Kjellstrom, Millhaven core (216.5 ft), Barnwell unit, Screven County, Ga., ?right-lateral view, upper focus (× 400).

16, 17. *Phthanoperidinium echinatum* Eaton, Millhaven core (466 ft), Congaree Formation, Screven County, Ga., ventral views; 16, ventral surface; 17, dorsal surface (× 600).

18. *Selenopemphix nephroides* Benedek, Millhaven core (413 ft), Warley Hill Formation, Screven County, Ga., ?apical view at midfocus (× 400).



ANDALUSIELLA, ISABELIDINIUM, DEFLANDREA, DRACODINIUM, PHELODINIUM, CHARLESDOWNIEA, LENTINIA, PALAEOPERIDINIUM, PHTHANOPERIDINIUM, AND *SELENOPEMPHIX*

PLATE 6

[All specimens are from Screven and Burke Counties, Georgia]

Figure 1. *Pseudorhombodinium lisbonense* Wrenn, Girard core (362–362.3 ft), Congaree Formation, Burke County, Ga., dorsal view of dorsal surface (× 400).

2. *Rhombodinium draco* Gocht, Millhaven core (313.5 ft), Santee Limestone, Screven County, Ga., dorsal view at midfocus (× 400).

3. *Rhombodinium perforatum* (Jan du Chêne & Châteauneuf) Lentin & Williams, Girard core (211.1–211.3 ft), Barnwell unit, Burke County, Ga., ventral view at midfocus (× 400).

4. *Selenopemphix* Benedek sp., Millhaven core (413 ft), Warley Hill Formation, Screven County, Ga., apical view of apex (× 400).

5. *Senegalinium microgranulatum* (Stanley) Stover & Evitt, Millers Pond core (237–242 ft), Ellenton Formation, Burke County, Ga., ventral view at midfocus (× 400).

6, 10. *Spinidinium pulchrum* (Benson) Lentin & Williams, Thompson Oak core (302 ft), Ellenton Formation, Burke County, Ga., ventral views: 6, ventral surface; 10, dorsal surface (× 400).

7. *Wetzeliella articulata* Eisenack sensu amplo, Millhaven core (490 ft), Congaree Formation, Screven County, Ga., dorsal view, upper focus (× 400).

8. *Spinidinium densispinatum* Stanley, Girard core (521.0–521.2 ft), Ellenton Formation, Burke County, Ga., dorsal? view of dorsal surface (× 400).

9. *Spinidinium* Cookson & Eisenack sp., reworked?, Millhaven core (216.5 ft), Barnwell unit, Screven County, Ga., ventral view at midfocus (× 400).

11. *Wetzeliella articulata* Eisenack sensu amplo, Millhaven core (483.5 ft), Congaree Formation, Screven County, Ga., ventral view at midfocus (× 400).

12. *Wetzeliella* Eisenack sp., Millers Pond core (124 ft), Santee Limestone, Burke County, Ga., dorsal view of dorsal surface (× 400).

13. Small peridiniacean form, Millhaven core (571 ft), Ellenton Formation, Screven County, Ga., ventral? view of dorsal surface (× 400).

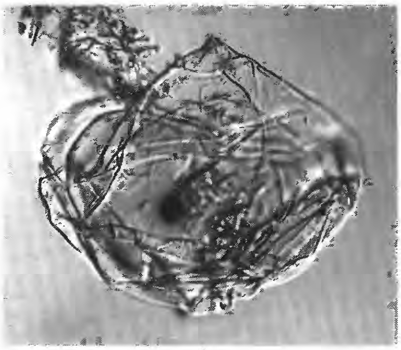
14. Small peridiniacean form, Millhaven core (564–565 ft), Snapp Formation, Screven County, Ga., ventral view of dorsal surface (× 400).

15. Small peridiniacean form, McBean core (276 ft), Ellenton Formation, Burke County, Ga., orientation uncertain, midfocus (× 400).

16. Small peridiniacean form, Millers Pond core (237–242 ft), Ellenton Formation, Burke County, Ga., ventral view at midfocus (× 400).

17. *Cyclopsiella vieta* Drugg & Loeblich, Millhaven core (205 ft), Barnwell unit, Screven County, Ga., high focus (× 400).

18. *Xenikoon australis* sensu Benson (1976), Millhaven core (571 ft), Ellenton Formation, Screven County, Ga., midfocus (× 400).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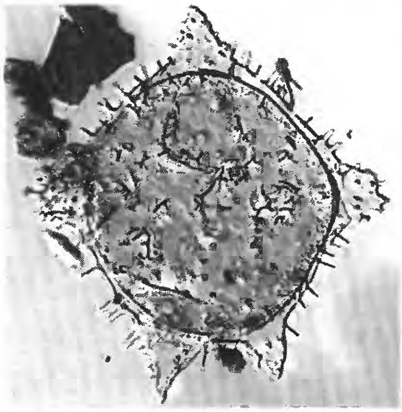
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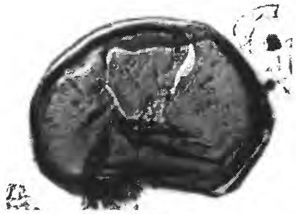
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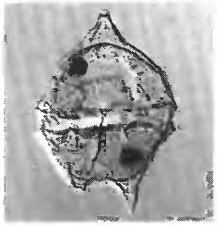
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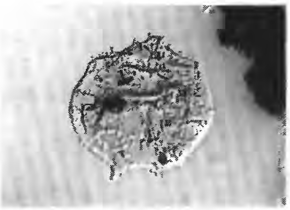
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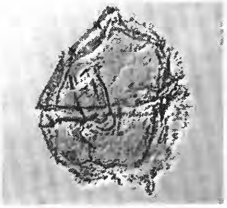
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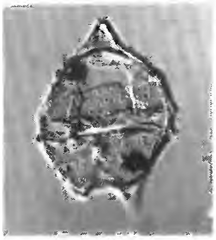
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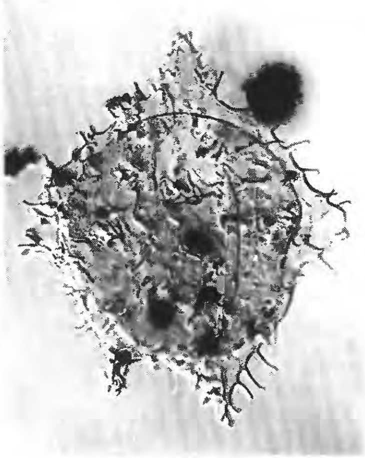
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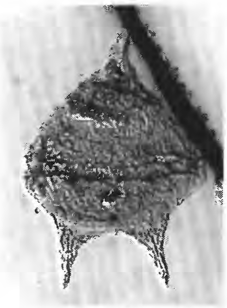
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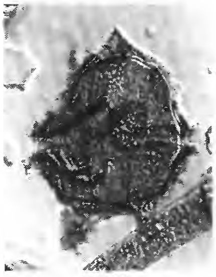
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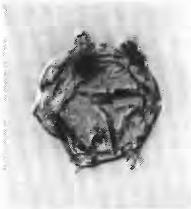
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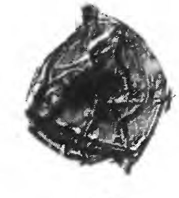
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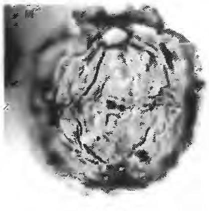
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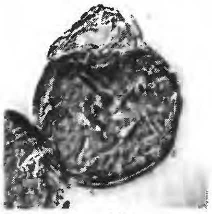
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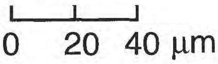

PSEUDORHOMBODINIUM, RHOMBODINIUM, SELENOPEMPHIX, SENEGALINIUM, SPINIDINIUM, WETZELIELLA, SMALL PERIDINIACEAN FORMS, *CYCLOPSIELLA,* AND *XENIKOON*

U.S. Department of the Interior
U.S. Geological Survey

Pollen Biostratigraphy of Lower Tertiary Sediments from Five Cores from Screven and Burke Counties, Georgia

By Norman O. Frederiksen

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1603–H

Prepared in cooperation with the
U.S. Department of Energy and the
Georgia Geologic Survey

GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Edited by Lucy E. Edwards

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SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Pollen Biostratigraphy of Lower Tertiary Sediments from Five Cores from Screven and Burke Counties, Georgia

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ABSTRACT

Seventeen biostratigraphically useful lower Tertiary samples were examined for their pollen taxa from five test holes (Millhaven, Girard, Thompson Oak, Millers Pond, and McBean) in Screven and Burke Counties, Georgia. Ten biostratigraphically useful samples from the Ellenton Formation have earliest and latest possible ages of late early Paleocene and late Paleocene, respectively, but most or all of the samples are probably late early or early late Paleocene. One good sample from the Snapp Formation is no older than earliest late Paleocene and no younger than middle late Paleocene. Four productive samples from the Congaree Formation are not very well dated using pollen, but possible ages are generally from late early to middle middle Eocene. Two samples from the Santee Limestone are poorly dated from pollen within the late early Eocene to middle Eocene (or younger?) interval.

INTRODUCTION

The Savannah River Site (SRS) in Aiken, Barnwell, and Allendale Counties, S.C. (fig. 1), has manufactured, disposed of, and stored a variety of hazardous materials since the early 1950's. The U.S. Geological Survey, in cooperation with the U.S. Department of Energy and the Georgia Geologic Survey of the Georgia Department of Natural Resources, is conducting a study of the subsurface geology, hydrology, and water quality in the vicinity of the SRS. The goal of the study is to understand the present and possible future ground-water flow in the aquifers of the area. Many test holes have been drilled in Georgia and South Carolina to study the flow of ground water in the SRS region (Aadland, 1992; Harris and others, 1992; Strom and others, 1992; Clarke, 1993; Gellici and Logan, 1993; Clarke and others, 1994, 1996; Clarke and West, 1994; Leeth and others, 1996). The Cretaceous and Cenozoic aquifers are difficult to correlate from area to area because of structural movement and rapid facies changes. Some biostratigraphic research has been completed toward the goal of correlating aquifers between some of the test holes (Prowell and others, 1985; Edwards, 1992; Edwards and Clarke, 1992; Edwards and Frederiksen, 1992; Lucas-Clark, 1992; Falls and others, 1993, 1997; Clarke and others, 1994, 1996; Leeth and others, 1996; Edwards and others, 1997). However, much biostratigraphic study remains to be done in the region.

This paper uses Tertiary pollen grains in core samples from five Georgia test holes to provide biostratigraphic data on both marine and nonmarine sediments in the area. The five Georgia test holes (Millhaven, Girard, Thompson Oak, Millers Pond, and McBean) in Burke and Screven Counties, Ga., are directly across the Savannah River from the SRS. Details of the Tertiary geologic framework of the region are presented elsewhere (Falls and Prowell, this volume, chap. A). Table 1 summarizes the number of samples containing pollen and the number of samples barren of pollen from each stratigraphic unit in each core.

Pollen grains from terrestrial plants are frequently found in marine and terrestrial rocks. However, the palynological preparations of samples from cored strata in the SRS region commonly contained much more abundant dinoflagellates of marine to brackish-water origin (Edwards, this volume, chap. G) than pollen grains of terrestrial origin. This dinoflagellate dominance was particularly true of the Eocene rocks and the downdip Paleocene rocks in the Millhaven and Girard cores. Yet, some Paleocene samples from the cores contained abundant pollen grains, and some others contained sufficient pollen to make age determinations of these samples possible by using these fossils.

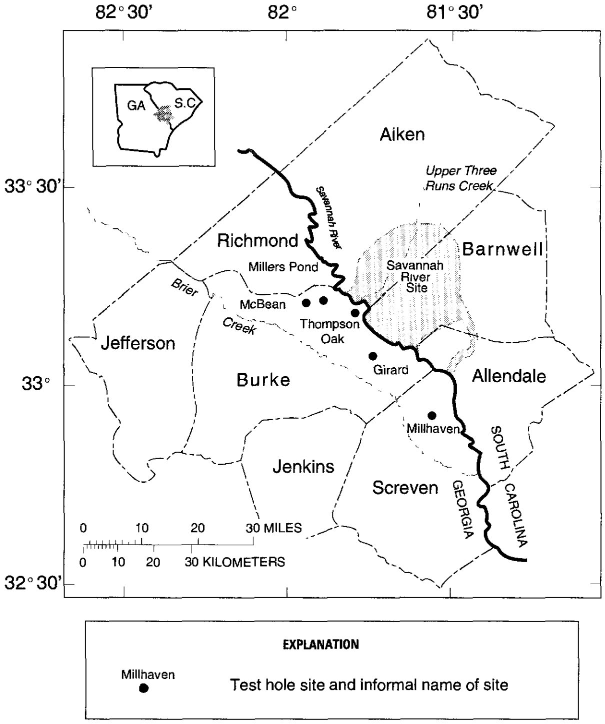

Figure 1. Index map showing the Savannah River Site and the location of test holes for this study.

ACKNOWLEDGMENTS

D.W. Engelhardt (University of South Carolina) and R.A. Christopher (Clemson University) reviewed drafts of this paper and provided helpful suggestions for its improvement.

MATERIAL AND METHODS

The samples discussed in this paper were processed by using normal palynological techniques involving treatment with hydrochloric, hydrofluoric, and nitric acids; short centrifugation with soapy water to remove fine material; removal of mineral grains by swirling; staining with Bismark brown; and screening on 8- or 10-micrometer (μm) sieves. The residues were mounted in glycerine jelly.

Table 2 shows the slide numbers and microscope coordinates of photographed pollen specimens; the slide designations show the sample number with the slide number in parentheses. The coordinates locate the specimens on Leitz microscope 871956 at the U.S. Geological Survey, Reston, Va. On this microscope, the coordinates for the center point of a standard 25.4×76.2-millimeter slide are 38.8 and 102.5 for the horizontal and vertical axes. The horizontal coordinates increase toward the right edge of the stage, and the vertical coordinates increase toward the front of the stage. Slides are stored at the U.S. Geological Survey, Reston, Va. The plates illustrate many of the pollen species found in the Tertiary samples. However, some of the species could not be usefully photomicrographed because of mediocre preservation or because the specimens were poorly oriented, crumpled, or partially covered with debris.

CORRELATIONS AND AGE DETERMINATIONS

Correlations and age determinations in this paper are based on many articles on spores and pollen grains from lower Tertiary strata in the Gulf Coast and the Mississippi embayment (Jones, 1962; Elsik, 1968a,b, 1974; Fairchild and Elsik, 1969; Nichols and Traverse, 1971; Nichols, 1973; Tschudy, 1973a,b, 1975; Potter, 1976; Frederiksen, 1978, 1980a, 1988, 1991, 1998; Jarzen, 1978; Christopher and others, 1980; Frederiksen and others, 1982), in the Southern Atlantic States (Frederiksen, 1978, 1980b, 1991; Frederiksen and Christopher, 1978; Prowell and others, 1985), and in the Middle Atlantic States (Frederiksen, 1979, 1984, 1991, 1998). The best pollen-stratigraphic control for the Paleocene and Eocene of eastern North America is in the eastern Gulf Coast. Therefore, in this paper, ages and correlations are made primarily by using ranges of pollen taxa in the eastern Gulf Coast. Most of the pollen taxa identified in this report (table 3) have been previously illustrated with photomicrographs in the papers listed, and many of the taxa are illustrated in plates 1 and 2.

Figure 2 shows the pollen zones that have been proposed for the Paleocene of the Eastern United States. No such zonation has been proposed for the Eocene of this region.

MILLHAVEN TEST HOLE

The Millhaven test hole (33X048) was drilled by the U.S. Geological Survey at lat 32°53'25" N., long 81°35'43" W., near Sylvania, Burtons Ferry 7.5 min quadrangle, Screven County, Ga. (fig. 1). The surface elevation is 110 ft above sea level. Sixteen Tertiary samples from this core were examined for pollen, from the depth interval of 639.5 to 105.0 ft. Seven contained biostratigraphically useful pollen assemblages.

ELLENTON FORMATION

Nine samples of the Ellenton Formation from 639.5 to 571.0 ft in the Millhaven core were examined for pollen, and six contained significant assemblages. Samples from 639.5, 632.0–632.2, and 577.0 ft were barren of pollen or recovered very poor assemblages. Distributions of pollen taxa in the six productive samples are shown in figure 3.

All of the pollen taxa in sample R4664 GD, from 620.8 ft, have long chronostratigraphic ranges within the Pale-

Table 1. Samples containing pollen and samples barren of pollen from each stratigraphic unit in each core.

[R numbers are U.S. Geological Survey paleobotanical numbers. Depths are in feet below the surface. P column: X = pollen grains are present, although not necessarily ones that are biostratigraphically important. B column: X = barren of pollen]

R number	Depth (ft)	Unit	P	B
Millhaven core				
R4664 AV	105	Barnwell	--	X
R4664 AT	195	Barnwell	--	X
R4664 AR	210	Barnwell	X	--
R4664 AL	260	Santee	--	X
R4664 K	490	Congaree	X	--
R4664 H	499	Congaree	--	X
R4664 E	564–565	Snapp	--	X
R4664 D	571	Ellenton	X	--
R4664 C	577	Ellenton	--	X
R4664 AW	579.5	Ellenton	X	--
R4664 B	581	Ellenton	X	--
R4664 A	589	Ellenton	X	--
R4664 GE	599.5	Ellenton	X	--
R4664 GD	620.8	Ellenton	X	--
R4664 CH	632–632.2	Ellenton	--	X
R4664 GC	639.5	Ellenton	--	X
R4664 FG	755.0–755.3	Steel Creek	X	--
Girard core				
R4705 F	322.3–322.5	Santee	X	--
R4705 AE	415.2–415.5	Fourmile Br.	X	--
R4705 D	484.1–484.3	Ellenton	X	--
R4705 C	514–514.3	Ellenton	X	--
R4705 AD	517.9–518.1	Ellenton	X	--
R4705 B	521–521.2	Ellenton	X	--
R4705 A	532.5–532.7	Ellenton	X	--
Thompson Oak core				
R4836 O	172	Santee	X	--
R4836 N	174	Santee	X	--
R4836 M	181.5	Santee	X	--
R4836 L	183	Congaree	X	--
R4836 K	192	Congaree	X	--
R4836 D	281	Ellenton	X	--
R4836 C	302	Ellenton	X	--
Millers Pond core				
R4581 Y	72–77	Barnwell	--	X
R4581 X	82–83	Santee	--	X
R4581 W	120	Santee	--	X
R4581 V	124	Santee	--	X
R4581 U	148	Santee	X	--
R4581 S	165	Congaree	X	--
R4581 Q	252–257	Ellenton	X	--
McBean core				
R4663 G	181	Santee	X	--
R4663 F	210	Congaree	--	X
R4663 E	243	Snapp	--	X
R4663 D	264	Snapp	X	--
R4663 C	276	Ellenton	--	X
R4663 B	294	Ellenton	--	X

ocene except for the *Caryapollenites prodromus* group of Frederiksen (1991). This group has its range base near the top of the Naheola Formation in the eastern Gulf Coast (fig. 4), in the lower part of the upper Paleocene in calcareous nannofossil Zone NP 5 and, by definition, at the base of the *Caryapollenites prodromus* Interval Zone (fig. 2). Nannofossil evidence indicates that this sample lies within the lower part of Zone NP 5 (Bybell, this volume, chap. F).

Only three pollen taxa were identified in sample R4664 GE, from 599.5 ft, and the only useful taxon was the *Caryapollenites prodromus* group. Nannofossil evidence indicates that this sample lies within the lower part of Zone NP 5 (Bybell, this volume, chap. F).

In sample R4664 A, from 589.0 ft, the only age-diagnostic species was *Choanopollenites* sp. cf. *C. consanguineus* Tschudy of Frederiksen (1979). This species was previously known only from the lowermost part of the Aquia Formation of Virginia, which belongs to the lower part of the *Carya* Interval Zone (Frederiksen, 1979, 1991) and which has been assigned to calcareous nannofossil Zone NP 5 (Bybell and Gibson, 1991) of early late Paleocene age. Sample R4664 A also belongs to nannofossil Zone NP 5 (Bybell, this volume, chap. F); therefore, scanty evidence suggests that *Choanopollenites* sp. cf. *C. consanguineus* Tschudy of Frederiksen (1979) may in fact be confined to rocks of NP 5 age. However, because nannofossil Zone NP 5 includes the upper part of the *Caryapollenites prodromus* Interval Zone as well as the lowermost part of the *Carya* Interval Zone, it is possible that *Choanopollenites* sp. cf. *C. consanguineus* Tschudy occurs in both of these pollen zones.

Sample R4664 B, from 581.0 ft, is no older than the upper part of the lower unnamed member of the Porters Creek Formation (latest early Paleocene) in the eastern Gulf Coast, according to the known range base of *Plicatopollis triradiatus* (Nichols) Frederiksen & Christopher. The sample from 581.0 ft is no younger than the Nanafalia Formation, which is late but not latest Thanetian (known range top of *Momipites dilatus* Fairchild; fig. 4). The chronostratigraphic range of the genus *Friedrichipollis* Krutzsch is poorly known because pollen of this genus is very rare. Nannofossil evidence indicates that this sample lies within the lower part of Zone NP 5 (Bybell, this volume, chap. F).

Sample R4664 AW, from 579.5 ft, contained only rare angiosperm pollen grains. Among the taxa present (fig. 3), the only one of biostratigraphic interest was *Spinaepollis spinosus* (Potonié) Krutzsch. This species has a range from near the NP 4–NP 5 calcareous nannofossil zone boundary (very low in the upper Paleocene) to the top of the Paleocene. Nannofossil evidence indicates that this sample lies within the lower part of Zone NP 5 (Bybell, this volume, chap. F).

Critical range bases and tops of taxa in sample R4664 D, from 571.0 ft, are displayed in figure 4. From these data, it is apparent that this sample can be assigned to the interval

Table 2. Slide numbers and microscope coordinates of photographed specimens.

[The slide designations show the sample number (table 1) followed by the slide number in parentheses. Coordinates are given for Leitz microscope 871956 at the U.S. Geological Survey, Reston, Va.]

Figure	Slide	Coordinates
Plate 1		
1	R4705 B(1)	58.7 × 95.0
2	R4836 K(1)	50.1 × 107.5
3	R4705 D(1)	61.8 × 111.3
4	R4663 D(1)	50.0 × 104.7
5	R4836 K(1)	56.3 × 109.0
6	R4664 D(1)	44.7 × 96.0
7, 8	R4664 K(1)	61.4 × 110.6
9, 10	R4664 FG(1)	58.7 × 111.7
11	R4664 K(1)	59.6 × 93.3
12	R4664 FG(1)	57.8 × 105.7
13	R4705 AE(1)	63.4 × 95.2
14	R4664 K(1)	56.1 × 96.8
15	R4663 D(1)	52.5 × 105.2
16	R4705 D(1)	62.0 × 109.4
17	R4705 D(1)	57.3 × 94.9
18	R4836 K(1)	58.1 × 104.6
19	R4664 AW(1)	57.4 × 102.5
20	R4836 K(1)	64.1 × 105.8
21, 22	R4836 N(1)	52.4 × 101.8
Plate 1—Continued		
23	R4836 D(1)	54.9 × 109.2
24	R4663 G(1)	45.8 × 99.2
Plate 2		
1	R4705 D(1)	55.9 × 106.3
2	R4705 A(1)	54.2 × 96.9
3	R4836 D(1)	50.9 × 105.4
4	R4663 G(1)	49.0 × 100.3
5	R4664 A(1)	42.0 × 109.9
6	R4663 D(1)	51.0 × 104.0
7	R4664 B(1)	42.2 × 95.0
8	R4581 Q(2)	55.5 × 99.8
9	R4836 C(1)	62.4 × 93.6
10	R4705 D(1)	61.0 × 101.0
11	R4581 U(1)	44.0 × 110.3
12	R4664 B(1)	42.2 × 95.0
13	R4581 Q(6)	45.7 × 93.8
14	R4664 D(1)	40.2 × 109.7
15	R4664 B(1)	44.4 × 102.0
16	R4836 L(1)	49.7 × 93.7

Table 3. List of pollen taxa mentioned in this report followed by the illustration location.

[Most pollen taxa have been previously illustrated by the authors listed]

Taxon	Plate	Figure
Aesculiidites circumstriatus (Fairchild *in* Stover and others, 1966) Elsik	1	23
Bombacacidites nacimientoensis (Anderson) Elsik	2	14
Bombacacidites reticulatus Krutzsch	2	13
Carya <29 µm	--	--
Carya >28 µm	--	--
Caryapollenites prodromus group of Frederiksen (1991)	--	--
Choanopollenites sp. cf. *C. consanguineus* Tschudy of Frederiksen (1979)	2	5
Eucommia type (tricolporate) of Frederiksen (1988)	1	20
Favitricolporites baculoferus (Pflug *in* Thomson and Pflug, 1953) Srivastava 1972	--	--
Friedrichipollis sp.	2	12
Holkopollenites chemardensis Fairchild *in* Stover and others (1966)	--	--
Holkopollenites sp. A	--	--
Ilexpollenites sp.	1	24
Insulapollenites rugulatus Leffingwell	2	6
Intratriporopollenites pseudinstructus Mai	--	--
Intratriporopollenites sp.	2	7
Lanagiopollis cribellatus (Srivastava) Frederiksen	2	15
Lanagiopollis sp., probably *L. hadrodictyus* Frederiksen	2	16

Table 3. List of pollen taxa mentioned in this report followed by the illustration location—Continued.

Taxon	Plate	Figure
Malvacipollis cf. *M. tschudyi* Frederiksen of Frederiksen (1988)	1	18
Milfordia hungarica (Kedves) Krutzsch & Vanhoorne *in* Krutzsch (1970)	1	2
Milfordia incerta (Pflug & Thomson *in* Thomson and Pflug, 1953) Krutzsch	1	3
Momipites actinus Nichols & Ott	--	--
Momipites coryloides Wodehouse	1	5
Momipites dilatus Fairchild *in* Stover and others (1966)	1	6
Momipites strictus Frederiksen & Christopher	--	--
Momipites tenuipolus group of Frederiksen and Christopher (1978)	1	4
Momipites-Plicatopollis-Platycaryapollenites complex of Frederiksen (1979)	1	14
Myrtaceidites sp.	--	--
Nudopollis terminalis (Pflug & Thomson *in* Thomson and Pflug, 1953) Pflug	2	2, 3
Nudopollis thiergartii (Thomson & Pflug) Pflug	--	--
Osculapollis? *colporatus* Frederiksen	2	9
Piolencipollis endocuspoides Frederiksen	--	--
Platycarya platycaryoides (Roche) Frederiksen & Christopher	1	7, 8
Platycarya sp. A of Frederiksen and Christopher (1978)	1	9, 10
Platycarya spp.	1	11–13
Platycaryapollenites sp. aff. *P. swasticoidus* (Elsik) Frederiksen & Christopher	--	--
Plicatopollis triorbicularis type of Frederiksen and Christopher (1978)	1	15
Plicatopollis triradiatus (Nichols) Frederiksen & Christopher	--	--
Porocolpopollenites ollivierae (Gruas-Cavagnetto) Frederiksen	--	--
Pseudolaesopollis ventosus (Potonié) Frederiksen	2	4
Pseudoplicapollis limitatus Frederiksen	2	1
Pseudoplicapollis serenus Tschudy	2	8
Retitrescolpites anguloluminosus (Anderson) Frederiksen	--	--
Rousea monilifera Frederiksen	--	--
Sparganiaceaepollenites sp.	1	1
Spinaepollis spinosus (Potonié) Krutzsch	1	19
Spinizonocolpites prominatus (McIntyre) Stover & Evans	1	21, 22
Subtriporopollenites anulatus Pflug & Thomson *in* Thomson and Pflug (1953)	--	--
Symplocos? sp. 1 of Frederiksen (1988)	--	--
Symplocos? sp. aff. *Symplocos*? sp. 1 of Frederiksen (1988)	2	11
"*Symplocospollenites* spp." of Tschudy (1973a)	--	--
Tetracolporopollenites lesquereuxianus (Traverse) Frederiksen	--	--
Tetracolporopollenites megadolium (Potonié) Frederiksen	--	--
Triatriopollenites sparsus group of Frederiksen (1988)	--	--
Tricolpites asper Frederiksen	--	--
Triporopollenites infrequens (Stanley) Frederiksen	--	--
Trudopollis plenus Tschudy	2	10
Trudopollis spp.	--	--
Ulmipollenites krempii (Anderson) Frederiksen	1	17
Ulmipollenites tricostatus (Anderson) Frederiksen	1	16

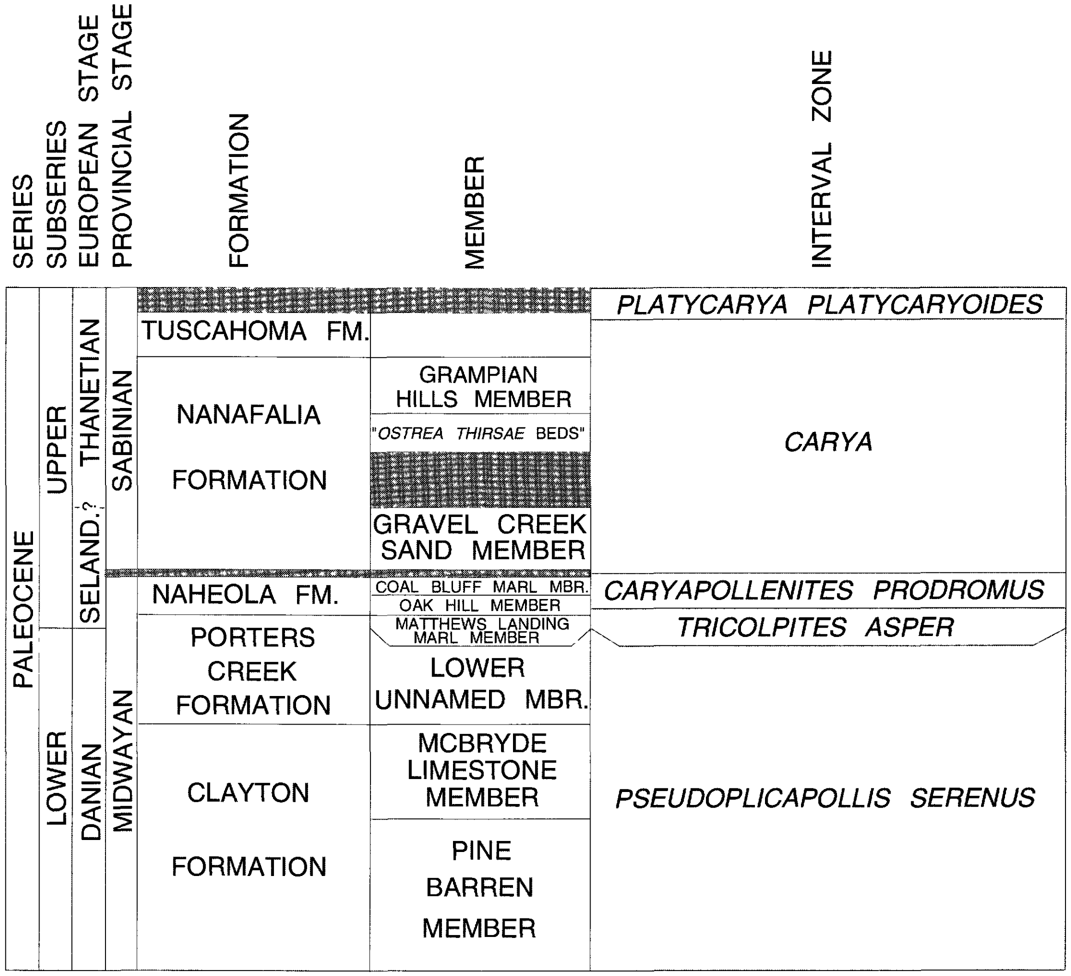

Figure 2. Pollen zonation chart for the Paleocene of the Eastern United States. Zones were proposed by Frederiksen (1991, 1998). Division of the Tertiary into European stages follows Berggren and others (1995).

from the lower part of the upper Paleocene (lower Selandian) to the upper part of the upper Paleocene (middle Thanetian). The sampled interval from the Ellenton Formation of this core contains the *Caryapollenites prodromus* group of Frederiksen (1991) but no specimens of *Carya* <29 µm were found. The latter taxon is common in samples above its range base at about the Midwayan-Sabinian Provincial Stage boundary (fig. 2), which is probably within calcareous nannofossil Zone NP 5. The apparent lack of this taxon in the Ellenton samples from the Millhaven core would suggest that this sampled interval belongs to the *Caryapollenites prodromus* Interval Zone. However, nannofossil evidence indicates that a sample from slightly deeper in this core, from 578.0 ft, is tentatively assignable to Zone NP 8 of middle Thanetian age, that is, within the upper half of the upper Paleocene (Bybell, this volume, chap. F), which is well within the range of *Carya* <29 µm. Thus, the apparent lack of this taxon in the sample from 571.0 ft is of no biostratigraphic significance. On the other hand, the lack of *Carya* <29 µm in the Ellenton samples assigned to the lower part of calcareous nannofossil Zone NP 5 in this core is thought to indicate a real absence of the taxon. *Carya* <29 µm is not known to range down to the lower part of Zone NP 5 in either the eastern Gulf Coast or South Carolina (Frederiksen, 1991).

SNAPP FORMATION

One sample, R4664 E, from 564.0–565.0 ft, was examined from the Snapp Formation in the Millhaven core. This sample contained rare dinoflagellates (Edwards, this volume, chap. G) but was barren of pollen grains.

CONGAREE FORMATION

Two samples were examined from the Congaree Formation in the Millhaven core. Sample R4664 H, from 499.0 ft, was barren of palynomorphs. Sample R4664 K, a fossiliferous sand from 490.0 ft, contained calcareous nannofossils of lower to middle Eocene Zone NP 14

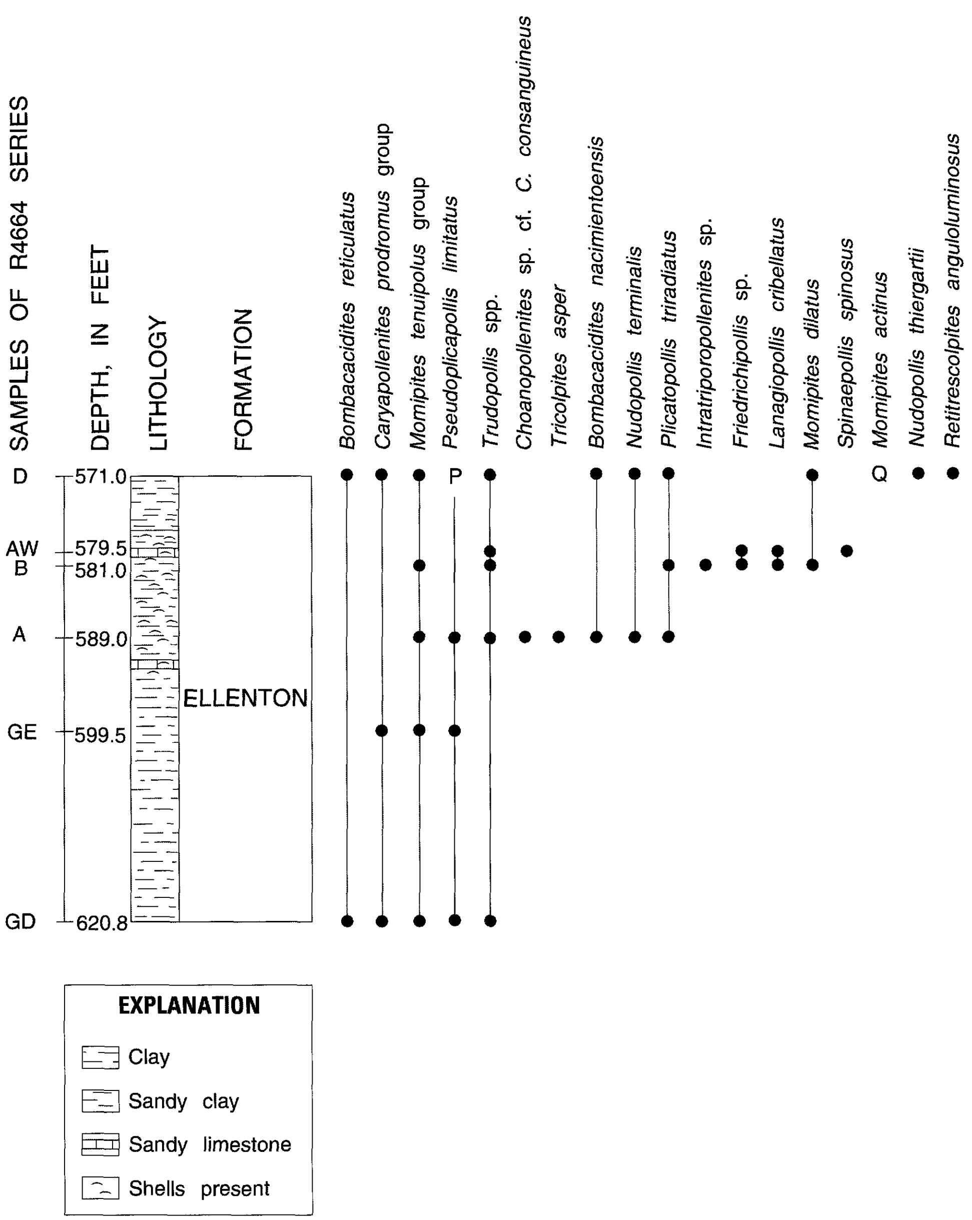

Figure 3. Chart showing pollen distributions in six samples from the Ellenton Formation in the Millhaven core. P indicates that the identification of the species was probable; Q indicates that the identification of the species was uncertain.

(Bybell, this volume, chap. F) and middle Eocene dinoflagellates (Edwards, this volume, chap. G) but only sparse pollen grains. Among the pollen taxa recovered were *Platycarya platycaryoides* (Roche) Frederiksen & Christopher and the *Momipites-Plicatopollis-Platycaryapollenites* complex of Frederiksen (1979). Both taxa have long chronostratigraphic ranges in the lower and middle Eocene, and both have their range bases a short stratigraphic distance below the top of the Paleocene.

WARLEY HILL FORMATION

No samples from the Warley Hill Formation in the Millhaven core were examined for pollen.

SANTEE LIMESTONE

One sample from the Santee Limestone in the Millhaven core, R4664 AL, from 260.0 ft, was examined for pollen. However, the sample was barren of these fossils.

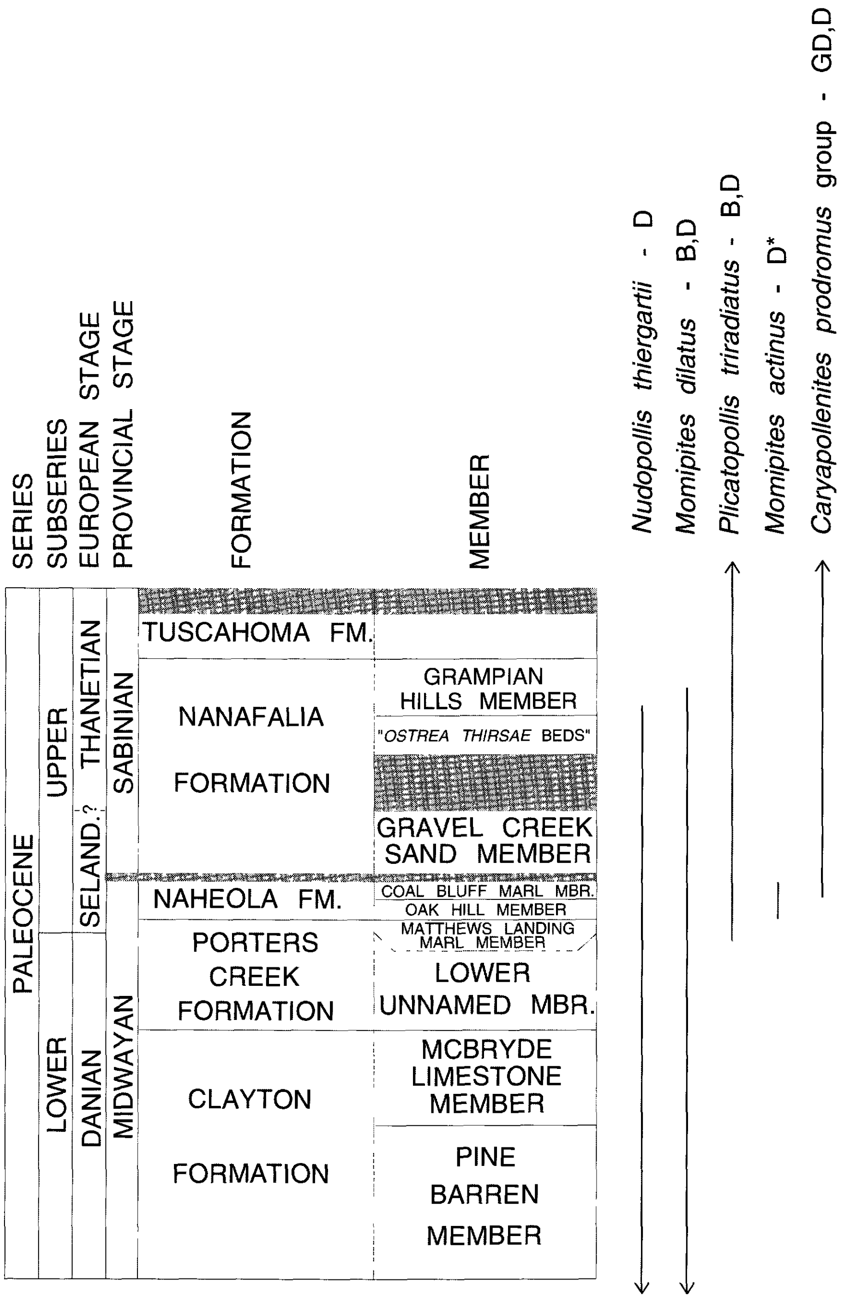

Figure 4. Chart showing known stratigraphic ranges in the eastern Gulf Coast of biostratigraphically important pollen species in samples R4664 GD, B, and D, from 620.8, 581.0, and 571.0 ft, respectively, in the Ellenton Formation in the Millhaven core. Samples in which each taxon was found are indicated by the sample initial following the taxon name; an asterisk following the name *Momipites actinus* indicates that this species was only tentatively identified.

BARNWELL UNIT

Sample R4664 AR, a fossiliferous sand from 210.0 ft in the Millhaven core, is from the Barnwell unit; the sample contained calcareous nannofossils of upper Eocene Zone NP 19/20 (Bybell, this volume, chap. F) and typical Eocene to Oligocene pollen species such as *Momipites coryloides* Wodehouse, *Pseudolaesopollis ventosus* (Potonié) Frederiksen, and *Tetracolporopollenites lesquereuxianus* (Traverse) Frederiksen. However, all of these pollen taxa have such long chronostratigraphic ranges that they are not useful for age determinations. Two additional samples of the Barnwell unit, from 195.0 and 105.0 ft, were barren of pollen.

GIRARD TEST HOLE

The Girard test hole was drilled by the U.S. Geological Survey in southern Burke County at the lookout tower on Griffins Landing Road, 2 miles north of the town of Girard, at lat 33°03'54" N., long 81°43'13" W., Girard 7.5 min quadrangle (fig. 1). The surface elevation is 250 ft above sea level. Seven Tertiary samples from this core were examined for pollen, from the depth interval of 532.7 to 322.3 ft.

ELLENTON FORMATION

Five samples from the Ellenton Formation of the Girard core were examined for pollen. One of these, sample R4705 A, from 532.5–532.7 ft, contained only two taxa (fig. 5), both long ranging. The second sample, R4705 C, from 514.0–514.3 ft (not shown in fig. 5), had only very rare pollen grains.

Samples R4705 B, from 521.0–521.2 ft, and AD, from 517.9–518.1 ft, included taxa listed in figure 5. Stratigraphic ranges of the key pollen taxa in the two samples are shown in figure 6. The overlap of ranges of *Osculapollis*? *colporatus* Frederiksen and *Caryapollenites prodromus* group of Frederiksen (1991) might suggest that the samples correlate with the Naheola Formation of the eastern Gulf Coast and are early late Paleocene in age. However, two specimens were found in the sample from 521.0–521.2 ft that might belong to the early Paleocene species *Pseudoplicapollis serenus* Tschudy. If *P. serenus* Tschudy actually is present, that might complicate the age interpretation because this species is not known to coexist with the late Paleocene taxon *Caryapollenites prodromus* group of Frederiksen (1991). However, *P. serenus* Tschudy ranges down into the Cretaceous (fig. 6) and, therefore, might be reworked.

Sparganiaceaepollenites sp. is an upper Paleocene to Holocene(?) species that is probably a result of drilling mud contamination of the sample. *Myrtaceidites* is a mainly Eocene to Oligocene genus in southeastern North America and is extremely rare below the Eocene. Therefore, this specimen also is probably a result of drilling mud contamination of the sample. Dinoflagellates in the samples from 521.0–521.2 ft and 517.9–518.1 ft indicate an early Paleocene, Danian age (Edwards, this volume, chap. G). Leeth and others (1996) interpreted the data as indicating that these samples are late Paleocene and contain reworked early Paleocene palynomorphs. However, it now seems more likely that *Myrtaceidites* sp., *Caryapollenites prodromus* group, and *Sparganiaceaepollenites* sp. are all contaminants from uphole, and that the samples from 521.0–521.2 ft and 517.9–518.1 ft are early Paleocene in age and assignable to the *Pseudoplicapollis serenus* Interval Zone (fig. 2).

Sample R4705 D, from 484.1–484.3 ft, contained a variety of pollen taxa (fig. 5), but all of them are long ranging within the Paleocene. Dinoflagellates in the sample were interpreted by Leeth and others (1996) and Edwards (this volume, chap. G) as indicating an early late Paleocene (Selandian) age.

SNAPP FORMATION

No pollen samples were examined from the Snapp Formation in the Girard core.

FOURMILE BRANCH FORMATION

Sample R4705 AE, from 415.2–415.5 ft in the Girard core, is from the Fourmile Branch Formation; the sample contained very rare pollen grains. However, two of the specimens identified were of *Platycaryapollenites* sp. aff. *P. swasticoidus* (Elsik) Frederiksen & Christopher and, therefore, are Eocene. These two specimens are probably of early Eocene or possibly early middle Eocene age.

CONGAREE FORMATION

No pollen samples were examined from the Congaree Formation in the Girard core.

SANTEE LIMESTONE

One sample of the Santee Limestone, R4705 F, from 322.3–322.5 ft in the Girard core, was examined, but the sample contained only rare pollen grains.

BARNWELL UNIT

No pollen samples were examined from the Barnwell unit in the Girard core.

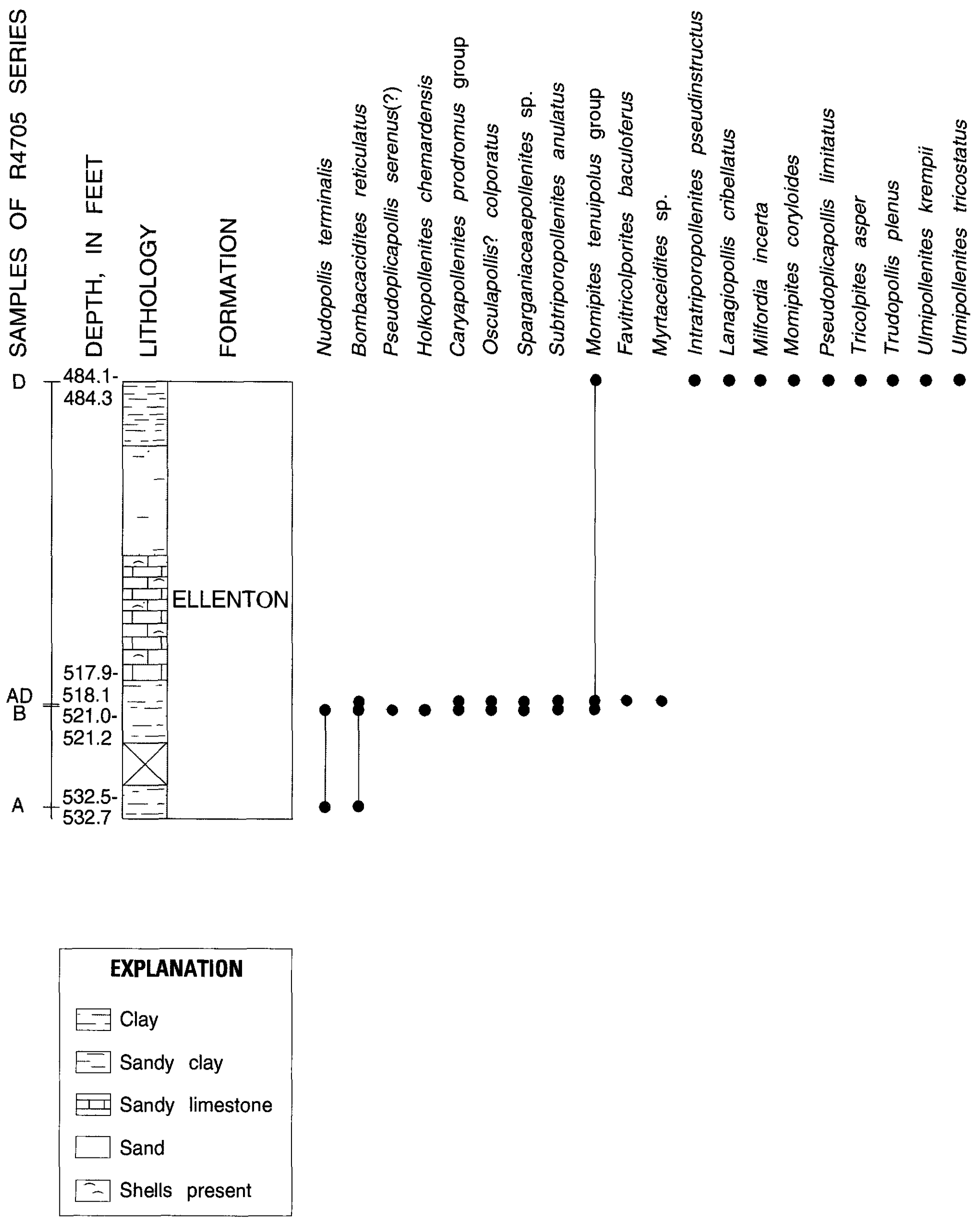

Figure 5. Chart showing pollen distributions in four of the five samples from the Ellenton Formation of the Girard core. A fifth sample, not shown, contained only very rare pollen grains.

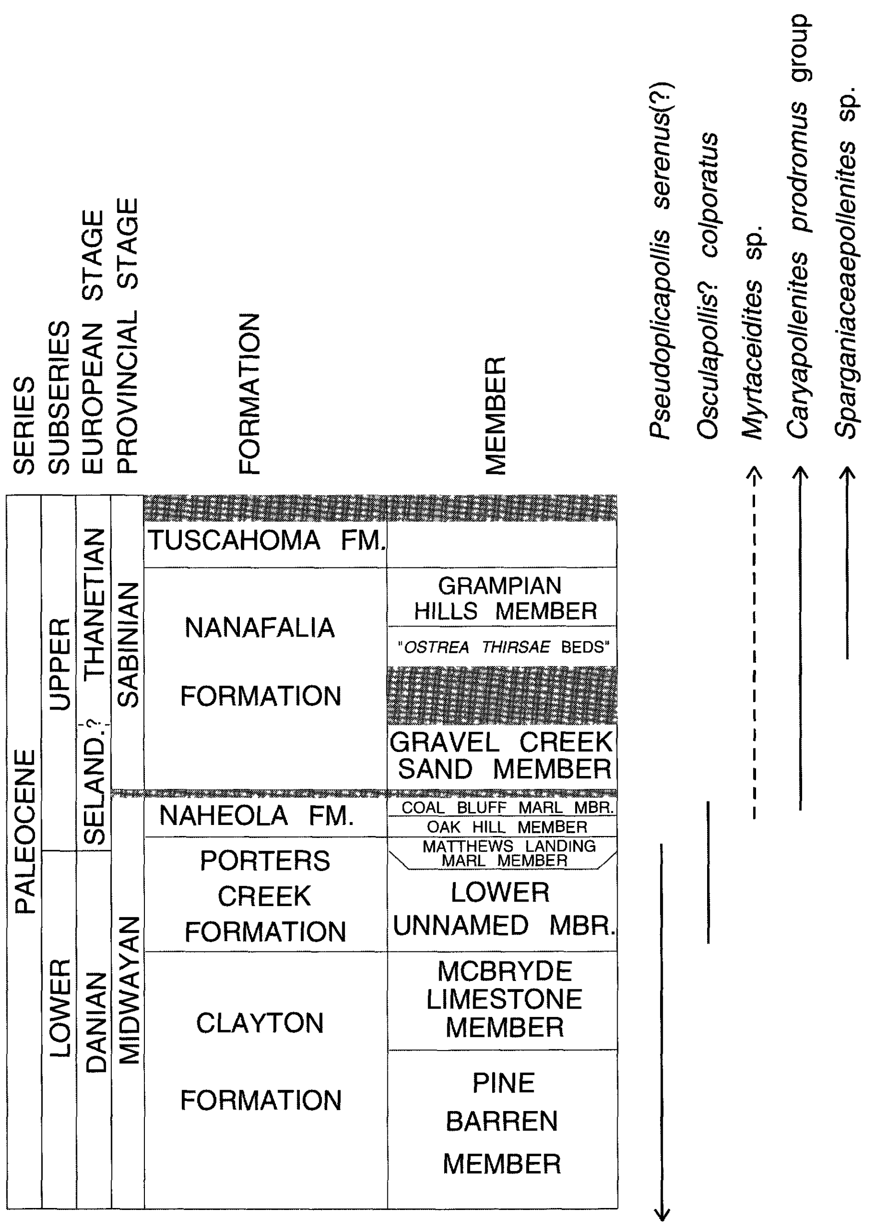

Figure 6. Chart showing known stratigraphic ranges in the eastern Gulf Coast of biostratigraphically important pollen species in sample R4705 B (from 521.0–521.2 ft) and AD (from 517.9–518.1 ft) from the Ellenton Formation in the Girard core.

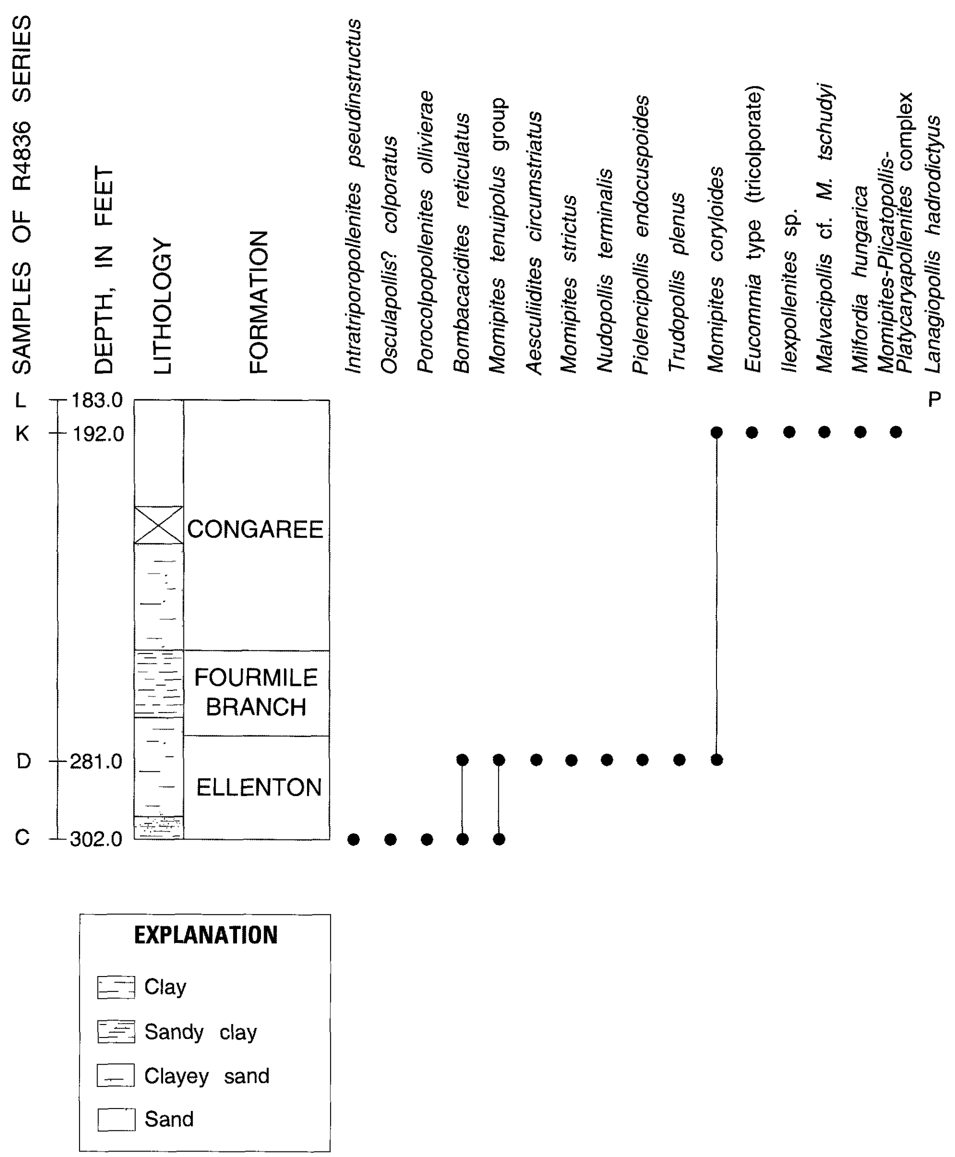

Figure 7. Chart showing pollen distributions in four samples, from 302.0 to 183.0 ft, of the Ellenton and Congaree Formations in the Thompson Oak core. P indicates that the identification of the species was probable.

THOMPSON OAK TEST HOLE

The Thompson Oak test hole was drilled by the Georgia Geologic Survey at lat 33°10'42" N., long 81°47'10" W., Shell Bluff Landing 7.5-min quadrangle, Burke County, Ga. (fig. 1). The surface elevation is 240 ft. Seven Tertiary samples from this core were examined for pollen, from a depth interval of 302.0 to 172.0 ft. Pollen distributions in four productive samples from this core are shown in figure 7.

ELLENTON FORMATION

Two pollen samples were examined from the Ellenton Formation in the Thompson Oak core. Sample R4836 C, from 302.0 ft, contained mainly long-ranging taxa. However, several specimens were observed of *Osculapollis*? *colporatus* Frederiksen, whose range in the eastern Gulf Coast is from the upper part of the lower Paleocene to very low in the upper Paleocene (fig. 6).

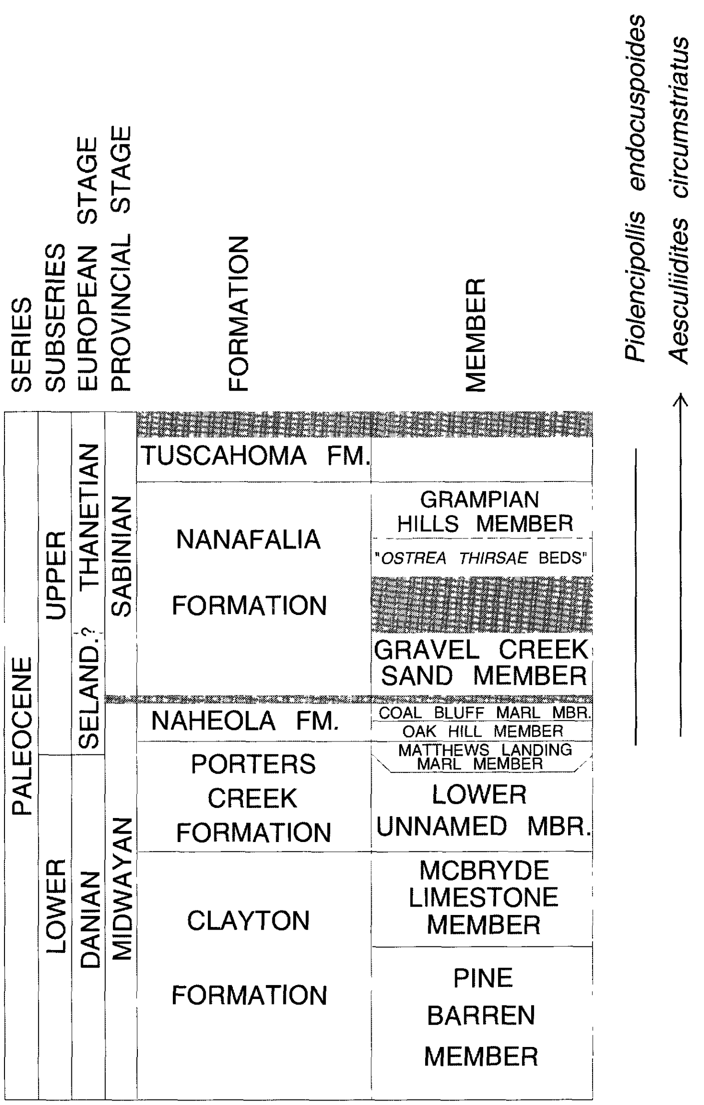

Figure 8. Chart showing known stratigraphic ranges in the eastern Gulf Coast of two biostratigraphically important pollen species found in sample R4836 D, from 281.0 ft, in the Ellenton Formation in the Thompson Oak core.

Most of the taxa in sample R4836 D, from 281.0 ft, have long stratigraphic ranges within the Paleocene. The presence of *Aesculiidites circumstriatus* (Fairchild) Elsik and *Piolencipollis endocuspoides* Frederiksen indicates that the sample could be any age within the late Paleocene (fig. 8).

FOURMILE BRANCH FORMATION

No pollen samples were examined from the Fourmile Branch Formation in the Thompson Oak core.

CONGAREE FORMATION

Two pollen samples were examined from the Congaree Formation in the Thompson Oak core. Sample R4836 K, from 192.0 ft, contained several pollen taxa having somewhat restricted ranges (figs. 7, 9). The known range of *Malvacipollis* cf. *M. tschudyi* Frederiksen of Frederiksen (1988), the most age-definitive species in the sample, is from the lower part of the Tallahatta Formation (Zone NP 12, middle lower Eocene) to the lower part of the Lisbon Formation (Zone NP 15 or lowermost Zone NP 16, lower

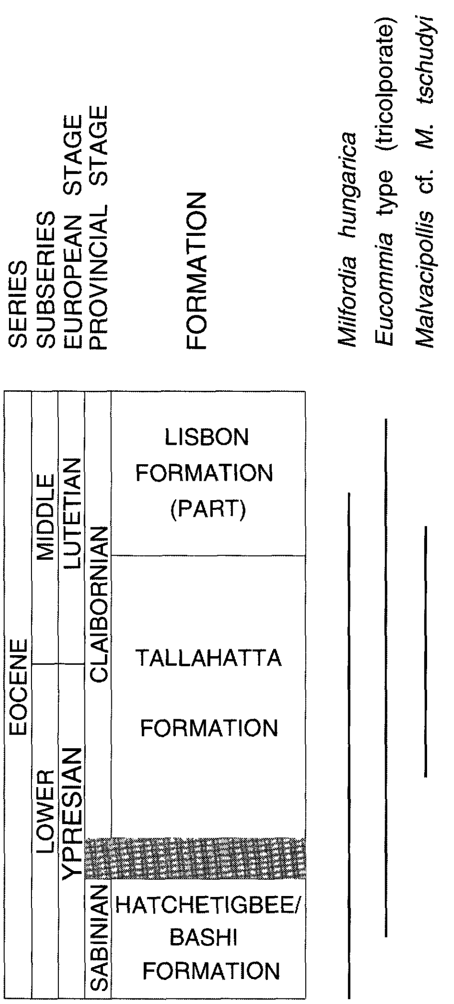

Figure 9. Chart showing known stratigraphic ranges in the eastern Gulf Coast of biostratigraphically important pollen species in sample R4836 K, from 192.0 ft, in the Congaree Formation in the Thompson Oak core.

middle Eocene) in the eastern Gulf Coast. Dinoflagellates in the sample indicate that it is probably correlative with the lower part of the Lisbon Formation (Edwards, this volume, chap. G).

The only species of interest found in sample R4836 L, from 183.0 ft, was a specimen probably belonging to *Lanagiopollis hadrodictyus* Frederiksen. In the eastern Gulf Coast, the known range of this species is from the lower part of the Tallahatta Formation, NP 12, to the lower part of the Lisbon Formation, lower NP 16, and possibly as high as the Moodys Branch Formation, NP 17.

SANTEE LIMESTONE

Samples R4836 M (181.5 ft), R4836 N (174.0 ft), and R4836 O (172.0 ft) were examined for pollen from the Santee Limestone in the Thompson Oak core, but they contained no biostratigraphically useful taxa. *Spinizonocolpites prominatus* (McIntyre) Stover & Evans was found in the sample from 174.0 ft (pl. 1, figs. 21, 22), but this species ranges throughout the Eocene.

BARNWELL UNIT

No pollen samples were examined from the Barnwell unit in the Thompson Oak core.

MILLERS POND TEST HOLE

The Millers Pond test hole was drilled by the Georgia Geologic Survey (Burke 2, GGS–3758) near Shell Bluff Landing on the Savannah River, lat 33°13'48" N., long 81°52'44" W., McBean 7.5-min quadrangle, Burke County, Ga. (fig. 1). The surface elevation is 245 ft above sea level. A lithologic description of the cored section was provided by Clarke and others (1994). Seven Tertiary samples from this core were examined for pollen, from the depth interval of 257.0 to 72.0 ft, and two contained pollen assemblages that conveyed useful information. Pollen distributions in three of the samples are shown in figure 10.

ELLENTON FORMATION

One sample from the Ellenton Formation in the Millers Pond core was examined for pollen—sample R4581 Q from 252.0–257.0 ft. Known Gulf Coast ranges of critical species in this sample are displayed in figure 11. It appears on the basis of the overlapping ranges of *Pseudoplicapollis serenus* and *Momipites coryloides* that this sample is from the upper part of the lower Paleocene (upper Danian). The sample is from the upper part of the *Pseudoplicapollis serenus* Interval Zone (fig. 2). This age determination is supported by a Danian (early Paleocene) dinoflagellate age for the sample (Edwards, this volume, chap. G).

SNAPP FORMATION

No pollen samples were examined from the Snapp Formation in the Millers Pond core.

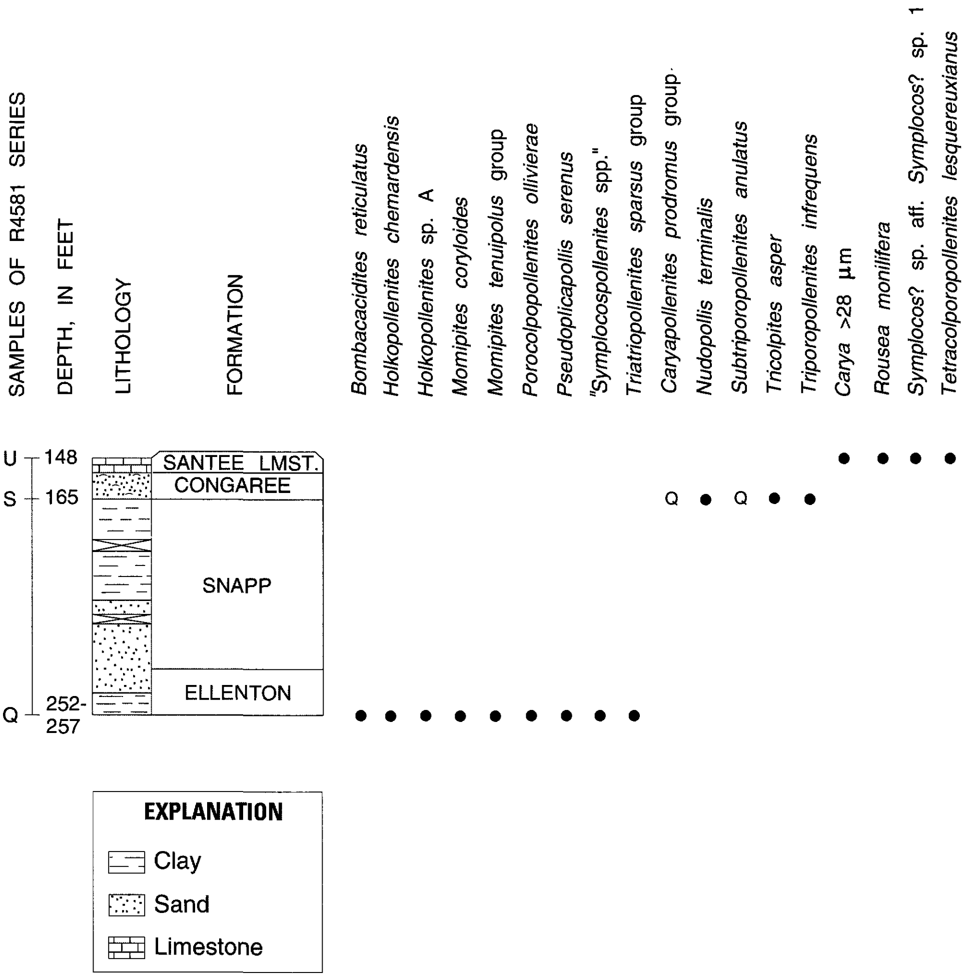

Figure 10. Chart showing pollen distributions in three samples between 257.0 and 148.0 ft in the Millers Pond core. Q indicates that the identification of the species was uncertain.

CONGAREE FORMATION

Sample R4581 S, from 165.0 ft, is just above the contact of the Snapp and Congaree Formations in the Millers Pond core. The sample contained only a few pollen taxa (fig. 10). Either these taxa are long ranging, or else the identification of the taxa was uncertain.

SANTEE LIMESTONE

Sample R4581 U, from 148.0 ft in the Santee Limestone of the Millers Pond core, had two pollen taxa that do not range below the lower Eocene part of the Tallahatta Formation in the eastern Gulf Coast (fig. 12). *Symplocos*? sp. 1 of Frederiksen (1988) is a rare species that has previously been found only in the lower part of the Lisbon Formation (lower middle Eocene, lower Lutetian) in Alabama and Georgia. However, the true range of this species is poorly known. Dinoflagellates in the sample indicate correlation with the upper part of the Lisbon Formation (middle part of the middle Eocene; Edwards, this volume, chap. G). Three additional samples of the Santee Limestone, from 124.0, 120.0, and 82.0–83.0 ft, were also examined, but they were either barren of pollen or else did not contain any biostratigraphically useful taxa.

BARNWELL UNIT

One sample from the Barnwell unit in the Millers Pond core was examined for pollen—sample R4581Y from 72.0–77.0 ft, but it was barren of palynomorphs.

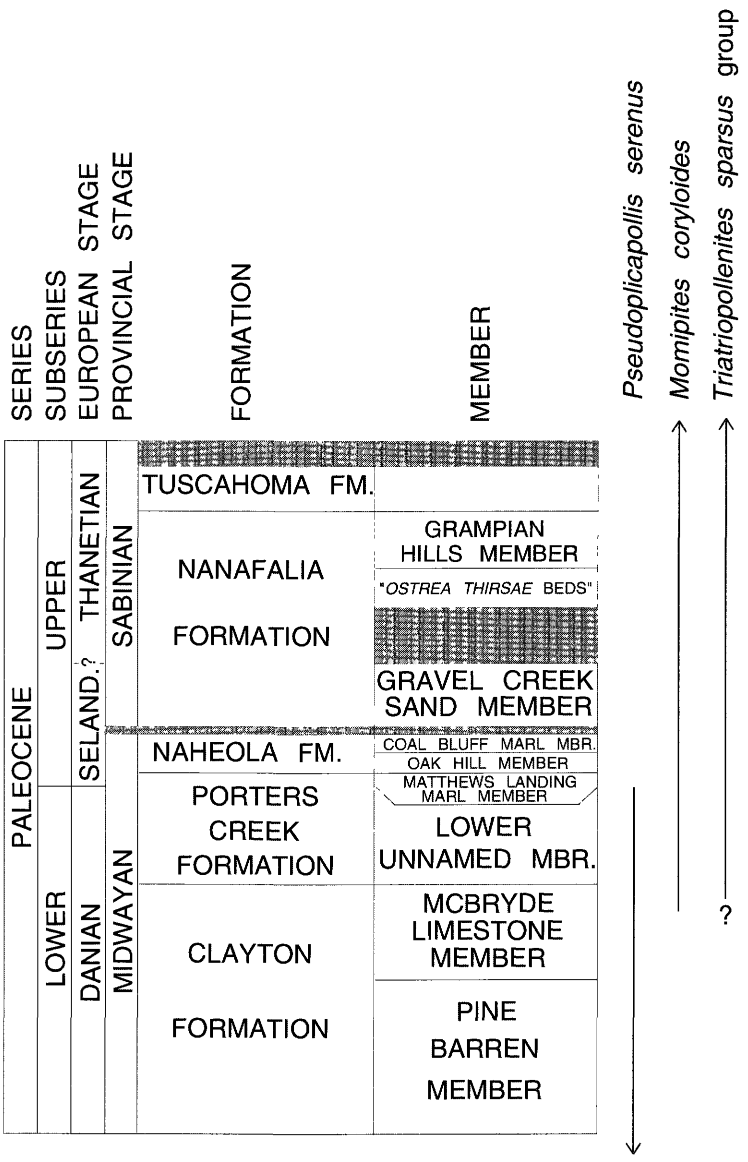

Figure 11. Chart showing known stratigraphic ranges in the eastern Gulf Coast of biostratigraphically important pollen species in sample R4581 Q, from 252.0–257.0 ft, in the Ellenton Formation in the Millers Pond core.

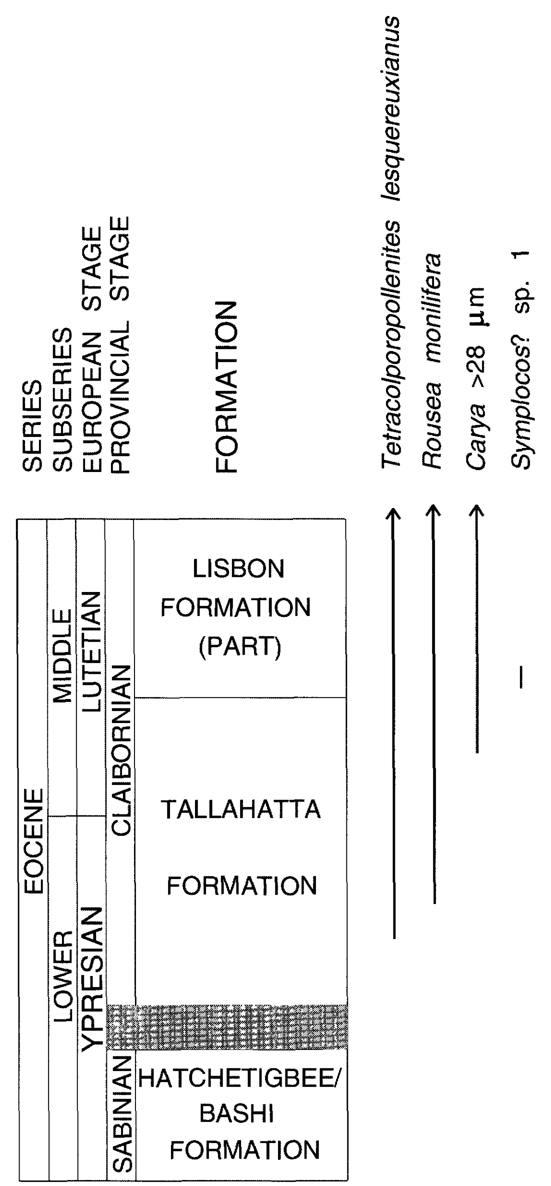

Figure 12. Chart showing known stratigraphic ranges in the eastern Gulf Coast of biostratigraphically important pollen species in sample R4581 U, from 148.0 ft, in the Santee Limestone in the Millers Pond core.

MCBEAN TEST HOLE

The McBean test hole (GGS–3757) was drilled by the Georgia Geologic Survey at lat 33°13'38" N., long 81°55'50" W., in the McBean 7.5-min quadrangle, Burke County, Ga. (fig. 1). The surface elevation is 297 ft above sea level. Six Tertiary samples from this core were examined for pollen, from the depth interval of 294.0 to 181.0 ft. Two samples contained more than rare pollen grains. These two samples were from 264.0 and 181.0 ft (fig. 13).

ELLENTON FORMATION

Two samples were examined from the Ellenton Formation (R4663 B and C, from 294.0 and 276.0 ft, respectively) in the McBean core, but they were barren or nearly barren of pollen grains.

SNAPP FORMATION

No dinocysts were found in sample R4663 D, from 264.0 ft in the Snapp Formation of the McBean core. The critical pollen taxa in this sample (fig. 14) were *Momipites dilatus* Fairchild and *Caryapollenites prodromus* group of Frederiksen (1991), whose overlapping ranges indicate that the sample is no older than earliest late Paleocene and no younger than middle late Paleocene. The sample belongs somewhere within the *Caryapollenites prodromus* or *Carya* Interval Zones (fig. 2). Sample R4663 E, from 243.0 ft, was barren or nearly barren of pollen grains.

CONGAREE FORMATION

Sample R4663 F, from 210.0 ft in the Congaree Formation of the McBean core, was barren or nearly barren of pollen grains.

SANTEE LIMESTONE

Sample R4663 G, from 181.0 ft in the Santee Limestone of the McBean core, contained few pollen taxa (fig. 13); however, *Ilexpollenites* Potonié and *Tetracolporopollenites megadolium* (Potonié) Frederiksen are known only from Eocene and younger strata.

BARNWELL UNIT

No pollen samples were examined from the Barnwell unit in the McBean core.

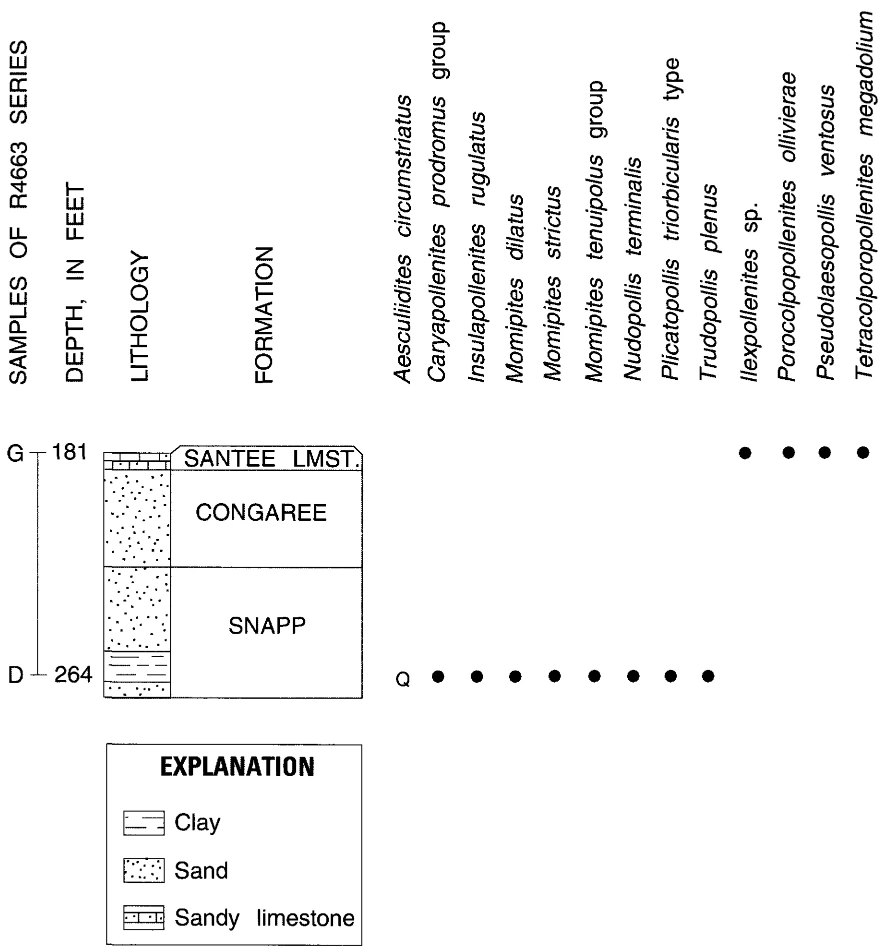

Figure 13. Chart showing pollen distributions in two samples, from 264.0 and 181.0 ft, in the Snapp Formation and Santee Limestone in the McBean core. Q indicates that the identification of the species was uncertain.

SUMMARY

Seventeen biostratigraphically useful lower Tertiary samples were examined for pollen from five cores (Millhaven, Girard, Thompson Oak, Millers Pond, and McBean) in Screven and Burke Counties, Ga. Ten biostratigraphically useful samples from the Ellenton Formation were analyzed, from the Millhaven, Girard, Thompson Oak, and Millers Pond cores. Most samples are not older than early late Paleocene, but one or two of them are older—late early Paleocene in age. The youngest possible age for some of the Ellenton samples is more difficult to establish. On the basis of pollen evidence, several of the Ellenton samples might be as young as middle late or even late late Paleocene. However, most of the samples are probably not younger than the *Caryapollenites prodromus* Interval Zone of early late Paleocene age.

Only one productive sample was obtained from the Snapp Formation; it was from the McBean core. This sample is no older than earliest late Paleocene and no younger than middle late Paleocene.

One productive sample was obtained from the Fourmile Branch Formation, from the Girard core. The sample appears to be early Eocene or possibly early middle Eocene in age.

Three productive samples were obtained from the Congaree Formation from the Millhaven and Thompson Oak cores. The pollen taxa in these samples mainly have long stratigraphic ranges within the lower and middle Eocene. However, one of the samples from the Thompson Oak core appears to be late early to early middle Eocene in age.

Two productive samples were examined from the Santee Limestone from the Millers Pond and McBean cores. These are poorly dated within the late early Eocene to middle Eocene (or younger?) interval.

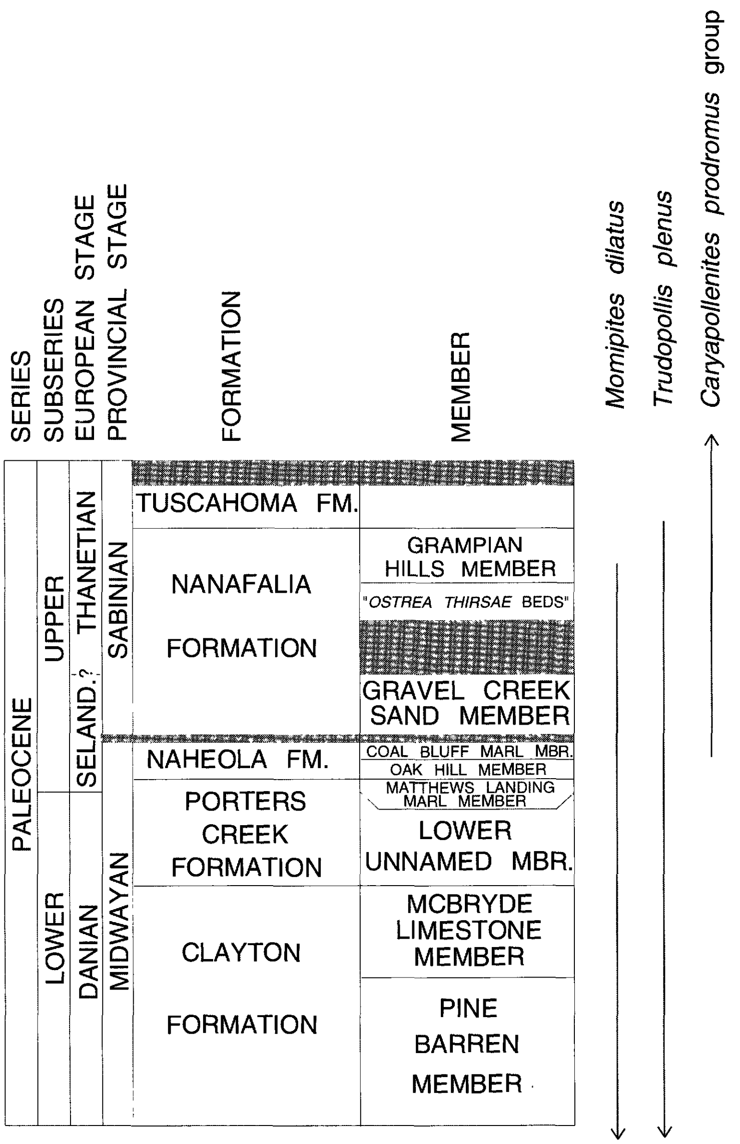

Figure 14. Chart showing known stratigraphic ranges in the eastern Gulf Coast of biostratigraphically important pollen species in sample R4663 D, from 264.0 ft, in the Snapp Formation in the McBean core.

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PLATES 1, 2

PLATE 1

[All specimens are from Screven and Burke Counties, Georgia]

Figure 1. *Sparganiaceaepollenites* sp., Ellenton Formation, Girard core (521.0–521.2 ft), Burke County.

2. *Milfordia hungarica* (Kedves) Krutzsch & Vanhoorne *in* Krutzsch (1970), Congaree Formation, Thompson Oak core (192.0 ft), Burke County.

3. *Milfordia incerta* (Pflug & Thomson *in* Thomson and Pflug, 1953) Krutzsch, Ellenton Formation, Girard core (484.1–484.3 ft), Burke County.

4. *Momipites tenuipolus* group of Frederiksen and Christopher (1978), Snapp Formation, McBean core (264.0 ft), Burke County.

5. *Momipites coryloides* Wodehouse, Congaree Formation, Thompson Oak core (192.0 ft), Burke County.

6. *Momipites dilatus* Fairchild *in* Stover and others (1966), Ellenton Formation, Millhaven core (571.0 ft), Screven County.

7, 8. *Platycarya platycaryoides* (Roche) Frederiksen & Christopher, Congaree Formation, Millhaven core (490.0 ft), Screven County. Interference contrast.

9, 10. *Platycarya* sp. A of Frederiksen and Christopher (1978) (from drilling mud contamination), Steel Creek Formation (Cretaceous), Millhaven core (755.0–755.3 ft), Screven County.

11. *Platycarya* sp., Congaree Formation, Millhaven core (490.0 ft), Screven County. The specimen has several irregular pseudocolpi; interference contrast.

12. *Platycarya* sp. (from drilling mud contamination), Steel Creek Formation (Cretaceous), Millhaven core (755.0–755.3 ft), Screven County.

13. *Platycarya* sp., Fourmile Branch Formation, Girard core (415.2–415.5 ft), Burke County.

14. *Momipites-Plicatopollis-Platycaryapollenites* complex of Frederiksen (1979), Congaree Formation, Millhaven core (490.0 ft), Screven County.

15. *Plicatopollis triorbicularis* type of Frederiksen and Christopher (1978), Snapp Formation, McBean core (264.0 ft), Burke County.

16. *Ulmipollenites tricostatus* (Anderson) Frederiksen, Ellenton Formation, Girard core (484.1–484.3 ft), Burke County.

17. *Ulmipollenites krempii* (Anderson) Frederiksen, Ellenton Formation, Girard core (484.1–484.3 ft), Burke County.

18. *Malvacipollis* cf. *M. tschudyi* Frederiksen of Frederiksen (1988), Congaree Formation, Thompson Oak core (192.0 ft), Burke County.

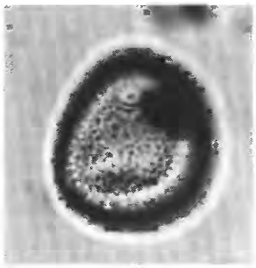
19. *Spinaepollis spinosus* (Potonié) Krutzsch, Ellenton Formation, Millhaven core (579.5 ft), Screven County.

20. *Eucommia* type (tricolporate) of Frederiksen (1988), Congaree Formation, Thompson Oak core (192.0 ft), Burke County.

21, 22. *Spinizonocolpites prominatus* (McIntyre) Stover & Evans, Santee Limestone, Thompson Oak core (174.0 ft), Burke County.

23. *Aesculiidites circumstriatus* (Fairchild *in* Stover and others, 1966) Elsik, Ellenton Formation, Thompson Oak core (281.0 ft), Burke County.

24. *Ilexpollenites* sp., Santee Limestone, McBean core (181.0 ft), Burke County.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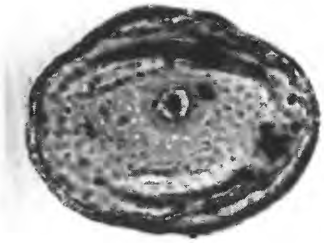
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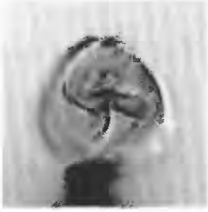
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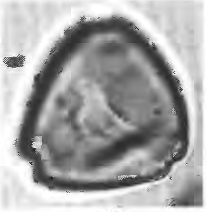
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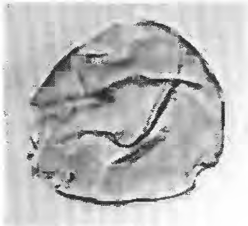
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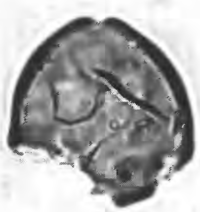
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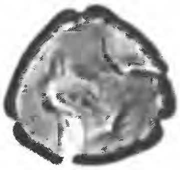
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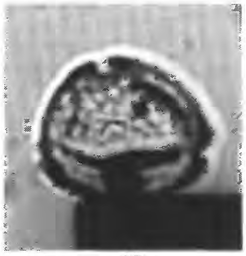
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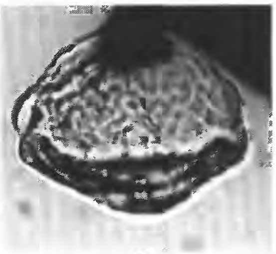
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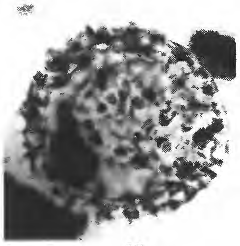
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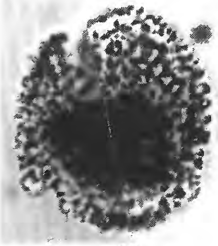
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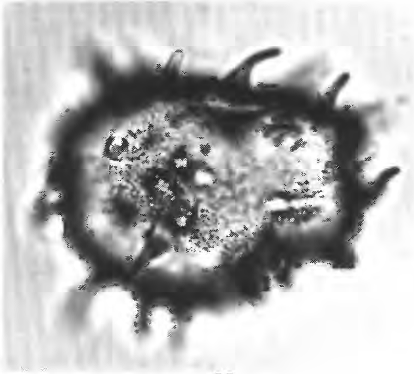
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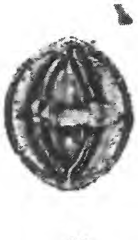
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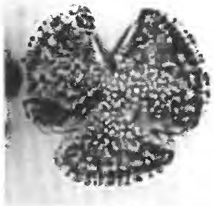
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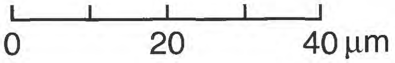


ANGIOSPERM POLLEN GRAINS

PLATE 2

[All specimens are from Screven and Burke Counties, Georgia]

Figure 1. *Pseudoplicapollis limitatus* Frederiksen, Ellenton Formation, Girard core (484.1–484.3 ft), Burke County.

2, 3. *Nudopollis terminalis* (Pflug & Thomson *in* Thomson and Pflug, 1953) Pflug, Ellenton Formation. 2, Girard core (532.5–532.7 ft), Burke County; 3, Thompson Oak core (281.0 ft), Burke County.

4. *Pseudolaesopollis ventosus* (Potonié) Frederiksen, Santee Limestone, McBean core (181.0 ft), Burke County.

5. *Choanopollenites* sp. cf. *C. consanguineus* Tschudy of Frederiksen (1979), Ellenton Formation, Millhaven core (589.0 ft), Screven County.

6. *Insulapollenites rugulatus* Leffingwell, Snapp Formation, McBean core (264.0 ft), Burke County.

7. *Intratriporopollenites* sp., Ellenton Formation, Millhaven core (581.0 ft), Screven County.

8. *Pseudoplicapollis serenus* Tschudy, Ellenton Formation, Millers Pond core (252.0–257.0 ft), Burke County.

9. *Osculapollis*? *colporatus* Frederiksen, Ellenton Formation, Thompson Oak core (302.0 ft), Burke County.

10. *Trudopollis plenus* Tschudy, Ellenton Formation, Girard core (484.1–484.3 ft), Burke County.

11. *Symplocos*? sp. aff. *Symplocos*? sp. 1 of Frederiksen (1988), Santee Limestone, Millers Pond core (148.0 ft), Burke County.

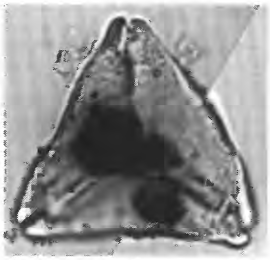
12. *Friedrichipollis* sp., interference contrast. Ellenton Formation, Millhaven core (581.0 ft), Screven County.

13. *Bombacacidites reticulatus* Krutzsch, Ellenton Formation, Millers Pond core (252.0–257.0 ft), Burke County.

14. *Bombacacidites nacimientoensis* (Anderson) Elsik, Ellenton Formation, Millhaven core (571.0 ft), Screven County.

15. *Lanagiopollis cribellatus* (Srivastava) Frederiksen, Ellenton Formation, Millhaven core (581.0 ft), Screven County.

16. *Lanagiopollis* sp., probably *L. hadrodictyus* Frederiksen, Congaree Formation, Thompson Oak core (183 ft), Burke County.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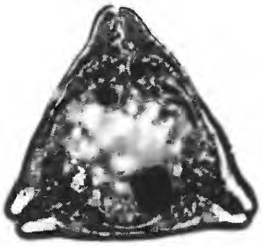
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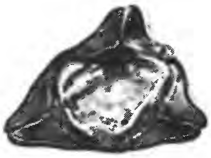
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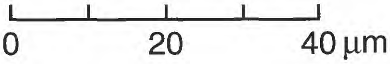


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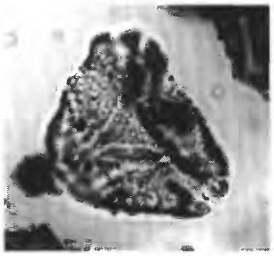
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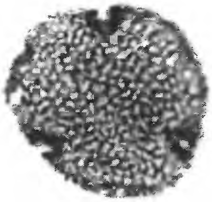
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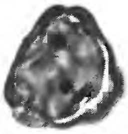
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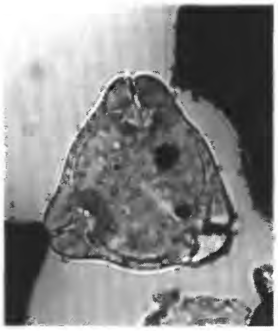
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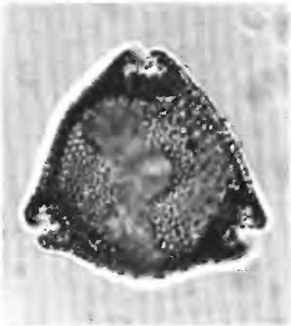
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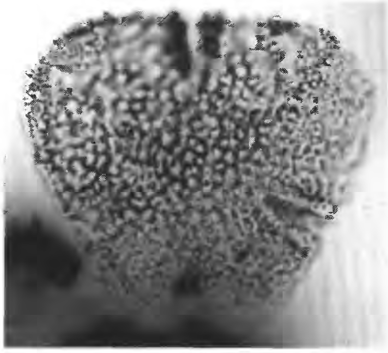
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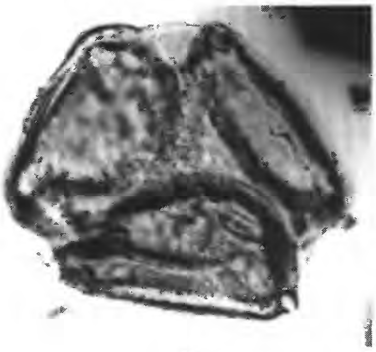
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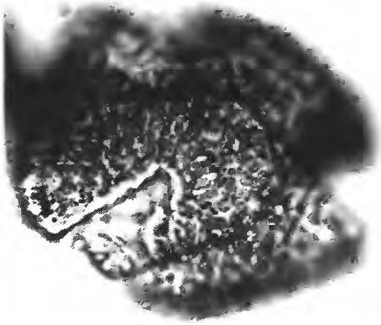
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ANGIOSPERM POLLEN GRAINS

U.S. Department of the Interior
U.S. Geological Survey

Foraminifera from Paleogene Sediments from the Millhaven and Millers Pond Cores, Screven and Burke Counties, Georgia

By Thomas G. Gibson

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Georgia Geologic Survey

GEOLOGY AND PALEONTOLOGY OF FIVE CORES FROM
SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

Edited by Lucy E. Edwards

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SCREVEN AND BURKE COUNTIES, EASTERN GEORGIA

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By Thomas G. Gibson[1]

ABSTRACT

Paleocene and Eocene foraminifers were studied for biostratigraphic and paleoenvironmental analysis in cores from two test holes in the eastern Georgia Coastal Plain. The Millhaven test hole, located southeast of the Millers Pond test hole, is in the more downbasin position. In the Millhaven core, foraminifers are present in lower and upper Paleocene strata of the Ellenton Formation, lower middle Eocene strata of the Congaree and Warley Hill Formations, upper middle Eocene strata of the Santee Limestone, and upper Eocene and questionable lower Oligocene strata of the Barnwell unit. Foraminifers were recovered only from upper middle Eocene strata of the Santee Limestone in the Millers Pond core. The Millers Pond site is the more westerly of the two sites and is in a more upbasin position.

Foraminifers are moderately to highly altered diagenetically in many of the sandy or carbonate-rich intervals in these cores, and the alteration makes specific identifications difficult. Diagnostic planktonic species are found only in beds of early Paleocene age. Some benthic foraminiferal species that have restricted regional biostratigraphic ranges are present. These species suggest placements for some strata in the early part of the late Paleocene and in the middle Eocene.

Foraminiferal assemblages suggest that most upper Paleocene and Eocene beds were deposited in shallow-marine environments with water depths of less than 100 ft. Assemblages in a few intervals, however, suggest somewhat deeper inner-middle to middle neritic environments. Foraminiferal assemblages suggest well-oxygenated environments during the deposition of most upper Paleocene and Eocene beds, but an upper Paleocene dark clay interval contains assemblages suggestive of high-productivity and low-oxygen environments.

INTRODUCTION

Paleogene foraminifers from the Millhaven and Millers Pond cores were examined during a study of the hydrogeologic framework of easternmost Georgia across the river from the Savannah River Site in South Carolina (fig. 1). This study examined foraminiferal assemblages both for biostratigraphic placement of the strata and for interpretation of depositional environments. Foraminiferal assemblages are discussed in a sample-by-sample format to provide the maximum amount of information from this area where little foraminiferal information is currently available.

In the more easterly, and thus downbasin, Millhaven core, foraminifers are found both in Paleocene and Eocene strata. The specimens are well preserved in the more clayey strata, but most are highly altered in the more sandy and limy beds. In the more upbasin Millers Pond core, foraminifers are found only in the Santee Limestone of late middle Eocene age. These specimens occur in carbonate-rich, sandy sediments, and their tests are moderately to highly altered diagenetically.

Some common and important stratigraphic marker benthic species and one stratigraphically important planktonic species are illustrated by scanning electron microscope (SEM) photographs (pl. 1). A high degree of recrystallization within many assemblages, however, makes it difficult to obtain satisfactory pictures of many species, particularly those from the middle Eocene.

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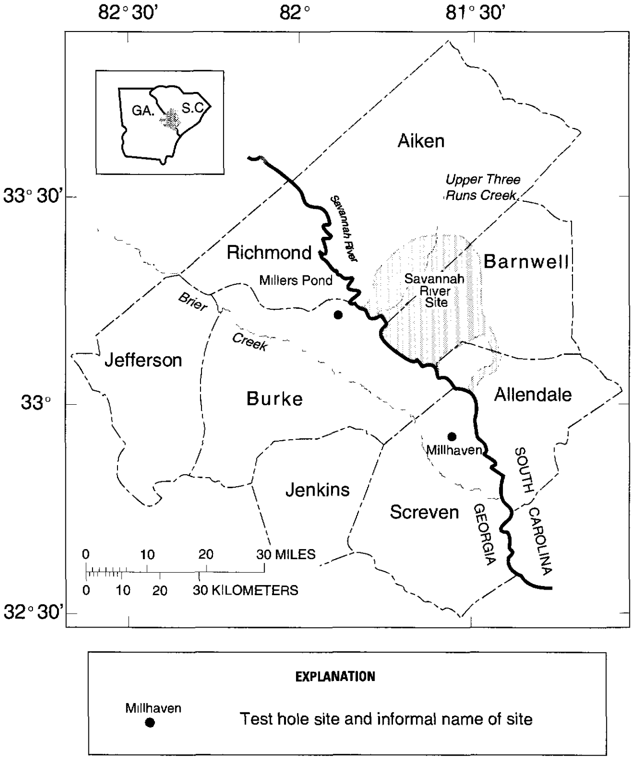

Figure 1. Index map showing the Savannah River Site and the location of the Millhaven and Millers Pond test holes in Screven and Burke Counties, Georgia.

ACKNOWLEDGMENTS

Thomas Servais (U.S. Geological Survey) prepared the foraminiferal samples and aided in the sediment descriptions. Jean M. Self-Trail and Amanda Chapman (U.S. Geological Survey) prepared the illustrations. Raymond A. Christopher (Clemson University) and Harry J. Dowsett (U.S. Geological Survey) made helpful suggestions on the manuscript.

MATERIAL AND METHODS

Foraminifers were prepared from core sections several inches in length. The outside rind of each core segment, which may contain contaminated drilling mud, was removed before processing. Core sections were washed over a 63-micrometer screen that retained all sand-sized and coarser particles.

We then followed two procedures depending upon the state of foraminiferal preservation. In samples containing well-preserved foraminiferal assemblages, the specimens were concentrated from other sand-sized sedimentary particles by soap flotation. However, in many samples, the foraminifers were altered diagenetically and exhibited one or more of the following conditions: extraneous sedimentary particles adhering to the specimens, chamber infillings, calcareous overgrowths, or heavy recrystallization of the test wall. In these samples, the foraminifers were picked from the entire sediment residue that remained after washing.

The degree of diagenetic alteration of the foraminifers in many samples makes it difficult to identify these specimens to the species level. In addition, diagenetic alteration may have selectively removed certain taxa from the original foraminiferal assemblage. Because of these possible biases, samples were studied on a qualitative (species present or absent) basis only.

In the Millhaven core, 23 samples from 5 Paleocene and Eocene units contained foraminifers (fig. 2). In the Millers Pond core, only three samples from the Santee Limestone contained foraminifers (fig. 3). Sample depths are recorded to the nearest 0.5 ft, except in the lower part of the Millhaven core where sample depths are recorded to the nearest 0.1 ft.

Illustrated specimens, other study specimens, faunal slides, and foraminiferal concentrates are deposited in the Cushman Foraminiferal Collection at the U.S. National Museum of Natural History (USNM), Smithsonian Institution, Washington, D.C.

BIOSTRATIGRAPHY

Gohn (1988) summarized the early Cenozoic geology of the southern Atlantic Coastal Plain. This work contains numerous references to the lithostratigraphy of Paleogene deposits in Georgia and South Carolina. Relatively few publications, however, exist on the biostratigraphy of Paleogene Foraminifera in Georgia and South Carolina, and even fewer contain illustrations of the species. Herrick (1961) summarized the occurrence of many benthic species in subsurface samples from Paleogene formations of Georgia, but the species were not illustrated.

Biostratigraphic ranges of many benthic foraminiferal taxa occurring in Georgia and South Carolina deposits largely are undocumented, both in terms of their ranges in Paleogene deposits of the Southeastern United States and in terms of the intercontinental biostratigraphic zonations. I compared the benthic species, when possible, with their biostratigraphic distribution in neighboring areas to the north in North Carolina (Copeland, 1964; Jones, 1983) and Virginia and Maryland (Nogan, 1964; Gibson and others, 1980; Poag, 1989), and to the southwest in Alabama (Bandy, 1949), where more detailed studies of these faunas have been made. Even in these areas, however, the ranges of benthic species in terms of intercontinental biostratigraphic zonations are largely unknown at the present time.

Planktonic foraminifers can be widely distributed in the oceans and, therefore, are widely used in intercontinental correlation and zonations. Unfortunately, they are quite rare in Paleogene strata in the two studied

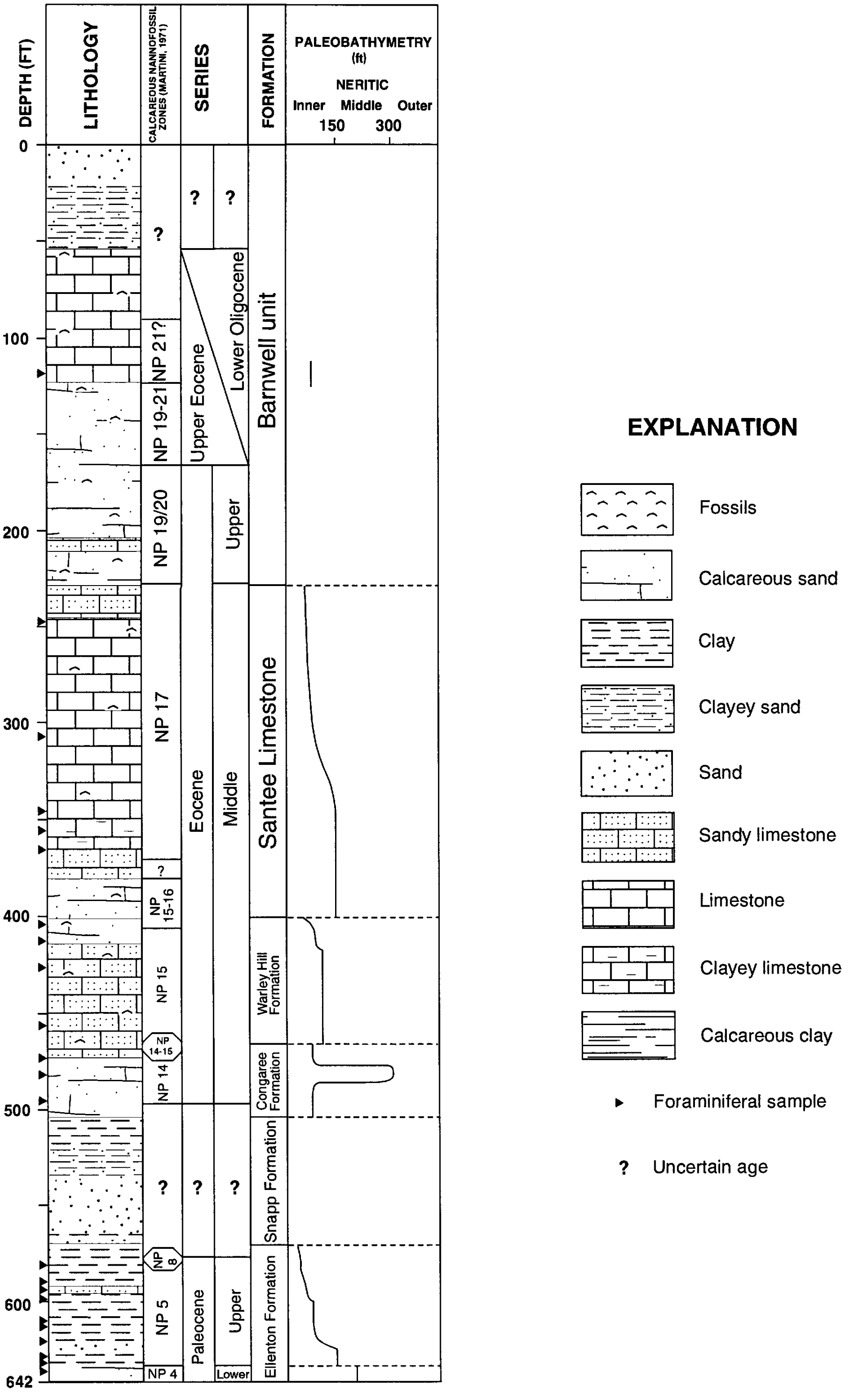

Figure 2. A lithologic log and paleobathymetry of the Millhaven core. The solid triangles indicate the locations of the productive foraminiferal samples. A nonproductive sample from 219 ft is not shown. The calcareous nannofossil zones are from Bybell (this volume, chap. F).

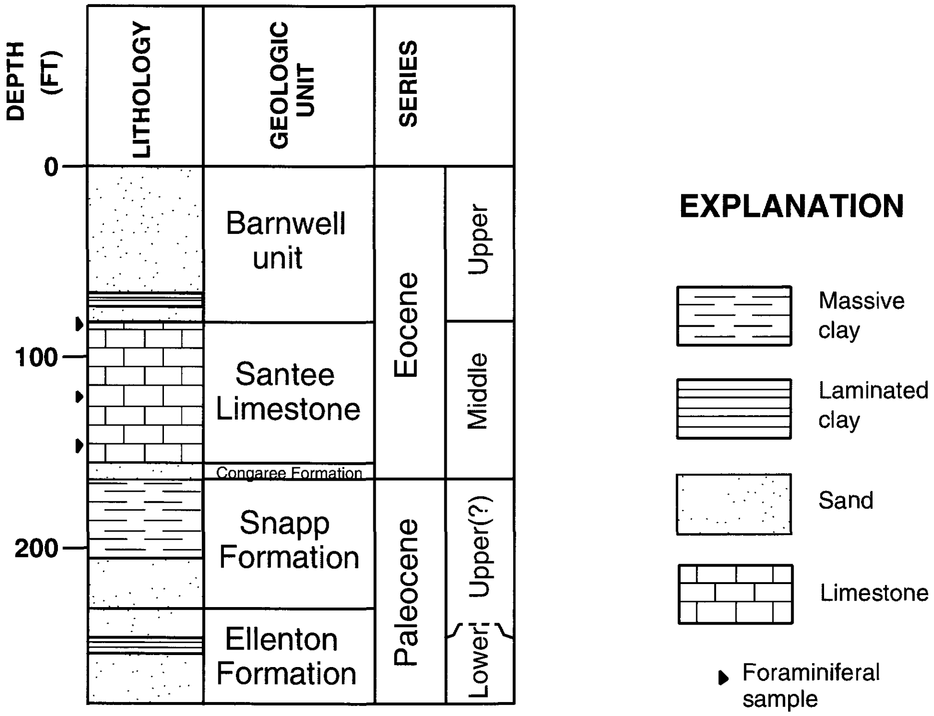

Figure 3. A lithologic log of the Millers Pond core. The solid triangles indicate the locations of the foraminiferal samples. The lithology is from Clarke and others (1994) and the lithostratigraphy is from Falls and Prowell (this volume, chap. A).

cores. The few planktonic specimens recovered from most samples consist mainly of juvenile individuals, which are difficult to place in a specific taxon. The rarity of adult planktonic specimens in the deposits is due primarily to the shallow-water depositional environments of the preserved Paleogene strata in this area. The natural rarity of planktonic specimens in these environments may be augmented by the extensive diagenetic history of many of the samples. Tests of planktonic species are more vulnerable to dissolution during diagenesis than are tests of most benthic species (Murray, 1991). Much less is known biostratigraphically about benthic foraminifers, and they are more closely subjected to environmental controls. Yet, benthic foraminifers compose more than 95 percent of most assemblages.

Most age assignments of strata used in this paper result from the calcareous nannofossil study of these cores by Bybell (this volume, chap. F). Bybell and I have found in studies of Paleogene strata in other parts of the Eastern and Southeastern United States that diagnostic calcareous nannofossil species are much more common in shallow-water deposits than are diagnostic planktonic foraminiferal species (Gibson and Bybell, 1995). In the Millhaven core, planktonic foraminifers, in conjunction with calcareous nannofossils, were valuable in a more accurate placement of the upper lower Paleocene strata.

PALEOENVIRONMENTAL ANALYSIS

The paleoenvironmental analysis is largely based on two approaches: (1) the specific and generic composition of the benthic foraminiferal assemblage and (2) the population characteristics of the entire foraminiferal assemblage. Most benthic species occurring in Paleogene assemblages became extinct during the early and middle Cenozoic. Therefore, for Paleogene species, data on environmental tolerances and distribution in modern environments usually is not possible. However, general paleoenvironmental limits on some extinct species were suggested in studies of Paleogene assemblages in adjacent areas such as those of Olsson and Wise (1987) in New Jersey and Poag (1989) in Virginia.

Numerous benthic genera, however, range from the Paleogene into modern faunas. Although benthic foraminiferal genera usually have wider environmental tolerances than any single contained species, some benthic genera have relatively restricted environmental tolerances for all their modern species. The occurrences of fossil species within these genera also seem to mirror similar environmental controls. Generalized environmental interpretations regarding depth, productivity, and oxidation levels were reconstructed from these genera wherever possible.

Population characteristics of the entire foraminiferal assemblage that can be used for paleoenvironmental analysis include benthic species diversity and the planktonic/

benthic ratio. Gibson and Buzas (1973) conducted studies on species diversity, and Gibson (1988, 1989) studied planktonic/benthic ratios. Both sets of studies show that patterns of these assemblage characteristics found with increasing water depth are similar between the early and middle Cenozoic faunas of the Atlantic and eastern Gulf Coastal Plains and the modern faunas of the western Atlantic Ocean and the Gulf of Mexico.

MILLHAVEN CORE

The Millhaven test hole (33X048) site, lat 32°53'25" N., long 81°35'43" W., is located in Screven County, Ga. (fig. 1). Land surface elevation of the drill site is 110 ft. Twenty-four samples between the depths of 637 and 118 ft were examined for foraminifers (table 1, fig. 2). Foraminifers are present in both lower and upper Paleocene strata of the Ellenton Formation, lower middle Eocene strata of the Congaree and Warley Hill Formations, upper middle Eocene strata of the Santee Limestone, and upper Eocene and possibly lower Oligocene strata of the Barnwell unit in the Millhaven core.

ELLENTON FORMATION

The lower beds of the Ellenton Formation in the Millhaven core, as seen in the lowest foraminiferal sample studied at 636.8 ft, contain a more highly altered and a lower diversity benthic assemblage than the nine samples studied from the middle and upper parts of the formation (631.3 to 581 ft). The lowest sample is of early Paleocene age (lower part of calcareous nannofossil Zone NP 4) as discussed below, and the nine higher samples are of early late Paleocene age (calcareous nannofossil Zone NP 5) (Bybell, this volume, chap. F).

Lower Paleocene beds in the Millhaven core have a thickness of approximately 10 ft or less. These beds apparently represent a relatively thin remnant of a formerly much thicker lower Paleocene deposit in this area that underwent significant erosional removal during the latest early and earliest late Paleocene. Several of the highest Cenozoic sea levels occurred in the early Paleocene (Haq and others, 1987), and deposits representing these extensive seas are found in many areas in the Atlantic Coastal Plain. Studies on Paleogene deposits of western Georgia and eastern Alabama (Gibson, 1992) and Maryland (Gibson and Bybell, 1994) found that these lower Paleocene deposits represented the deepest water deposition and the highest sea levels of any Paleogene unit that is found in those areas. However, the lower Paleocene middle to outer neritic deposits are very patchy in their present-day occurrence in the Atlantic Coastal Plain, which suggests that widespread erosion of these deposits occurred during latest early Paleocene, late Paleocene, and younger times.

The nine samples examined from the higher part of the Ellenton Formation (631.3–581 ft) are of early late Paleocene age (calcareous nannofossil Zone NP 5) according to Bybell (this volume, chap. F). Some benthic foraminiferal species, such as *Cibicides compressus* Olsson, that occur in these samples have their highest occurrences in Virginia and Maryland in strata placed in Zone NP 5 (Nogan, 1964; Bybell and Gibson, 1991), which supports this age assignment.

Five intervals with differing foraminiferal assemblages are present in the formation: (1) a highly altered, low-diversity assemblage of early Paleocene age at 636.8 ft; (2) an assemblage containing apparent mixing of specimens from lower Paleocene beds with early late Paleocene specimens at 631.3 ft; (3) an assemblage suggesting normal productivity and oxygen levels with a probable water depth range of 100 to 200 ft, which occurs at 628.7 ft in clayey glauconitic sand; (4) an assemblage suggestive of water depths of less than 100 ft but having high-productivity and (or) low-oxygen conditions, which occurs in dark clay samples from 621.2 to 599.1 ft; and (5) an assemblage suggestive of water depths of less than 100 ft with normal marine oxygen conditions in samples from 593.7 to 581 ft, which occurs in calcareous and clayey sand beds.

636.8 ft (early Paleocene).—The sample from 636.8 ft contains relatively few specimens of a low-diversity assemblage of highly corroded foraminifers, most of which have calcite rhombohedrons attached to their tests. The poor preservation precludes definitive identifications of some specimens beyond the generic level.

Cibicides compressus Olsson, *Bulimina* sp., *Cibicides* sp., and *Gyroidina* sp. are present in the benthic foraminiferal assemblage. *Cibicides compressus* Olsson occurs in both lower and lower upper Paleocene strata in Virginia and Maryland (Nogan, 1964; Thomas Gibson, unpub. data). The highly altered specimens and the few species present in the assemblage suggest that much of the original assemblage was removed during diagenesis. Extensive diagenesis could be expected as this sample is near the top of the lower Paleocene beds. There is a disconformity between lower Paleocene and lower upper Paleocene strata located somewhere between this sample and the overlying sample at 631.3 ft. Subaerial exposure of these beds was likely during the formation of the disconformity.

The foraminiferal assemblage also contains recognizable specimens of the important planktonic species *Globoconusa daubjergensis* (Bronnimann). This planktonic species ranges through much of the early Paleocene (planktonic foraminiferal Zone P1, Danian) but does not range into the latest early Paleocene (Toumarkine and Luterbacher, 1985; Berggren and others, 1995). Bybell (this volume, chap. F), on the basis of the calcareous nannofossils, places this sample interval into calcareous nannofossil Zone NP 4, which is of latest early Paleocene and earliest late Paleocene age (Berggren and others, 1995). The presence of

Table 1. Sedimentary characteristics of foraminiferal samples from the Millhaven core.

Sample depth (ft)	Sedimentary characteristics
	Barnwell unit
118	Calcareous sand; 71 percent sand size by weight; sand fraction consists of abundant recrystallized shell fragments and bryozoan fragments with about 10 percent quartz; trace of glauconite.
219	Calcareous quartz silty sand; 87 percent sand size by weight; sand fraction consists of 70 percent quartz, 20 percent calcareous grains, and 10 percent shell fragments.
	Santee Limestone
248	Calcareous sand; 73 percent sand size by weight; sand fraction consists of 85 percent carbonate and 15 percent glauconite; just traces of shell debris and quartz.
307	Limestone with some recrystallized shell fragments and a trace of pyrite.
346	Calcareous unit with trace of glauconite.
355	Calcareous unit with traces of quartz and glauconite.
365	Calcareous unit with 15 percent glauconite.
	Warley Hill Formation
404	Calcareous quartz sand; 85 percent sand size by weight; sand fraction consists of 45 percent carbonate, 30 percent quartz, and 25 percent shell fragments.
413	Calcareous quartz sand; 84 percent sand size by weight; sand fraction consists of 55 percent quartz, 40 percent carbonate, and 5 percent glauconite.
426.5	Calcareous unit with 10 percent glauconite and 5 percent pyrite, trace of quartz.
456	Calcareous unit with 20 percent glauconite, 10 percent shell hash, and 5 percent quartz.
	Congaree Formation
473.5	Quartz sand, 88 percent sand size by weight; sand fraction consists of 60 percent quartz and 40 percent glauconite.
481.5	Quartz sand, 90 percent sand size by weight; sand fraction consists of 55 percent quartz and 45 percent glauconite.
495.5	Quartz sand, 95 percent sand size by weight; sand fraction consists of 85 percent quartz and 15 percent glauconite with a trace of phosphate.
	Ellenton Formation[1]
581	Calcareous unit with 20 percent shell fragments and 10 percent quartz.
589	Calcareous unit with 15 percent shell fragments.
593.7	Clayey very fine sand, discontinuous clay laminae, very shelly including small oyster.
[At 595.2 ft, there appears to be burrowed contact of sand into underlying clay]	
599.1	Dark clay, thin discontinuous sand lenses, highly bioturbated, small clam shells.
609.8	Dark clay, thin discontinuous sand lenses, highly bioturbated.
613.1	Dark clay, thin discontinuous sand lenses, highly bioturbated.
621.2	Dark clay, thin discontinuous sand lenses, highly bioturbated.
[At 622.4 ft, there is a rapid downward change with no noticeable break from clay to quite glauconitic medium sand, mostly slightly indurated; this change occurs with a gradual downward decrease in the amount of clay over the upper 2 ft to considerably lower levels]	
628.7	Clayey glauconitic fine to medium sand with the more sandy intervals being somewhat indurated.
631.3	Clayey glauconitic fine to medium sand.
636.8	Clayey glauconitic fine to coarse sand.

[1] The Snapp Formation was cored above the Ellenton Formation from 570 to 504 ft in the Millhaven core; no foraminifers were observed and no samples were taken.

G. daubjergensis (Bronnimann) indicates that this interval belongs to the older, or early Paleocene, part of calcareous nannofossil Zone NP 4 (Berggren and others, 1995).

The probable diagenetic removal of much of the assemblage makes a meaningful paleoenvironmental interpretation of the sample difficult. However, the moderate abundance of the more dissolution susceptible planktonic specimens suggests that planktonic specimens were abundant and that this sample reflects a relatively offshore environment.

631.3 ft (late Paleocene with mixing of early Paleocene specimens).—The sample from 631.3 ft contains shallow-marine benthic foraminiferal species that are similar to those found in Paleocene strata to the north. Benthic taxa present include *Lenticulina*, *Hanzawaia*, *Cibicides compressus* Olsson, *Cibicides neelyi* Jennings, *Cibicides* sp., *Pulsiphonina prima* (Plummer), *Gyroidina*, *Alabamina*, and *Nodosaria latejugata carolinensis* Cushman. These taxa occur both in lower and lower upper Paleocene strata in North Carolina, Virginia, and Maryland (Nogan, 1964; Gibson and others, 1980, Thomas Gibson, unpub. data).

The calcareous nannofossil assemblage occurring in this sample suggests placement in Zone NP 5 of the lower upper Paleocene (Bybell, this volume, chap. F). However, this sample also contains moderately abundant lower Paleocene planktonic foraminifers including *Globoconusa daubjergensis* (Bronnimann) and *Morozovella pseudobulloides* (Plummer). The presence of a calcareous nannofossil assemblage that is indicative of an early late Paleocene age suggests that the early Paleocene planktonic foraminifers in this sample have been reworked from underlying lower Paleocene deposits. The reworking of early Paleocene planktonic foraminifers into lower upper Paleocene beds placed in Zone NP 5 is seen in other localities in the Atlantic Coastal Plain (Thomas Gibson, unpub. data). As discussed above, much of the lower Paleocene material appears to have been removed through erosion from the Millhaven test hole site.

Relatively deep water depositional environments are present during some intervals of Zones NP 3 and NP 4 of the early Paleocene. Foraminiferal assemblages from these intervals in the Atlantic Coastal Plain deposits thus contain abundant planktonic specimens, mostly composed of *G. daubjergensis* (Bronnimann) and *M. pseudobulloides* (Plummer) (Thomas Gibson and Laurel Bybell, unpub. data). The abundant planktonic specimens apparently are reworked from these lower Paleocene deposits and incorporated into the lower part of the strata that formed during the widespread marine transgression of Zone NP 5 in the early late Paleocene. The exact location in the Millhaven core of the disconformable contact between the two different age units within the Ellenton is uncertain, but apparently occurs somewhere between 636.8 and 631.3 ft.

For the Millhaven core, I consider a similar reworking of lower Paleocene planktonic foraminifers into basal transgressive beds of the lower upper Paleocene more likely than either of two other interpretations for the age disparity. These basal transgressive beds contain calcareous nannofossils indicative of Zone NP 5. One other interpretation for the age disparity is downhole contamination of early late Paleocene calcareous nannofossils into lower Paleocene strata. Another is an unrecognized disconformity that could have separated the foraminiferal and nannofossil samples taken from the core segment from 631.3–631.6 ft (whether the two samples were taken from opposite ends of this core segment or both from the same end is unknown and undeterminable).

628.7 ft (late Paleocene).—The sample from 628.7 ft contains a well-preserved and diverse benthic assemblage. Benthic taxa include *Hanzawaia*, *Cibicides compressus* Olsson, *Lenticulina*, *Alabamina*, *Pulsiphonina prima* (Plummer), *Eponides lotus* (Schwager), *Nodosaria latejugata carolinensis* Cushman, *Pseudonodosaria tenuistriata* (Franke), *Spiroplectammina wilcoxensis* Cushman and Ponton, *Loxostomum*, *Nodogenerina plummerae* (Cushman), *Epistominella minuta* (Olsson), *Bolivinopsis emmendorferi* (Jennings), *Pararotalia perclara* (Loeblich and Tappan), and *Pyramidina virginiana* (Cushman). This assemblage is characteristic of the lowermost part of the Aquia Formation in Virginia and Maryland (Nogan, 1964; Thomas Gibson, unpub. data). Some of these species also range into the middle part of the Aquia Formation. The lowermost beds of the Aquia Formation are placed in calcareous nannoplankton Zone NP 5 of the lower upper Paleocene; the middle beds extend from Zone NP 6 to NP 8 (Gibson and others, 1991). Planktonic specimens make up a small proportion of the assemblage. The foraminiferal assemblage suggests shallow-marine environments having water depths less than 200 ft, but possibly in the 100-ft or slightly deeper range. Normal marine productivity and oxygen levels were present.

621.2 ft (late Paleocene).—The sample from 621.2 ft contains a well-preserved and moderately diverse assemblage that differs considerably from the underlying assemblages. Benthic taxa include *Epistominella minuta* (Olsson), *Fursenkoina*, *Pararotalia perclara* (Loeblich and Tappan), *Pulsiphonina prima* (Plummer), and *Pyramidina virginiana* (Cushman). *Pararotalia perclara* (Loeblich and Tappan) is commonly found in Paleocene strata, but it is not found in beds younger than those placed in calcareous nannofossil Zone NP 8 in Virginia and Maryland (Thomas Gibson, unpub. data). The assemblage suggests shallow-marine environments having water depths around 100 ft or shallower. The above-noted species dominate the assemblage. Their abundance suggests high-productivity and (or) low-oxygen depositional environments for the interval containing this sample and the three overlying ones. This is in contrast to the relatively normally oxygenated environments that are characteristic of samples below 621.2 ft. The high-productivity and (or) low-oxygen assemblages occur in a dark clay interval, which contrasts with the underlying interval of clayey, glauconitic, fine to medium sand. The dark color of the clay also supports the idea that low-oxygen environments were present that would lead to increased preservation of organic matter in the sediments.

613.1 ft (late Paleocene).—The well-preserved assemblage from 613.1 ft contains a relatively low diversity benthic component with few planktonic specimens. The benthic assemblage is dominated by *Pararotalia perclara* (Loeblich and Tappan) and *Fursenkoina*, with lesser proportions of *Epistominella minuta* (Olsson), *Pulsiphonina prima* (Plummer), and *Pyramidina virginiana* (Cushman). This benthic assemblage is similar to that of the underlying sample. These species are either characteristic of, or found in, high-productivity or low-oxygen environments (Poag, 1989; Gibson and others, 1993; Thomas Gibson, unpub. data).

609.8 ft (late Paleocene).—The benthic assemblage from 609.8 ft is well preserved but shows relatively low species diversity. The composition is similar to the two underlying assemblages, with *Pararotalia perclara* (Loeblich and Tappan) and *Fursenkoina* being dominant.

599.1 ft (late Paleocene).—The well-preserved benthic assemblage from 599.1 ft has relatively low species diversity and is highly dominated by *Pararotalia perclara* (Loeblich and Tappan). Other abundant species include *Epistominella minuta* (Olsson), *Fursenkoina*, and *Pyramidina virginiana* (Cushman). The assemblage is similar to those of the underlying three samples and suggests shallow-marine environments of about 100-ft water depth or less with high-productivity and (or) low-oxygen conditions.

Burrowed contact.—At 595.2 ft, there appears to be a burrowed contact of overlying clayey very fine sand into the dark clay unit. The foraminiferal assemblages above and below this surface differ considerably.

593.7 ft (late Paleocene).—The sample from 593.7 ft contains a low-diversity benthic assemblage consisting of moderately well preserved to slightly recrystallized specimens, and it also contains a few planktonic specimens. The assemblage is highly dominated by *Anomalinoides umboniferus* (Schwager) and also contains *Cibicides alleni* (Plummer), *Gyroidinoides*, *Pyramidina virginiana* (Cushman), and *Buliminella elegantissima* (d'Orbigny). These species commonly occur in upper Paleocene deposits, but most of them also occur in lower Eocene and younger strata. The assemblage is characteristic of shallow-marine environments having water depths less than 100 ft. The assemblage differs from those in the underlying four samples by the presence of *A. umboniferus* and *C. alleni*, which are characteristic of more oxygenated waters. This change suggests that the burrowed surface at 595.2 ft separates two differing depositional settings.

589 ft (late Paleocene).—The small benthic assemblage from 589 ft consists of moderately well preserved to partially recrystallized specimens. The low-diversity assemblage is highly dominated by *Anomalinoides umboniferus* (Schwager) with lesser numbers of *Pyramidina virginiana* (Cushman). The assemblage is characteristic of shallow-marine environments of less than 100-ft water depth.

581 ft (late Paleocene).—The small benthic assemblage from 581 ft consists of moderately well preserved to partially recrystallized specimens. The low-diversity assemblage is dominated by *Anomalinoides umboniferus* (Schwager) with lesser numbers of *Pyramidina virginiana* (Cushman), compositionally similar to the two underlying samples. However, the proportion of *Pararotalia perclara* (Loeblich and Tappan) is considerably higher than found in the underlying samples. The increase in *P. perclara* (Loeblich and Tappan) in this sample possibly signifies that somewhat higher productivity and (or) lower oxygen levels were present.

SNAPP FORMATION

The Snapp Formation was cored above the Ellenton Formation from 570 to 504 ft in the Millhaven test hole. No foraminifers were observed and no samples were taken.

CONGAREE FORMATION

Three samples of the Congaree Formation from the Millhaven test hole were examined; they came from between depths of 495.5 and 473.5 ft. Benthic foraminiferal species characteristic of middle Eocene strata in the Southeastern United States, such as *Cibicides westi* Howe, *Siphonina claibornensis* Cushman, *Cancris involutus* Copeland, and *Guembelitria columbriana* Howe occur in these samples. Bybell (this volume, chap. F) placed these Congaree samples in calcareous nannofossil Zone NP 14 (earliest middle Eocene).

Foraminiferal assemblages in the lower and upper Congaree samples suggest shallow-marine environments with water depths of approximately 100 ft. However, a considerably deeper water pulse with water depths of around 300 ft is suggested by the assemblage in the middle sample at 481.5 ft.

The Congaree samples, which are placed in calcareous nannofossil Zone NP 14 by Bybell (this volume, chap. F), contain much greater amounts of sand-sized particles (mostly very fine to fine grained, with both quartz and glauconite being abundant) (table 1), than do the calcareous samples from the overlying Warley Hill Formation.

495.5 ft (middle Eocene).—The sample from 495.5 ft contains a moderately well preserved, moderately diverse benthic assemblage that contains a few adult planktonic specimens. The most common or diagnostic benthic taxa are *Cibicides westi* Howe, *Cibicides* sp., *Gyroidinoides*, *Siphonina claibornensis* Cushman, *Eponides lotus* (Schwager), and *Anomalinoides umboniferus* (Schwager). *Siphonina claibornensis* Cushman has its initial appearance in the Southeastern United States in strata placed in calcareous nannofossil Zone NP 13 of the late early Eocene. This species survives into the late Eocene (Thomas Gibson, unpub. data). The joint occurrence of this species and *C. westi* Howe, which is characteristic of the middle Eocene, suggests a middle Eocene age for the sample. The assemblage suggests fairly shallow marine environments having water depths of approximately 100 ft.

481.5 ft (middle Eocene).—The sample from 481.5 ft contains a moderately well preserved and moderately diverse benthic assemblage, and it also contains a moderate number of planktonic specimens. Benthic taxa include *Gyroidina*, *Siphonina claibornensis* Cushman, *Cibicides westi* Howe, *Cibicides alleni* (Plummer), *Cibicidoides* sp., *Cancris involutus* Copeland, *Eponides lotus* (Schwager), *Trifarina*, *Bulimina*, *Bolivina*, and *Guembelitria columbiana* Howe. *Pseudohastigerina micra* (Cole) and *Acarinina* spp. compose the planktonic component. The presence of *Cibicides westi* Howe, *Cancris involutus* Copeland (which occurs in middle Eocene beds in North Carolina, Jones, 1983), and *Guembelitria columbiana* Howe indicates a middle Eocene age. The composition of the benthic assemblage and the relative abundance and diversity of planktonic specimens, including the presence of common adult forms, suggest deposition in middle neritic environments with water depths of approximately 300 ft. This interpreted depth is significantly greater than that proposed for the underlying sample. This projected depth increase is accompanied by an increase in glauconite content to 45 percent of the sand fraction from 15 percent in the lower sample.

473.5 ft (middle Eocene).—Most specimens in the sample from 473.5 ft are recrystallized to a lesser or greater degree. The species diversity of the benthic assemblage is moderately low, and some planktonic specimens are present. Important benthic taxa include *Cibicides westi* Howe, *Eponides lotus* (Schwager), *Eponides carolinensis* Cushman, *Bulimina*, *Bolivina*, *Lenticulina*, and *Valvulineria involuta* Cushman and Dusenbury. The benthic assemblage, plus the occurrence of the planktonic species *Pseudohastigerina micra* (Cole), places this sample in the middle Eocene. The assemblage suggests deposition in water depths of approximately 100 ft or slightly deeper, which represents a considerable shallowing from the underlying sample. Glauconite remains an important constituent in the sample, but it is less abundant than in the underlying sample.

WARLEY HILL FORMATION

Four Warley Hill samples were examined between depths of 456 and 404 ft in the Millhaven core. Benthic foraminiferal species that are characteristic of middle Eocene strata in the Southeastern United States, such as *Cibicides westi* Howe and *Guembelitria columbiana* Howe, occur in these samples. Bybell (this volume, chap. F) placed the Warley Hill in Zone NP 15 (early middle Eocene).

Foraminiferal assemblages in most of these samples suggest shallow-marine environments with water depths of approximately 100 ft with even shallower depths for the uppermost sample.

The Warley Hill samples from 413 and 404 ft are calcareous quartz sands, but they contain much more carbonate matrix and carbonate sand grains, less glauconite and quartz, and somewhat coarser sand grains than do samples in the quartz sand of the Congaree Formation. Shell fragments are present in large amounts in the uppermost sample at 404 ft, which supports the interpretation of very shallow marine environments for this interval.

456 ft (middle Eocene).—The specimens in the sample from 456 ft range from moderately well preserved to slightly recrystallized. Benthic species diversity is moderate, and there are some planktonic specimens. Benthic species found include *Valvulineria involuta* Cushman and Dusenbury, *Eponides carolinensis* Cushman, *Eponides lotus* (Schwager), *Cibicides westi* Howe, *Gyroidinoides octocameratus* (Cushman and Hanna), *Hanzawaia*, and *Caucasina*. These benthic taxa place this sample in the middle Eocene. The depositional environment had water depths around 100 ft or slightly deeper.

426.5 ft (middle Eocene).—The foraminifers in the sample from 426.5 ft are moderately well preserved. The assemblage has a moderately low species diversity and contains a moderately low number of planktonic specimens. Important benthic taxa include *Gyroidinoides octocameratus* (Cushman and Hanna), *Cibicides westi* Howe, *Eponides lotus* (Schwager), *Guembelitria columbiana* Howe, and *Caucasina*. The benthic species suggest a middle Eocene age. The assemblage suggests deposition in water depths of approximately 100 ft or slightly deeper.

413 ft (middle Eocene).—The sample from 413 ft contains a moderately diverse benthic assemblage in which most specimens are slightly recrystallized. A few planktonic specimens are present. Important benthic taxa present in the sample include *Gyroidinoides octocameratus* (Cushman and Hanna), *Cancris involutus* Copeland, *Cibicides westi* Howe, *Valvulineria involuta* Cushman and Dusenbury, *Eponides lotus* (Schwager), and *Guembelitria columbiana* Howe. These benthic species indicate a middle Eocene age for the sample. The assemblage suggests a depositional environment with water depths of approximately 100 ft.

404 ft (middle Eocene).—Most foraminifers in the sample from 404 ft are slightly recrystallized. The species diversity is moderately low. The benthic assemblage contains *Cibicides westi* Howe, *Cibicides* sp., *Gyroidinoides octocamerata* (Cushman and Hanna), *Valvulineria involuta* Cushman and Dusenbury, *Eponides carolinensis* Cushman, *Eponides ouachitaensis* Howe and Wallace, and *Textularia*. There are only a few planktonic specimens. The presence of *C. westi* Howe and other benthic species indicates a middle

Eocene age. The assemblage suggests warm, shallow-marine waters, probably within the shallower part of a 0- to 100-ft depth range.

SANTEE LIMESTONE

Five samples were examined from the Santee Limestone, between the depths of 365 and 248 ft in the Millhaven core; all samples are placed by Bybell (this volume, chap. F) in calcareous nannofossil Zone NP 17 (upper middle Eocene). Most of these samples contain *Cibicides westi* Howe and *Siphonina claibornensis* Cushman; the co-occurrence of these benthic species is characteristic of middle Eocene strata in the Southeastern United States.

The lower three samples are from soft calcareous beds and contain a slightly recrystallized but diverse foraminiferal fauna that suggests water depths of 100 to 200 ft. Foraminifers in the upper two samples (limestone and calcareous sand) are highly recrystallized; the relatively few recognizable specimens suggest possibly slightly shallower water depths of 100 ft or less.

365 ft (late middle Eocene).—Most foraminifers in the sample from 365 ft are slightly recrystallized. A diverse benthic assemblage is present, including *Pseudononion*, *Cibicides westi* Howe, *Cibicides* sp., *Siphonina claibornensis* Cushman, *Gyroidinoides octocameratus* (Cushman and Hanna), *Bolivina*, *Lagena*, *Textularia*, *Pyramidina*, *Trifarina*, and *Uvigerina*. A moderate number of planktonic specimens are present, including *Pseudohastigerina micra* (Cole) and *Cheiloguembelina*. The foraminiferal assemblage suggests water depths of 100 to 200 ft. This assemblage is similar to those found in the two overlying samples of the Santee Limestone. These assemblages suggest slightly deeper water environments than those found in the underlying sample from the upper part of the Warley Hill Formation.

355 ft (late middle Eocene).—The foraminifers in the sample from 355 ft are slightly to moderately recrystallized. A diverse benthic assemblage similar to that of the underlying sample is present, along with a small to moderate proportion of planktonic specimens. *Cibicides westi* Howe, *Pseudononion*, *Siphonina claibornensis* Cushman, *Gyroidinoides octocameratus* (Cushman and Hanna), *Pyramidina*, and *Lagena*, are present among other benthic taxa. The assemblage suggests water depths of 100 to 200 ft.

346 ft (late middle Eocene).—The foraminifers in the sample from 346 ft range from moderately well preserved to slightly recrystallized. A diverse benthic assemblage includes *Pseudononion*, *Cibicides westi* Howe, *Gyroidinoides octocameratus* (Cushman and Hanna), *Siphonina claibornensis* Cushman, *Valvulineria*, *Nonionella*, *Anomalinoides*, *Hanzawaia*, *Bolivina*, *Pararotalia*, *Trifarina*, *Textularia*, *Spiroplectammina*, *Guembelitria columbiana* Howe, and *Lagena*. A small proportion of planktonic specimens is present. This assemblage, as well as the underlying two, suggests water depths between 100 to 200 ft, which are slightly deeper than any interpreted for age-equivalent strata in the limited number of samples from the Millers Pond core.

307 ft (late middle Eocene).—Only a few highly recrystallized foraminifers are present in the sample from 307 ft. Identifiable benthic taxa include *Cibicides westi*, *Cibicides* sp., *Cibicidoides* sp., *Elphidium*, and *Nonion*. The identifiable assemblage suggests shallow waters with depths of 0 to 100 ft.

248 ft (late middle Eocene).—A few highly recrystallized foraminifer specimens are present in the sample from 248 ft. *Cibicides* and *Quinqueloculina* are the most abundant genera. No planktonic specimens or any age-diagnostic benthic taxa were recognized. The preserved assemblage suggests warm-water environments with depths of probably less than 100 ft.

BARNWELL UNIT

The lower sample examined from the Barnwell unit at 219 ft in the Millhaven core did not contain foraminifers. The upper sample examined from the Barnwell unit is considered either latest Eocene or earliest Oligocene in age (Bybell, this volume, chap. F).

118 ft (latest Eocene or earliest Oligocene).—The foraminifers in the sample from 118 ft are moderately to highly recrystallized. *Cibicides* is the most abundant benthic taxon, and lesser numbers of *Siphonina*, *Gyroidinoides*, and *Eponides* are present. A small proportion of adult planktonic foraminifers is present. No age-diagnostic taxa were noted. The assemblage suggests shallow-marine environments, probably in the deeper portion of the 0- to 100-ft depth interval.

MILLERS POND CORE

The continuously cored Millers Pond test hole (GGS–3758, Burke 2) in Burke County, Ga. (fig. 1), penetrated Upper Cretaceous through upper Eocene deposits. The land surface elevation is 245 ft at the drill site. The site is located at lat 33°13'48" N., long 81°52'44" W. This test hole is in a more upbasin location than is the Millhaven test hole, and beds containing calcareous microfossils are much less numerous. Only three Cenozoic samples, between a depth of 148 and 82 ft, yielded foraminifers (table 2, fig. 3). Foraminifers in all three assemblages are moderately to highly recrystallized. The three samples are from strata placed in the Santee Limestone of middle Eocene age (Falls and Prowell, this volume, chap. A). The uppermost sample at 82–83 ft is in carbonate-rich quartzose sand of the upper Three Runs Aquifer of Clarke and others (1994). The underlying samples from 148 ft and 120 ft are in carbonate-rich

Table 2. Sedimentary characteristics of foraminiferal samples from the Millers Pond core.

Sample depth (ft)	Sedimentary characteristics
	Santee Limestone
82–83	Carbonate-rich quartzose sand; 59 percent sand size by weight; quartz composes 75 percent of the sand-sized material with carbonate as the remainder; quartz is very angular to angular; echinoid spines present; no glauconite present, but there are trace amounts of red jasper and obsidian.
120	Carbonate sand; 77 percent sand size by weight, and all is carbonate; echinoid spines present; no glauconite present.
148	Calcareous silty sand; 93 percent sand size by weight; sand fraction mostly carbonate with only 5 percent angular to subangular quartz; no glauconite present, but there are trace amounts of obsidian and chalcopyrite.

and quartz-poor sediments of the lower confining unit of this aquifer system. The general lithologic nature of each sample and the most important foraminiferal components of each sample are given below. More detailed sedimentologic information is in table 2.

SANTEE LIMESTONE

Most foraminifers from the Santee Limestone in the Millers Pond core are moderately to highly recrystallized. The identifiable taxa suggest shallow-marine environments with water depths of 100 ft or shallower for the calcareous sediments of the three samples from the Santee Limestone. There is considerable variability in the proportion of quartz grains in these sands.

148 ft (middle Eocene).—The sample from 148 ft is a calcareous, slightly silty sand that contains a small amount (5 percent) of quartz. Few foraminifers are present, and most of these are poorly preserved. The specimens mainly belong to several species of *Cibicides* (but *C. westi* Howe is not present) with a few poorly preserved miliolid specimens probably belonging to *Quinqueloculina*. No species known to be significant biostratigraphically were recognized in the assemblage.

Because of the poor state of preservation and the likely removal of some or many species of the original foraminiferal assemblage, little definitive interpretation of the paleoenvironments is possible. The species found in the sample are in keeping with a warm marine environment with water depths of less than 100 ft as found for the overlying two samples discussed below.

120 ft (middle Eocene).—The sample from 120 ft is a carbonate sand that does not contain quartz grains. Foraminiferal specimen preservation ranges from moderately to highly recrystallized. This assemblage contains more genera than noted in the overlying sample at 82–83 ft, but this higher diversity may reflect only the better preservation that is present in this sample. The dominant benthic forms belong to *Hanzawaia* and *Cibicides*, but the sample also contains *Nonion*, *Elphidium*, *Bolivina*, *Lenticulina*, *Globocassidulina*, *Gyroidina*, and *Cibicides westi* Howe. *Pseudohastigerina micra* (Cole) is the only planktonic species noted. *Cibicides westi* Howe is characteristic of middle Eocene strata in the Southeastern United States, being found in the Lisbon and Gosport Formations in Alabama (Bandy, 1949), other middle Eocene strata in Georgia (Herrick, 1961), and middle Eocene strata in North Carolina (Jones, 1983). The presence of this species suggests a middle Eocene age for this sample.

The generic composition of the benthic foraminiferal assemblage and the presence of only a few planktonic specimens suggests shallow-marine, probably well-oxygenated depositional environments having water depths less than 100 ft. The faunal similarity to Alabama middle Eocene faunas and the carbonate substrate suggest warm temperate to subtropical paleotemperatures. The abundance of *Cibicides* and *Hanzawaia* specimens and the presence of echinoid spines in the sample suggest a relatively firm substrate during deposition. The absence of glauconite in the sample may suggest moderately high sedimentation rates, as the apparently open marine conditions would not preclude glauconite formation, which was common in this time interval in other areas in the Southeastern United States.

82–83 ft (middle Eocene).—The sample from 82–83 ft is a carbonate-rich quartzose sand. The benthic assemblage is moderately to highly recrystallized, which makes it difficult to identify specimens to the species level. The benthic assemblage is dominated by taxa of *Discorbis*, *Hanzawaia*, *Elphidium*, *Nonion*, *Cibicides*, *Cancris*, and *Textularia*. The sample contains common specimens of *Cibicides westi* Howe, which is characteristic of middle Eocene strata, and *Cancris involutus* Copeland, which is found in middle Eocene beds in North Carolina (Jones, 1983). No planktonic specimens were noted.

The generic composition of the foraminiferal assemblage suggests a shallow-marine, probably well-oxygenated depositional environment having water depths less than 100 ft, similar to that proposed for the underlying sample. A significant quartzose sand component is present in this sample in contrast with its absence in the underlying two samples. Its presence suggests possible shallowing of the marine environment or a change in the sediment source, transportation system, or energy level in the depositional regime of this interval.

CONCLUSIONS

Foraminiferal assemblages indicative of late early and early late Paleocene and middle Eocene ages are present in the more downbasin Millhaven test hole. A late early Paleocene age assignment for the lowest beds of the Ellenton Formation is based on the co-occurrence of planktonic foraminiferal taxa and calcareous nannofossil taxa. Early late Paleocene and middle Eocene age assignments are based on the ranges of benthic foraminiferal taxa in the Southeastern United States. More detailed age assignments of the strata on the basis of the foraminifers are not possible. This is because the ranges of most benthic taxa in terms of the intercontinental zonations, which are largely based upon planktonic microfossils, are not yet known, and diagnostic planktonic foraminiferal species are not present in most beds. Detailed age assignments of most foraminifer-bearing beds were possible, however, on the basis of the calcareous nannofossils (Bybell, this volume, chap. F).

In the Millhaven core, one sample from the Ellenton Formation contains both early Paleocene planktonic foraminiferal specimens and calcareous nannofossils diagnostic of the lower part of the upper Paleocene. The planktonic foraminifers apparently were derived during erosional removal of lower Paleocene strata in this area and reworked into the basal part of the lower upper Paleocene transgressive sequence. Lower Paleocene strata that are now eroded from this area apparently represent middle to outer neritic environments because the reworked assemblages are dominated by planktonic specimens. Similar situations of abundant deeper water lower Paleocene specimens being reworked into shallow-water lower upper Paleocene beds are also present in Atlantic Coastal Plain deposits in North Carolina and Virginia.

In the more upbasin Millers Pond core, foraminiferal assemblages were obtained only from the Santee Limestone. The assemblages contain benthic species characteristic of a middle Eocene age.

Most foraminifer-bearing beds examined in the two cores were deposited in inner neritic (0- to 100-ft water depth) to inner-middle neritic (100- to 200-ft water depth) environments. One interval in the Congaree Formation, in the early middle Eocene, at 481.5 ft, contains assemblages suggestive of deeper water environments with depths around 300 ft. Some intervals in the upper middle Eocene strata of the Santee Limestone in the more southeasterly, more downbasin Millhaven core suggest slightly deeper water environments (inner-middle neritic) than presumably coeval inner neritic strata of the Santee Limestone, which is found in the more northwesterly, more upbasin Millers Pond core. This paleobathymetric interpretation suggests that the upbasin-downbasin relationship now present in these two cores is similar to that present during the middle Eocene.

Depositional environments generally had near-normal to normal oxygenation levels except for an interval in early late Paleocene time. This interval is represented by beds of the Ellenton Formation where high-nutrient and (or) low-oxygen environments were present as reflected by the benthic foraminiferal assemblage. The sediments in this interval, however, are bioturbated and contain some small clam shells, so oxidation levels were not so low as to preclude some bottom organic activity.

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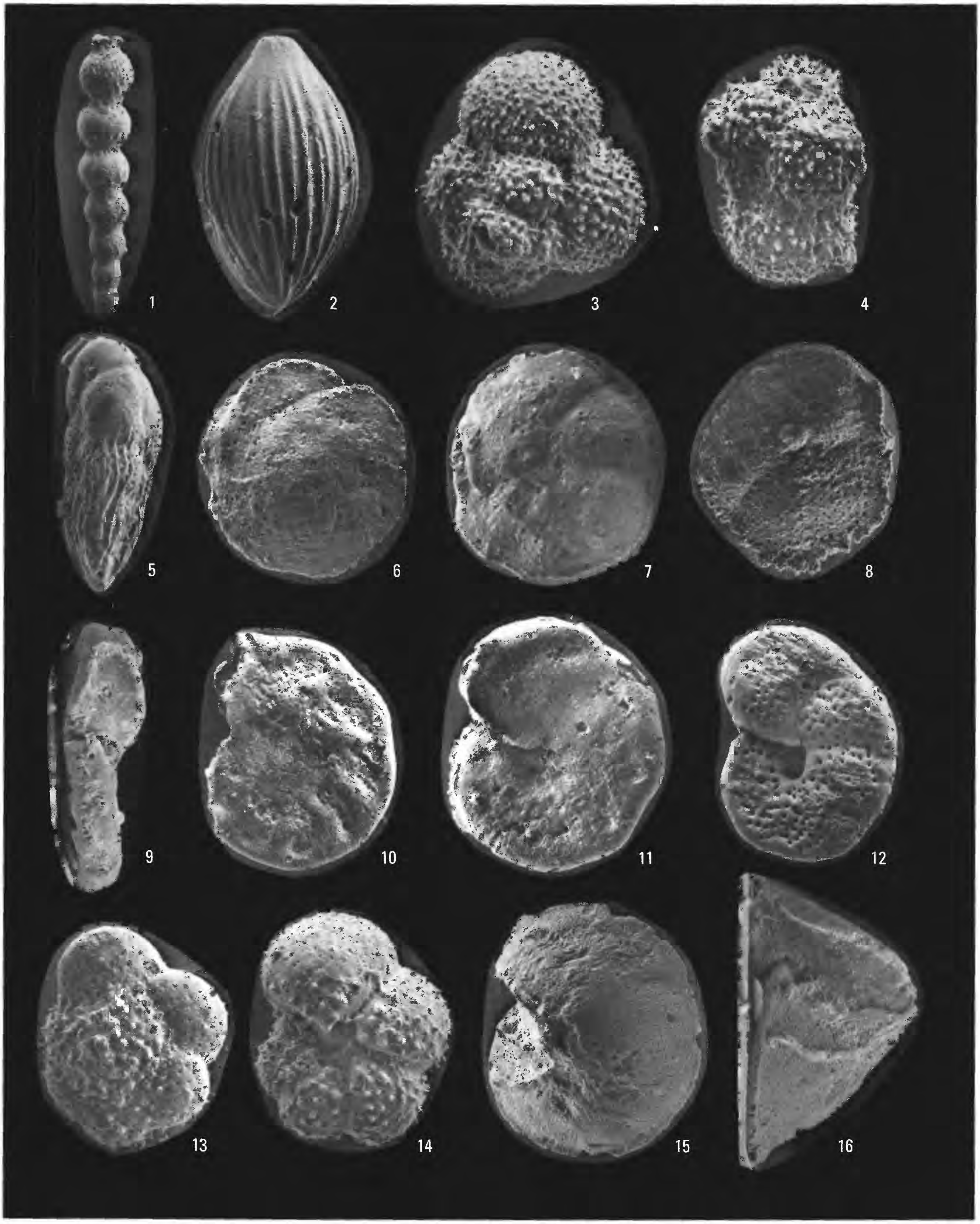
PLATE 1

PLATE 1

[Illustrated specimens are from the indicated depths in the Millhaven core, Screven County, Georgia. All specimens are benthic except for *Globoconusa daubjergensis*. USNM, U.S. National Museum of Natural History, Washington, D.C.]

Figure 1. *Nodogenerina plummerae* (Cushman), USNM 493350 (628.7 ft), Ellenton Formation, side view (× 85).
2. *Pseudonodosaria tenuistriata (*Franke), USNM 493351 (628.7 ft), Ellenton Formation, side view (× 42).
3. *Globoconusa daubjergensis* (Bronnimann), USNM 493352 (631.3 ft), Ellenton Formation, spiral view (× 292).
4. *Globoconusa daubjergensis* (Bronnimann), USNM 493353 (631.3 ft), Ellenton Formation, side view (× 256).
5. *Pyramidina virginiana* (Cushman), USNM 493354 (593.7 ft), Ellenton Formation, side view (× 228).
6. *Pulsiphonina prima* (Plummer), USNM 493355 (631.3 ft), Ellenton Formation, spiral view (× 148).
7. *Pulsiphonina prima* (Plummer), USNM 493356 (628.7 ft), Ellenton Formation, umbilical view (× 182).
8. *Siphonina claibornensis* Cushman, USNM 493357 (355 ft), Santee Limestone, umbilical view (× 104).
9. *Cibicides compressus* Olsson, USNM 493358 (631.3 ft), Ellenton Formation, spiral view (× 148).
10, 11. *Cibicides compressus* Olsson, USNM 493359 (631.3 ft), Ellenton Formation; 10, side view (× 149); 11, umbilical view (× 148).
12. *Cibicides neelyi* Jennings, USNM 493360 (631.3 ft), Ellenton Formation, umbilical view (× 91).
13. *Pararotalia perclara* (Loeblich and Tappan), USNM 493361 (628.7 ft), Ellenton Formation, spiral view (× 287).
14. *Pararotalia perclara* (Loeblich and Tappan), USNM 493362 (628.7 ft), Ellenton Formation, umbilical view (× 297).
15, 16. *Cibicides westi* Howe, USNM 493363 (355 ft), Santee Limestone; 15, umbilical view (× 170); 16, side view (× 174).



NODOGENERINA, PSEUDONODOSARIA, GLOBOCONUSA, PYRAMIDINA, PULSIPHONINA, SIPHONINA, CIBICIDES, AND *PARAROTALIA*

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