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

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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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

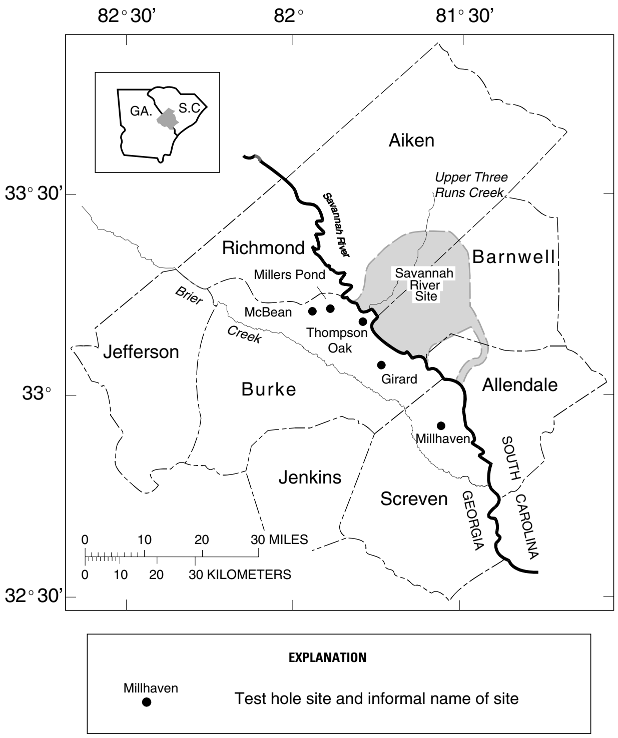


Figure 1. Index map showing the Savannah River Site and the location of stratigraphic test holes in the study area.

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.

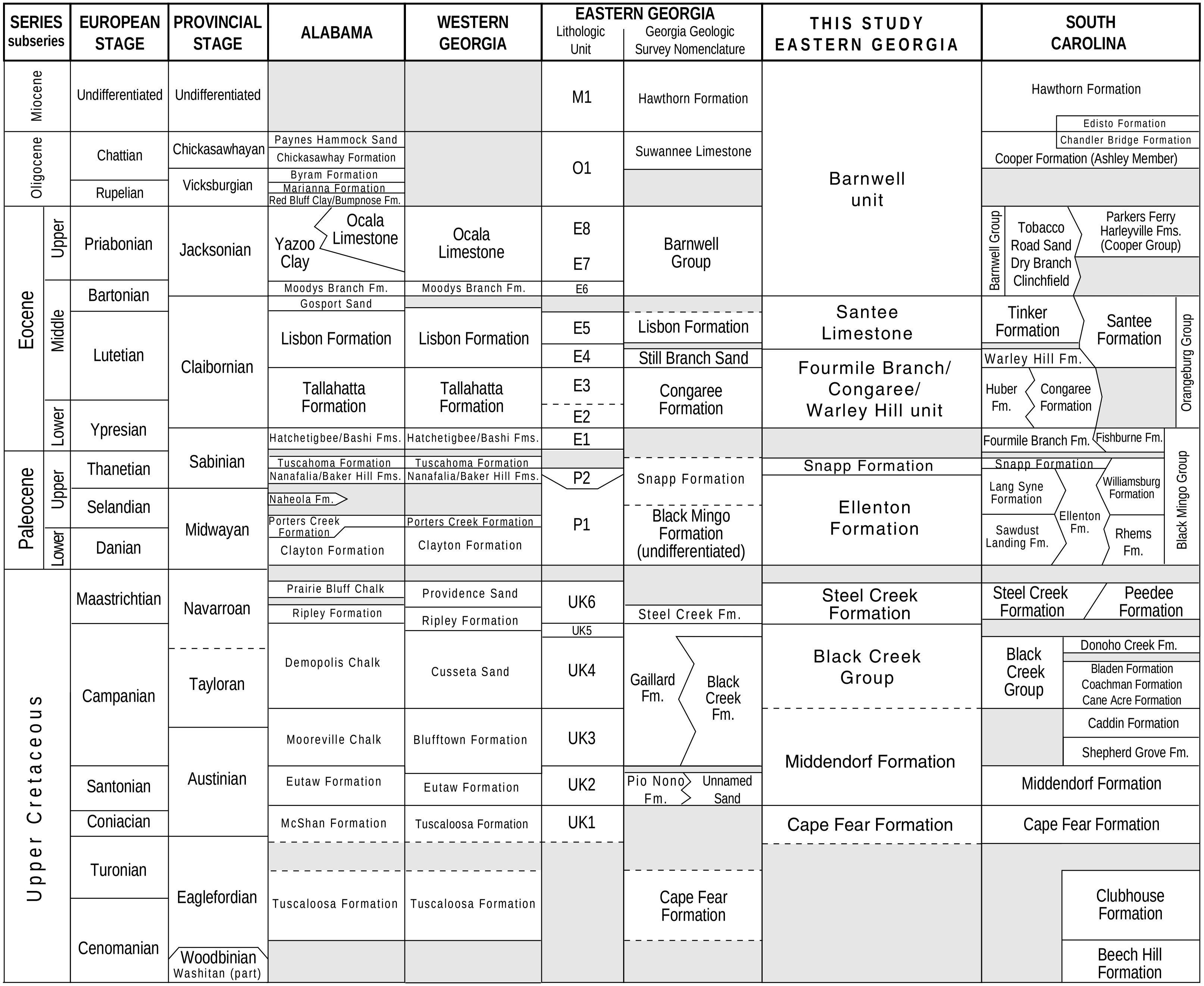
TEST HOLE AND CORE INFORMATION

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

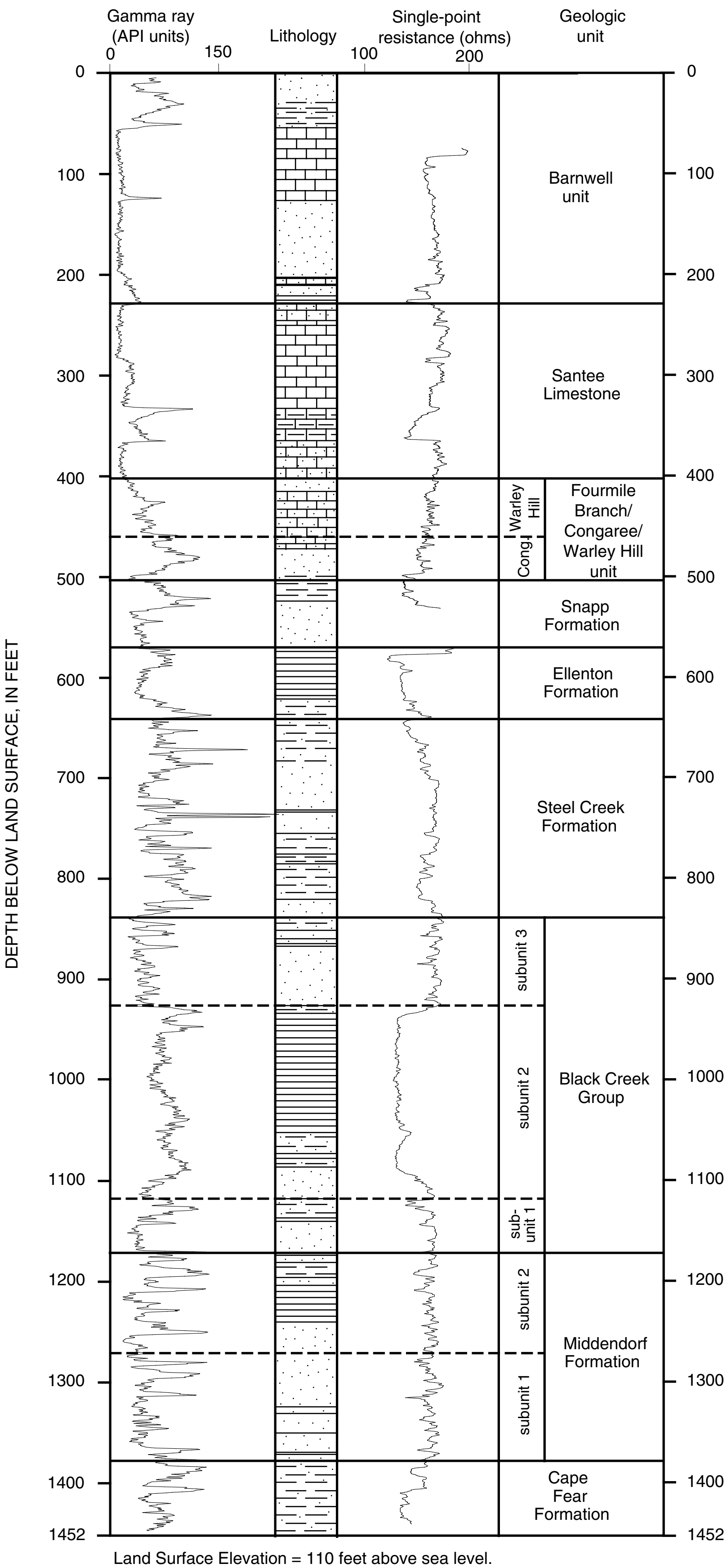
Previous reports on the geology of Burke and Screven Counties and adjacent areas of Georgia include those by Veatch and Stephenson (1911), Brantley (1916), Cooke and Shearer (1918), Cooke (1943), LaMoreaux (1946a,b), LeGrand and Furcon (1956), Herrick (1960, 1961, 1964, 1972), Herrick and Vorhis (1963), 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).



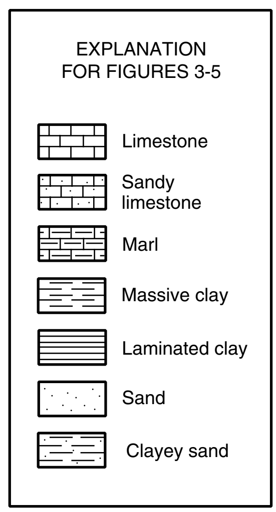


Figure 3. Gamma-ray, single-point resistance, and lithologic logs and geologic units of the Millhaven test hole in Screven County, Ga. Abbreviation used: API, American Petroleum Institute.

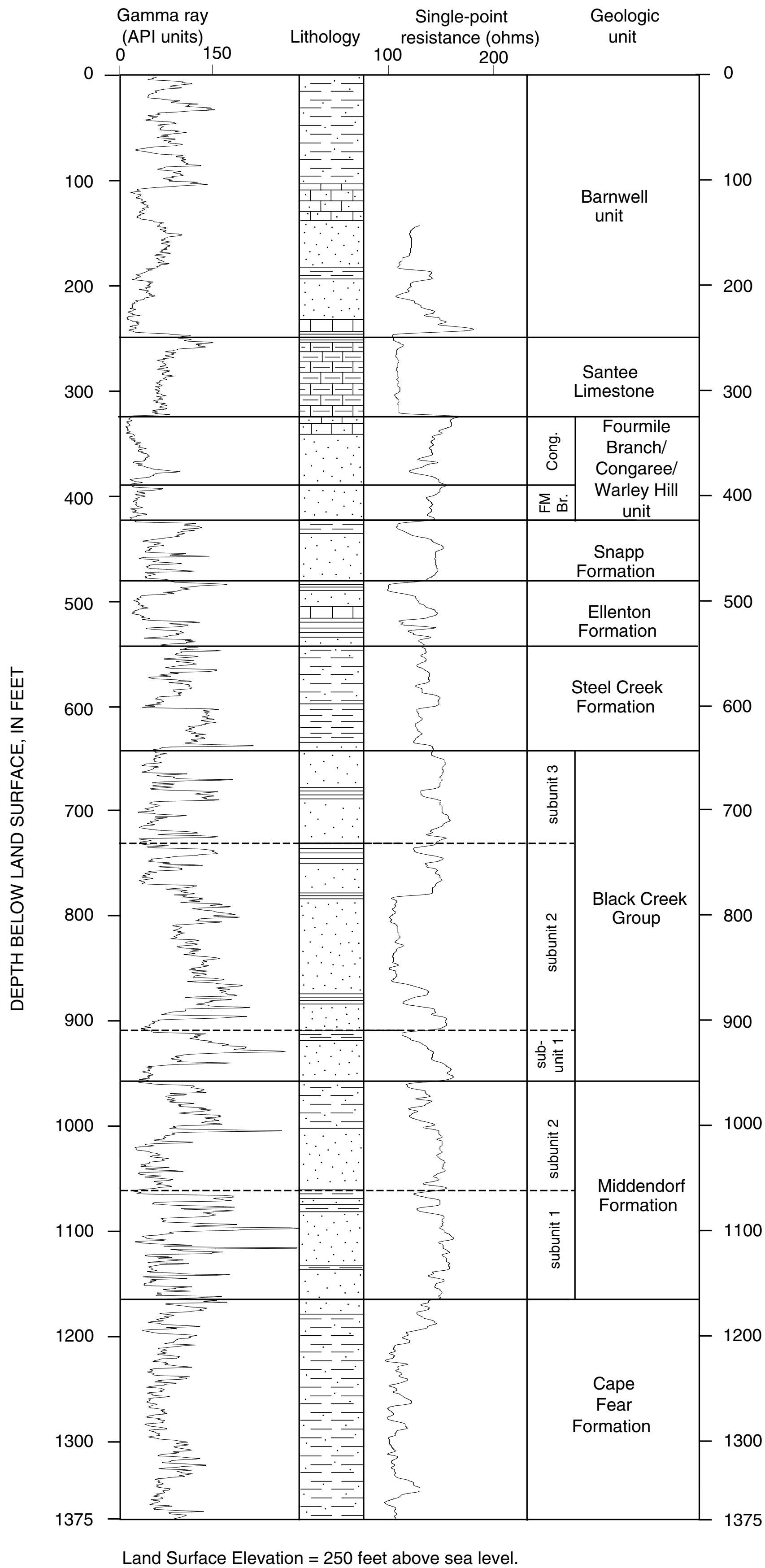


Figure 4. Gamma-ray, single-point resistance, and lithologic logs and geologic units of the Girard test hole in Burke County, Ga. Abbreviation used: API, American Petroleum Institute. Lithologic patterns are explained in figure 3.

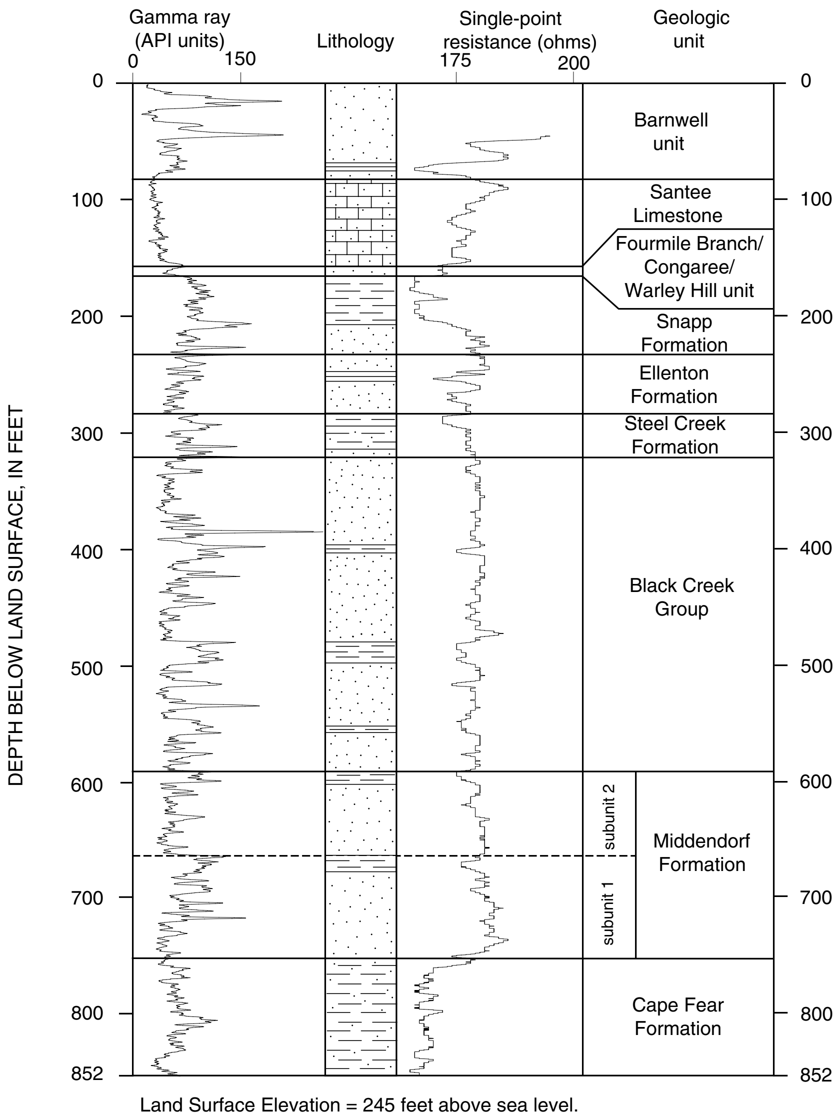


Figure 5. Gamma-ray, single-point resistance, and lithologic logs and geologic units of the Millers Pond test well 1 and test hole in Burke County, Ga. Abbreviation used: API, American Petroleum Institute. Lithologic patterns are explained in figure 3.

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

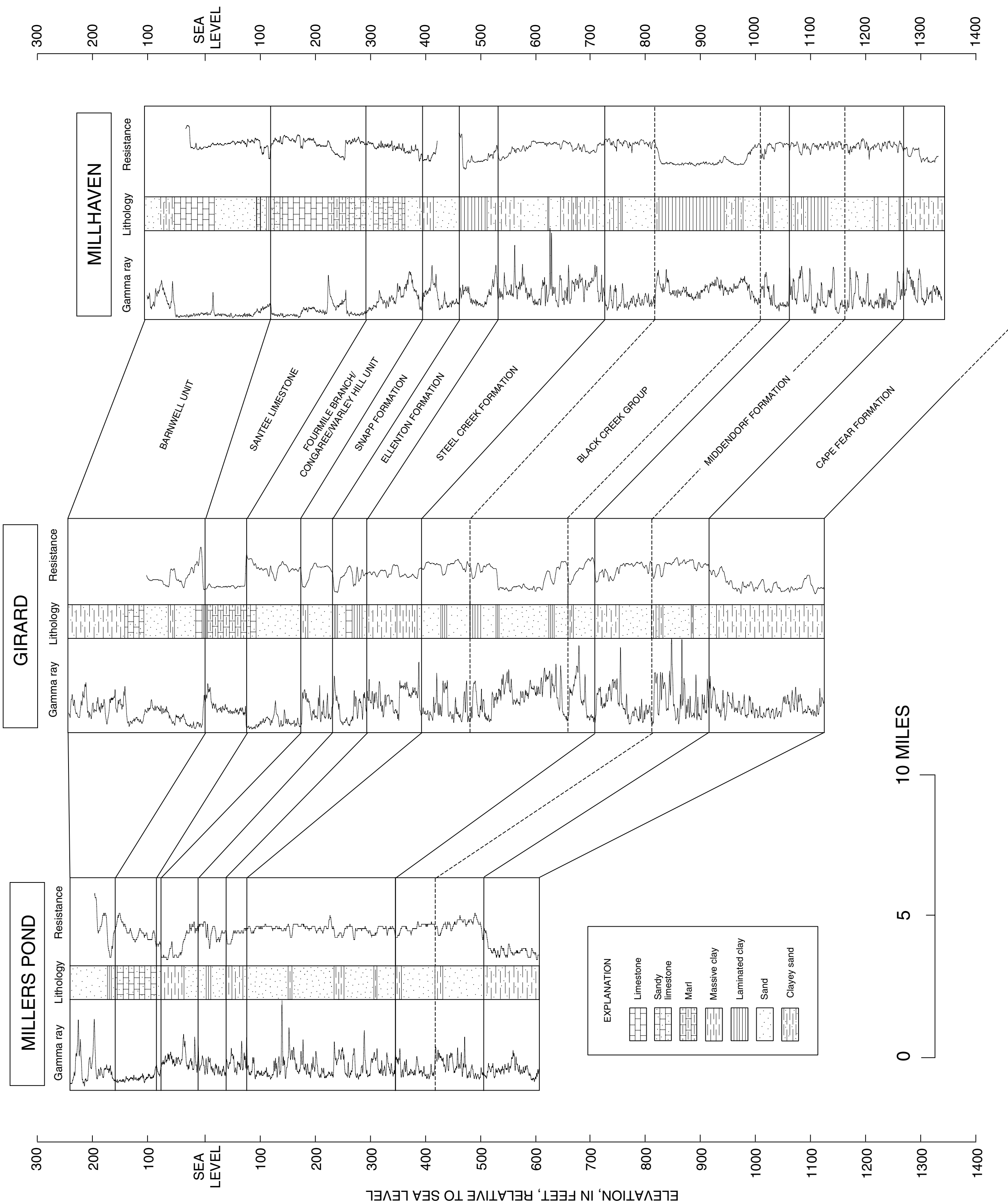


Figure 6. Gamma-ray, single-point resistance, and lithologic logs (from figs. 3–5) showing dip-oriented correlation of geologic units from the Millers Pond test hole to the Millhaven test hole. Datum is sea level.

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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