THE LITHOSTRATIGRAPHIC FRAMEWORK OF THE UPPERMOST CRETACEOUS AND LOWER TERTIARY OF EASTERN BURKE COUNTY, GEORGIA

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ABSTRACT

One new formation, two new members, and a redefinition of an established lithostratigraphic unit are formally introduced here. The Oconee Group is formally recognized in the Savannah River area and four South Carolina Formations not previously used in Georgia by the Georgia Geologic Survey are recognized in eastern Burke County. The Still Branch Sand is a new formation and the two new members are the Bennock Millpond Sand Member of the Still Branch Sand and the Blue Bluff Member of the Lisbon Formation. The four South Carolina formations recognized in eastern Burke County include the Steel Creek Formation and Snapp Formation of the Oconee Group, the Black Mingo Formation (undifferentiated), and the Congaree Formation. The Congaree Formation and Still Branch Sand are considered to be lithostratigraphic components of the Claiborne Group. The Congaree Formation is included in the Claiborne Group because it extends westward to the Chattahoochee River area of Georgia and Alabama, and perhaps farther west into Alabama. In this area, the Congaree has been called the Tallahatta Formation for many years and the Alabama and western Georgia "Tallahatta" is an essential formation of the Claiborne Group. The age and correlation of all of the lithostratigraphic units are discussed. In addition, the Pen Branch fault is recognized in the vicinity of Hancock Landing in eastern Burke County.

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INTRODUCTION

The Georgia Geologic Survey (GGS) Tritium Project was initiated to investigate the nature and distribution of tritium in aquifers in eastern Burke County, Georgia (Summerour, et al, 1994). This investigation began following discovery of measurable tritium in a public water supply well (DeLaigle Mobile Home Park, Figure 1) in January and July, 1991. Core drilling for the project began at the TR92-1 site (Figure 2) in December, 1991. In March, 1992, the U. S. Department of Energy (DOE) provided the Environmental Protection Division (EPD) of the Georgia Department of Natural Resources with $800,000 to conduct the project.

In July, 1991, DOE entered into an agreement with the United States Geological Survey (USGS) for an investigation of the conditions under which ground water from the Savannah River Site (SRS) in South Carolina could migrate beneath the Savannah River into Georgia aquifers. This study, originally referred to as the Underflow Project, is now known as the Trans-River Flow Project (Clarke, et al, 1994). Both the Tritium and the Trans-River Flow projects were initiated due to environmental concerns arising from radioactive releases from the Savannah River Site (SRS) nuclear weapons and research facility, operated by DOE, in South Carolina.

Purpose and Scope

The nature of local ground-water conditions is important to both the GGS Tritium and USGS Trans-River Flow Projects. In order to properly evaluate these conditions, an understanding of the geology and stratigraphy is needed. The objective of this report is to lay a lithostratigraphic foundation, based on the North American Stratigraphic Code (1986), upon which further geologic studies and stratigraphic refinements may be made. Lithologic descriptions of core samples and outcrops in areas to the east (South Carolina) and to the west (central and west Georgia) were included to provide information concerning the lateral extent of described units and correlation with Coastal Plain sedimentary units outside the Burke County study area.

Location of Study Area

Burke County is located along the Georgia-South Carolina border (Figure 1). The northern boundary of the county (McBean Creek) is approximately 15 miles southeast of Augusta, Georgia and the southeastern boundary of the county is approximately 70 miles northwest of Savannah, Georgia. The Savannah River Site (SRS) is located directly across the Savannah River from Burke County.

The Tritium Project study area is located in the eastern third of Burke County from the Savannah River on the east to Brier Creek on the west and from the Richmond-Burke County line (McBean Creek) on the north to the Burke-Screven County line on the south (Figure 1). The study area is 12 to 19 miles south of the Fall Line, which separates the Coastal Plain and Piedmont physiographic provinces.

Physiographic Setting

The Tritium Project study area is within the Louisville Plateau of Cooke (1925), characterized by broad, very gently rolling uplands that contain deeply incised streams. The Louisville Plateau is moderately dissected, with 100 to 150 feet of topographic relief. McBean Creek defines the northern boundary of the Louisville Plateau as well as forming the Richmond/Burke County line in the study area (Figure 1). The Fall Line hills district lies directly across McBean Creek to the north. The Screven/Burke county line approximates the southern boundary of the Louisville Plateau in the study area, to the south of which is the Vidalia Upland district (Clark and Zisa, 1976).

Previous Work

Prior to the present investigations, detailed subsurface geology (both litho-stratigraphy and hydrogeology) of eastern Burke County was poorly understood. Exploratory drilling results in northern Burke County were described by LeGrand and Furcron (1956).

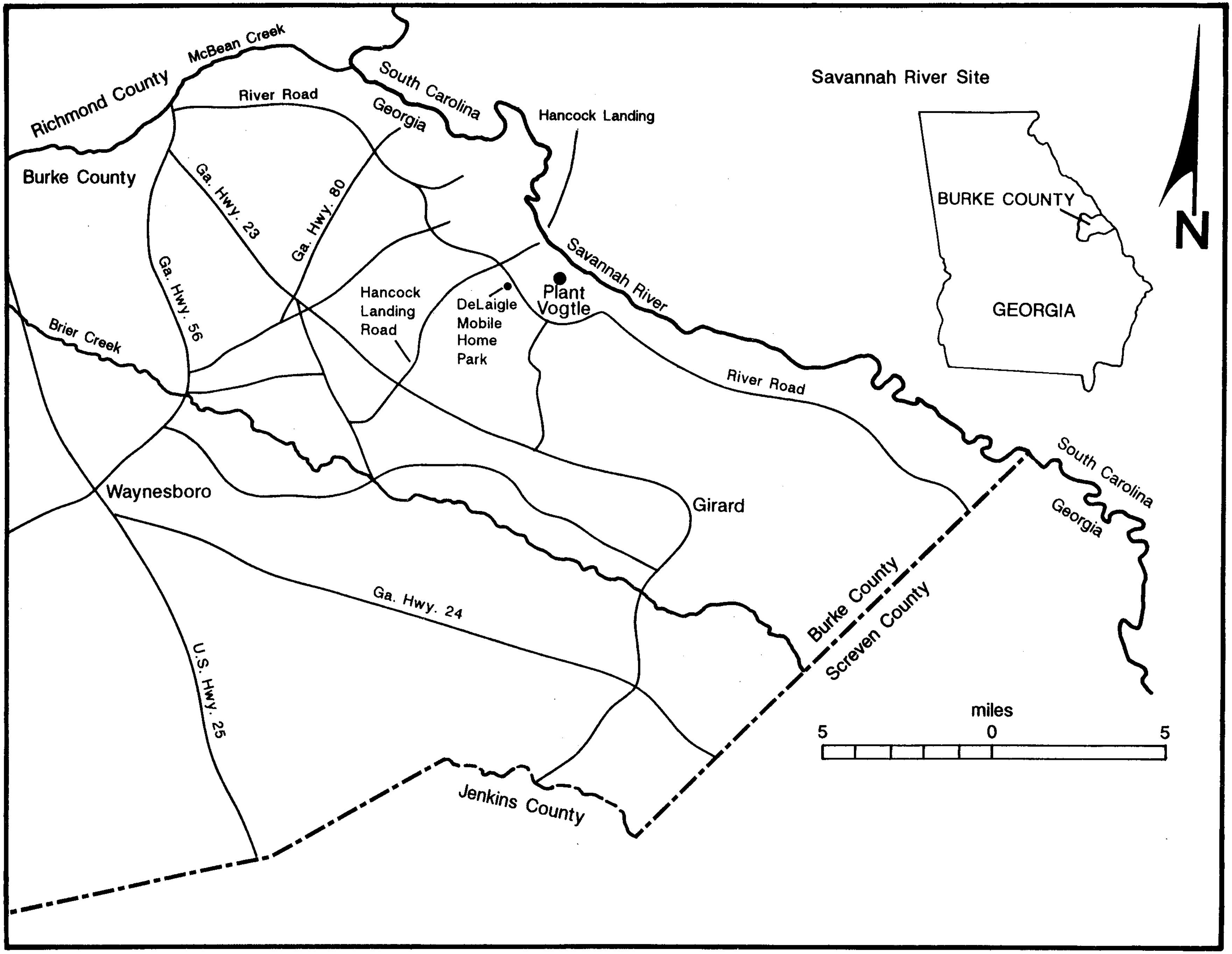

Figure 1. Index map of eastern Burke County, Georgia. Modified from Summerour and others (1994).

Subsurface studies of Burke County and adjacent areas were conducted by Herrick (1961) and Herrick and Vorhis (1963). Reconnaissance mapping was conducted by John Sandy for a study of mineral resources in the Central Savannah River area (Hurst, et al, 1966). Huddlestun and Hetrick (1979, 1986) provided a definition of the Barnwell Group in Burke County, as well as areas to the west and southwest. Huddlestun (1988) defined the Altamaha Formation in Burke County. Structural studies in Burke County were conducted by Faye and Prowell (1982) and Bechtel Corporation (1982). Aquifer studies included Upper Three Runs (Vincent, 1982); Gordon (Brooks, et al, 1985; Gorday, 1985); and Dublin and Midville (Clarke, et al, 1985). Prowell and others (1985) produced a cross-section of the upper Coastal Plain in eastern Georgia and western South Carolina.

Outside the study area, extensive subsurface studies were conducted at SRS and the western South Carolina Coastal Plain to the east (Siple, 1967; Nystrom and Willoughby, 1982) and the Georgia Coastal Plain to the west and northwest (Huddlestun, 1988; Huddlestun and Hetrick, 1986, 1991). Fallaw and Price (1995) named a number of new formations at SRS, some of which are adopted in this report, and presented a very thorough listing of previous work in the area.

Methods

During this study, approximately 9244 feet of core were examined and described. The core samples studied (Figure 2, Table 1) were collected from the six GGS Tritium Project sites (TR92-1 through TR92-6), two USGS sites (Millers Pond and Girard), and one core drilled by Georgia Power Company at Plant Vogtle (B-246). Eight cores were drilled in 1982 by Bechtel Corporation (VG-1 through VG-8) in southeastern Burke County along River Road, as well as several across the Savannah River in South Carolina, two of which were used in this study (VSC-3 and VSC-4). Other cores from SRS in South Carolina were examined in the interest of correlation and comparison. Within the text of this report, the field name of each well, e.g., TR92-1 (Tritium Project), USGS Millers Pond (Trans-River Flow Project), VG-1 (Bechtel Corp., for Georgia Power), etc. is used. Core samples from other Georgia Coastal Plain sites are included in Table 2. Lithologic descriptions from these cores are included for the purpose of describing the lateral extent and correlation with other units. Appendix 1 gives a physical description of the drill site locations as well as other designations for these core samples, including GGS numbers. The cores used in this report are stored in the following locations: GGS cores (McBean, Tritium Project) and USGS Millers Pond core are stored at the GGS warehouse in Atlanta, Ga.; the Bechtel cores (VG-1 through VG-8 and VSC-3 and VSC-4) are stored at Georgia Power Plant Vogtle, east of Waynesboro, the USGS Albany core is stored at the USGS warehouse in Reston, Virginia, and the USGS Girard core is stored at the South Carolina Geological Survey warehouse in Columbia, South Carolina. Core B-246 was inadvertently destroyed while in storage on Plant Vogtle property in the late 1970's. Cores P-18, P 21TA, and P 22TA (Table 1) are in storage in a warehouse at SRS.

Initially, the core samples were recovered in order to determine well screen intervals for the Tritium Project and Trans-River Flow Project monitoring wells. Subsequently, the cores were analyzed to evaluate the subsurface lithostratigraphic and hydrostratigraphic framework of the local aquifers (Figure 3).

In addition to lithostratigraphic analysis, micropaleontological identifications were conducted by the senior author, Lucy Edwards and Norm Frederiksen (both of the USGS) for chronostratigraphic and correlation purposes.

Acknowledgements

We wish to extend our appreciation to property owners of the drill sites in Burke and Screven Counties for their cooperation and assistance. We also gratefully acknowledge Lucy Edwards and Norm Fredericksen of the USGS for their time and efforts. Outside reviews were conducted by John Clarke (USGS), Tom Temples (DOE), and Lucy Edwards (USGS).

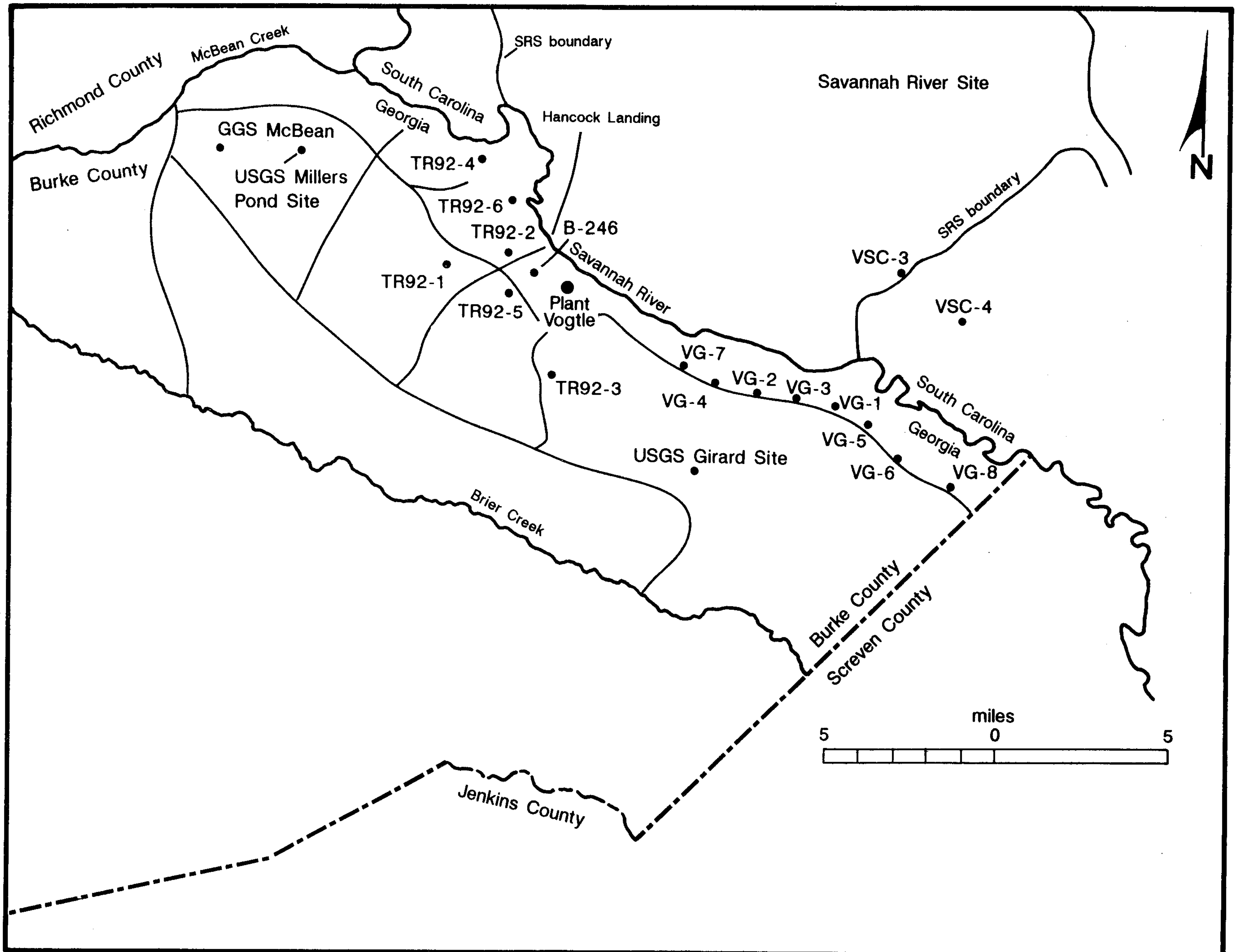

Figure 2. Index map of core sites within the Trans-River Flow Project area (used in this report). Additional information is within the text, Table 1, and Appendix 1. Modified from Summerour and others (1994).

Table 1
Core data from study area.

Core Site	USGS grid number	GGS core number	North latitude (est.)	West longitude (est.)	Surface Elevation-feet above Mean Sea Level
TR92-1	31Z038	3764	33° 09' 37"	81° 49' 19"	235
TR92-2	31Z047	3762	33° 09' 27"	81° 47' 23"	285
TR92-3	31Y017	3781	33° 06' 35"	81° 46' 54"	195
TR92-4	31Z050	3782	33° 11' 30"	81° 48' 34"	192
TR92-5	31Z089	3792	33° 08' 07"	81° 47' 03"	235
TR92-6	31Z108	3794	33° 10' 42"	81° 47' 10"	240
McBean	30Z018	3757	33° 13' 38"	81° 55' 50"	297
Millers Pond	30Z016	3758	33° 13' 48"	81° 52' 44"	245
Girard	32Y020	n/a	33° 03' 54"	81° 43' 13"	250
VG-1	32Y027	n/a	33° 04' 45"	81° 38' 39"	155
VG-2	32Y017	n/a	33° 05' 08"	81° 40' 31"	253
VG-3	32Y016	n/a	33° 04' 54"	81° 39' 32"	165
VG-4	32Y018	n/a	33° 04' 28"	81° 41' 38"	150
VG-5	33Y008	n/a	33° 04' 06"	81° 37' 27"	94
VG-6	33Y007	n/a	33° 03' 11"	81° 36' 47"	217
VG-7	32Y028	n/a	33° 05' 54"	81° 42' 30"	250
VG-8	33Y011	n/a	33° 02' 06"	81° 35' 00"	102
VSC-3	n/a	n/a	33° 07' 28"	81° 35' 42"	177
VSC-4	n/a	n/a	33° 06' 29"	81° 34' 05"	165
B-246	n/a	n/a	33° 08' 53"	81° 46' 22"	220
P 21TA	n/a	n/a	33° 08' 48"	81° 36' 27"	207
P 22TA	n/a	n/a	33° 11' 28"	81° 30' 48"	215
P-18	n/a	n/a	33° 15' 11"	81° 40' 21"	354

"n/a"-not available or not applicable

This project was supported, in part, through Cooperative Agreements with the United States Department of the Interior (U. S. Geological Survey) (Cooperative Agreement Number 1434-92-A-0959) and the U. S. Department of Energy (Cooperative Agreement Number DE-FG-09-92SR12868).

GEOLOGY AND HYDROLOGY

Geologic Setting

Subsurface stratigraphy of the Tritium Project study area consists of a southeast dipping package of Upper Cretaceous, Paleogene, and Neogene siliciclastic and carbonate rocks (Figures 3, 4, and 5 and Plate 1). Regional dip

Table 2
Core data from outside study area.

Core Site	USGS grid number	GGS core number	North latitude (est.)	West Longitude (est.)	Surface Elevation -feet above Mean Sea Level
GGS Pulaski 3	n/a	3111	32^0 15' 51"	83^0 28' 47"	300
USGS Albany	n/a	3187	31^0 08' 36"	84^0 06' 50"	195
GGS Sumter 9A	n/a	3366	32^0 04' 03"	83^0 59' 23"	270
GGS Pulaski 5	n/a	3511	32^0 22' 50"	83^0 29' 17"	355
GGS Laurens 1	n/a	3523	32^0 30' 59"	83^0 02' 43"	285
GGS Colquitt 11	n/a	3545	31^0 17' 53"	83^0 53' 55"	350
GGS Houston 9	n/a	3629	32^0 39' 26"	83^0 37' 42"	310

"n/a"-not available or not applicable

on the top of the Claiborne Group (typical for the area) is approximately ten feet per mile to the southeast.

The fluvial, coastal marine, and shallow inner neritic marine deposits which compose the subsurface of the study area lie within a transitional "zone" between the Atlantic and Gulf Coastal Plain provinces. Within this zone, abrupt lateral variations in lithofacies characteristics are common. The Cape Fear Formation, Steel Creek Formation, undifferentiated Black Mingo Formation, and Snapp Formation, McBean Member of the Lisbon Formation and the Irwinton and Griffins Landing Members of the Dry Branch Formation and Tobacco Road Sand of the Barnwell Group are southern Atlantic Coastal Plain stratigraphic units (Figure 4 and Plate 1). The Still Branch Formation and Bennock Millpond Sand Member, undifferentiated Lisbon Formation, Blue Bluff Member of the Lisbon Formation, and Twiggs Clay lithofacies of the Barnwell Group are eastern Gulf Coastal Plain stratigraphic units. The Pio Nono Formation, Gaillard Formation, and Congaree Formation occur both in the Gulf Coastal Plain and the southern Atlantic Coastal Plain (Figure 4 and Plate 1).

Hydrogeologic Setting

The Upper Coastal Plain sediments of the study area are included in the Southeastern Coastal Plain hydrogeologic province (Aadland, et al, 1992). The aquifers of interest in the Trans-River Flow study area are (in descending order): 1.) Upper Three Runs (unconfined) (Aadland, et al, 1992; Summerour, et al, 1994); 2.) Gordon (confined) (Brooks, et al, 1985); 3.) Millers Pond (confined) (Falls and Baum, 1995); 4.) Dublin (confined) (Clarke, et al, 1985); and 5.) Midville (confined) (Clarke, et al, 1985). The hydrostratigraphic units discussed in this report include the Upper Three Runs, Gordon, and Millers Pond aquifers.

Downdip, the siliciclastic and carbonate sediments of the Upper Three Runs aquifer become part of the predominantly carbonate Upper Floridan aquifer system (Clarke, et al, 1994) and the siliciclastic sediments of the Gordon aquifer become part of the predominantly carbonate Lower Floridan aquifer (Clarke, et al, 1994). The siliciclastic sediments of the Millers Pond aquifer grade downdip into the clays of the Meyers Branch confining system (Falls, personal communication, 1995) (Figure 3).

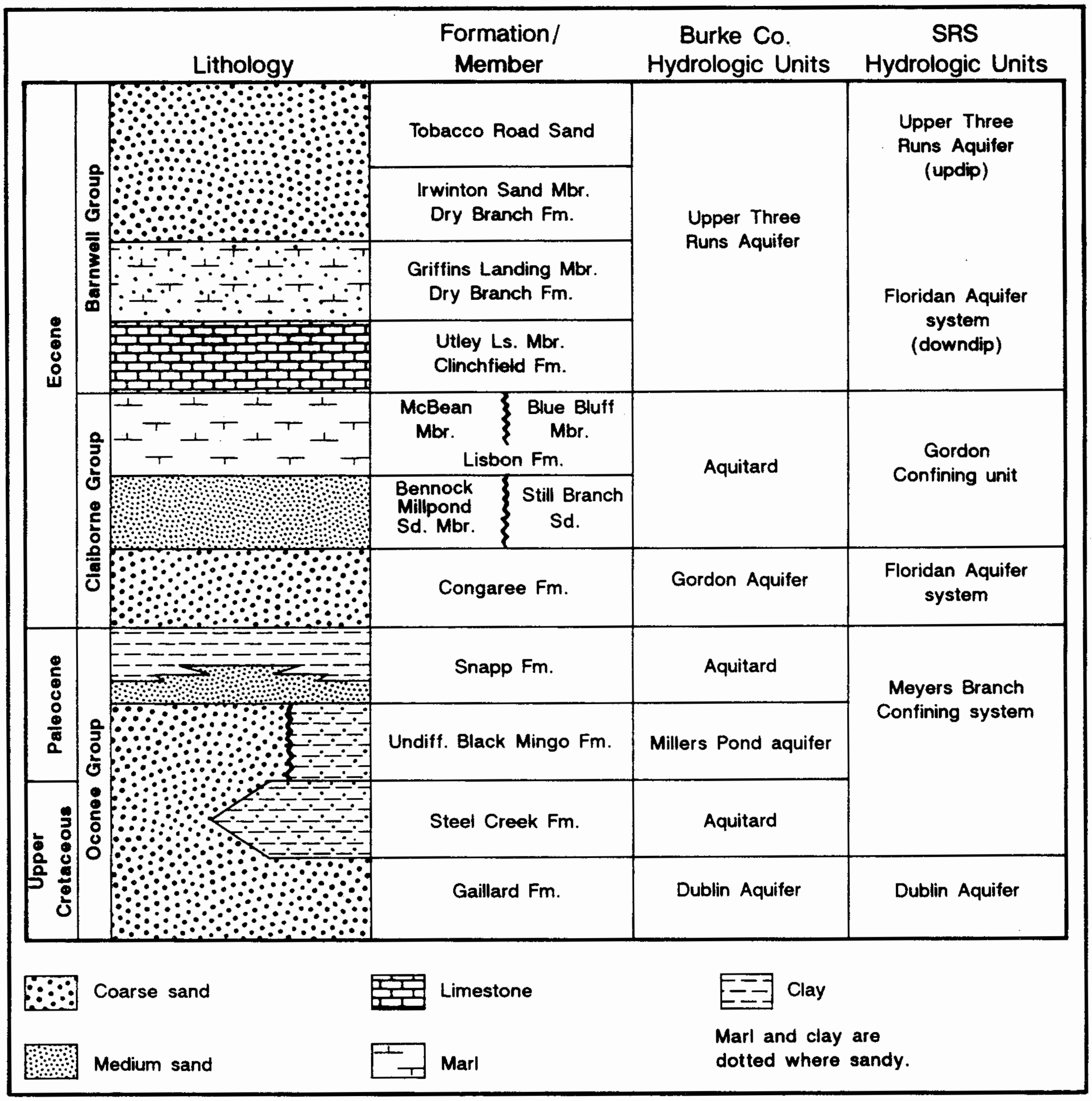

Figure 3. Tritium Project stratigraphic and hydrostratigraphic units for Burke County and SRS area. SRS terminology from Aadland and others (1992), Millers Pond aquifer from Falls and Baum (1995). Modified from Summerour and others (1994).

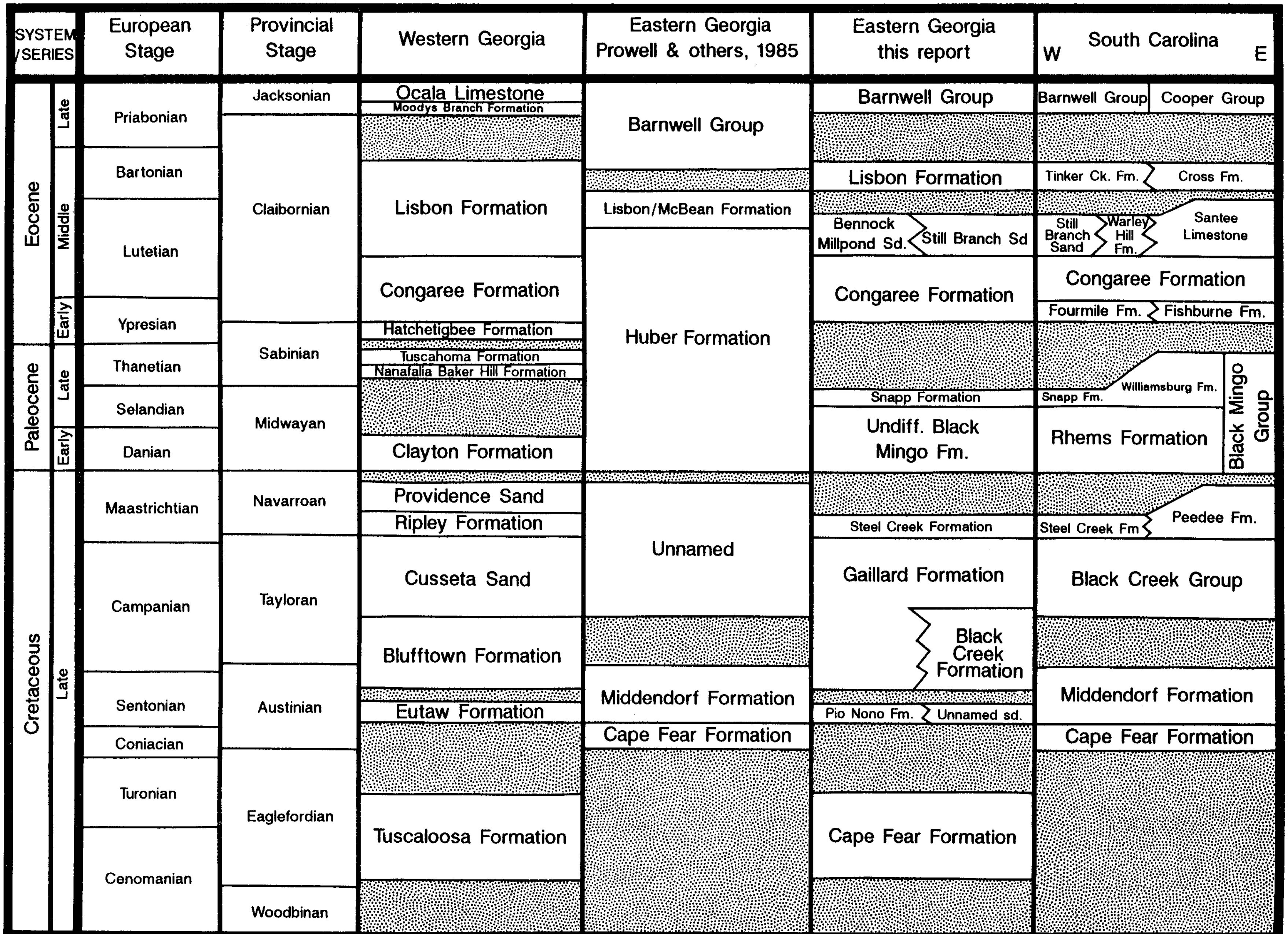

Figure 4. Correlation chart for the study area and adjacent regions. Shaded areas inidicate missing stratigraphic intervals. Modified from Prowell and others (1985) and Summerour and others (1994). A more detailed chart is shown in Plate 1.

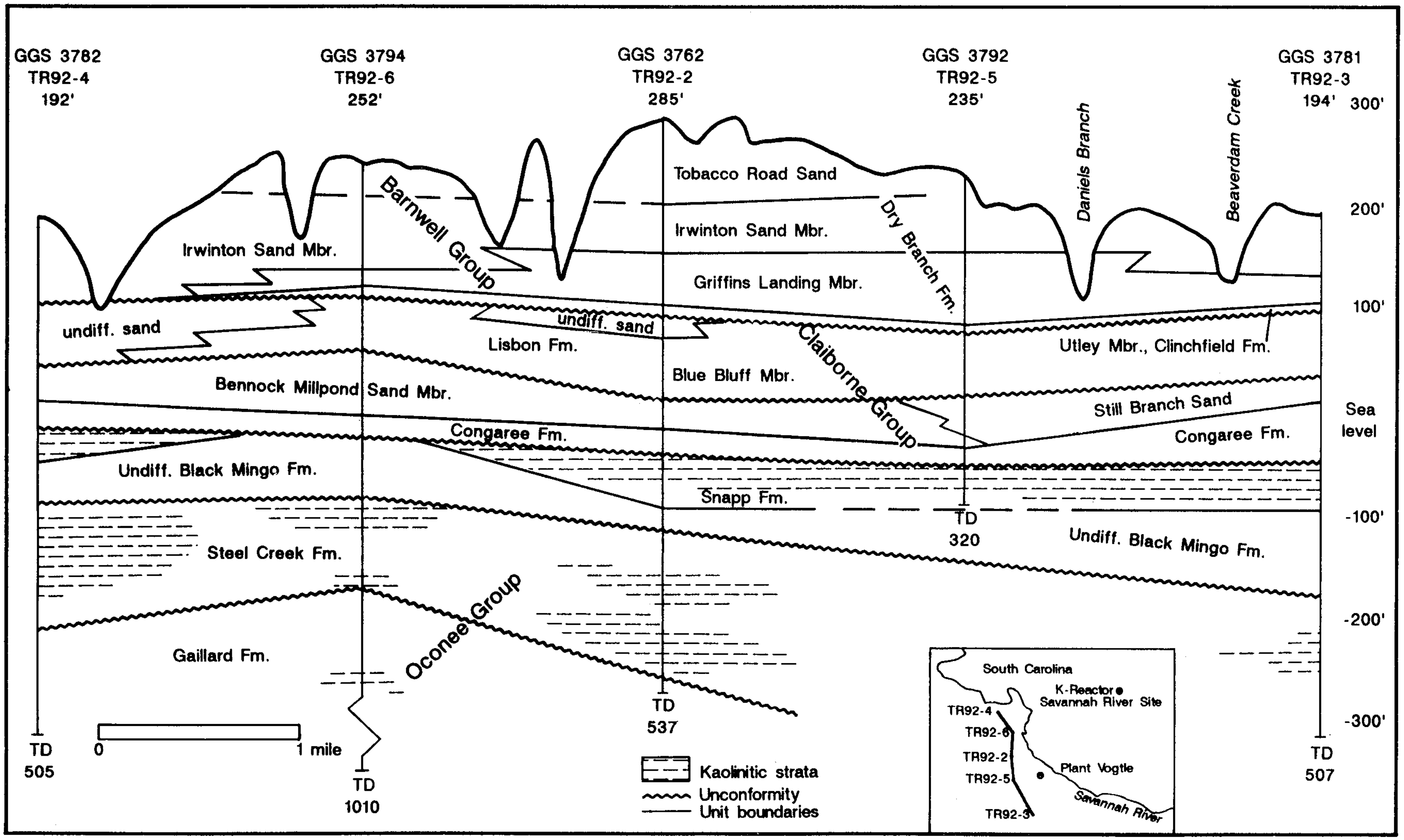

Figure 5. North-south stratigraphic cross-section between core holes TR92-4 and TR92-3. Modified from Summerour and others (1994.)

Structural Features

The most important basement structural feature in the study area is the buried Triassic extensional Dunbarton graben basin (Marine and Siplė, 1974; Snipes, et al, 1992, 1993) (Figure 6). Based on simultaneous gravity and magnetic modeling (Cumbest, et al, 1992), the dimensions of the Dunbarton basin are approximately 30 miles (48 km) long, 5,500 feet (1,700 m) deep, and 8 to 10 miles (12.8 to 16 km) wide (Snipes, et al, 1993).

The basement rocks adjacent to the Dunbarton basin consist primarily of Paleozoic greenschist facies metavolcanic rocks and amphibolite facies schists and gneisses (Snipes, et al, 1993). Red bed sediments and conglomerates were deposited within the graben (Siple, 1967; Marine and Siple, 1974; Cumbest, et al, 1992; and Snipes, et al, 1993). In Georgia, core TR92-6, north of the basin (Figure 2) terminates in weathered biotite schists, whereas the USGS Girard core (Figure 2) terminates in Triassic red beds of the Dunbarton basin.

The southeastern boundary fault (or fault zone) of the Dunbarton basin is believed to be the Martin fault (Figure 6) (Snipes, et al, 1993). The northwestern boundary fault (or fault zone) of the Dunbarton basin appears to be coincident with the known location of the Pen Branch fault (Snipes, et al, 1992, 1993). Based on data provided by 57 wells on SRS (Snipes, et al, 1992, 1993), the Pen Branch fault is slightly sinuous with an average strike of N 55^0 E. If the Pen Branch fault extends into Georgia, as projected, it would lie beneath the Savannah River channel near Hancock Landing, north of Georgia Power Plant Vogtle (Snipes, et al, 1993). According to Snipes and others (1993, p. 195): *"Stratigraphic relationships and seismic studies indicate that the Pen Branch fault is a subvertical growth fault with down-to-the northwest movement sense. Near the center of SRS, the thickness of the Upper Cretaceous clastic strata is about 670 feet (201 m) on the downthrown side, in contrast to 610 feet (185 m) on the up-thrown side. The throw decreases in successively younger beds from 80 to 100 feet (24 to 30 m) at the base of the Late Cretaceous Cape Fear Formation to 30 feet (9 m) at the top of the Late Eocene Dry Branch Formation. These relationships yield estimated slip ranges from 0 to 1.5 m/m.y. with an average of about .4 m/m.y. over the last 85 m.y..*

The down-to-the northwest movement sense for the Pen Branch fault is intriguing in that early Mesozoic deposition of fluvial sequences in the Dunbarton basin indicates that the base surface must have been lower that the erosional surface of the crystalline terrain to the northwest. However, this paleoerosional surface is presently about 80 to 100 feet (24 to 30 m) below the basin surface at the location of the fault. This relationship has led to speculation that the Pen Branch fault is a Dunbarton basin border fault reactivated in a reverse sense due to compressional stresses or that it is an antithetic basin fault."

Based on core data, the presence of the fault in Georgia is suggested by structure contour and thickness anomalies along the projected Pen Branch fault in eastern Burke County. The anomalies become more pronounced with depth, suggesting continuing fault movement with time. Movement on the Pen Branch fault does not appear to have occurred since the end of the Middle Eocene because there are no anomalies associated with the fault for sediments deposited after the Middle Eocene (Snipes, et al, 1992, 1993). There is also a lack of historic seismic activity near the fault and an apparent lack of recognizable earthquake-produced liquefaction structures in any of the Tertiary sediments near the fault. Additional information has been provided by a shallow seismic reflection survey conducted during June, 1995, by University of South Carolina personnel. This seismic survey was conducted along a line between cluster sites TR92-1 and TR92-5 (Figure 2) and indicated the possible existence of a river or scour channel (of unknown orientation) overlying the Pen Branch fault (zone) (Mike Waddell, University of South Carolina, personal communication, 1995). As indicated by the seismic survey data, the channel has a width of approximately 0.75 miles (1.2 km) and a depth of approximately 750 feet (250 m) below current surface level, and has cut as deep as the Middendorf Formation of Prowell and others (1985) (Waddell, personal communication,

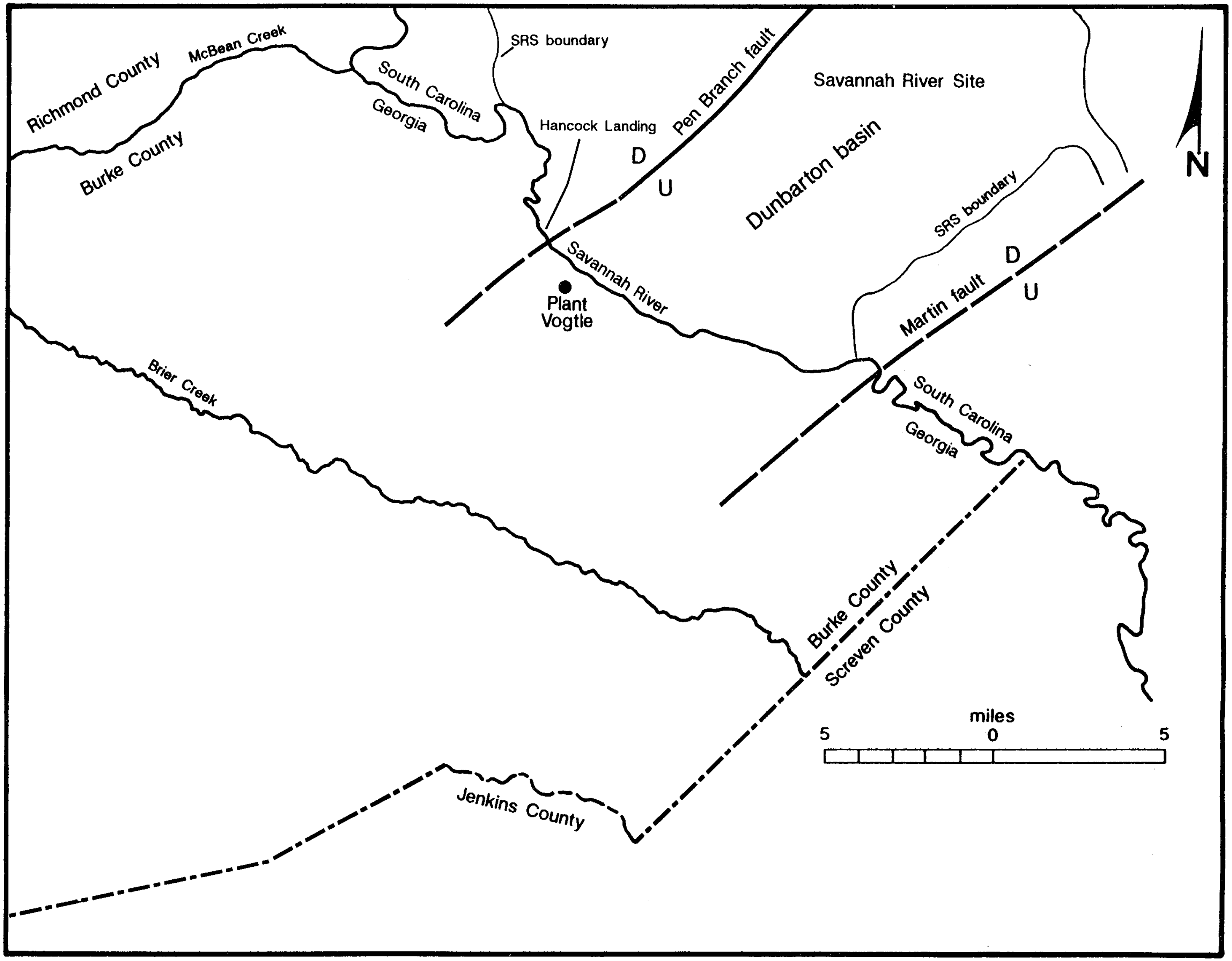

Figure 6. Map showing location of Dunbarton basin and Pen Branch and Martin faults on SRS and projected extensions into Georgia. Fault data from Snipes, et al, 1993.

1995). A re-examination of the shallow seismic survey of the Savannah River channel (Henry, 1994) shows the possible existence of a buried channel feature near Hancock Landing (John Clarke, USGS, personal communication, 1995; Waddell, personal communication, 1995). Structure contour and isopach anomalies shown in this report (based on core data), north of Plant Vogtle, may be due to the influence of both the Pen Branch fault zone and the buried channel feature. Detailed results of this survey will be provided in the Tritium Project Phase II report (Summerour, et al, *in preparation*).

STRATIGRAPHY

Oconee Group

Definition

The Oconee Group was introduced informally by Huddlestun (1981) and Schroder (1982), and was formally proposed as a new group by Huddlestun and Hetrick (1991). The Oconee Group includes all pre-Upper Eocene, or pre-Barnwell Group kaolin and kaolinitic sand deposits of fluvial origin in the Fall Line Hills districts of the Coastal Plain of Georgia, South Carolina, and North Carolina (Cooke, 1925; Fenneman, 1938; Cooke, 1936; Clark and Zisa (1976), excluding the Cape Fear Formation. The named formations that constitute the Oconee Group in Burke County include from oldest to youngest: Pio Nono Formation, Gaillard Formation, Steel Creek Formation, and Snapp Formation of Price and others (1992). The first three formations above are Late Cretaceous in age whereas we consider the Snapp to be Late Paleocene, Selandian, late Midwayan age (Figure 4). Prior to this report, only the Gaillard Formation had been recognized in the study area (Gorday, 1985). The Black Creek Formation (downdip equivalent of the Gaillard Formation) and the Cape Fear Formation (basal Coastal Plain unit in the area) are not considered to be part of the Oconee Group.

Type Locality

The name Oconee was taken from the Oconee River in Georgia, that flows through the heart of the Georgia kaolin mining district. The type area extends from near the Ocmulgee River, in the west, into Washington County, Georgia, in the east. In outcrop, formations that constitute the Oconee Group in its type area include the Pio Nono Formation, Gaillard Formation, and Huber Formation.

Huddlestun and Hetrick (1991) did not select a type locality for the Oconee Group because all good exposures of the soft sands and kaolins are transient. Oconee sediments are best exposed in sand pits and kaolin mines (that will be reclaimed) and are rarely well-exposed in roadcuts. Natural exposures are either too small or too weathered to observe the wide variation in lithologies present within the Oconee Group. Two cores from the Deepstep area of Washington County include parts of the Oconee Group, whereas core GGS Houston 9 (Table 2), though not in the "type area", contains a more complete Oconee Group section.

Lithology

Typical Oconee Group deposits consist of a series of fining-upward sequences. Basal sediments generally consist of crudely cross-bedded, poorly sorted, pebbly to gravelly, kaolinitic sand with variable quantities of kaolin clasts and kaolin cobbles (rarely bauxite or pseudo-bauxite cobbles). These basal sand units are prominently and, in many places, dramatically stratified with horizontal to undulatory bedding, and planar and trough cross bedding on small to large scales.

Above the basal beds, sands generally fine upward and become better sorted, more thinly bedded, and more finely micaceous. The middle and upper parts of the fining-upward sequences generally consist either of heavy mineral-rich, moderately to well-sorted, undulatory to horizontally bedded, fine- to medium-grained sand or of small to large lenses of finely sandy and micaceous to relatively pure kaolin.

The tops of fining-upward sequences have uneven surfaces, indicating some scour and erosion prior to deposition of the overlying fining-upward sequence. Fining-upward sequences generally cannot be traced across large pits and, therefore, are not laterally continuous. Channel cut-and-fill structures of variable scale are commonly well-exposed in kaolin pits.

Sands of the Oconee Group are kaolinitic to some degree, micaceous and feldspathic. Some formations and beds are more feldspathic than others. The sands are laminated to thickly bedded, finely to coarsely micaceous, with common micaceous bedding planes. Dark minerals are locally abundant and occur both scattered through the sands or as thin dark layers or lenses that appear to be carbonaceous or manganiferous wad (MnO_2).

All the formations of the Oconee Group are kaolinitic (rarely smectitic or bauxitic), and contain clasts and cobbles of kaolin, small to large lenses and irregular-shaped masses of kaolin, small to large lenticular masses of micaceous, sandy kaolin to relatively pure kaolin. The lenses of kaolin range in thickness from a few feet (less than 1 m) to approximately 70 feet (21 m), and in extent from several hundred square yards (approximately several hundred square meters) to several hundred acres.

Small to large lenses of variably carbonaceous and lignitic sands and clays commonly are scattered throughout the Oconee Group. The organics occur as finely disseminated carbonaceous material, chiefly as lignitic or carbonaceous flecks of uncertain origin, discrete carbonized fragments of woody material (lignite), and carbonized impressions of vegetation. Generally the carbonaceous lenses grade in all directions into noncarbonaceous sand, kaolinitic sand, or kaolin. Organic content of the lenses range from minor (based on gray coloration of the sediment due to finely disseminated carbonaceous material in the sand and kaolin) to lenses of almost pure carbonaceous kaolin and lignite.

In the Gaillard Formation, Middendorf Formation, Steel Creek Formation, Snapp Formation, and Huber Formation, the sand is characteristically white to light gray in color; however, the kaolins of the Pio Nono Formation, Steel Creek Formation, and Snapp Formation typically are strongly pigmented (weathered) over most of their surface and subsurface extent. This suggests that the high pigmentation of the formations was penecontemporaneous with deposition of the formations. Numerous sand intervals in the Steel Creek Formation have little pigmentation and lithologically resemble the Gaillard Formation.

Stratigraphic Relationships

The outcrop belt of the Oconee Group extends from eastern Alabama through South Carolina into North Carolina. Because there are local outliers of the group north of the Fall line, the Oconee Group probably extended some distance north of the present Fall Line. The Oconee Group in Burke County is a subsurface unit. It grades downdip or seaward into various Upper Cretaceous and lower Tertiary formations coastal marine to marine formations in Burke and Screven Counties, Georgia.

In Burke County, the Oconee Group disconformably overlies the Cape Fear Formation. The uppermost formation of the Oconee Group in Burke County, the Snapp Formation, is disconformably overlain by the Congaree Formation. The Congaree appears to pinch out updip in Richmond County immediately north of McBean Creek.

Only three cores penetrate the entire Oconee Group in Burke County: the USGS Millers Pond core, the GGS Tritium Project core TR92-6, and the USGS Girard core (Figure 2). The total cumulative thickness of the Oconee Group in the USGS Millers Pond core is 525 feet (160 m), in core TR92-6 the cumulative thickness is 517 feet (158 m), and in the Girard core the Oconee Group is 522 feet (159 m). There is no apparent thickening of the Oconee Group southeastward through Burke County because the Gaillard Formation grades downdip into 155 feet (47 m) of Black Creek Formation in the southern part of the county and the Pio Nono grades downdip into an unnamed formation in central and southern Burke County that is not Oconee Group.

Sedimentary features such as bioturbation and herring-bone cross bedding, and lithic components such as limestone, calcite, dolostone, dolomite, glauconite, phosphate, and marine fossils characteristic of coastal and near-shore marine deposits are absent in the Oconee Group. Fossils include palynomorphs and plant fossils. Land vertebrate fossils and associated trace fossils such as animal trails have not been reported from Oconee Group deposits. Similarly, shallow water sedimentary structures such as symmetrical ripple marks or mud cracks also have not been reported from the Oconee Group in Georgia.

Considering the above observations, the Oconee Group appears to have been deposited in an area of rapidly shifting river channels and currents such as in a continuously-saturated, braided river system.

Age

In Burke County, Georgia, the age range of the Oconee Group is Late Cretaceous, probably Austinian (early Santonian) through early Navarroan (early Maastrichtian), to Late Paleocene, late Midwayan, Selandian. In southern Richmond County the upper part of the Oconee Group is Maastrichtian, Danian, and Selandian in age (see Huddlestun and Hetrick, 1991 for more discussion of the age of the Oconee Group).

Steel Creek Formation

Definition

The Steel Creek Formation was named by Fallaw and Price (1992, 1995) for a subsurface, interbedded, varicolored and mottled, kaolin and light-gray sand formation in the Cretaceous part of the Oconee Group in SRS in Barnwell County, South Carolina. In eastern Burke County, Georgia, the Steel Creek Formation overlies the Gaillard Formation and disconformably underlies the undifferentiated Black Mingo Formation. Although the Steel Creek is a subsurface formation in Burke County, it may be the uppermost Cretaceous formation that crops out in Richmond County south of Augusta.

In the past, the Steel Creek Formation was included in the Tuscaloosa Formation of Siple (1967) and Bechtel (1982), undifferentiated Oconee Group by Huddlestun (1981), Gaillard Formation by Gorday (1982) and Black Creek Formation (?) by Faye and Prowell (1982). The lithology of the Steel Creek Formation resembles that of the Pio Nono Formation more than any other formation of the Oconee Group.

Type Locality

The Steel Creek Formation is named for Steel Creek, a small tributary of the Savannah River, approximately 3 miles (0.9 km) northwest of the Allendale/Barnwell Counties line and 1.3 miles (0.4 km) northeast of S.C. Hwy. 125 in southern Barnwell County. The site of the core P 21TA in the Savannah River Site is the type locality of the formation. The coordinates of the site of the core P 21TA is 33^0 08' 48" North Latitude and 81^0 36' 27" West Longitude. The core site is on the Girard NE, USGS 1:24,000 topographic quadrangle sheet. The type section, or unit-stratotype (holo-stratotype), of the Steel Creek Formation is in the interval from 453 feet to 594 feet in the core. The Paleocene Sawdust Landing Formation overlies the Steel Creek at 453 feet in the type core and the Black Creek Formation underlies the Steel Creek at 594 feet. Three GGS Tritium Project cores, TR92-2, TR92-4, and TR92-6 (Figure 2) are designated as reference localities for the Steel Creek Formation in Georgia. The core site localities are described in Appendix 1, and the coordinates are listed in Table 1. The core intervals for these reference sections (hypostratotypes) for the Steel Creek Formation are listed in Table 3.

The Steel Creek in core TR92-2 is typical for the formation in eastern Burke County and consists of several fining-upward sequences. In core TR92-4, the Steel Creek consists mostly of highly pigmented kaolins to sandy kaolins with minor light gray sand and is disconformably underlain by the Gaillard Formation. In core TR92-6, the Steel Creek Formation interval is lithologically typical of the unit and is conformably or paraconformably

Table 3
Steel Creek Formation reference sections in eastern Burke County.

Core Site, see Figure 2 Table 1	GGS core number	Site Elevation above Mean Sea Level	Top of formation- feet below surface	Bottom of formation- feet below surface
TR92-2	GGS-3762	285	402	537 (core bottom)
TR92-4	GGS-3782	192	386	501
TR92-6	GGS-3794	240	324	415

underlain by the Gaillard Formation. The Steel Creek is disconformably overlain by the undifferentiated Black Mingo Formation in all three cores. In the USGS Girard core, the Gaillard grades downward into the Black Creek Formation.

Lithology

The Steel Creek Formation commonly is made up of a series of fining upward sequences. Kaolin and sand are the dominant lithic components of the formation. Kaolin occurs interstitially and, more commonly, as thin to thick beds or lenses. Some beds of sand appear to be almost devoid of kaolin. Scattered kaolin clasts are rare. Minor lithic components include sparse to common, finely to coarsely grained mica. The Steel Creek is more micaceous than overlying formations. Gypsum- and sulphur-bloom occurs in some thin intervals on the cores; carbonaceous intervals and lignitic fragments are rare; pyrite is rare and occurs as dustings along partings or within the kaolins and dark minerals are common. Quartz pebbles are rare, and scattered throughout beds of coarser sand.

The sand ranges from very fine grained and well-sorted (especially in the upper part of fining upward sequences) to coarse, granular, pebbly, and very poorly sorted in the lower part of a fining upward sequences. The quartz sand is variably coherent to incoherent, probably depending on the amount of interstitial kaolin. Sand beds generally are massive-bedded and structureless. However, crude bedding is commonly seen in some of the intervals of coherent sand, and scattered concentrations of dark minerals define some crude bedding planes.

The colors of most sand intervals range from light-gray to white. Where the sands are pigmented, the colors range from shades of reddish brown, purple, pale orange, brown, and gray.

Kaolin beds are generally silty to sandy, variably and finely micaceous, and contain varying amounts of dark minerals. Some beds appear to contain a trace of interstitial silica. "Hematitic" spherules or "ooids" occur within the kaolin in one core (TR92-4). Sand content within the kaolin beds is variable, some intervals are almost barren of sand whereas other intervals are very sandy. Sand size within kaolin beds ranges from very fine-grained and well-sorted, to coarse-grained and very poorly sorted.

The kaolin beds are commonly massive-bedded and structureless. The kaolin is dense, tough, brittle and hard, breaking with an irregular, hackly fracture reminiscent of the commercial "hard" kaolins. Some kaolin is waxy to the touch and slickensided joints are common. Kaolin with subconchoidal fracture occurs in some rare and scattered thin intervals. Individual kaolin beds may be as much as 69 feet (21 m) thick.

Kaolin in the top several feet of the formation is commonly "bleached" very light gray to very pale orange and may contain finely disseminated pyrite. Kaolin beds in general are highly and complexly pigmented throughout with extremely irregular mottles, blotches, and almost microscopic root-like streaks. Colors range from white to varying shades of gray where carbonaceous and pyritic. Other colors include shades of red, pink, reddish brown, purple, orange, yellowish brown, yellow, gray, and yellowish green.

Stratigraphic Relationships

The Steel Creek Formation is known to underlie eastern Burke County and has also been identified in Bechtel Corporation cores from Allendale County, South Carolina. Neither its known western nor southern limits have been identified in Georgia. However, its downdip limit is probably in Screven County.

The Steel Creek Formation is not known to crop out in the kaolin mining district in Georgia. Farther west, the coastal marine Nakomis Formation of Huddlestun and Hetrick (1991) is the most updip lower Navarroan formation that occurs in the Steel Creek stratigraphic position. Either early Navarroan fluvial deposits were eroded prior to the Paleocene or were not deposited in central and southwestern Georgia.

In all sufficiently deep cores in Burke County, the Steel Creek Formation conformably or paraconformably overlies the Gaillard Formation. The contact relationships between the Gaillard and the Steel Creek are generally ambiguous due to several factors including: 1.) poor core recovery; 2.) the frequent lithologic similarity of uppermost Gaillard and lowermost Steel Creek sands or Gaillard sands underlying lithologically similar Steel Creek sands; or 3.) massive reworking of Gaillard sediments into basal Steel Creek sediments during initial deposition of the Steel Creek. In southernmost Burke County, south of Girard, the Steel Creek Formation probably directly overlies the Black Creek Formation, the downdip equivalent of the Gaillard Formation.

The Steel Creek Formation in Burke County is disconformably overlain by the undifferentiated Black Mingo Formation. This contact is especially dramatic where carbonaceous clays or fine sands of the Black Mingo lie directly on Steel Creek kaolins. In those examples, the top few feet of the Steel Creek Formation is "bleached" of pigment and fine-grained pyrite has formed in joints or burrows in the underlying sediment. Where the basal Black Mingo and uppermost Steel Creek are coarsely sandy, micaceous, and poorly sorted, the contact between the two formations is difficult to discern. In this situation, the Black Mingo/Steel Creek contact appears to be only a minor bed change.

The Steel Creek Formation is distinguished from other formations of the Oconee Group in that; 1.) the kaolin beds are numerous and may constitute more than half of the Steel Creek section in any particular core; 2.) the kaolins (and some sands) are generally highly pigmented and mottled (generally the associated sands are not pigmented or only mildly pigmented); and 3.), the Steel Creek kaolins are tough, waxy, commonly slickensided and break with a hackly, uneven fracture. We know of no soft, conchoidally fracturing kaolin beds in the Steel Creek Formation that resemble the soft kaolins of the Gaillard Formation (especially the Buffalo Creek Kaolin Member).

Only five cores have penetrated the entire Steel Creek Formation; therefore, the regional or local thickness distribution patterns cannot be clearly defined. However, assuming the upper and lower contacts of the formation have been correctly identified, there appears to be no systematic thickness changes in the formation in the Savannah River area. The thickness of the Steel Creek Formation ranges from 68 feet (21 m) thick in the USGS Millers Pond core, to more than 135 feet (41 m) thick in the Bechtel core VSC-4 near the Savannah River in northern Allendale County, South Carolina (Table 4).

There is a relatively consistent southeast dip of the upper surface of the Steel Creek, except where influenced by the projected location of the Pen Branch fault, northwest of Plant Vogtle (Figure 7).

The environment of deposition of the Steel Creek Formation was fluvial, and the formation was probably deposited by a system of braided streams draining the adjacent Piedmont Province.

Table 4
Thickness variations for Steek Creek Formation.

Core Site	GGS number	Thickness in feet
USGS Millers Pond	GGS-3758	68
TR92-4	GGS-3782	119
TR92-6	GGS-3794	90
USGS Girard	n/a	78
VSC-4	n/a	135+

"n/a"-not applicable

Age

The Steel Creek Formation is mostly nonfossiliferous. Samples from the few, thin carbonaceous intervals of the formation in Georgia are barren of pollen so no direct biostratigraphic information is available. However, in terms of stratigraphic position and physical correlation, the Steel Creek Formation stratigraphically overlies the Campanian (Tayloran) Gaillard Formation which suggests that the Steel Creek may be early Maastrichtian (early Navarroan) in age. According to Fallaw and Price (1995): *"Wood fragments, spores, pollen, and rare dinoflagellates have been found in the SRS wells. Dinoflagellates and pollen yield a Maastrichtian age. If the Steel Creek is the same age as the redefined Pee Dee (Sohl and Owens, 1991), it correlates with the middle and upper Ripley and Providence Formations of Georgia and Alabama."*

The Steel Creek Formation is overlain disconformably by the Paleocene (Midwayan) undifferentiated Black Mingo Formation and, therefore, is older than Paleocene age.

Snapp Formation

Definition

The Snapp Formation was named by Fallaw and Price (1992, 1995) for a distinctive, subsurface, lower Tertiary kaolin and sand formation that underlies SRS. It is recognized in Burke, Screven, and Jefferson Counties, Georgia. In eastern Burke County, the Snapp Formation appears to consist of one fining upward sequence capped with a strongly pigmented, hard, hackly kaolin with irregular fracture. The mottled kaolin is found in eighteen out of nineteen cores from Burke, Richmond and Jefferson Counties, Georgia, and western Barnwell and Allendale Counties, South Carolina. The kaolin bed, therefore, appears to be a useful marker bed across that entire area. The Snapp Formation is included here in the Oconee Group.

The Snapp Formation in Georgia has not generally been recognized as a separate and distinct lithostratigraphic unit. LeGrand and Furcron (1956) and Herrick (1961) included it in the Tuscaloosa Formation and Huddlestun (1981) and Bechtel (1982) included it in the Huber Formation. In South Carolina, the Snapp has been called the Williamsburg Formation by Colquhoun and others (1983), Steele (1985) and McClelland (1987).

Type Locality

The Snapp Formation is named for an old railroad stop in the southeastern part of SRS (Fallaw and Price, 1992). The type locality of the Snapp Formation is the site of the core (and water well) P 22TA in SRS (Fallaw and Price, 1992, 1995). The type section, or unit-stratotype (holostratotype), of the formation is the interval 310 feet to 360 feet in core P 22TA. Three Georgia cores and one South Carolina core (Table 5) have been designated as reference localities for the Snapp Formation in the Tritium Project study area (Figure 2).

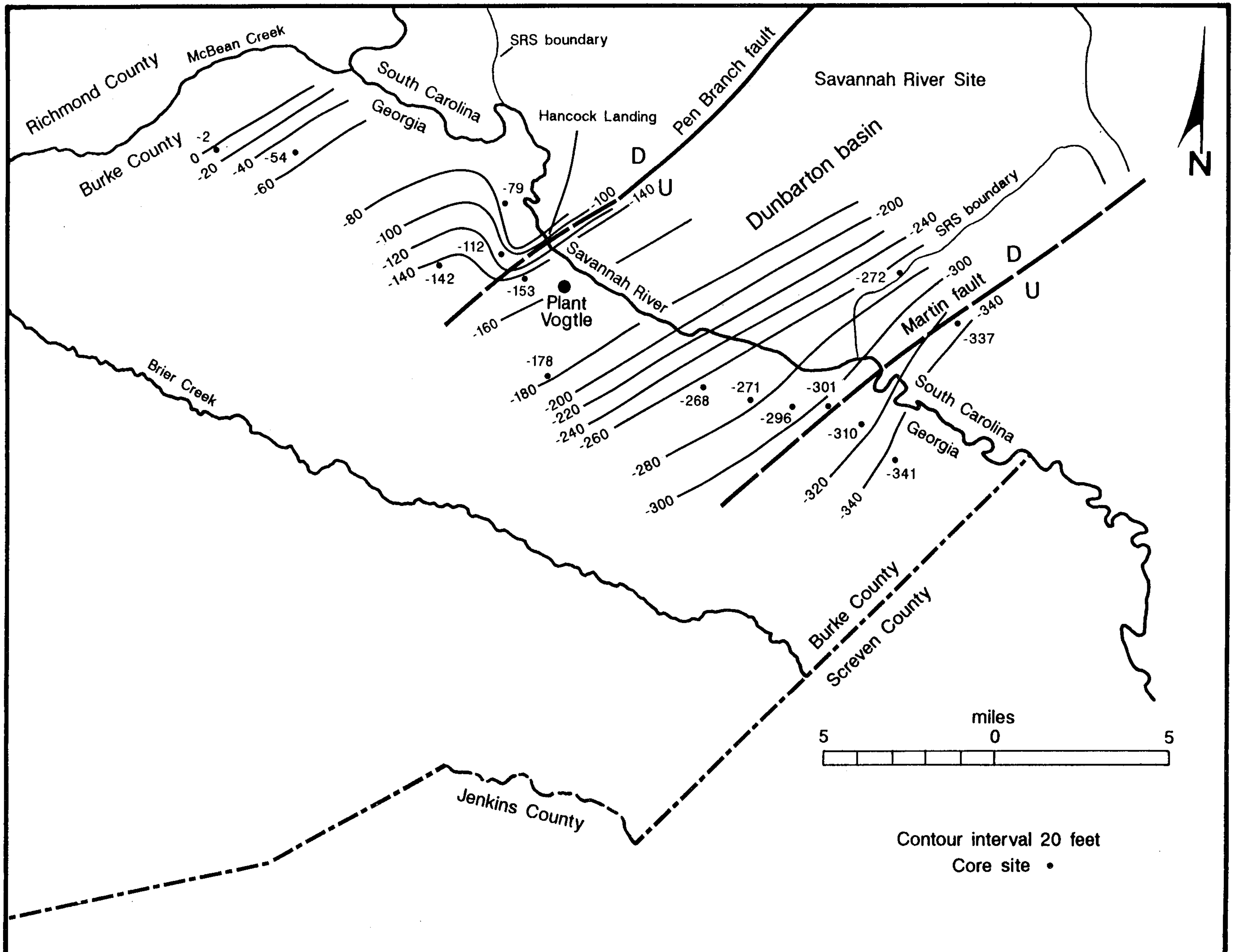

Figure 7. Structure contour map of the top of the Steel Creek Formation. Elevations are in feet relative to mean sea level. Modified from Summerour and others (1994).

Table 5
Snapp Formation reference sections in the Savannah River area.

Core Site	GGS core numbers	Site Elevation above Mean Sea Level (feet)	Top of formation- feet below surface	Bottom of formation- feet below surface
USGS Millers Pond	GGS-3758	245	165	236
TR92-2	GGS-3762	285	330	386
TR92-4	GGS-3782	192	231	282
VSC-4	n/a	165	322	377.5

"n/a"-not applicable

The USGS Millers Pond core was chosen as a reference section because it contains typical Snapp lithologies and is clearly overlain disconformably by the Congaree Formation and is underlain with apparent disconformity by the undifferentiated Black Mingo Formation (to be discussed in the following section). Core TR92-2 is chosen as a Snapp Formation reference section because: 1.) it displays the typical single fining upward sequence; 2.) the highly pigmented kaolin and the "bleached" zone at the top of the formation is present; 3.) the lower kaolinitic, micaceous, poorly sorted coarse sand in the lower part is well-developed; and 4.) there was moderately good (72%) core recovery within the formation. Core TR92-4 is chosen as a reference section because: 1.) it displays well the "bleached" zone with burrows at the top of the kaolin; 2.) spherical "ooids" or "pellets" that are locally common within the kaolin component of the formation; 3.) the entire Snapp section is distinctive and consists of kaolin without any sand beds; 4.) <u>Planolithes</u> are present at 228 to 229 feet (also see Schroder, 1982); and 5.) the contact with the underlying undifferentiated Black Mingo Formation is apparently gradational. In the Bechtel core VSC-4, from South Carolina (Figure 2), the entire Snapp Formation consists of kaolin and the lower part of the Snapp is gradational over approximately two feet into a gray, hard, siliceous clay and claystone (Williamsburg Formation of the Black Mingo Group (Figure 4). The claystone is in a stratigraphically intermediate position to, and is gradational with, the overlying Snapp Formation and the underlying sand (Rhems Formation (?) of the Black Mingo Group). Core recovery between the Williamsburg and the Snapp is 100%. There is no evidence for disconformity.

Lithology

The Snapp Formation commonly consists of one fining upward sequence in Georgia. In all cores but one in Burke County (GGS McBean), there is a bed of kaolin of varying thickness in the upper part of the formation, the top several feet of which are "bleached". In two cores (TR92-4) in Georgia and VSC-4 in South Carolina) the entire section consists of kaolin. Elsewhere, the lower part of the formation is a sand. The kaolin is variably silty and finely micaceous. Fine-grained pyrite commonly occurs in burrows, along joints or in irregular concentrations near the top of the Snapp. Very fine grained pyrite is found elsewhere scattered in the formation. Fine "limonite-hematite" and kaolin "ooids" or "pellets" (about 1 mm to 2 mm across) are scattered throughout the upper part of the kaolin in several cores.

The kaolin generally is massive-bedded and structureless but some intervals are crudely stratified. The Snapp kaolin is characteristically hackly with irregular fracture and is generally hard and tough when dry. Slickensided joints are common. Less silty intervals of the kaolin are soapy or waxy to the touch. As previously mentioned, the trace-fossil *Planolithes* sp. occurs in the interval 228 to 229 feet in core TR92-4.

The few feet of burrowed and pyritic kaolin at the top of the section is generally white (N 9) and appears to be "bleached". The rest of the kaolin is irregularly mottled with some highly pigmented, thread-like veins. Pigmentation of the Snapp kaolin ranges through several shades of red, reddish brown, purple, gray, orange, and rarely olive. Neutral hues range from light gray to white.

The kaolin of the Snapp Formation generally grades downward into the sand, but locally, the contact is very sharp, having the appearance of a diastem. The transitional lithology contains common to abundant, and fine- to coarse-grained mica and interstitial kaolin. The sand size ranges from fine- to very fine grained and well-sorted to medium- to coarse-grained and moderately sorted. Some intervals are distinctly stratified whereas others are massive-bedded and structureless.

The lower sand of the Snapp Formation is very finely to coarsely micaceous. Kaolin is mostly interstitial but there are rare and scattered beds of thin, carbonaceous clay with plant impressions. Quartz pebbles are found at the base of the formation in some cores and, less commonly, are scattered throughout the sand section. Dark minerals, fine-grained pyrite, and sulphur-bloom on the core surfaces are sporadic.

Sand size and sand sorting ranges from very fine and well-sorted to very coarse grained and poorly sorted. The sand is massively bedded and structureless, but thinly bedded kaolinitic sand also occurs in scattered sections. The sand is generally firm, but it is rarely soft and incoherent. Unlike the kaolin, the sand is not pigmented but is very light gray to white.

Stratigraphic Relationships

The Snapp Formation underlies all of eastern Burke County, Georgia and is present in the subsurface in the vicinity of Wrens, Jefferson County, Georgia. Its full aerial extent in eastern Georgia and western South Carolina is not yet known due to insufficient subsurface data. It does not, however, exist as far west as the kaolin mining district in the central Georgia Coastal Plain, nor is it known to exist in outcrop in the kaolin mining district in Aiken County, South Carolina. However, because the Black Mingo is thought to be exposed in some deep creek valleys in southern Aiken County, the overlying Snapp Formation may also crop out.

In all cores of eastern Georgia and adjacent Allendale County, South Carolina, the Snapp Formation appears to grade downward into the undifferentiated Black Mingo Formation. Although some of the Snapp-Black Mingo contacts appear to be disconformable, having basal coarse sands containing pebbles, we think these disconformable contacts are due to channel scour from a prograding, fluvial environment. A few of the cores have good recovery across the contact and display gradation and conformity over 1 to 2 feet. The stratigraphic interpretations of these gradational contacts are considered to be more reliable because sharp "disconformities" may occur at the base of channels in any formation of coastal marine to fluvial origin.

In contrast, the upper contact of the Snapp is strongly disconformable, exhibiting irregular, surfaces. Burrows and joints in the uppermost Snapp Formation are filled with sediment from the overlying Congaree Formation. The "bleached", commonly pyritic zone in the upper several feet of the formation is conspicuous.

The Snapp Formation ranges in thickness from 27 feet (8.2 m) updip to 93.5 feet (28.5 m) downdip (Figure 8). Thickness remains constant along strike into South Carolina. The kaolin bed ranges in thickness from about 11 feet (3.5 m) to 30 feet (9.0 m).

Structure contour lines of the upper surface of the Snapp Formation show the characteristic regional southeast dip (Figure 9). In the vicinity of the Pen Branch fault, the structure contours are somewhat subdued, with a small negative anomaly (<10 feet (3 m)) on the northern (downthrown) block and a more prominent area of positive relief on the southern (upthrown) block.

The environment of deposition of the Snapp Formation is interpreted to have been fluvial, of braided stream origin. It could be interpreted, with the available evidence, that the Snapp Formation represents the final withdrawal of the Midwayan sea, and the progradation of fluvial coastal plain environments.

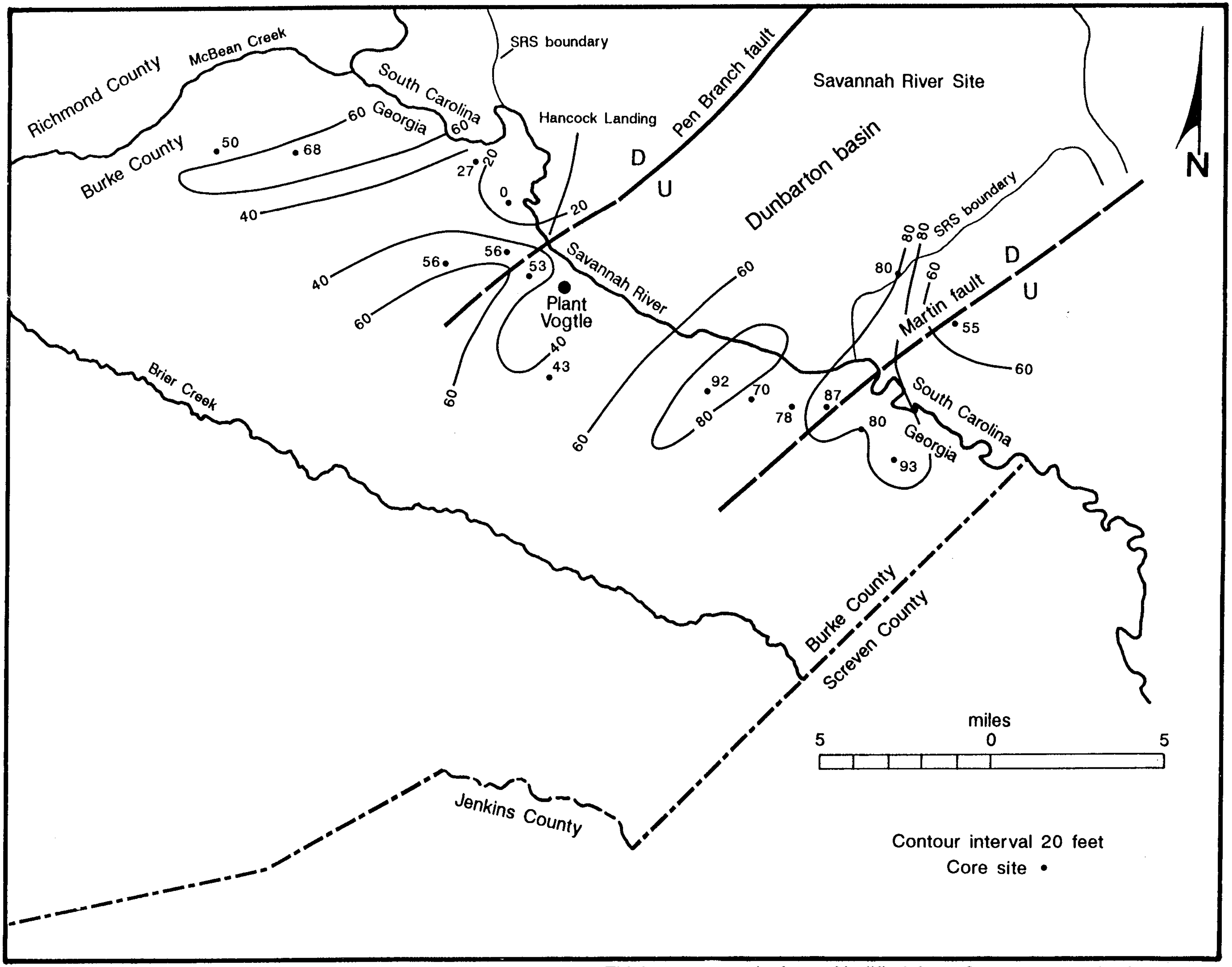

Figure 8. Snapp Formation isopach (thickness distribution) map. Thicknesses are in feet. Modified from Summerour and others (1994).

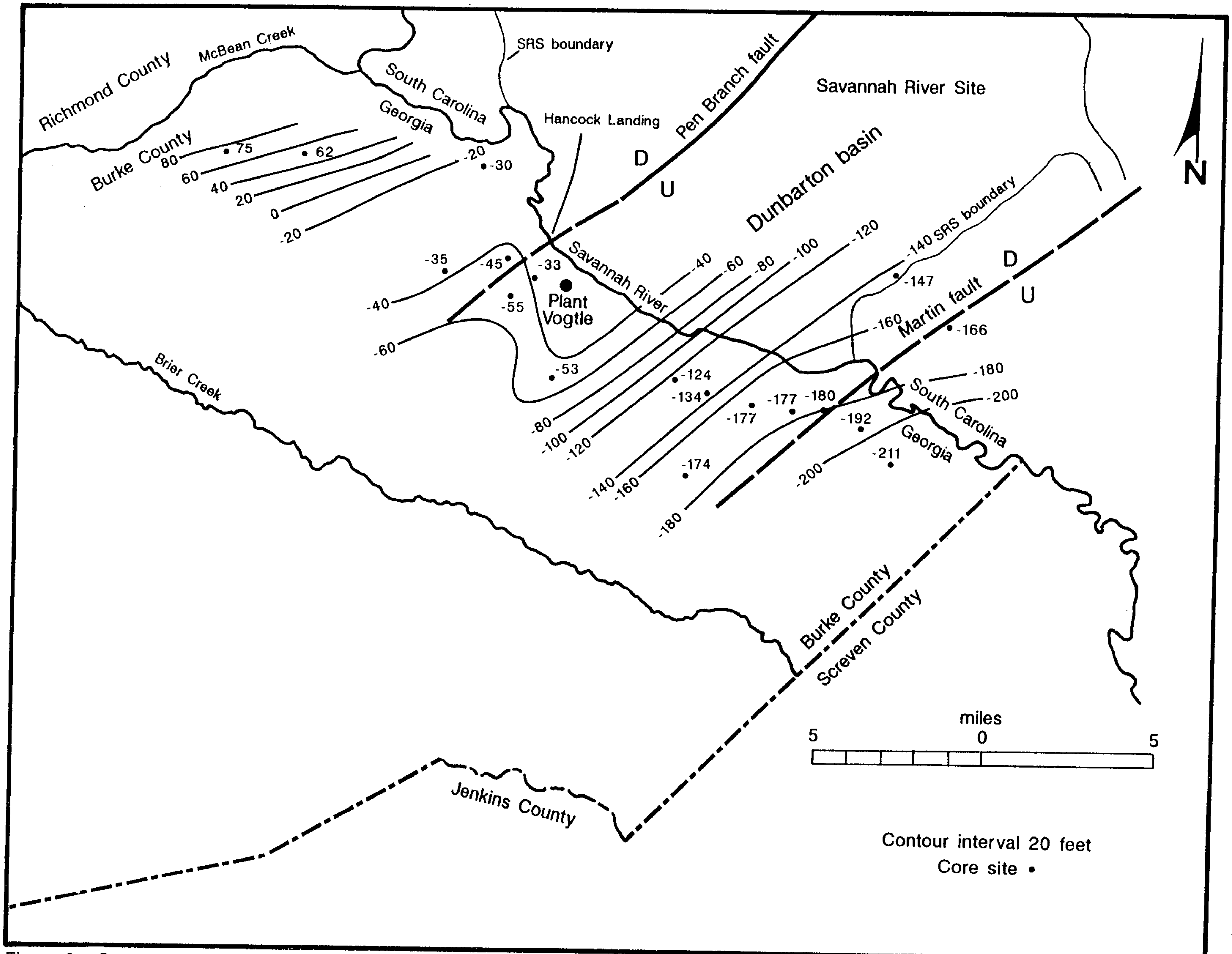

Figure 9. Structure contour map of the top of the Snapp Formation. Elevations are in feet relative to mean sea level.

Age

In South Carolina, Fallaw and Price (1995) considered the Snapp Formation to be Late Paleocene in age: *"Fossils are rare in the Snapp. There are not many age determinations, but judging from a few palynological assemblages, and well-dated strata above and below, the unit is probably zone NP9, middle Sabinian, perhaps correlating with the upper part of the Williamsburg Formation (Van Nieuwenhuise and Colquhoun, 1982; Colquhoun, et al, 1983) of eastern South Carolina. It appears to correlate with the Tuscahoma Sand and perhaps the upper parts of the Nanafalia and Baker Hill (Gibson, 1982) formations of the Gulf Coastal Plain (middle Sabinian; upper Thanetian or Selandian)."*

Based in part on the broadly gradational lower contact with the underlying Midwayan Black Mingo Formation at some sites, and in part on a late Midwayan, Upper Paleocene (Selandian) (Naheola-equivalent) age of the uppermost Black Mingo (Edwards, personal communication, 1995), the most likely age for the Snapp Formation in the Savannah River area is late Midwayan, early Late Paleocene, Selandian. There is no evidence for an early Sabinian, Thanetian age for the Snapp Formation in Georgia, nor have any deposits of Sabinian age been identified in Burke County.

In the eastern Gulf Coastal Plain, the most severe fall in sea level during the Paleocene occurred near the end of the Early Paleocene, Midwayan (pre-Nanafalia) Stage. This regression and low stand of the sea resulted in the deposition of the basal Gravel Creek Member of the Nanafalia Formation in Alabama (LaMoreaux and Toulmin, 1959), and development of karst topography on the top of the Clayton Formation in the Chattahoochee River area (Toulmin and LaMoreaux, 1963; Marsalis and Friddell, 1975; Reinhardt and Gibson, 1981). The two apparently severe low stands of the sea, the post-Midway-pre-Nanafalia event of the eastern Gulf Coastal Plain and the post-Snapp event in the Savannah River area, are considered here to be contemporaneous. If they were not, the tectonics of the eastern Gulf Coastal Plain were significantly different from that of the southern Atlantic Coastal Plain.

Undifferentiated Black Mingo Formation

Definition

The undifferentiated Black Mingo Formation in eastern Burke County, as defined in this report, is a variably carbonaceous and lignitic, fine- to medium-grained, moderately to well-sorted sand with scattered beds or lenses of gray to black, thinly stratified to laminated clay. It is easily identified in cores and well-cuttings because it is sandwiched between white to mottled kaolinitic sands (overlying Snapp Formation) and white to mottled sandy kaolins (underlying Steel Creek Formation). The sands of the undifferentiated Black Mingo compose the locally restricted Millers Pond aquifer (Figure 3) (Falls and Baum, 1995).

In its type area in the central Coastal Plain of South Carolina, the Black Mingo has been elevated to group status (Van Nieuwenhuise and Colquhoun, 1982) with a lower Rhems Formation (divided into two members) and an upper Williamsburg Formation (also divided into two members). The lower Black Mingo Rhems Formation consists mainly of sandy clay, and the upper Black Mingo Williamsburg Formation is predominantly a siliceous claystone. The lower Black Mingo is Midwayan in age, and the upper Black Mingo is early Sabinian in age. Because the lower Black Mingo is mainly a clay and the upper Black Mingo is a claystone, and because there is no Sabinian Black Mingo in Burke County, Georgia, the precise stratigraphic relationships between the Black Mingo in its type area and the Burke County Black Mingo is not clear. However, the unit in Burke County is lithologically closely related to the Black Mingo and, therefore, is included in that lithostratigraphic unit as undifferentiated Black Mingo.

In the past, the undifferentiated Black Mingo in Burke County has been called Ellenton Formation. For a discussion on the historical review and relationship of the Black Mingo and Ellenton Formations, see Appendix 2.

Type Locality

The type locality of the Black Mingo, as assigned by Sloan (1908, p. 452), is at Perkins Bluff on the Black River near the confluence of the Black River with Black Mingo Creek. Sloan (1908) recognized both a lower and upper Black Mingo and the Black Mingo exposed at Perkins Bluff is lower Black Mingo. However, it is not clear from the text whether Sloan (1908) intended Perkins Bluff to be the type locality for the entire Black Mingo phase or whether he intended Perkins Bluff to be the type locality only for the lower Black Mingo. He did not assign a type locality to the upper Black Mingo. We conclude, therefore, on the basis of default and original designation, that the type locality of the Black Mingo Formation must be at Perkins Bluff on the Black River.

The section of Black Mingo exposed at Perkins Bluff is therefore, the type section, or unit-stratotype (holostratotype) of the Black Mingo Formation (Group). Perkins Bluff on the Black River is in Georgetown County, South Carolina, 10 miles northeast of Harpers and about three miles west of Rope Ferry (Sloan, 1908, p. 452, 360).

For the Savannah River area, we propose that the core from the monitoring well P-18, taken less than 10 feet from the site of the well 52-C, the type locality of the Ellenton Formation of Siple (1967) be considered a reference locality and reference section (lectostratotype) for the undifferentiated Black Mingo Formation. The surface elevation of the core P-18 is 354 feet above sea level and the elevation of the top of the Ellenton is at 250 feet in the core (104 feet above sea level).

Useful reference sections (hypostratotypes) of the undifferentiated Black Mingo Formation in Burke County, Georgia are listed in Table 6. The core sites (Figure 2) are described in Appendix 1 and the coordinates are listed in Table 1.

The GGS McBean core was chosen as a hypostratotype because it is the only core in northern (northern-most) Burke County where the undifferentiated Black Mingo is clearly divisible into an upper and lower part. The upper part is a conspicuously glauconitic sand and the lower part is a resistant, hackly, dark gray clay. TR92-3 is designated as a reference locality for the Black Mingo Formation in central eastern Burke County because it is characteristic of the formation in northern Burke County and because the core recovery in the formation was good (~77%). The Black Mingo in this core is overlain with an apparent diastem by the Snapp Formation. Core TR92-6 is designated as a reference locality because it is characteristic of the undifferentiated Black Mingo Formation in northern Burke County, consisting of approximately 87% sand beds and 13% clay beds. Core recovery through the undifferentiated Black Mingo was good in the core (~73%). The undifferentiated Black Mingo Formation in core TR92-6 overlies the Steel Creek Formation with a clear disconformity and is overlain paraconformably by the Congaree Formation. The USGS Girard core was chosen as a hypostratotype because the Black Mingo Formation in this core has a lower and upper part and resembles the lithologic descriptions of the Rhems, Williamsburg, and Lang Syne lithologies in the type area in South Carolina. Core VG-6 is designated as a reference locality because it is lithologically characteristic of the formation in southern Burke County, and because there is a distinction between an upper and lower part. However, the distinction is less obvious than in the Girard core. Bechtel core VSC-4 is chosen because it is lithologically characteristic of the formation in western Allendale County, South Carolina, and because the Black Mingo is overlain gradationally by the Williamsburg Formation, a stratigraphic juxtaposition that does not exist in Burke County. The Black Mingo Formation also is characteristically sandier in South Carolina near the Barnwell-Allendale County line than across the Savannah River in Burke County.

Lithology

In Burke County, Georgia, sand is the dominant lithic component of the undifferentiated Black Mingo Formation but clay is

Table 6
Undifferentiated Black Mingo Formation reference sections.

Core Site see Figure 2 Table 1	GGS core number	Site Elevation above Mean Sea Level (feet)	Top of formation- feet below surface	Bottom of formation- feet below surface
SRS P-18[1]	n/a	354	250	n/a
TR92-3	GGS-3781	195	290	370
TR92-6	GGS-3794	240	274	324
GGS McBean	GGS-3757	297	272	299
USGS Girard	n/a	250	482	542
VSC-4	n/a	156.5	377.5	494
VG-6	n/a	217	522	588

"n/a"-Not applicable or not available
1. Not in area covered by Figure 2 map.

ubiquitous. Clay occurs both interstitially and in thin and, rarely, thick beds. The gray to black clays in the upper part of the formation probably are dominantly smectitic but kaolin occurs in updip, lower beds of the formation. A thin bed of claystone (0.1 foot thick), virtually identical to the Williamsburg Formation, in Barnwell and Allendale Counties, S.C., is present in the middle of the undifferentiated Black Mingo in core VG-4. Carbonaceous material, including lignite flecks, fragments and scattered thin beds of lignite are characteristic of the Black Mingo Formation in Burke County, and are present in all cores that penetrate the formation. Other lithic components include fine (common) to coarse mica (rare), dark minerals, scattered glauconite, scattered pyrite and rare pyrite-cemented sandstone, both acicular and cauliflower-like gypsum-bloom on core surfaces, some sulphur-bloom on core surfaces, rare and local phosphatic vertebrate debris and a trace of pelletal phosphate in southernmost Burke County, rare interstitial silica(?) in sandstones, traces of feldspar, thin limestone beds, and calcareous macro- and microfossiliferous beds in southernmost Burke County.

Black Mingo sand in Burke County is most commonly medium- to fine-grained and moderately to well-sorted, but may range from very fine to coarse-grained, with local occurrences of pea-gravel. Coarse to granular, pebbly, poorly sorted sand, at the base of the Black Mingo in some cores in northern Burke County, is similar to the Sawdust Landing Formation of SRS of Fallaw and Price (1992, 1995). Sorting ranges from very well-sorted to very poorly sorted. In some cores, (e.g., VG-3), the grain-size is relatively coarse (medium-grained) and the sorting is relatively poor (moderately to moderately poorly sorted).

Sand is mostly incoherent to barely coherent and soft. However, the degree of induration or consolidation of the sand ranges from incoherent, soft and disturbed to very coherent, tough, and slightly indurated but friable. Hard, pyrite or silica-cemented sandstone is rare. Sand color ranges from white to light-gray, shades of brown, and olive gray to olive black.

Clay beds are variably silty and finely to coarsely micaceous, variably carbonaceous and lignitic, with rare and scattered thin beds of lignite, rare carbonaceous leaf prints on bedding planes or partings, and carbon films on bedding planes. Common to abundant sulphur- and gypsum-bloom occurs on the surfaces of the cores. Sand content of the clay is variable. The clay and fine sand layers are of varying thicknesses, ranging from thinly interbedded fine sand and clay, to interlaminated very fine sand and clay, to laminated silty clay. Bedding is generally thin to laminated, fissile and papery, but there are some beds of clay that are massive and structureless. Clay beds in southernmost Burke County are calcareous and macro- and microfossiliferous.

Carbonaceous clay colors range from black to dark gray, and shades of brown and olive gray. Noncarbonaceous clays range in color from shades of gray (rarely very light gray).

Bedding in the Black Mingo ranges from massive and structureless to crudely bedded, faintly bioturbated, and thinly bedded (interlaminated in the clay intervals). There is some undulatory bedding and weakly inclined bedding.

In two Bechtel cores in Barnwell and Allendale Counties, South Carolina, a short distance across the Savannah River, the Black Mingo divides into an upper Black Mingo, Williamsburg claystone (or mudstone) lithology and a lower sandy part that resembles the Burke County Black Mingo, but is neither carbonaceous nor lignitic. The two parts of the formation are gradational. In the VSC-3 in Barnwell County, the entire Black Mingo stratigraphic interval is 43 feet (13 m) thick, whereas in the VSC-4, the interval is 67 feet (20 m) thick, due in large part to the thicker claystone section in the unit.

Stratigraphic Relationships

Eastward, at SRS in South Carolina, the stratigraphic equivalent of the undifferentiated Black Mingo Formation of this report is the Ellenton Formation of Siple (1967), the Rhems Formation of Colquhoun and others (1983) and McClelland (1987), and the Sawdust Landing Formation of Muthig and Colquhoun (1988), and Fallaw and Price (1992, 1995).

In eastern Burke County the Black Mingo Formation disconformably overlies the Upper Cretaceous Steel Creek Formation of the Oconee Group and gradationally (or paraconformably) underlies the Snapp Formation.

The thickness of the Black Mingo Formation in eastern Burke County, Georgia is unusually variable, ranging from 82 feet (25 m) to 16 feet (4.9 m), a difference of 66 feet (20 m) (Figure 10). This variability in thickness is particularly notable in northern Burke County. The average thickness of the Black Mingo in northern Burke County is approximately 48 feet (15 m).

In southern Burke County the range of thickness of the Black Mingo is from 52 feet (16 m) to 24+ feet (7.3+ m). Average thickness of the Black Mingo in southern Burke County is about 38 feet (about 12 m). Thickness of the Black Mingo Formation in southern Burke County is uncertain, however, because there are intervals with no core recovery between the Black Mingo and Snapp Formation in all cores.

The direction of dip on the top of the Black Mingo Formation in Burke County is generally to the southeast (Figure 11). However, the angle of dip is variable. Dip angles range from 15 feet per mile to 26 feet per mile. There is a dip reversal in the vicinity of the Pen Branch fault.

In Burke County the Black Mingo Formation appears to consist of interfingering or interlensed coastal marine and inner neritic, marine, siliciclastic deposits. This interpretation is based on the presence of dinoflagellates which live only in a marine environment. Dinoflagellates are found throughout the formation across Burke County. Other evidence for marine deposition includes scattered glauconite in the formation throughout Burke County, and a shark tooth in the upper glauconitic sand in the GGS McBean core near McBean Creek in northern Burke County. On the other hand, a sample from 402-405 feet in the core VG-3 contains the freshwater alga *Pediastrum*, indicating a freshwater influence even in southern Burke County (Edwards, personal communication, 1995).

The Black Mingo-Snapp stratigraphic interval may represent two depositional episodes in which the lower part of the Black Mingo Formation represents one separate, lower Midwayan (Lower Paleocene, Danian) depositional episode, and the other an upper Midwayan (Upper Paleocene, Selandian) depositional episode (Figure 12). The two depositional episodes are separated by a diastem or paraconformity (Edwards, personal communication, 1995). The Snapp Formation

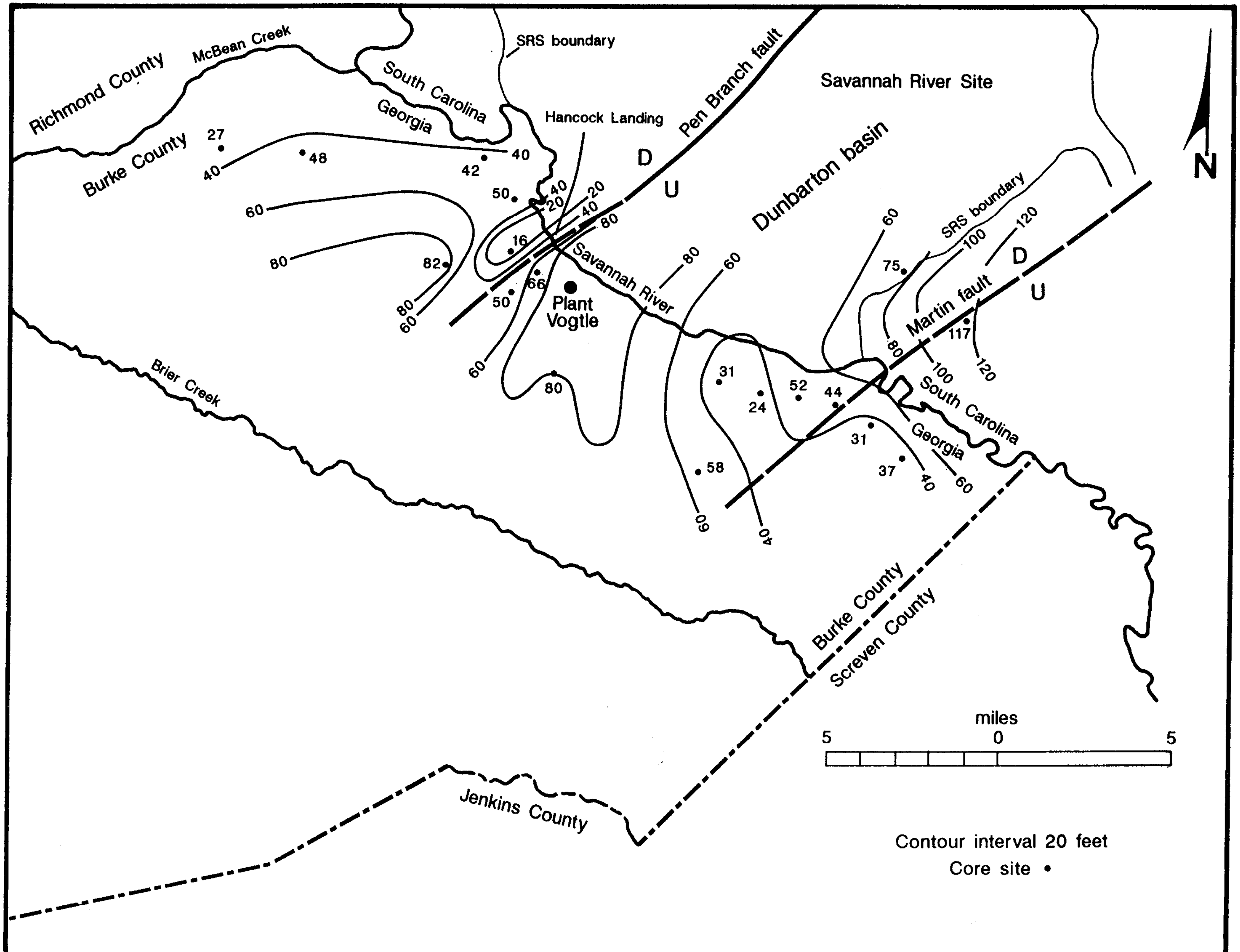

Figure 10. Undifferentiated Black Mingo Formation isopach (thickness distribution) map. Thicknesses are in feet.

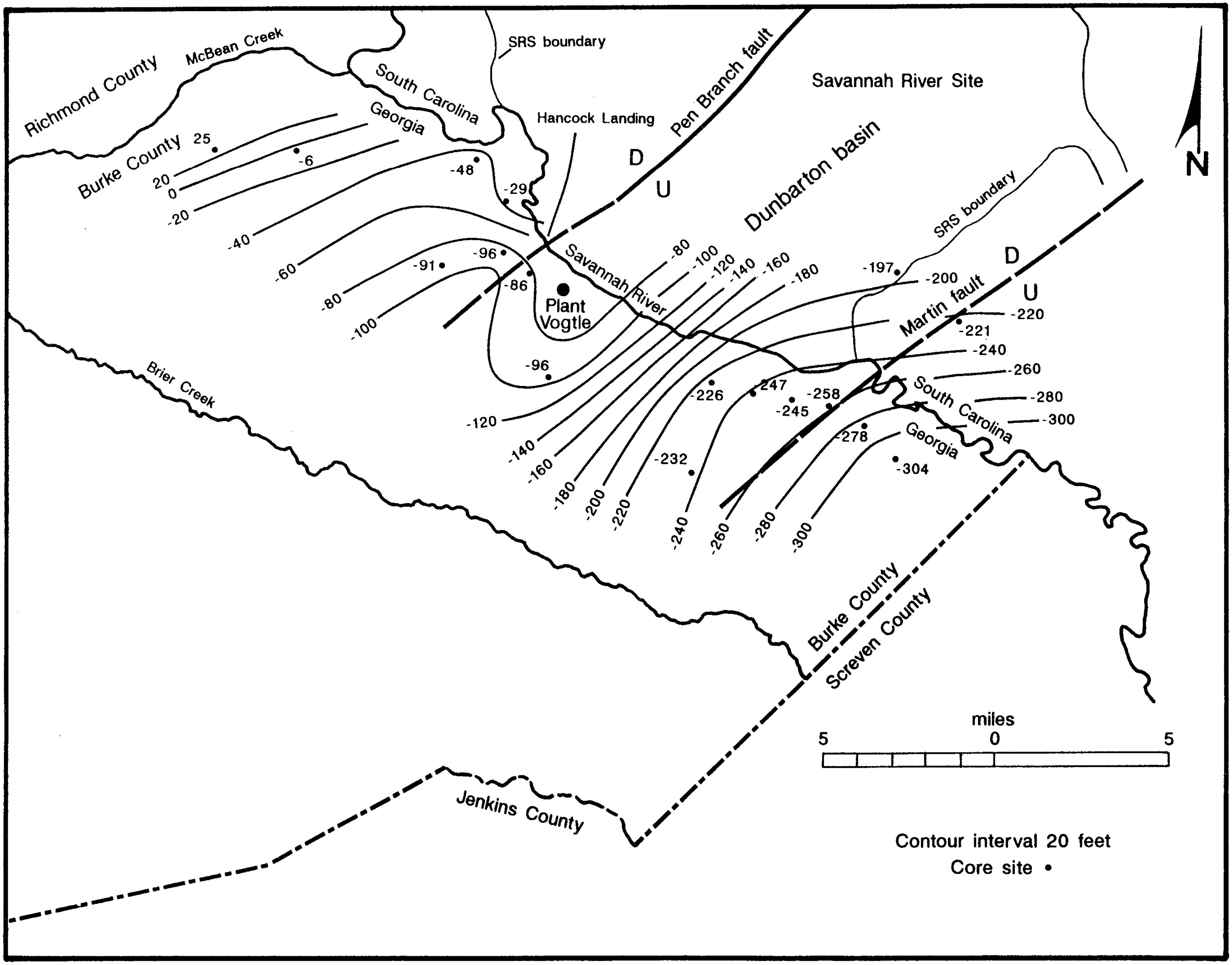

Figure 11. Structure contour map of the top of the undifferentiated Black Mingo Formation. Elevations are in feet relative to mean sea level.

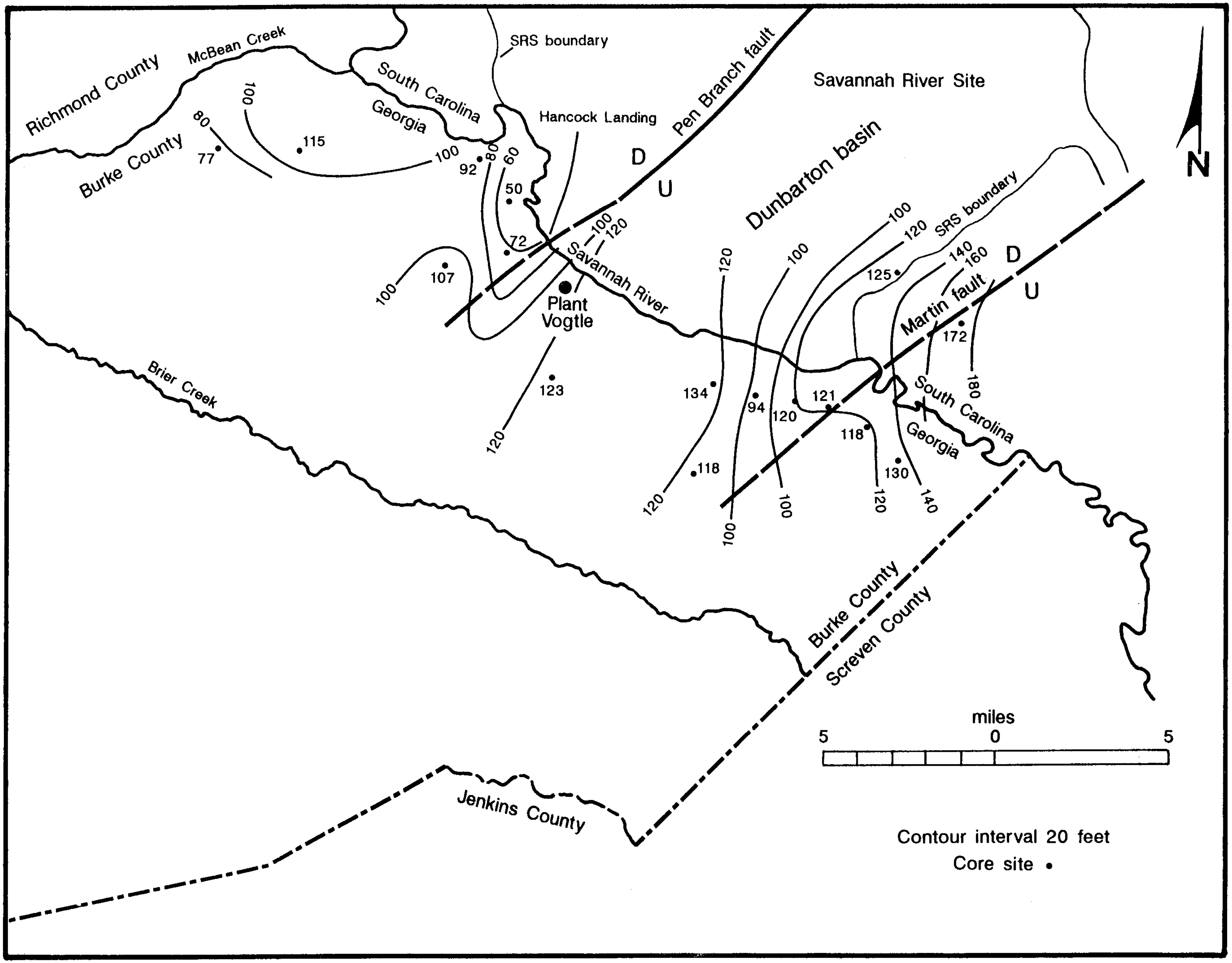

Figure 12. Undifferentiated Black Mingo/Snapp Formations isopach (thickness distribution) map. Thicknesses are in feet.

represents the regressive, falling sea level of the Selandian, Upper Paleocene.

Age

The undifferentiated Black Mingo Formation in southern Burke County, Georgia is early to late Midwayan in age based on planktonic foraminifera, dinoflagellate assemblages and pollen floras (Edwards, *Globorotalia pseudobulloides* is early Late Paleocene, and *Globorotalia perclara* is especially characteristic of the Early Paleocene, all of Midwayan age, in Georgia. The benthic foraminifer, *Eouvigerina excavata*, has been reported only from Early Paleocene, Midwayan deposits in the Coastal Plain. This assemblage is characteristic of, and restricted to, the Clayton and lower Porters Creek Formations of Alabama and western Georgia.

Edwards (personal communication, 1994) identified the following dinocysts from a sample at 281 feet in core TR92-6 from Burke County, Georgia:

Andalusiella sp. aff. *A. polymorpha* of Edwards (1980)
Gordosphaeridium fibrospinosum
Glaphyrocysta ordinata
Lejeunecysta spp.
Operculodinium spp.
Palaeocystodinium golzowense
Phelodinium sp. of Edwards (1989)
Spiniferites spp.
small peridiniaceans

According to Edwards, "*The dinocysts are most probably of the early part of Late Paleocene age, but again ranges are not well established and many forms are unnamed. The environment is marine, but probably not very far offshore.*"

Edwards identified the following dinocysts from a sample at 302 feet in the core TR92-6:

Alterbidinium? n. sp., near *A. pentaradiata*
Areoligera-Cyclonephelium group
Cordosphaeridium fibrospinosum
Damassadinium californicum
Diphyes colligerum
Glaphyrocysta reticulosa of Firth (1993)
Hystrichokolpoma cinctum?
Hystrichosphaeridium tubiferum
Impagidinium? sp.
Lejeunecysta sp.
Palaeocystodinium (fat)
Phelodinium magnificum s.s.
Spiniferites spp.
Tectadodinium rugulatum?
small peridiniaceans

Edwards concluded that "*the dinocysts are most probably of the latter part of Early Paleocene age, but ranges are not well established and many of the forms are unnamed -- so don't be surprised if it turns out to be early in the Late Paleocene. The environment is marine, but probably not very far offshore.*"

Further, in VG-3, Edwards identified the following dinoflagellate flora from a sample at 459 feet in the Black Mingo Formation:

Alterbidinium? aff. *A.*? *pentaradiatum*
Caligodinium amiculum
Palaeoperidinium pyrophorum
Spinidinium densispinatum
Spinidinium pulchrum
small, pale peridinioids

According to Edwards (personal communication, 1994), "*The age [of the above flora] is Early Paleocene. The distinctive, but unnamed species, Alterbidinium? aff. A.? pentaradiatum is known from the Brightseat Formation in Maryland and the McBryde Limestone Member of the Clayton Formation in Alabama.*"

Edwards identified the following dinoflagellate flora from the Black Mingo Formation at 423 feet in the core VG-3:

Areoligera sp.
Cordosphaeridium inodes
Danea californica?
Fibradinium annetorpense
Kallosphaeridium sp.
Operculodinium centrocarpum
Palaeocystodinium golzowense
Phelodinium magnificum-group
Spinidinium cf. *S. densispinatum*
Spiniferites sp.

She concluded that *"The age is Paleocene, somewhere in the early or 'mid' part."*

Based on the above microfossil identifications and comments, the Black Mingo Formation in eastern Burke County is early to "middle" Paleocene, entirely Midwayan in age (Figure 4). This corresponds to Early and earliest Late Paleocene, Danian and Selandian age. Most of the formation is Selandian in age.

Claiborne Group

Definition

The name Claiborne was first applied by Conrad (1848a, 1848b) to deposits that contain a shelly fauna of similar composition to that of the abundantly fossiliferous deposits exposed at Claiborne Bluff on the Alabama River in Monroe County, Alabama. Smith (1907, p. 17) raised the name Claiborne to group rank and included the Tallahatta buhrstone, Lisbon Formation, and Gosport Greensand in the Claiborne Group. The name Claiborne Group was extended into Georgia by Veatch and Stephenson (1911, p. 235-296) and subsequent usage of the name in Georgia has been varied (Brantley, 1916; Cooke and Shearer, 1918; MacNeil, 1944a, 1944b, 1947; Herrick, 1961; Marsalis and Friddell, 1975).

In this report, the Claiborne Group in Georgia is recognized as a lithostratigraphic unit with the same or similar lithologic characters and stratigraphic position as the Claiborne Group in its type area in southwestern Alabama. It consists of calcareous to noncalcareous, variably fossiliferous, variably glauconitic, argillaceous, fine- to coarse-grained sand with scattered beds of clay, siliceous claystone (buhrstone), and limestone. The Claiborne Group consists of three formations in Georgia; the Congaree Formation, Still Branch Sand (new name), and Lisbon Formation. In outcrop in western Georgia, the Claiborne Group consists of the Congaree Formation (Tallahatta Formation of past usage) in the lower part, and the Lisbon Formation in the upper part. Both the Congaree Formation and Lisbon Formation extend across Georgia from eastern Alabama to the Savannah River in Georgia, however, from the vicinity of the Flint River to the Savannah River, the Congaree and Lisbon Formations are known only as subsurface units. Except for one exposure on lower McBean Creek in Burke County, the Still Branch Sand is entirely a subsurface unit in Georgia.

The Congaree Formation is included in the Claiborne Group in this report because of its lithology and stratigraphic position. It has consistently been called Tallahatta Formation in the Chattahoochee River area since 1947 (MacNeil, 1947a, 1947b; Toulmin and LaMoreaux, 1963; Marsalis and Friddell, 1975; Reinhardt and Gibson, 1981; Huddlestun, et al, 1988) and, therefore, is an integral part of the concept of the Claiborne Group in Georgia.

The Still Branch Sand is included in the Claiborne Group because of its general lithologic similarity to Claiborne Group deposits (i.e., it is a fossiliferous, variably argillaceous, calcareous sand). Undifferentiated Still Branch Sand grades updip into the Bennock Millpond Sand Member. The Bennock Millpond Sand is marginally a part of the Claiborne Group. Some of the Bennock Millpond lithofacies (e.g. shell beds) are lithologically much like the Lisbon Formation in southwestern Alabama. However, the stratified, fine-grained, well-sorted sand of the Bennock Millpond is lithologically very similar to the Perry Sand of the Fort Valley Group (Huddlestun and Hetrick, 1991) in central and southwestern Georgia. The upper, outcropping part of the Lisbon Formation (= *Cubitostrea sellaeformis* Zone) in Burke County is divided into two formal members in this report: the Blue Bluff Member and the McBean Limestone Member. An undifferentiated Lisbon sand (Figure 5) is also associated with the McBean and Blue Bluff Members in northern Burke County.

Type Locality

The type locality of the Claiborne Group is the section of Lisbon Formation and Gosport Sand exposed at Claiborne Bluff on the Alabama River in Monroe County, Alabama.

Lithology

The lithology of the Claiborne Group as a whole is dominated by quartz sand, clay and, to a lesser degree, calcite and biogenic debris. Locally, or in some beds or stratigraphic subdivisions, any of the primary three lithic components may be minor or, rarely, absent. Subordinate lithic components include chert "buhrstone" (or cristobolitic claystone), glauconite, greensand, phosphate (both in the forms of vertebrate bone debris and black to brown, pelletal apatite), mica, pyrite, lignitic and carbonaceous material, zeolites, and shells and other bioclastic debris.

Stratigraphic Relationships

The Claiborne Group in Georgia extends across the state from the Chattahoochee River to the Savannah River and into western South Carolina. In Georgia east of the Ocmulgee River, the Congaree Formation appears to pinch out in the shallow subsurface. The stratigraphic relationship of the Congaree Formation with the Fort Valley Group and Oconee Group are unknown. The northern limit of the lower Lisbon Formation (*Cubitostrea lisbonensis* Zone) is in the subsurface from central or eastern Alabama to the western edge of the Savannah River where the formation crops out near McBean Creek. Stratigraphic relationships between the lower Lisbon-equivalent Still Branch Sand, and the Fort Valley and Oconee Groups are unknown. The location of the northern limit of the upper Lisbon Formation in eastern Georgia is probably defined by a coastward facies change into the kaolin-bearing "Jeffersonville" member of the Huber Formation (Oconee Group) of Huddlestun and Hetrick (1991). This stratigraphic relationship appears to hold as far east as the Savannah River area in Georgia. In Burke County, Georgia, the Claiborne Group disconformably overlies the Snapp Formation and is overlain by the Barnwell Group.

The lithology of the Claiborne Group differs from that of the underlying Wilcox Group in western Georgia in being typically less argillaceous and more calcareous and fossiliferous. In addition, the Wilcox Group sediments appear to be more abundantly and coarsely micaceous. The lithology of the Claiborne Group differs from that of the overlying Ocala Group (where the two groups are in contact) in being more sandy, argillaceous, glauconitic, less calcareous, and finer textured. In eastern Georgia, it differs from the overlying Barnwell Group in being more calcareous with less separation of sand, calcite, and clay "marl".

In general, the depositional environment of the Claiborne Group was open marine, inner to middle neritic, relatively fine-grained, siliciclastic-dominated, continental shelf. Coastal marine deposits, outer shelf deposits, and carbonate bank deposits are not present in the Claiborne Group.

Age

The Claiborne Group is mostly Middle Eocene, Lutetian and Bartonian in age in Georgia. The oldest formation of the group in Georgia, the Congaree Formation, is interpreted to be contained in planktonic foraminiferal Zone P 10 or P 11 (*Hantkenina aragonensis* Zone or *Globigerinatheka subconglobata* Zone). Gibson and Bybell (1983) reported Early Eocene ages for the lower part of the Tallahatta in Mississippi, Alabama, and Georgia. However, the senior author has identified no Early Eocene planktonic foraminifera indicating the presence of planktonic foraminiferal zones P7, P8, or P9 in Georgia or Alabama. In western South Carolina, the upper Lower Eocene (Edwards, personal communication, 1993) Fourmile Creek Formation of Fallaw and Price (1992, 1995) is of Congaree Formation lithology and considered here to be lithostratigraphically a part of that formation. Although we cannot confirm a late Early Eocene age for the Congaree and Tallahatta Formations, based on the identifications of Edwards (personal communication, 1995) we can assign a late Early Eocene age for the lower part of the Claiborne Group in Georgia. The age range of the Claiborne Group in Georgia, therefore, is late Early Eocene through the Middle Eocene. This will be discussed more fully in the section on the age of the Congaree Formation. The youngest confirmable Claiborne Group in Georgia, the upper part of the Lisbon Formation (*Cubitostrea sellaeformis* Zone) is interpreted to be in the planktonic foraminiferal zone P 13 (*Orbulinoides beckmanni* Zone). Unless the Clinchfield Sand is temporally equivalent to the Gosport (Huddlestun and Hetrick, 1986), no post-Lisbon, Claibornian sediments are currently recognized in Georgia. In that case, it is possible that the upper Claibornian Gosport Sand of the eastern Gulf Coast stratigraphically correlates with the Clinchfield Formation of Barnwell Group, which is lower Jacksonian. According to established usage (Huddlestun and Hetrick, 1986), the Clinchfield may be Late Eocene in age but Claibornian in stage.

Congaree Formation

Definition

As applied here, the Congaree Formation in South Carolina and Georgia consists of an updip, variably siliceous clay, and clay and sand lithofacies, and a downdip, shallow subsurface, massive-bedded, fine- to medium-grained, moderately to well-sorted, soft and barely coherent sand lithofacies. The Congaree Formation of this report differs from the Congaree Formation of SRS in South Carolina (Fallaw and Price, 1992, 1995) in that the Fourmile Branch Formation of Fallaw and Price (1992, 1995), lithostratigraphically is included in the Congaree Formation, in Burke County. A further discussion of the Congaree nomenclatural history is included in Appendix 3.

Based on literature from the outcropping, type area of the Congaree Formation (Sloan, 1907, 1908; Cooke, 1936; Cooke and MacNeil 1952), the type Congaree consists primarily of shale and clay with subordinate amounts of quartz sand occurring either in beds or interstitially. According to Paul Nystrom (personal communication, 1995) of the South Carolina Geological Survey, however, there is more sand in the Congaree Formation in its type area than has been reported in the literature.

If the type Congaree were consistently a clay and shale in its type area, as indicated in early reports, it would not be litho-stratigraphically proper to extend the name Congaree to shallow subsurface sand sections in SRS in South Carolina or in Georgia. However, we believe the discrepancy between the reported outcropping Congaree shale and clay lithology in its type area, and that in the shallow subsurface, is a result of relative ease of erosion and mass wasting of the soft sand lithofacies in outcrop. This leaves a relatively high proportion of the argillaceous lithofacies exposed. As a result, we propose to formally expand (redefine) the name Congaree to include the shallow subsurface sand sections in South Carolina and across Georgia westward to the Chattahoochee River.

In the northern, updip part of Burke County, the Congaree Formation is more lithologically variable than it is in southern Burke County and consists of sand and clay. In southern Burke County, the Congaree Formation is homogeneous and consists of sand. The Congaree sand extends across the subsurface of Georgia to the Chattahoochee River area.

In the past the lower Claibornian section in Georgia and in the vicinity of the Chattahoochee River has been called Tallahatta Formation (MacNeil, 1944a, 1944b; Herrick, 1961; Toulmin and LaMoreaux, 1963; Owen, 1963; Marsalis and Friddell, 1975; Reinhardt and Gibson, 1981; McFadden, et al, 1986). In its type area, the Tallahatta Formation is a lightweight, siliceous claystone (buhrstone), and quartz sand, if present, is a minor lithic component. The Tallahatta is very resistant to erosion and, therefore, forms a cuesta where the formation is present. Typical Tallahatta Formation lithology is present only as lenses in an updip, predominantly argillaceous sand formation east of southwestern Alabama and in the type area of the Congaree. The Tallahatta Formation exists neither in the lower Claibornian stratigraphic position in the Chattahoochee River area, nor in the shallow subsurface of Georgia east of the Chattahoochee. The lower Claibornian of the Chattahoochee River area contains exposures that cannot be distinguished from the Congaree Formation in its type area. Therefore, we recommend the adoption of the name Congaree for the lower

Claibornian westward across the state of Georgia to the Chattahoochee River.

The Congaree Formation is placed in the Claiborne Group in this report because exposures of the formation in east central Alabama and the Chattahoochee River area have always been considered an integral part of the Claiborne Group.

Type Locality

Sloan (1907, 1908) did not designate a type locality for the Congaree Formation and, therefore, there is no type locality by original designation for the formation. However, Cooke (1936, p. 59) assigned the amphitheater at the head of First Creek as the principal reference locality (lectostratotype) for the formation. The exposure of the Congaree in the amphitheater is the principal reference section (lectostratotype) for the Congaree Formation. The principal reference locality is in Lexington County, 0.8 mile (1.28 km) west of Gaston in the updip central Coastal Plain of South Carolina.

In eastern Burke County, five cores are designated as Congaree Formation reference localities in Georgia (Table 7). The core site localities are described in Appendix 1, and the coordinates are listed in Table 1.

Core TR92-1 has good recovery of the formation (66%) and is representative of the updip, mixed sand and clay lithofacies of the Congaree in northern Burke County. Core TR92-2 contains a representation of the bioturbated and burrowed lithofacies. The TR92-4 core contains siliceous clay as the dominant lithic component. This lithofacies is similar to the typical outcropping Congaree in the type area in central South Carolina. Core TR92-5 contains some of the ranges of lithology seen in the Congaree in northern Burke County. Core VG-6 is characteristic of the downdip, massive-bedded, barely coherent, fine-grained, well-sorted sand lithofacies in Burke County and of the shallow subsurface in Georgia westward to the Chattahoochee River area. The core recovery of the Congaree Formation (93%) in core VG-6 is unusually good for the formation.

Other useful reference sections of the Congaree Formation in Georgia include three exposures in the area covered on the 1:24,000 Columbia NE Ala.-Ga. quadrangle map, and four cores from sites in southwestern and central Georgia. The three exposures in the Columbia 1:24,000 quadrangle are hypostratotypes and are located: 1.) in Factory Creek, at and downstream from the County Road 140 bridge over the creek, two miles (3.2 km) from the northern-most measured section of the Tallahatta Formation of Toulmin and LaMoreaux (1963). This is stop 8, second day of the Georgia Geological Society field trip (Marsalis and Friddell, 1975); 2.) exposures of the formation along Red Branch, a small tributary of the Chattahoochee River, three miles (4.8 km) north of Factory Creek; and 3.) the exposure of the Congaree on Odum Creek, less than 0.25 mile (0.4 km) from the public boat ramp at the confluence of Odum Creek with the Chattahoochee River (near Mile 56 on the Chattahoochee River). The Congaree exposed at the waterfall on Odum Creek exposure contains a calcareous and fossiliferous bed, with the oyster *Cubitostrea perplicata* and may represent Bed 28 of Toulmin and LaMoreaux (1963).

The other core sites (hypostratotypes), not located in Burke County (Table 8), are listed to illustrate lithofacies variations of the Congaree Formation across central and southwestern Georgia.

In the USGS Albany core (GGS-3187), the Congaree Formation occurs in the interval from 401 feet to 539 feet. It is representative of the massive-bedded, poorly coherent to incoherent, sand lithofacies. The upper part of the Congaree, from 401 feet to 478 feet, is characteristically devoid of calcite (except for widely scattered thin sandy limestone beds), and consists of variably coherent to incoherent, massive-bedded, sparsely and sporadically glauconitic, variably and slightly argillaceous sand with scattered clay laminae and variable bioturbation. From 478 feet to the top of the Bashi Member of the Hatchetigbee Formation at approximately 539 feet, the Congaree Formation consists of glauconitic, calcareous, microfossiliferous, argillaceous, fine sand. The Congaree Formation is overlain with apparent gradation by the lower Lisbon Formation

Table 7
Congaree Formation reference sections in eastern Burke County.

Core Site see Figure 2 Table 1	GGS core number	Site Elevation above Mean Sea Level (feet)	Top of formation- feet below surface	Bottom of formation- feet below surface
TR92-1	GGS-3674	235	245	270
TR92-2	GGS-3762	285	308	330
TR92-4	GGS-3782	192	182.5	213
TR92-5	GGS-3792	235	272	290
VG-6	n/a	217	328	428

"n/a"-Not applicable

(*Cubitostrea lisbonensis* Zone?) and is underlain with apparent gradation (paraconformity?) by the Bashi Member of the Hatchetigbee Formation.

In the GGS Sumter 9A core from eastern Sumter County, the Congaree Formation is characteristically a poorly coherent, fine- to medium-grained sand that is difficult to recover in coring operations (~28 % recovery). The sand is characteristically noncalcareous, massive-bedded and structureless with rare scattered beds of laminated clay.

The GGS Laurens County core contains the only Congaree Formation that has been identified in the Ocmulgee River area. The sand lithology is typical soft, incoherent (14% recovery), fine- to medium-grained and well-sorted, with scattered, thin carbonaceous or lignitic beds. There is a bed (9 feet thick) of hard, silty kaolin at the top of the formation. Dinoflagellate identifications by Edwards (personal communication, 1995) indicate a late Early Eocene to early Middle Eocene age for the formation in this core. The GGS Pulaski 5 core contains the only section of Congaree Formation that has been identified from the vicinity of the Oconee River in the central Georgia Coastal Plain. The sand lithology is typical for the formation (fine- to coarse-grained and well-sorted). However, there are beds (< 8 feet [2 m] thick) of argillaceous, carbonaceous sand scattered throughout the formation as thin beds to laminae of clay and carbonaceous clay. There is also a 10 foot thick, massive-bedded, greenish gray kaolin at the top of the formation. Dinoflagellates identified by Edwards (personal communication, 1995) indicate an early Middle Eocene age for the Congaree Formation.

Lithology

In northern Burke County, the lithology of the Congaree Formation is variable, with more beds of clay ("cristobolitic" claystone in the core TR92-4), interstitial clay, some scattered clay clasts(?), and bioturbation. This lithofacies is similar to the Congaree Formation in its type area. In the southern part of the county the sand is almost barren of interstitial clay and is lithologically the same as that in the subsurface in central and western Georgia. In general, in Burke County, there is more clay and silica in updip (nearshore) Congaree Formation, and relatively clean sand with minor clay and silica in downdip (seaward) sections.

Subordinate lithic components of the Congaree Formation in Burke County include mica, sporadic occurrences and low concentrations of pelletal phosphate (sandy phosphate pebbles occur rarely at the base of the formation), scattered thin beds of siliceous sandstone, variable occurrences of dark minerals, variable but minor amounts of lignitic fragments, lignitic flecks, and carbonaceous streaks (mostly in updip, northern Burke County), rare to common acicular gypsum-bloom on cores (as opposed to "cauliflower"-shaped gypsum-bloom), some sulphur bloom?, and minor pyrite. A thin bed of fossiliferous, glauconitic, very calcareous sandstone to very sandy limestone occurs at the base of the formation in southernmost Burke County (core

Table 8
Congaree Formation reference sections in Georgia west of Burke County.

Core Site see Appendix 1	GGS core number	USGS quadrangle map/ Latitude-N /Longitude-W (est.)	Elevation feet above mean sea level	Top of formation-feet below surface	Bottom of formation-feet below surface
USGS Albany	GGS-3187	Albany East 31° 31' 05" 84° 06' 44"	195	401	539
GGS Sumter 9A	GGS-3366	Drayton 32° 04' 03" 83° 59' 23"	270	114	188
GGS Pulaski 5	GGS-3511	West Lake 32° 22' 50" 83° 29' 17"	355	228	380
USGS Laurens 1	GGS-3523	Dudley 32° 30' 59" 83° 02' 43"	285	312.5	421

VG-8). Glauconite, limestone, calcite, and shells are especially characteristic of the formation in the more downdip outcrop in southwestern Georgia whereas traces of pelletal phosphate are more conspicuous in central and eastern Georgia.

The Congaree typically is massive-bedded and devoid of primary sedimentary structures. However, some intervals at some sites contain vaguely and crudely bedded to conspicuously bedded sands and some thinly layered to laminated lignitic clay beds. Bioturbation is common in some cores from northern Burke County; the sand and clay components are marbled in those cores. Only a few, thin, clearly stratified sand intervals have been observed in the Congaree.

The color of the Congaree sands includes shades of brown, orange, greenish grays, olive grays, olive black to brownish black, and light grays.

Smectitic clay beds from cores in the Congaree are commonly gypsiferous, noncalcareous, fissile and papery, waxy, and may be slightly sandy to silty. They are finely micaceous with some dark minerals found along partings. There are some interbeds or interlaminae of fine to very fine grained sand. Interstitial clay commonly occurs in the bioturbated intervals. There is minor "cristobolitic" claystone and silica-cemented sandstone in Burke County. The claystone is siliceous, indurated, and shaley with very fine sand to silt and mica on bedding planes. The claystone displays irregular to conchoidal fracture.

The colors of Congaree clays range from shades of olive grays, yellowish grays, greenish grays, brownish grays to light grays.

Near the Chattahoochee River and in northern Burke County, the outcropping, updip Congaree is lithologically more variable than in the shallow subsurface across Georgia. This lithofacies is also more reminiscent of the Congaree in its type area. We interpret this pattern of lithology distributions as being consistent with the more varied coastal marine to shallow, inner neritic lithofacies versus the much less varied lithofacies of offshore depositional environments.

Because of the presence of partially indurated, resistant, siliceous sand or thin beds of siliceous sandstone or claystone in the western Georgia outcrop, waterfalls and rapids are common along small tributary creeks of the Chattahoochee River. Typical Congaree in southwestern Georgia is commonly glauconitic with scattered beds that are highly glauconitic

(Toulmin and LaMoreaux, 1963). Phosphate is not apparent on casual inspection of the outcropping formation, but Herrick (1961) reported "phosphate" in this formation from cuttings from most wells between the Chattahoochee and Flint Rivers, and from sands we interpret to be Congaree Formation east of the Flint River. Silica-replaced shells are locally present and blocks or pods of fossiliferous chert or chert-cemented sandstone are locally conspicuous (Marsalis and Friddell, 1975), indicating that the formation was originally calcareous in the outcrop area.

In the downdip outcrop area in southwestern Georgia, the Congaree Formation is less variable than in the updip outcrop area and consists of thick, massive-bedded, noncalcareous to calcareous sand. Locally, scattered beds of calcareous sandstone or sandy limestone are present. Similarly in this area, the formation is more fossiliferous with locally abundant *Cubitostrea perplicata*.

There are no known lithologically varied, near shore lithofacies of the Congaree between the drainage basins of the Chattahoochee and Savannah Rivers. The characteristic, widespread sand lithofacies of the Congaree occurs in the shallow subsurface and extends westward across Georgia from the Savannah River area to the Chattahoochee River area. Congaree sands are typically soft, barely coherent to incoherent, massively bedded and structureless. Sand size ranges from fine- to coarse-grained with rare occurrences of very coarse sand, granules and pea gravel. Normally the sand is fine- to medium grained and well-sorted. Sand sorting is variable and ranges from well- to poorly sorted. Most commonly the sand is fine- to medium-grained and well- to moderately well sorted. Some coarser quartz sand grains are conspicuously rounded.

Core recovery in the sand is characteristically poor. The Congaree Formation is very permeable and constitutes the "Claiborne" part of the Clayton-Claiborne aquifer in southwestern Georgia and the Gordon aquifer in eastern Burke County. In this predominantly thick sand lithofacies, the Congaree is noncalcareous, nonglauconitic, nonphosphatic (see Herrick, 1961), nonsiliceous and very slightly argillaceous. Some scattered thin clay beds are commonly carbonaceous or lignitic to some degree. Lignitic material is most conspicuous in the updip areas and diminishes downdip. In the Pulaski County and Laurens County cores, a bed of hard, chunky and blocky fractured, Middle Eocene-type kaolin occurs at the top of the Congaree Formation.

Stratigraphic Relationships

In the central Coastal Plain of Georgia, from northern Burke County, southwestward through central Laurens County, through Pulaski County, through Lee County and into Randolph County, the Congaree appears to pinch out northward (updip) in the subsurface. Further westward, the Congaree grades laterally into the Tallahatta Formation in central and western Alabama.

In northern Burke County, Georgia, the Congaree Formation disconformably overlies the Snapp Formation and is gradationally (or paraconformably) overlain by the Bennock Millpond Sand Member of the Still Branch Sand. In southern Burke County, it is overlain conformably or paraconformably by the Still Branch Sand.

In western Georgia, the Congaree Formation disconformably, or paraconformably, overlies the Bashi Member of the Hatchetigbee Formation, and is overlain by the Lisbon Formation. Elsewhere in the state, the Congaree disconformably overlies the Tuscahoma Formation and undifferentiated Wilcox or Midway Groups. It is disconformably overlain by the Lisbon Formation (*Cubitostrea sellaeformis* Zone) in outcrop in western and central Georgia but appears to be conformable with the *Cubitostrea lisbonensis* Zone of the lower Lisbon Formation in the subsurface of Georgia.

Throughout the subcrop area in Georgia, the Congaree Formation thickens rapidly downdip, increasing from 0 to over 100 feet thick within a few miles. In the Savannah River area, however, the rate of seaward thickening is much less, approximately 2.3 feet per mile. The thickest known section of the Congaree Formation is 192 feet (59 m) near Albany, Georgia, in the USGS Albany core. The known average thickness of the Congaree Formation in central and southwestern Georgia is 124 feet. In eastern Burke County, the thickness of the Congaree Formation ranges from 0 feet in the north to 62 feet (10 m) in the south (Figure 13). The average thickness of the Congaree in eastern Burke County is 38 feet (12 m). However, in the study area in northern Burke County, the Congaree Formation ranges in thickness from 0 feet in the GGS McBean core to 42 feet in core TR92-3. The average thickness of the formation is 21 feet (6.4 m). In the vicinity of the projected location of the Pen Branch fault, the Congaree Formation thins to less than 20 feet (Figure 13).

From northern Burke County to the Screven County line, average dip on the top of the Congaree Formation is approximately 12 feet per mile to the southeast (Figure 14). From the vicinity of McBean Creek to the vicinity of the Pen Branch fault, average dip is approximately 14 feet per mile. Southeast of the Pen Branch fault, there is a dip reversal (Figure 14), which is followed by a return to a dip of 14 feet per mile to the county line.

The Congaree Formation is distinguished from the underlying Snapp Formation by the presence of gray sand and thinly bedded to laminated clay in contrast to the top of the Snapp Formation which consists of "bleached", pyritic, very light gray to white kaolin.

Deeper in the Snapp Formation, the kaolin is mottled with various shade of red, reddish brown, orange, and gray. The underlying sand is characteristically white, kaolinitic, variably micaceous, poorly sorted and medium- to coarse-grained.

In northern Burke County, the Congaree is distinguished from the overlying Bennock Millpond Sand Member of the Still Branch Sand in that the Bennock Millpond consists of fine- to very fine grained sand, the sand commonly is thinly to very thinly bedded (some intervals are massive-bedded and structureless), and variably calcareous and fossiliferous with conspicuous aragonitic mollusk shells. The underlying Congaree consists of interbedded, fine-grained sand and siliceous clay with some sections consisting mostly of variably siliceous, laminated, papery clay. The Congaree is invariably noncalcareous and nonmacro-fossiliferous.

In southern Burke County, the overlying Still Branch Sand is invariably calcareous, microfossiliferous (calcitic microfossils), and yellowish in color (due to calcareous particles). The Congaree consists of gray, noncalcareous sand. The two formations are lithologically similar except for the invariable presence of calcite in the Still Branch Sand.

Based on the presence of dinoflagellates, the environment of deposition of the Congaree Formation, in outcrop and in the shallow subsurface, is inner neritic continental shelf. Farther downdip (in more offshore sections), the Congaree was deposited in more open marine conditions, based on the presence of glauconite, phosphate, and diverse assemblages of planktonic foraminifera and dinoflagellates.

Normally, in updip and downdip lithofacies relationships, the updip, shoreward deposits consist of coarser siliciclastics, and the grain-size of the siliciclastics decrease in a downdip, seaward direction. One would expect, then, to find nearshore sands, offshore clays, and far-offshore limestones. In the case of the Congaree, the deposits are relatively fine updip, and coarsen downdip. There are two possible interpretations of this depositional pattern.

The first interpretation is that the updip, fine-grained Congaree may have been deposited in a coastal marine, back-barrier environment. In Burke County, the Pen Branch fault appears to mark the area of lithofacies change from argillaceous, siliceous, and carbonaceous Congaree in the north, to medium to coarse, relatively clean sand to the south. A barrier island may have developed along the crest of the upthrown, south side of the fault although no barrier island-type deposits have been identified along the projected trend of the fault. A second interpretation is that the Congaree deposits in Burke County were deposited at different times. The oldest Congaree in northern Burke County is youngest Early Eocene, but most of the dinoflagellate floras identified by Edwards are older Middle Eocene or near the Middle/Early Eocene boundary. This contrasts with the sandy, downdip Congaree in southern Burke County where there are many youngest Early

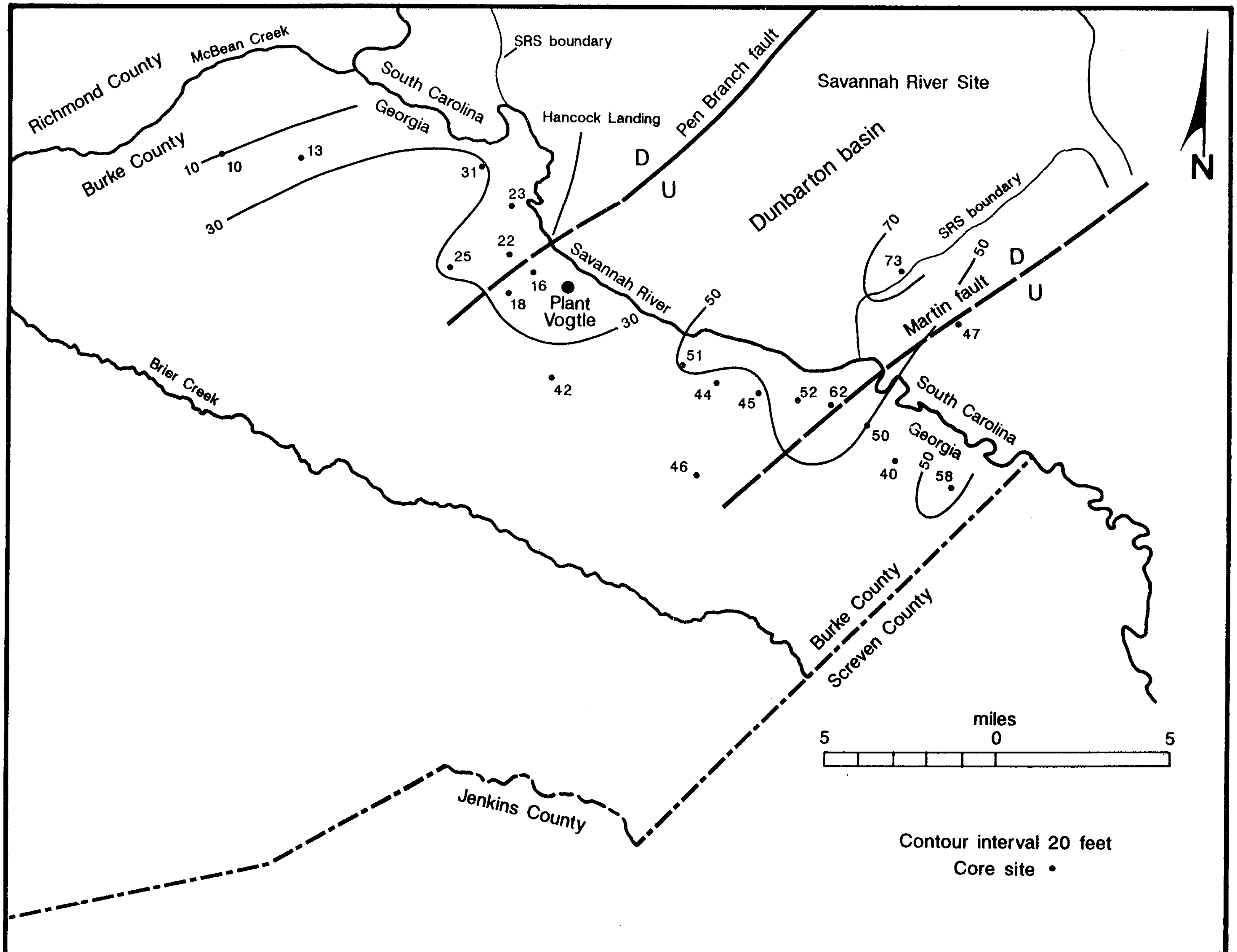

Figure 13. Congaree Formation isopach (thickness distribution) map. Thicknesses are in feet. Modified from Summerour and others (1994).

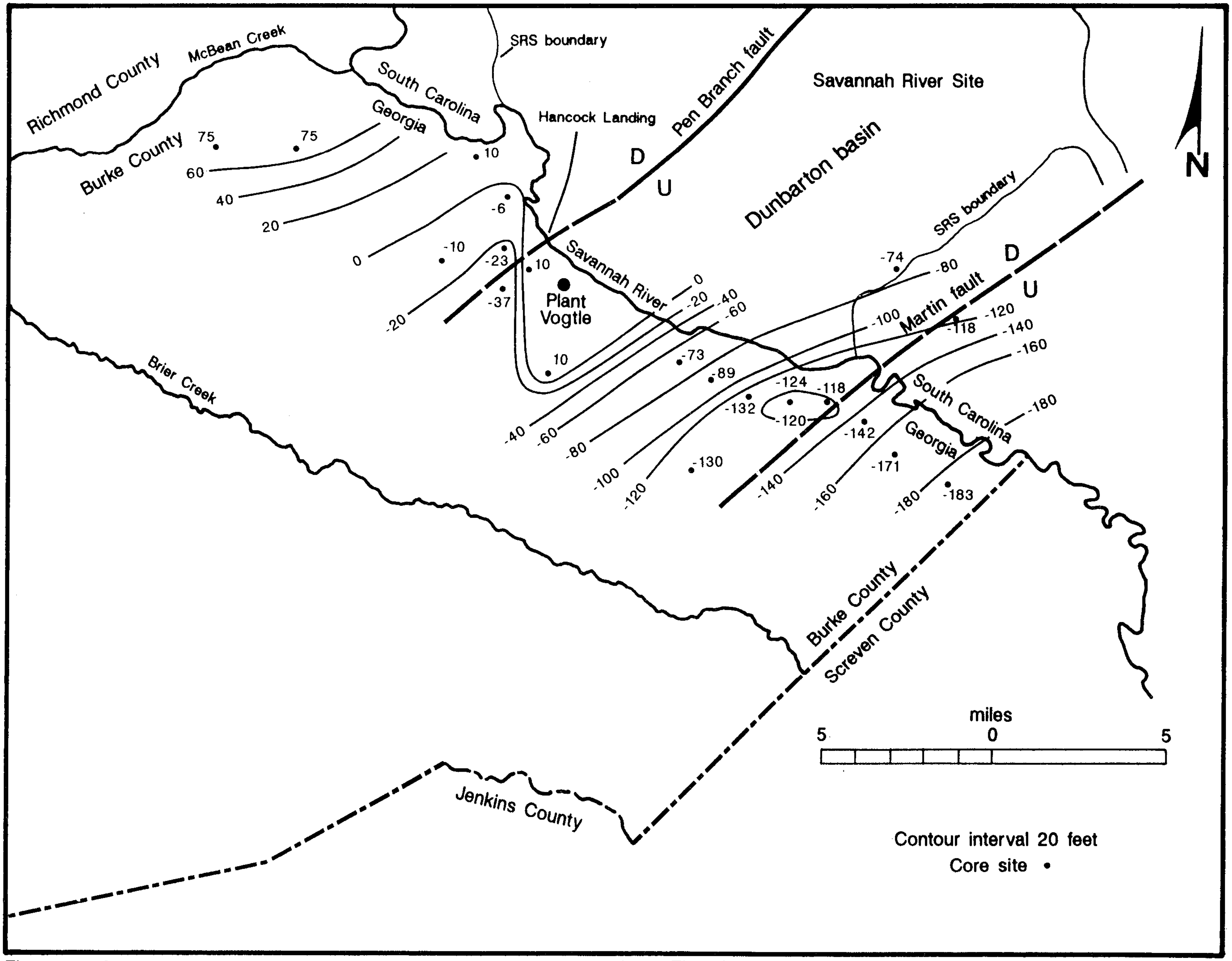

Figure 14. Structure contour map of the top of the Congaree Formation. Elevations are in feet relative to mean sea level.

Eocene floras and fewer Middle Eocene floras. The depositional patterns could be interpreted to indicate that the Congaree is a diachronous deposit. Most sedimentation first took place in a more open marine environment in southern Burke County, and later, after broaching the subtle topographic high on the Pen Branch fault, most sedimentation took place during the earliest Middle Eocene when carbonaceous, siliceous clays with interbedded fine sand was deposited in a protected coastal environment.

Age

In Georgia (and Alabama) the only planktonic foraminifera from the Congaree Formation (and Tallahatta Formation) are of early Middle Eocene age. This defines the typical Congaree (and Tallahatta) as being of early Middle Eocene, Lutetian, conventional early Claibornian age. Planktonic foraminiferal suites that determine the age of the Congaree and correlation of the Congaree Formation with the Tallahatta Formation include the following suite that the senior author has identified from the Tallahatta and Congaree Formations in sites from Alabama and western and central Georgia (subsurface):

Morosovella aragonensis
M. spinulosa
Globorotalia cerroazulensis pomeroli
G. bolivariana
Globigerina frontosa
G. linaperta
G. inaequispira
G. cf. *eocaena*
G. higginsi
Acarinina spinuloinflata
A. broedermanni (in part *Globorotalia crassata densa* of Bandy, 1949)
A. pentacamerata (in part *Globigerinoides pseudodubia* of Bandy, 1949)
Pseudohastigerina wilcoxensis

The planktonic foraminifera restricted to the Tallahatta Formation of Alabama (*C. perplicata* Zone), the Congaree Formation of Georgia and the basal *Cubitostrea lisbonensis* Zone of the Lisbon Formation include the following:

Morozovella aragonensis
Globigerina frontosa
G. higginsi
G. inaequispira
Acarinina spinuloinflata
A. broedermanni
A. pentacamerata

The association of *Globorotalia cerroazulensis pomeroli* and forms close to *Globigerina eocaena* with *Globigerina higginsi*, *Acarinina broedermanni*, *Morozovella aragonensis*, and *Pseudohastigerina wilcoxensis* (Stainforth et. al., 1975) indicates that the Tallahatta Formation, the basal part of the Lisbon Formation (*C. lisbonensis* Zone), and the Congaree Formation of western Georgia are in the *Hantkenina aragonensis* Zone (P10 of Berggren, 1971, 1972; Haq, et al, 1987).

"Anodontia"? augustana is a useful macroguidefossil for the Congaree Formation in its type area. *"Anodontia"? augustana* is also found in the Congaree Formation in the Chattahoochee River area and in the upper part of the Tallahatta Formation in Alabama (Toulmin, 1977).

Bybell and Gibson (1982) have assigned the lower part of the Tallahatta Formation of Alabama and the Congaree Formation of western Georgia to the late Early Eocene on the basis of calcareous nannofossils. The lower part of the Congaree and Tallahatta Formations are normally noncalcareous and, therefore, do not contain foraminifera. However, the lower part of the Congaree section in the USGS Albany core near Albany, Dougherty County, Georgia, is calcareous and contains planktonic foraminifera, that do not differ in any way from that of the upper part of the Congaree Formation in the core (except for being less well preserved).

We have seen no planktonic foraminifera from either the Tallahatta Formation or Congaree Formation that can be assigned an Early Eocene age. Those planktonic foraminifera that would be diagnostically late Early Eocene include the following:

Acarinina soldadoensis soldadoensis
A. soldadoensis angulosa

Morozovella formosa formosa
M. caucasica
M. palmerae

On the other hand, Edwards (personal communication, 1993) has identified post-Hatchetigbee, Early Eocene dinoflagellate floras from the Congaree Formation in Burke County, Georgia. She (personal communication, 1994) identified the following dinoflagellate flora taken from core samples of the Congaree Formation in Burke County, Georgia:

Achilleodinium biformoides
Adnatosphaeridium sp.
Areoligera coronata
Areoligera spp.
Charlesdowniea tenuivirgula
Cordosphaeridium fibrospinosum
Cordosphaeridium gracile
Cordosphaeridium inodes
Cribroperidinium giuseppei
Diphyes colligerum
Eocladopyxis? n. sp.
Fibrocysta radiata
Glaphyrocysta intricata
Glaphyrocysta? vicina
Glaphyrocysta sp.
Hafniasphaera goodmanii
Hafniasphaera septata
Homotryblium tenuispinosum
Hystrichokolpoma cinctum
Hystrichokolpoma spp.
Lejeunecysta sp.
Lingulodinium machaerophorum
Muratodinium fimbriatum
Operculodinium centrocarpum
Pentadinium favatum
Pentadinium favatum (primitive forms)
Phthanoperidinium echinatum
Polysphaeridium subtile
Polysphaeridium zoharyi
Samlandia sp.
Spiniferites spp.
Turbiosphaera galatea
Turbiosphaera cf. *T. galatea*
Wetzeliella lunaris
Wetzeliella spp.

According to Edwards, some dinoflagellate floras look: "*... to be slightly older than the Tallahatta Formation at Little Stave Creek and younger than Gibson and Bybell's NP 12 Tallahatta. ... and ...should correlate to NP 13 or NP 14. ... Another scarce dinoflora (289-294 feet in the core VG-4) is indicative of the later part of Early Eocene time.*"

The dinoflagellate flora from the core has an age that: "*is noticeably younger than the type Fishburne and the flora closely resembles that of the upper part of the Nanjemoy Formation in Virginia and Maryland.*"

The stratigraphically higher dinoflagellate flora from 274-279 feet in the core VG-4 consists of the following dinoflagellates:

Areosphaeridium arcuatum/G. intricata
Cordosphaeridium fibrospinosum
Cordosphaeridium gracile
Cribroperidinium giuseppei
Glaphyrocysta divaricata
Glaphyrocysta? *vicina*
Hystrichokolpoma sp.
Operculodinium centrocarpum??
Pentadinium favatum (primitive)
Systematophora placacantha
Wetzeliella lunaris

For this sample, Edwards concluded that: "*The species Hafniasphaera goodmanii presumably gives rise to Pentadinium favatum. H. goodmanii is known from Early Eocene material in Virginia and Maryland in sediments that have been correlated to nannofossil zone NP 13. Pentadinium favatum is known from the upper part of the Tallahatta Formation and the lower part of the Lisbon Formation in Alabama. Primitive forms, such as found here, suggest correlation with the upper part of the Tallahatta. I think the latest information on the Tallahatta Formation is that it includes zones NP 12-14. So the age of this sample is likely to be NP 14 -- which conveniently straddles the Early-Middle Eocene boundary.*"

According to Snipes and others (1993) most of the Congaree in the Savannah River Site in South Carolina is Early Eocene in age. According to Gohn and others (1983), the Congaree Formation: "*... contains fossil assemblages indicating an Early Eocene age, at least for most of the unit. The lower part of the Congaree is moderately to well-sorted, fine to* *coarse quartz sand with clays a few feet thick in the middle and at the top in places. Glauconite, muscovite, and iron sulfide are common accessories. The lower part of the Congaree, as the term is used in this paper, correlates biostratigraphically with the Fishburne Formation, a downdip carbonate".*

Assuming that the age assignment and correlation between the Congaree and Tallahatta Formations is correct, the time intervals and lack of significant lithology differences (or sharp contacts) within the formations indicate that during the long period of Tallahatta and Congaree deposition, eustatic changes in sea level and depositional environments on the continental shelf of Georgia remained unusually stable.

Still Branch Sand

Definition

The Still Branch Sand is a subsurface formation proposed here for a calcareous sand in Burke County. In the past, the Still Branch Sand has been called the "unnamed basal sand of the Lisbon Formation" and "unnamed sands and limestone of the Lisbon Formation" (Bechtel, 1982), and "unnamed member of the Lisbon Formation" (Gorday, 1985). We know of no references to the Still Branch Sand in the past, although it is likely that part of the surface and subsurface Santee Limestone of Fallaw and Price (1992, 1995) and D. Colquhoun and his students may be the Still Branch Sand of this report.

There is one named member of the Still Branch Sand in Burke County, the Bennock Millpond Sand (new name). The member will be described in the next section. The Still Branch Sand is considered to be a formation of the Claiborne Group because it is dominantly a calcareous, sporadically macrofossiliferous sand similar to the lower Lisbon in southwestern Alabama.

Type Locality

The name Still Branch is taken from Still Branch, a tributary of Sweetwater Creek (itself a small tributary of the Savannah River) east of Girard in southern Burke County, Georgia. The type locality of the formation is core VG-6 taken by Bechtel Corporation for Southern Company. The core site is at the intersection of River Road and an unimproved county road approximately 1.3 miles (2.1 km) southeast of the River Road bridge over Sweet Water Creek. The site of core VG-6 is on the USGS 1:24,000 quadrangle map Millett, S.C.-Ga. The type section or unit-stratotype (holostratotype), of the formation is the interval 328 feet to 388 feet in the core. The Still Branch Sand is disconformably overlain by the Blue Bluff Member of the Lisbon Formation at 328 feet, and is paraconformably underlain by the Congaree Formation at 388 feet.

Three other core sites, VG-5 and TR92-5, from Burke County, and the GGS Colquitt County 11, are designated reference localities (parastratotypes) for the Still Branch Sand in Georgia (Table 9, Appendix 1). Core VG-5 is chosen as a reference section because its basal bed is lithologically distinctive and a planktonic foraminiferal fauna that correlates with the lower part of the Lisbon Formation of Alabama was identified at 227 feet in the core. Core TR92-5 is designated a parastratotype because the typical calcareous sand of the Still Branch can be seen to intertongue with the updip, nearshore to coastal marine, Bennock Millpond Sand Member. Core Colquitt County 11, near Doerun in northwestern Colquitt County, on the western flank of the Gulf Trough, is designated a reference locality and parastratotype because the general lithology of the formation is within the range of typical Still Branch and because it also represents a more downdip (offshore) lithofacies of the formation. It is disconformably overlain by a limestone lithofacies of the Blue Bluff Member of the Lisbon Formation and conformably or paraconformably underlain by a very glauconitic to greensand lithofacies of the Congaree Formation.

Lithology

The Still Branch Sand is dominantly a calcareous sand but there commonly is a bed of moldic, sandy limestone or moldic, calcareous sandstone at the top of the formation. Subordinate lithic components include minor interstitial clay, rare thin beds of clay with acicular gypsum-bloom, (some beds appear to contain no clay minerals), glauconite, rare and scattered carbonaceous material, scattered phosphate pellets and phosphatized limestone pebbles near the top of the formation, a trace of dark minerals?, traces of pyrite in a few cores and a trace of interstitial silica and silicified shell fragments at the base of the formation in some cores. Some chalky calcitic fossils and common to abundant molluscan molds are present in the upper limestone or sandstone.

Limestone or sandstone at the top of the Still Branch Sand is typically moldic and coquinoid. The degree of cementation is variable. The limestone is generally indurated and the sandstone may be hard, dense and well-indurated or soft and friable. Limestone or sandstone also occur in scattered, thin beds or nodules throughout the formation in downdip areas. The limestone bed is also rubbly in places with bioclastic texture and much secondary porosity.

Sand distribution is irregular or patchy in the limestone which may be the result of bioturbation. The sand is fine- to medium-grained and moderately to well-sorted. Sand-size and sorting may be variable within any given section. In the upper limestone-sandstone bed, the quartz sand component may be medium- to coarse-grained and moderately poorly sorted. Quartz sand size and shell abundance decreases downward through the Still Branch. The sand is generally poorly consolidated to incoherent. Core recovery is typically low in sand sections of the formation and is especially low in the lower or basal sand.

The sand is generally massive bedded and devoid of sedimentary or biogenic structures. Sand bedding, where evident, is typically vague and the stratification crude. There are rare thin clay beds and some horizontal orientation of shells. The rare and scattered clay beds within the Still Branch have either fine, hackly fracture or are fissile. In the intermediate lithofacies (in core TR92-5) calcareous sand of the undifferentiated Still Branch Sand appears to grade downward into noncalcareous sand of the Bennock Millpond Sand Member.

Most fossils consist of molds and casts of mollusks but chalky calcitic mollusk shells, small macrofossil debris, smaller foraminifera, scattered bryozoan debris, dinoflagellates and palynomorphs also occur in the lower part of the Still Branch Sand below the upper limestone-sandstone bed. Some burrows from the overlying Blue Bluff can be found near the top of the formation.

Still Branch color is mostly yellowish-gray, with other minor shades of gray. Clay colors range from olive-gray to light olive gray.

Stratigraphic Relationships

The Still Branch Sand grades updip (shoreward) into the coastal marine Bennock Millpond Sand Member. Its downdip limit and western limit are not known at this time, although it does occur as far west as northwestern Colquitt County, Georgia. Because of the similarity of the limestones within the Still Branch with the Santee Limestone, and also because of comparable stratigraphic position, it is possible that the Still Branch Sand may grade laterally eastward in South Carolina into the lower part of the Santee Limestone.

The Still Branch Sand overlies the Congaree Formation either conformably or paraconformably in Burke County. It is disconformably overlain by the Blue Bluff Member of the Lisbon Formation. The contact between the two formations is very pronounced, as the top of the Still Branch commonly has the appearance of a hard ground. In eastern Burke County, the thickness of the Still Branch Sand ranges from 24 feet (8 m) to approximately 80 feet (26 m) (Figure 15).

The average dip of the Still Branch Sand is approximately 8 to 10 feet per mile, with a slight dip reversal near Hancock Landing and a return to the typical dip southeast of Plant Vogtle (Figure 16).

The Still Branch Sand is distinguished from the underlying Congaree Formation in being invariably calcareous, micro-fossiliferous (calcitic microfossils), and yellowish in color (due to calcareous particles). The Congaree consists

Table 9
Still Branch Sand reference sections.

Core Site see Figure 2 Table 1 Appendix 1	GGS core number	Site Elevation above Mean Sea Level (feet)	Top of formation- feet below surface	Bottom of formation- feet below surface
VG-5	n/a	94	187	236
TR92-5	GGS-3792	235	227	272
Colquitt County 11	GGS-3545	350	791	1113

"n/a"-Not applicable

of gray, noncalcareous sand. The two formations are lithologically similar except for the invariable presence of calcite in the Still Branch.

The Still Branch is distinguished from the overlying Blue Bluff Member of the Lisbon Formation in that the Blue Bluff is a very calcareous clay to very argillaceous limestone, typically massive-bedded in appearance but, on close inspection, is seen to be thinly bedded to laminated. The top of the underlying Still Branch Sand is an indurated coarsely fossiliferous, moldic, sandy limestone to very calcareous sandstone.

The environment of deposition of the Still Branch Sand is interpreted to have been offshore, inner continental shelf. Because the upper part of the formation (limestone-sandstone) extends the farthest updip where the Still Branch gradationally overlies the Bennock Millpond Sand Member, the Still Branch Sand appears to represent a transgressive half-cycle. However, the foraminifera increase in diversity downward in the section and coarse sand in the limestone or sandstone at the top of the formation may indicate a regressive half-cycle.

Age

The age of the Still Branch Sand is Middle Eocene, Claibornian, and appears to be correlative with the lower or middle part of the Lisbon Formation of Alabama (*Cubitostrea lisbonensis* Zone to the lower part of the *Cubitostrea sellaeformis* Zone). The senior author has identified the following planktonic foraminifera from the Still Branch Sand at a depth of 278 feet in core VG-8 in southern Burke County:

Acarinina spinuloinflata (in part = *G. bullbrooki* of some authors)
A. pentacamerata
A. crassata densa (*sensu* Bandy, 1949)
Globigerina eocaena
G. primitiva
G. frontosa
G. cf. *senni*
Globorotalia cf. *G. renzi*
Globigerapsis sp.
Truncorotaloides rohri
Pseudohastigerina micra

The overlapping ranges of typical *Pseudohastigerina micra*, with *Acarinina pentacamerata*, typical *Globigerina frontosa* and typical *Acarinina spinuloinflata* is characteristic of the Middle Eocene *Globorotalia lehneri* Zone or planktonic foraminiferal Zone P12. This zone is between the Congaree Formation (Tallahatta-equivalent) and the upper Lisbon Formation (Cook Mountain-equivalent) (probably P13). In terms of calcareous nannofossil zones, the Still Branch should be within upper-most NP 15 to lower-most NP 16. It is probably within the *Cubitostrea lisbonensis* Zone of the eastern Gulf of Mexico Coastal Plain but no fragments of *Cubitostrea* were noted in any of the cores.

Lucy Edwards of the USGS has identified the following dinoflagellate flora from the Still Branch Sand in the core VG-3:

Achilleodinium biformoides
Cribroperidinium giuseppei
Diphyes cf. *D. ficusoides*
Eocladopyxis n. sp.
Heteraulacacysta pustulata

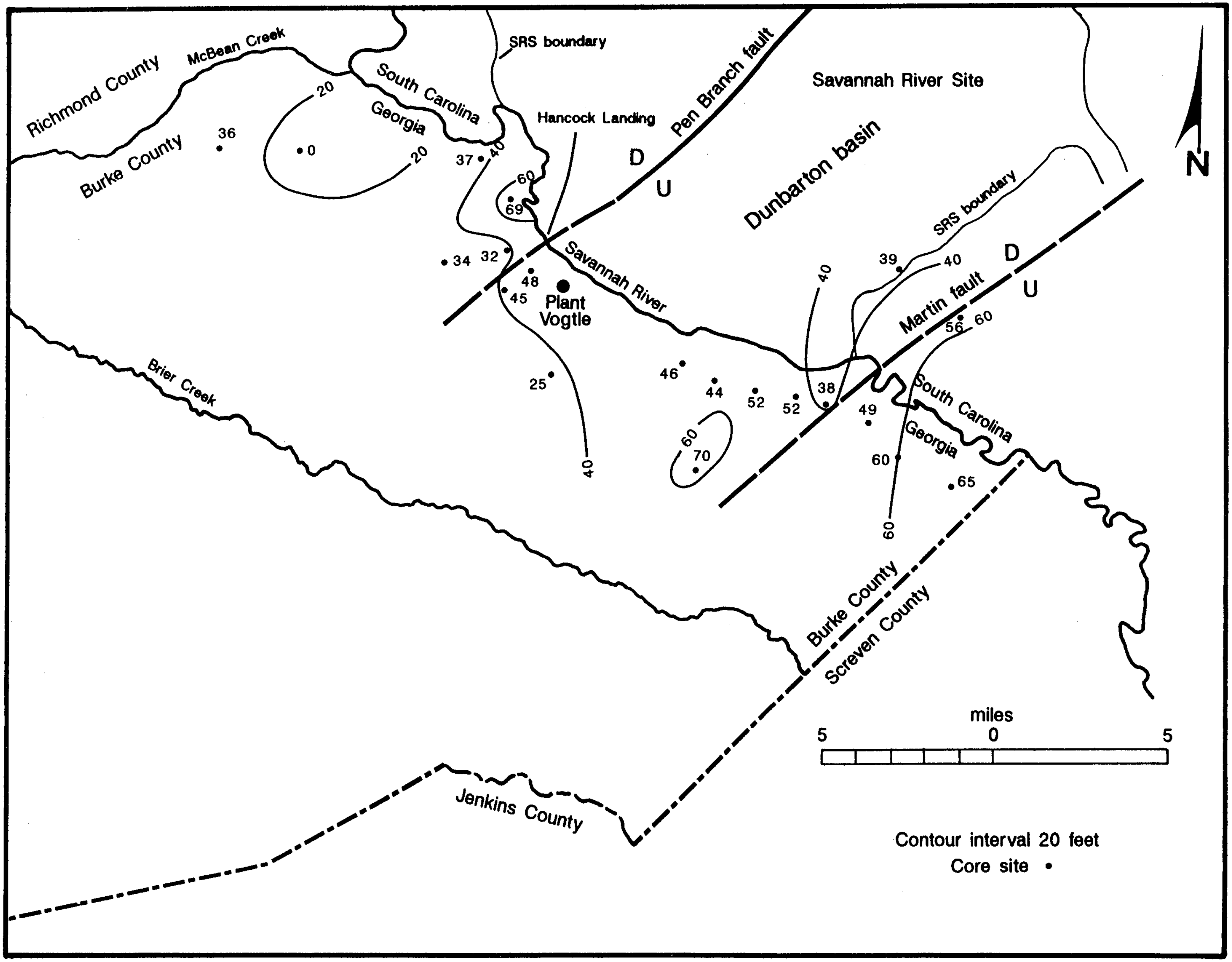

Figure 15. Still Branch Sand isopach (thickness distribution) map. Thicknesses are in feet.

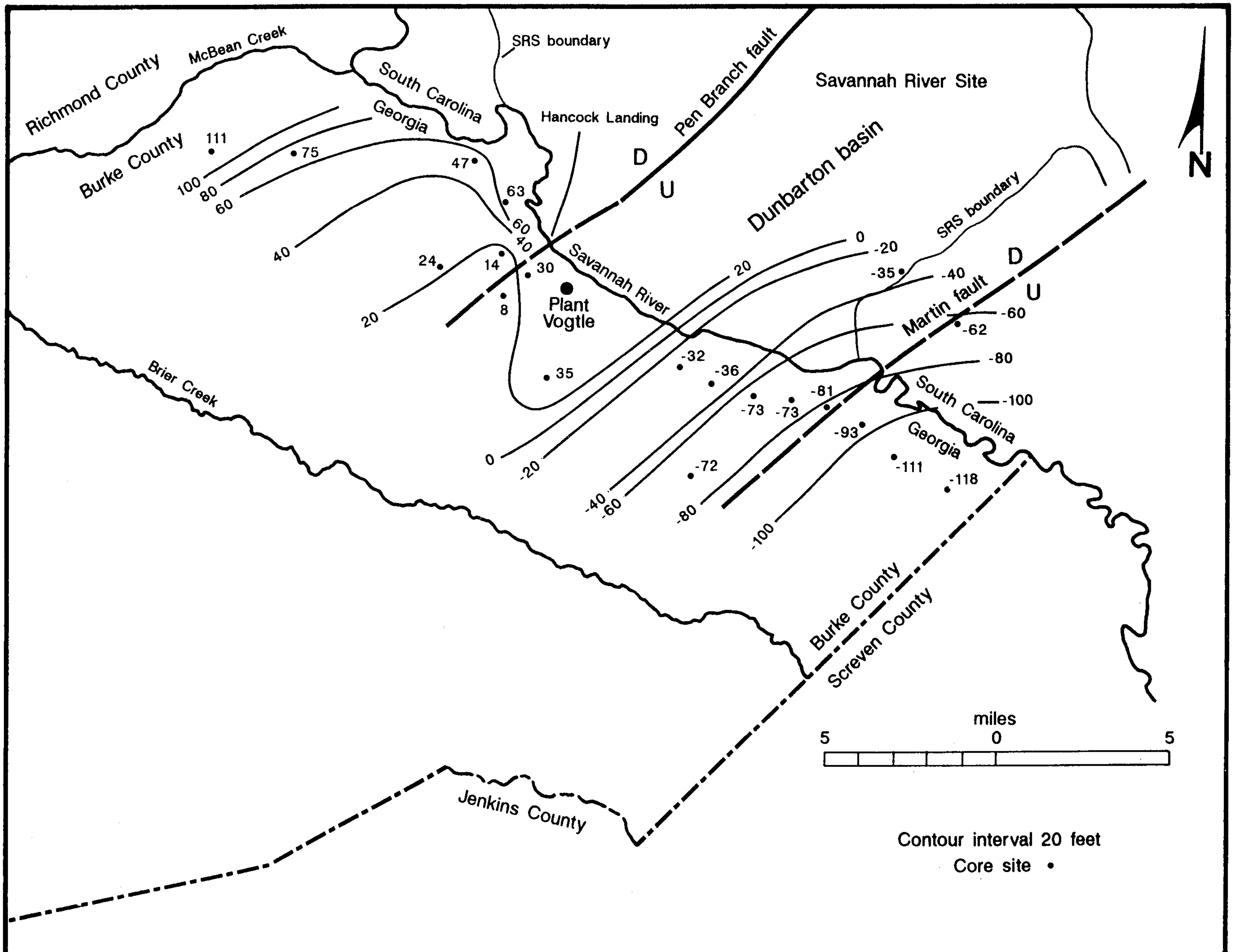

Figure 16. Structure contour map of the top of the Still Branch Sand. Elevations are in feet relative to mean sea level.

Hystrichokolpoma rigaudiae
Lingulodinium machaerophorum
Membranophoridium sp.
Muratodinium fimbriatum
Pentadinium favatum
Samlandia chlamydophora (var. 1)
Spiniferites spp.
Systematophora placacantha
Thalassiphora pelagica
Wetzeliella articulata (var. 1)

Edwards (personal communication, 1995) considers the above flora to be "*of Middle Eocene Age. ...Based on the overall floral similarity ...most likely correlative with the lowest Lisbon at Little Stave Creek*".

Bennock Millpond Sand Member
(new name)

Definition

The Bennock Millpond Sand is a new member proposed here for a lithologically variable sand member of the Still Branch Sand in northern Burke County. The Bennock Millpond Sand Member grades downdip into undifferentiated Still Branch Sand in southern Burke County. The Bennock Millpond Sand Member underlies the McBean Limestone and Blue Bluff Members of the Lisbon Formation. It is mostly a subsurface unit but it crops out in a small area along lower McBean Creek, overlooking the Savannah River flood plain near the base of "Sloan's scarp" in Burke County.

The "McBean" shell bed, from which an extensive collection was made by Sloan (1908) and reported on by Veatch and Stephenson (1911) and Cooke and Shearer (1918), is apparently from the Bennock Millpond Sand Member of the Still Branch Sand and not from the overlying McBean Limestone Member of the Lisbon Formation as was previously thought. There are few other references in the literature to the Bennock Millpond Sand Member. These include the shell bed, called the McBean Formation by Veatch and Stephenson (1911), Cooke and Shearer (1918) Cooke (1936, 1943), Cooke and MacNeil (1952). LeGrand and Furcron (1956, p. 33) penetrated the Bennock Millpond (Beds 2 and 3) during exploratory drilling and they considered it to be McBean Formation. We know of no other references to the Bennock Millpond Sand Member.

The Bennock Millpond Sand Member is a lithologically variable unit and is composed broadly of three distinctive sand lithofacies: 1.) a fossiliferous, calcareous, fine sand; 2.) a massive-bedded to thinly bedded, noncalcareous, fine to very fine grained sand that resembles the Perry Sand (Hetrick, 1990; Huddlestun and Hetrick, 1991; Huddlestun, 1992) and 3.) a noncalcareous, bioturbated sand. Most commonly, the fossiliferous sand gradationally overlies the massive-bedded to thinly bedded sand.

Type Section

The name Bennock Millpond is taken from a pond or small lake that was formed by the damming of McBean Creek where it enters the Savannah River flood plain. The type locality of the Bennock Millpond Sand Member is along McBean Creek, at the base of the northwestern part of "Sloan's scarp" (a term used by Cooke, 1936), the western valley wall of the Savannah River. The type section or unit-stratotype (holostratotype) of the member is that section (now mostly covered) exposed near the base of the valley wall. The type locality is located in the southeastern corner of the USGS 1:24,000 Mechanic Hill Ga.-S.C. and the southwestern corner of the USGS 1:24,000 Jackson S.C.-Ga. quadrangle maps. Due to erosion and vegetation cover, little can be seen of the member at the type locality. As a result, the five cores, GGS-McBean, TR92-1, TR92-2, TR92-4, and TR92-6, are designated as reference localities (parastratotypes) for the Bennock Millpond Sand (Table 10).

Lithology

Quartz sand is the dominant lithic component of the Bennock Millpond Sand Member. Subordinate lithic components includeclay that occurs interstitially, as rare clay clasts, and scattered laminae and thin beds (<1 foot thick). The thin clay beds are finely

Table 10
Bennock Millpond Sand Member reference sections.

Core Site see Figure 2 Table 1	GGS core number	Site Elevation above Mean Sea Level	Top of member- feet below surface	Bottom of member- feet below surface
GGS McBean	GGS-3757	297	186	222
TR92-1	GGS-3674	235	211	245.5
TR92-2	GGS-3762	285	277	308
TR92-4	GGS-3782	192	145	182.5
TR92-6	GGS-3794	240	182	251

micaceous, noncalcareous and are thinly layered to laminated and fissile. All other lithic components are relatively minor and include calcite; aragonite; variable amounts of fine-grained mica (mica is coarser grained in the updip area); glauconite; carbonaceous material; lignitic flecks and rare lignite fragments (rare thin beds of lignite are present in the updip area); pelletal phosphate; traces of bone debris and rare phosphatic clasts (in basal beds). Acicular stellate gypsum-bloom; acicular gypsum-bloom; cauliflower-like gypsum-bloom and rare sulphur-bloom occur on the surface of the desiccated cores. The Bennock Millpond Sand Member is largely noncalcareous but in the upper part there are local or scattered beds of calcareous, macro-fossiliferous (both aragonitic and calcitic fossils) fine sand.

The sand is mainly fine to very fine and well-sorted to very well sorted. In the lower part of the Bennock Millpond Sand Member, grain sizes and textures are more variable, ranging from fine to medium-fine, moderately sorted sand to medium to coarse, well to poorly sorted sand. Granules and pebbles occur near the base of member in the updip area.

Bedding in the member varies from massive-bedded and structureless, to very crudely and vaguely stratified, to massive-bedded and bioturbated. Many sand intervals are almost homogenized by bioturbation. Burrows are present but rare in core samples. Some of the massive-bedded and structureless sands are incoherent.

The fossil shells (mollusks) of this member are distinct from the other fossil shells in other formations in Burke County. The Bennock Millpond Sand Member contains the only well-preserved aragonitic shell fauna (Veatch and Stephenson, 1911; Cooke and Shearer, 1918) that the senior author has found from the early Tertiary in eastern Georgia. Although the McBean does contain a few scattered lenses that contain some aragonitic shell fragments, mollusk shells of the Bennock Millpond Sand Member (both aragonitic and calcitic) are commonly thin shelled, delicate, relatively small in size, and are commonly fragmented. Preservation of the shells is variable and range from very well preserved to chalky and soft. The color of the well-preserved shells is tan to cream whereas the chalky shells are light gray to white. In general, the well-preserved aragonitic shells resemble, in size, color and preservation, those of the Lisbon Formation of western Alabama.

Sand colors range through varying shades of olive-gray to yellowish-gray, shades of brown, orange, gray, brownish-black to olive black where carbonaceous, and varying shades gray.

The colors of the clay beds range through shades of olive-gray to olive-black to brownish-black to yellowish brown.

Stratigraphic Relationships

The Bennock Millpond Sand Member is known to be present in eastern Georgia from northern Burke County, Georgia, in the east, westward to the vicinity of Wrens in Jefferson County. In Burke County, its updip limit appears to be the vicinity of McBean Creek where it is truncated by erosion. The downdip limit in Burke County is in the vicinity of the Pen Branch fault of Snipes and others (1992; 1993) near Hancock Landing where the Bennock Millpond Sand Member intertongues with and grades laterally into undifferentiated Still Branch Sand (Figure 5).

The only clear patterns in the distribution of the three lithofacies mentioned in the section on lithology is that, where the shelly sand lithofacies is present, it occurs near the top of the Bennock Millpond section and overlies the Perry-like sand.

The Perry-like sand lithofacies in the Bennock Millpond Sand Member resemble lenses of Perry sand lithology (Huddlestun, 1992) in the upper Middle Eocene Tinker Creek Formation of Fallaw and Price (1992, 1995). However, all evidence we are aware of indicates that the Tinker Creek Formation is a nearshore, coastal marine facies of the Lisbon Formation. The Bennock Millpond Sand Member, on the other hand, is a nearshore, coastal marine facies of the older, downdip Still Branch Sand of Georgia.

The McBean and Blue Bluff Members of the Lisbon Formation overlie the Bennock Millpond Sand Member with a gradational contact over an interval of one to two feet. This is surprising, because, farther downdip, the same contact between the Blue Bluff and the Still Branch is very distinctly disconformable. In addition, the Bennock Millpond Sand Member and Still Branch Sand both contain lower Lisbon to upper Tallahatta dinoflagellate floras (Edwards, personal communication, 1995), indicating an Early to middle Middle Eocene age. The senior author has identified a small lower (but not lowest) Lisbon planktonic foraminiferal suite from core VG-8. The planktonic foraminiferal fauna is diagnostically Middle Eocene and is younger than the Congaree Formation and older than the Blue Bluff. There appears, then, to be a hiatus between the McBean-Blue Bluff and the underlying Bennock Millpond although the appearance of paraconformity or disconformity is certainly not obvious. This may be due to reworking and mixing of the top of the Bennock Millpond Sand Member by infaunal organisms during the initial deposition of the Blue Bluff. Mixing of Blue Bluff and Still Branch sediments was not possible farther south because the top of the Still Branch was indurated prior to deposition of the Blue Bluff.

The Bennock Millpond Sand Member overlies the Congaree Formation with uncertain contact relationships. There are only two cores (TR92-1 and TR92-4) that have close to 100% recovery across the contact. In TR92-1 the basal bed of the Bennock Millpond Sand Member is a phosphatic, rather coarse, poorly sorted sand that abruptly overlies a thinly bedded to laminated gray clay of the Congaree. In TR92-4, the contact appears to be a bed change with a thin bed (< 6 inches) of powdery chert at the top of the Congaree. These contacts appear to be a disconformity and paraconformity respectively. In all other cores that contain this contact, recovery was not good and the contacts are apparently conformable. It is noted here that the Bennock Millpond/Congaree contact and the Still Branch/Congaree contact in Burke County, Georgia, and the Lisbon/Tallahatta contact in Alabama commonly appear to be gradational. Additionally, the planktonic foraminiferal faunas from the basal Lisbon Formation and the uppermost Tallahatta Formation in Alabama are in the same planktonic foraminiferal zone P10. Similarly the planktonic foraminiferal faunas from either side of the equivalent contact between Tallahatta-equivalent and lower Lisbon-equivalent formations at 1113 feet in core GGS Colquitt County 11, come from the same planktonic foraminiferal zone P10. In general, it appears that this particular formational contact in Georgia is subtle and may be locally disconformable but generally appears to be conformable and gradational (paraconformable).

The Bennock Millpond Sand Member grades laterally downdip into the Still Branch Sand in Burke County, Georgia. Based on stratigraphic position and physical correlation, the Bennock Millpond may grade laterally eastward and northeastward in South Carolina into the Warley Hill Formation.

The Bennock Millpond Sand Member is distinguished from the overlying McBean Member of the Lisbon Formation in that the latter consists of an impure, variably fine grained, sandy limestone that contains scattered calcitic fossils or molds and casts of aragonitic fossils in the limestone. Shell beds or scattered aragonitic shell fragments within the calcareous sand are typical of the Bennock Millpond. Where the Bennock Millpond sands are noncalcareous, the sands are thinly bedded to laminated or massive-bedded with scattered lignitic and carbonaceous material.

The Bennock Millpond Sand Member is distinguished from the underlying Congaree Formation in being variably calcareous and macrofossiliferous, and in containing a significant amount of prominently and thinly bedded, fine- to very fine grained sand whereas the Congaree consists mainly of interbedded, noncalcareous, fine-grained, well-sorted sand with thinly bedded to laminated clay beds and silicified clay. Locally, the thinly bedded clay may constitute the major lithic component of the Congaree whereas clay is not known to be a significant component of the Bennock Millpond Sand Member.

The Bennock Millpond Sand Member is distinguished from the downdip-equivalent Still Branch Sand in that the Still Branch is mostly massive-bedded and structureless, consistently calcareous and macrofossiliferous to some degree (calcitic fossils), and contains a bed of moldic, sandy limestone or, more rarely, moldic, calcareous sandstone at the top of the formation. The Bennock Millpond is a fine- to very fine grained sand that is variably calcareous with noncalcareous sand being predominant. It is variably thin-bedded to laminated and massive-bedded and structureless. The Bennock Millpond Sand Member consists of three different lithofacies whereas the Still Branch is consistently a calcareous, fine-medium to medium-coarse grained sand with either massive-bedded, moldic, sandy limestone or very calcareous sandstone at the top of the formation. The Still Branch Sand is least calcareous at its base and becomes progressively more calcareous upward in the section. The sandy limestone-calcareous sandstone of the Still Branch appears to be correlative with the shell beds in the upper part of the Bennock Millpond Sand Member.

Thickness of the Bennock Millpond Member ranges from 0 feet in the USGS Millers Pond core (Figure 2), to 69 feet (21 m) in core TR92-6. Average thickness in northern Burke County is close to 30 feet (9 m).

The depositional environment of the Bennock Millpond Sand Member appears to have been in the interfingering area between the coastal marine and the inner neritic continental shelf (Still Branch Sand), and most likely represents the shoreface environment of the middle Claibornian. The Perry-like sand lithofacies is a significant lithic component of the Bennock Millpond Sand Member. In the Fort Valley area to the southwest, Huddlestun and Hetrick (1991) ascribed the depositional environment of the Perry Sand to the shoreface based on geographic and facies position. The shallow to middle continental shelf Lisbon Formation lies immediately to the south of the Perry Sand, and the coastal marine Mossy Creek Sand lies to the north. The outcrop band of the Perry Sand is only a few miles across, similar to the outcrop-subcrop band of the Bennock Millpond in northern Burke County.

It appears that the Bennock Millpond Sand Member represents a transgressive half cycle. This interpretation is based on the assumption that shell beds occur seaward of the shoreface and represent more open marine conditions. This is compatible with the Still Branch Sand grading downsection into the Bennock Millpond Sand Member where the two units intertongue (i.e., in TR92-4 and TR92-5). Similarly, the Still Branch Sand also appears to represent a transgressive half cycle because the formation fines and becomes more calcareous and fossiliferous upward.

Age

Edwards identified the following dinoflagellates from GGS core samples of the Bennock Millpond Sand Member from northern Burke County, Georgia:

Achilleodinium biformoides

Adnatosphaeridium? sp.
Cordosphaeridium, gracile
Cordosphaeridium multispinosum
Cordosphaeridium fibrospinosum
"*Dinopterygium cladoides sensu* Morgenroth
Diphyes colligerum
Emmetrocysta n. sp.
Fibrocysta sp.
Glaphyrocysta cf. *G. exuberans*
Glaphyrocysta? cf. *G. vicina*
Hystrichokolpoma rigaurdiae
Lejeunecysta sp.
Lentinia sp.
Lingulodinium machaerophorum
Microdinium sp.
Muratodinium fimbriatum
Nematosphaeropsis spp.
Operculodinium centrocarpum
Operculodinium sp.
Pentadinium favatum
Pentadinium favatum (including advanced forms)
Pentadinium favatum (including primitive forms)
Pentadinium goniferum
Pentadinium laticinctum laticinctum
(1 fragment) small peridiniacean
Phthanoperidinium comatum
Phthanoperidinium echinatum
Polysphaeridium subtile
Polysphaeridium subtile or
Eocladopyxis n. sp.
Polysphaeridium zoharyi
Samlandia chlamydophora var. 1
Samlandia reticulata
Samlandia reticulifera
Spiniferites spp.
Systematophora placacantha
Tectatodinium pellitum
Thalassiphora pelagica
Thalassiphora pelagica n. var.
Turbiosphaera magnifica
Wetzeliella articulata
Wetzeliella articulata s.l.
Wetzeliella articulata var. 1
Wetzeliella lunaris
Wetzeliella/Gochtodinium sp.

According to Edwards, the upper part of the Bennock Millpond Member contains a ... *"dinoflora (that) is definitely what I would call 'Tallahatta or lower Lisbon equivalent' and looks more like the lower Lisbon. I think the latest correlations place this in NP 14 or NP 15, early Middle Eocene. The sample contains ...Middle Eocene dinocysts, dominated by Wetzeliella.*

The environment is likely to be more nearshore than the samples below."
For the middle part of the member, her comments on the flora are as follows: *"The dinoflora looks to be the same age as the Tallahatta Formation at Little Stave Creek. I think it falls within NP 14, early Middle Eocene."*

For the lower part of the member: *"The dinoflora looks to be the same age or slightly older than the Tallahatta Formation at Little Stave Creek and younger than Gibson and Bybell's NP 12 Tallahatta. Thus this sample should correlate to NP 13 or NP 14. That makes it latest Early Eocene or earliest Middle Eocene. ...I didn't see any specimens of* <u>*Wetzeliella*</u> *sp."*

Based on dinoflagellates, the age of the Bennock Millpond Sand Member appears to range from earliest Early Eocene (older Tallahatta-Congaree) to the middle Middle Eocene (*Cubitostrea lisbonensis* Zone of Lisbon Formation).

The senior author has found no planktonic foraminifera in the Bennock Millpond Sand Member. However, a list of planktonic foraminifera from the stratigraphically equivalent Still Branch Sand was given in the previous section. The age of the Still Branch should be applicable to the age of the Bennock Millpond Sand Member.

At this time, we conclude that the best approximation to the age of the Bennock Millpond Sand Member is early Middle Eocene, approximately correlative to the lower Lisbon (*Cubitostrea lisbonensis* Zone) of Alabama and Mississippi.

Lisbon Formation

Definition

The Claiborne beds and Claiborne Formation of Smith, Johnson, and Langdon (1894, p. 122-137) were elevated to group rank by Smith (1907, p. 17). The middle part of the earlier Claiborne Formation was named the Lisbon Formation for calcareous, fossiliferous, clayey sands and sandy clay exposed at Lisbon Bluff on the Alabama River in Clarke County, Alabama (Smith, 1907, p. 18). Veatch and Stephenson (1911, p. 235-237) recognized Claiborne Group deposits in Georgia but did not apply any of the Claiborne Group formations of Alabama (i.e, Tallahatta, Lisbon and Gosport) to the Georgia deposits.

MacNeil (1947a, 1947b) introduced the name Lisbon Formation in Georgia and included all Claiborne Group deposits in it that overlie the Tallahatta Formation and underlie what he believed to be Gosport Sand in the western part of the state. Subsequent to MacNeil (1947a, 1947b), all investigators of Tertiary deposits in western and central Georgia have recognized only the Lisbon Formation for the upper part of the Claiborne Group (Herrick, 1961; Herrick and Vorhis, 1963; Toulmin and LaMoreaux, 1963; Owen, 1963; Wait, 1963; Marsalis and Friddell, 1975; Huddlestun, 1981; Huddlestun, et al, 1988).

Herrick (1961) and Herrick and Vorhis (1963) were the first to extend the name Lisbon Formation across the entire state for Claiborne Group deposits (i.e., of Cook Mountain equivalency) overlying the Tallahatta Formation. Subsequent investigators (Huddlestun, et al, 1974; Huddlestun 1981; Huddlestun, 1982; Bechtel, 1982; Gorday, 1985) also recognized the Lisbon Formation in the Savannah River area.

As used in this report, the Lisbon Formation of Georgia lithostratigraphically is the same as the upper Lisbon Formation of Alabama (*Cubitostrea sellaeformis* Zone-Cook Mountain equivalent). Deposits correlative with the lower part of the Lisbon (*C. lisbonensis* Zone), crop out only along lower McBean Creek in Burke County, Georgia, and are mostly confined to the subsurface in Georgia.

The Lisbon Formation of this report differs from past usage of the name Lisbon or McBean in Georgia. The Lisbon Formation in Burke County of this report includes only those siliciclastic dominated, Claiborne Group deposits that overlie the Still Branch Sand and that are overlain by the Barnwell Group. Usage of the name Lisbon by Herrick (1961) and usage in this report is similar, except that Herrick (1961) included within the Lisbon Formation sands, clays and limestones that contained what he considered to be a Lisbon or Cook Mountain foraminiferal fauna.

Lithology of the typical Lisbon Formation in Alabama and Georgia is too similar to warrant formational distinction between the two states. In addition, application of the name McBean to the Lisbon component of the Claiborne Group in Georgia is inappropriate because the distinctive lithology of the McBean in its type area in Georgia is a soft, impure limestone distinct from the typical Lisbon Formation.

The Lisbon Formation is subdivided into two formal members and an undifferentiated sand (or undifferentiated Lisbon) in this report. The McBean Limestone Member (restricted) is reduced in rank, and the Blue Bluff Member (new member) is formally described. The McBean Limestone Member consists dominantly of sandy limestone whereas the Blue Bluff Member consists dominantly of finely and variably sandy and silty, very calcareous clay or argillaceous and silty "marl" limestone. Beds or lenses of very calcareous sand to finely sandy limestone are volumetrically minor. The undifferentiated sand consists of calcareous, argillaceous, fine- to medium-grained sand with some finely sandy, calcareous clay beds or lenses. Undifferentiated Lisbon sand is found only in the updip and nearshore area, and it occurs spatially between the areas of typically developed McBean and Blue Bluff.

Type Locality

The type locality of the Lisbon Formation is Lisbon Bluff on the Alabama River in Clarke County, Alabama. The section of

Lisbon Formation exposed is the type section or unit-stratotype (holostratotype).

Lithology

In Georgia, and especially in the Savannah River area, the Lisbon Formation is characteristically a calcareous, finely sandy to silty clay or "marl". The three lithic components, clay, sand, and calcite, are present in most beds or lithostratigraphic units. However, specific beds may consist mostly or completely of one or two of the major lithic components. Commonly the formation is more sandy updip or shoreward, and more argillaceous and calcareous downdip where it is a very argillaceous limestone to calcareous "marl". Subordinate lithic components include mica, chert, lignitic and carbonaceous material, shells and other bioclastic debris, glauconite, pelletal phosphate, scattered vertebrate debris, pyrite, zeolite, feldspar, and dark minerals such as epidote, zircon, staurolite, garnet, tourmaline and hornblende.

Smectite is the dominant clay mineral in the Lisbon Formation whereas kaolinite and illite are minor components of the clay mineral assemblage. Clay occurs both in discrete beds and interstitially in the sand, silt, or calcitic "marl". Clay is the dominant lithic component of the Blue Bluff Member of the Lisbon.

The quartz sand component of the Lisbon Formation in Georgia is generally fine- to very fine grained. However, specific beds, especially in the updip, nearshore area may contain medium- to coarse-grained sand. Calcite occurs in variable proportions, absent only near the top of the formation in updip areas, or in areas where the lithofacies changes into stratigraphic equivalent, coastal marine and fluvial deposits (Perry Sand and Jeffersonville member of the Huber Formation of Huddlestun and Hetrick, 1991).

Calcite is most commonly present interstitially in clay in the form of minute bioclastic debris and particles. The downdip, offshore transition from silty, calcareous clay "marl" to silty, argillaceous limestone takes place both by gradation and interfingering. Consequently, the downdip, subsurface Lisbon is very calcareous and may be more properly considered to be an impure argillaceous limestone.

Bedding in typical Lisbon Formation is thick and massive with scattered thin beds that may form either ledges or reentrants. Sediments within the beds generally are partially to completely homogenized by burrowing organisms so that, other than scattered burrows or traces of bioturbation, the sediment is devoid of primary sedimentary or biogenic structures. Bedding contacts in this lithofacies are gradational and rarely sharp. Where the beds are not homogenized or bioturbated, the Lisbon Formation is characterized by thin bedding and lamination, with intricate and prominent bioturbation structures.

Degree of consolidation in the Lisbon Formation ranges from unconsolidated and incoherent to indurated and recrystallized. Most commonly, however, the sediments are compact and resistant but unconsolidated. Sediments of the argillaceous sand lithofacies are generally unconsolidated, but the degree of consolidation increases seaward with increasing clay and calcite content. Generally, only the very calcareous beds or limestone beds are indurated. Consistent with this pattern, the nearshore McBean Member in Burke County is variably indurated.

The sandy, undifferentiated Lisbon is lithologically distinct from McBean and Blue Bluff. In core TR92-4, the lower 26 feet of the Lisbon consists of unconsolidated sand that is very calcareous, argillaceous, glauconitic and phosphatic (pelletal) with fine bioclastic debris. The sand is, in part, massive-bedded and structureless, but also contains some crudely bedded or bioturbated intervals. The sand is mostly fine and well-sorted, and the sediment is granular in texture. The basal bed is an indurated, structureless sandy limestone.

The color of the lower part of the undifferentiated Lisbon in core TR92-4 is mostly yellowish-gray with minor dark yellowish gray but is grayish-orange where oxidized. The limestone at the base of the member is yellowish-gray.

The upper part of the Lisbon Formation in core TR92-2 is a sand but differs lithologically from the sand in the TR92-4. This lithology probably represents and interfingering between sandy McBean and undifferentiated sand. The upper 22.5 feet of the Lisbon Formation in the core consists predominantly of unconsolidated, glauconitic, calcareous sand with a trace of mica and delicate, aragonitic shell fragments, and very sandy limestone. It is massive-bedded and structureless, but with some indication of stratification by horizontal orientation of shell fragments and medium to thick beds or lenses of calcareous sandstone. This sandy interval in the upper part of the Lisbon Formation appears to result from a seaward decrease in calcite content of the Lisbon and a simultaneous increase in quartz sand content.

The colors of the calcareous, sandstone beds, lenses or nodules in the Lisbon Formation in the core TR92-2 are pale yellowish orange and are gray to light gray in the unconsolidated sand. In core TR92-2, the undifferentiated Lisbon grades downward into the Blue Bluff Member by diminishing sand content and increasing clay content.

Similarly, in core TR92-1, the upper 23 feet (7.0 m) of the Lisbon Formation also consists of a very sandy phase. Sand in the Lisbon is fine-grained and well-sorted, massive-bedded and structureless except for the presence of some thin lutitic limestone beds. It is slightly argillaceous, and calcareous with some calcite nodules and thin (< 1 foot thick) lutitic limestone beds. The fine sand is slightly glauconitic with fine-grained pyrite in the lower part. Both clay and calcite are minor components of the lithology and there was poor core recovery due to the incoherence of the fine-grained, well-sorted sand. The contact between the undifferentiated sand and Blue Bluff Member results from an abrupt decrease in the sand content and a simultaneous increase in clay content. Supporting the gradational character of the two lithologies, the basal bed of the Blue Bluff is more argillaceous than overlying beds, and the upper-most bed of the Blue Bluff is sandier than underlying beds.

Stratigraphic Relationships

Generally, the Lisbon Formation thickens in a seaward or downdip direction. It thins updip in Georgia by gradation into the Perry Sand (Huddlestun and Hetrick, 1991) in western Georgia and, in eastern Georgia, by gradation into the Perry Sand or the Jeffersonville member of the Huber Formation (Huddlestun and Hetrick, 1991). The Tinker Creek Formation of Fallaw and Price (1992, 1995) is thought to be a coastal marine equivalent of the Lisbon Formation in the northern part of the SRS and in southern Aiken County, South Carolina.

In Burke County, Georgia, known thicknesses of the Lisbon range from a minimum of 39 feet (12 m) in core TR92-6 to 84 feet (26 m) in core VG-1 (Figure 17). Thickness of the Lisbon Formation is most variable in northern Burke County where it ranges from 39 feet (12 m) to 83 feet (25 m) in core TR92-2. In southern Burke County, thickness of the Lisbon Formation is quite uniform, ranging from 71 feet (22 m) in core VG-7 to 84 feet (26 m) in core VG-1. Average thickness of the Lisbon Formation in eastern Burke County is approximately 71 feet (22 m).

The average dip on the top of the Lisbon Formation in eastern Burke County is approximately 10 feet per mile (Figure 18) with a minor dip reversal southeast of the Pen Branch fault, with a return to a shallow, variable southeast dip, to the Screven County line.

The Lisbon Formation (*Cubitostrea sellaeformis* Zone) contains a diverse fauna of tropical planktonic foraminifera and a diverse flora of dinoflagellates. Planktonic foraminifera inhabit only open marine water masses with normal salinity. Their presence in continental shelf waters far from the continental margin of eastern North America suggests that there must have been strong offshore currents on the shelf, and possibly some upwelling off the continental shelf, to bring planktonic foraminifera into nearshore waters. This is also compatible with the reports of scattered pelletal phosphate (which is derived from cold, deep, oceanic water) in the Lisbon Formation in Georgia (Herrick, 1961). The diverse planktonic foraminiferal faunas in the Lisbon Formation in Burke County, occur in scattered stratigraphic intervals throughout the sections, such as the exposure at the type locality of the McBean Limestone Member. However, many samples have small populations and low diversity.

In Burke County, benthic foraminifera from the Lisbon Formation are characterized by low diversity and high faunal dominance (a fauna dominated by a few species). This is consistent with an inner neritic, marine environment.

Age

Characteristic macrofossils of the outcropping Lisbon Formation in Georgia include:

Cubitostrea sellaeformis
Pteropsella lapidosa
Barbatia rhomboidella

Benthic foraminifera include:

Cibicides westi
Eponides mexicanus
Asterigerina lisbonensis

Larger foraminifera reported by Herrick (1961) and Herrick and Vorhis (1963) include:

Asterocyclina monticellensis
Lepidocyclina antillea

We have identified the following planktonic foraminifera from the Lisbon Formation in Georgia:

Truncorotaloides cf. *topilensis*
T. rohri
Globorotalia spinulosa
Acarinina cf. *spinuloinflata* (in part = *G. bullbrooki* of some authors)
A. crassata densa (*sensu* Bandy, 1949)
A. sp.
Globigerina eocaena
G. cf. *senni*
G. sp.
Globorotalia cf. renzi
Globigerinatheka sp.
Globigerapsis sp.
Pseudohastigerina micra

These groups of fossils establish biostratigraphic correlation of the Lisbon Formation of Georgia with the upper Lisbon Formation of Alabama (Toulmin, 1977; Harris, 1919; Palmer, 1937; Herrick and Vorhis, 1963). Although the nominate taxon of the *Orbulinoides beckmanni* Zone has not been reported from Middle Eocene Coastal Plain sediments, the abundance of *Truncorotaloides rohri* and the local occurrence of *T. topilensis* in the Lisbon Formation indicates an age close to that of P13 of Blow (1969) and the *Orbulinoides beckmanni* Zone of Bolli (1957) and Stainforth and others (1975).

Blue Bluff Member
(new name)

Definition

The name Blue Bluff Member of the Lisbon Formation has been used informally in the Savannah River area in Burke County (Huddlestun, 1981; Bechtel, 1982; Gorday, 1985; Laws, et al, 1992; Fallaw and Price, 1992, 1995) for several years. The Blue Bluff Member is formally named and described here for the characteristically thinly bedded, bioturbated, fine-grained, very calcareous clay ("marl") to very argillaceous limestone ("marl") lithofacies of the Lisbon Formation. It occurs across the state from the Chattahoochee River area in western Georgia to the Savannah River area in eastern Georgia and western South Carolina. It is largely a subsurface unit and represents an offshore, transitional phase between the nearshore, sandy undifferentiated Lisbon Formation (and McBean Limestone Member in Burke County), and an offshore, subsurface, unnamed Lisbon-equivalent limestone in Georgia.

In the past, deposits here called Blue Bluff have been included in the McBean Formation (Veatch and Stephenson, 1911, p. 249; Cooke, 1936; Cooke and MacNeil, 1952; Siple, 1967) and the Lisbon Formation generally (Herrick, 1961; Herrick and Vorhis, 1963; Bechtel, 1982).

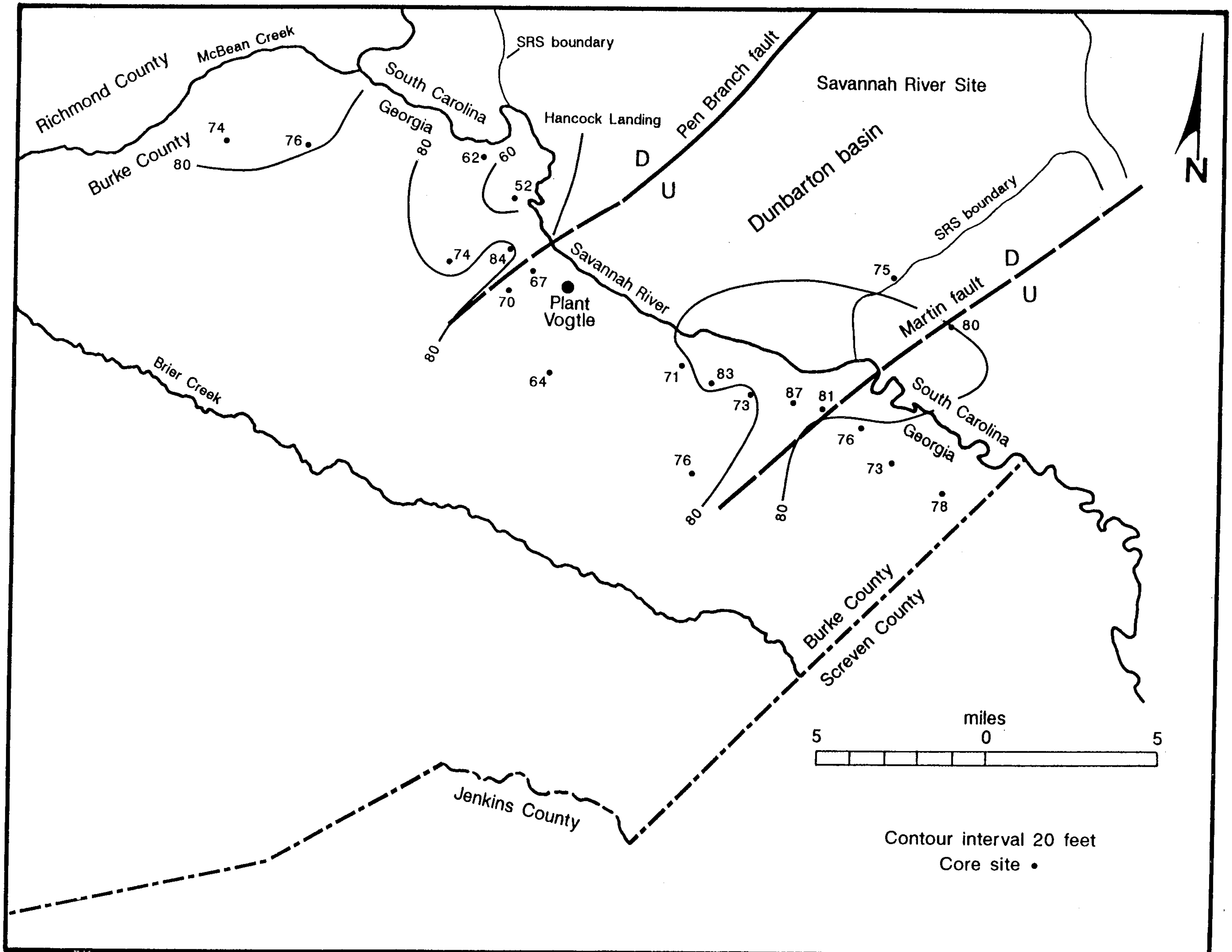

Figure 17. Lisbon Formation isopach (thickness distribution) map. Thicknesses are in feet.

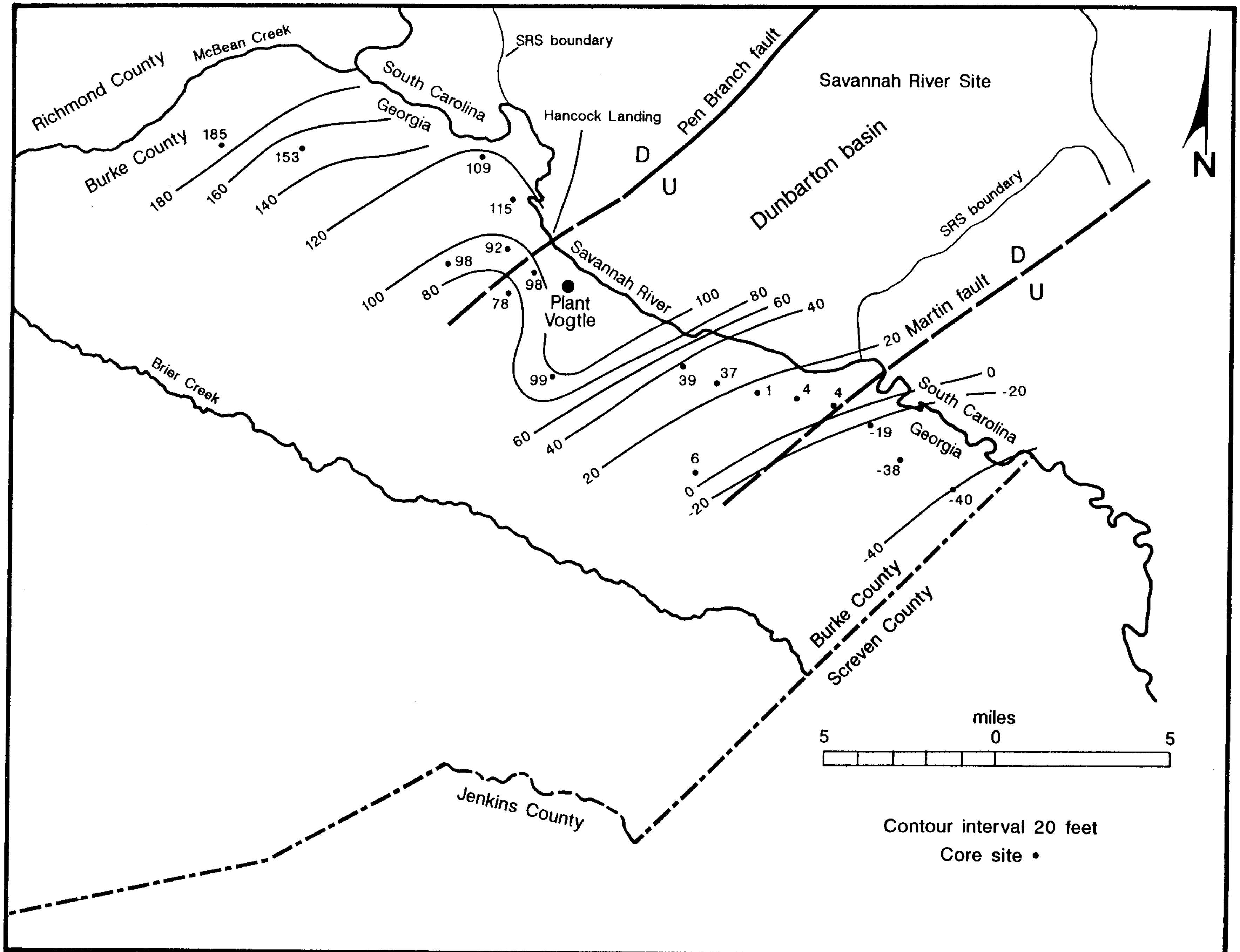

Figure 18. Structure contour map of the top of the Lisbon Formation. Elevations are in feet relative to mean sea level. Modified from Summerour and others (1994).

Type Locality

The name Blue Bluff is taken from Blue Bluff on the Savannah River in Burke County, Georgia. The exposure at Blue Bluff is here designated the type locality of the Blue Bluff Member of the Lisbon Formation (for described sections, see Veatch and Stephenson, 1911, p. 249-250, and Brantly, 1916, p. 54). Blue Bluff is approximately 2 miles (3.2 km) downriver from Hancock Landing, and is now in the southern part of the property of Georgia Power Company Plant Vogtle. The type section, or unit-stratotype (holostratotype) is the entire section exposed at Blue Bluff. Neither the lower nor upper boundaries are exposed at the type locality. Exposures of the member at Blue Bluff and north of Blue Bluff in the river bluffs at Plant Vogtle are the only known outcrops of the member in the Savannah River area (though it was intermittently exposed during construction of the power plant at Plant Vogtle and is the foundation on which the Plant is constructed).

In the Chattahoochee River area, the Blue Bluff Member is exposed at Coheelee Creek in Early County, Georgia (Marsalis and Friddell, 1975, stop 9, p. 68-70).

Four core sites (Table 11), and one outcrop are designated here as reference localities and reference sections (parastratotypes) of the Blue Bluff Member. In the Tritium Project study area, TR92-3 and core VG-6 are designated as reference localities. Outside the study area, USGS Laurens County core, GGS Pulaski 3, and the exposure of the Blue Bluff Member at Coheelee Creek in Early County, Georgia are designated as reference localities.

Core TR92-3 is chosen as a parastratotype because it is characteristic of the member near its lithofacies transition into the McBean Limestone Member. Core VG-6 is chosen as a parastratotype of the Blue Bluff Member because it is lithologically characteristic of the member in southern Burke County. The Blue Bluff lithology is well-developed and the core recovery was good. The Laurens County core and the Pulaski 3 are chosen as a reference sections for the Blue Bluff Member because the member is typically developed in the cores and are the only good example of the member in the Oconee River and Ocmulgee River areas respectively.

The reference locality at Coheelee Creek is in a state park, approximately 0.4 miles east of the confluence of the creek with the Chattahoochee River, 2 miles (3.2 km) northeast of Columbia, Alabama, and 1.6 miles (2.6 km) northwest of the community of Hilton, Early County, Georgia. All the deposits exposed along Coheelee Creek in the state park compose the parastratotype of the member.

Lithology

The Blue Bluff Member of the Lisbon Formation is best described as a "marl", consisting dominantly of clay and calcite with minor, but irregularly distributed fine-grained quartz sand. The Blue Bluff Member typically is a thinly bedded to laminated or bioturbated, silty to finely sandy, very calcareous clay ("marl") to very argillaceous limestone ("marl").

Although clay and calcite are the dominant lithic components of the Blue Bluff Member, it is difficult to determine which component is dominant. Some beds consist primarily of clay whereas others consist of fine-grained, argillaceous limestone. In addition, there are scattered but volumetrically minor lenses of sand in the Blue Bluff, especially at or near the top of the member. Brantley (1916, p. 54) presented one chemical analysis for a sample from Blue Bluff. The percent of carbonate in the sample was 56.1%, indicating that clay and calcite are present in nearly equal proportions. Most likely, calcite is the dominant component downdip, whereas clay is dominant updip. Fallaw and Price (1992) reported (by way of personal communication with Paul Thayer) that much of the Blue Bluff has more than 75% calcium carbonate from SRS cores.

Smectite is the dominant clay mineral, kaolinite and illite are minor constituents (Bechtel, 1982). Calcite principally is interstitial in the form of bryozoan fragments, foraminifera, ostracods, unidentified skeletal fragments. Undefinable microscopic calcite particles and limestone form thin beds, stratified lines of

Table 11
Blue Bluff Member reference sections.

Core Site see Figure 2 Table 1	GGS core number	Site Elevation above Mean Sea Level (feet)	Top of member-feet below surface	Bottom of member-feet below surface
TR92-3	GGS-3781	195	95.5	159.5
VG-6	n/a	217	255	328
GGS Laurens County	GGS-3523	285	247.5	312.5
Pulaski 3	GGS-3111	300	210	315

"n/a"-Not applicable

calcite nodules, and irregularly distributed calcite nodules.

Other subordinate lithic components include mica (which is commonly conspicuous), finely disseminated pyrite, lignitic flecks and fragments, heavy minerals including epidote, zircon, garnet (Bechtel, 1982); opaque minerals, glauconite, pelletal phosphate, zeolite, sodium and potassium feldspar (Na-feldspar and K-feldspar), chert, and minor calcitic, aragonitic, and phosphatic biogenic debris.

Clay-rich layers are a darker olive gray color than the sand or calcite-rich layers, which are lighter shades of olive gray. Bedding in the Blue Bluff Member, therefore, is commonly highlighted by color differences in the sediment rather than by definition by parting along bedding planes. As a result, the Blue Bluff commonly appears to be massive-bedded in outcrop and in cores, but, upon close inspection, the bedding can be clearly discerned. Bedding in the Blue Bluff Member ranges from thin to laminar, and bedding orientation varies from flat to undulatory and, rarely, to gently inclined. Bioturbation ranges from minor rupturing of stratification to complete homogenization.

The Blue Bluff Member is generally tough, cohesive, and dense. Although nonindurated (except for calcite nodules and thin limestone beds or lenses), the typical sediment disaggregates with some difficulty in microfossil preparation.

Stratigraphic Relationships

The Blue Bluff Member of the Lisbon Formation extends across southern Georgia from the Chattahoochee River into the southern part of SRS in western South Carolina (Fallaw and Price, 1992, 1995). In eastern Burke County, Georgia, the updip limit of the Blue Bluff Member is near Hancock Landing, north of Plant Vogtle, where it intertongues with undifferentiated Lisbon sand. There are also scattered lenses of Blue Bluff lithology within the McBean Limestone Member. The downdip limit of the Blue Bluff Member in the Savannah River area is in Screven County, where the upper part of the unit consists of an unnamed, fine-grained, dense limestone. Presumably the limestone thickens at the expense of the underlying, siliciclastic Blue Bluff Member. West of the Savannah River area, its downdip limit is uncertain but the southern-most limit could be the northern flank of the Gulf Trough. However, it seems unlikely that typical Blue Bluff Member lithology extends that far south.

Conventionally the Blue Bluff Member has been correlated with the Santee Limestone of South Carolina (Fallaw and Van Price, 1992, 1995). This correlation, however, is not certain in our estimation. We know of no evidence that the Blue Bluff grades laterally into the Santee Limestone or know of no area where the Santee and Blue Bluff are present in the same geographic area or stratigraphic position. The Blue Bluff certainly does not appear to grade southeastward or downdip in Georgia into

Santee lithology. Rather, it grades downdip into an unnamed, dense, fine-grained limestone in Screven County.

In Burke County, the Blue Bluff Member disconformably overlies the Still Branch Sand, except in core TR92-6 (two miles updip from the Pen Branch fault), where it overlies the Bennock Millpond Sand Member (of the Still Branch Sand). Normally the Blue Bluff Member disconformably underlies the Utley Limestone Member of the Clinchfield Formation, but locally, where the Utley is absent, the Blue Bluff disconformably is overlain by the Dry Branch Formation.

There is 33 feet (10 m) of Blue Bluff Member at the type section at Blue Bluff on the Savannah River. Neither the upper nor the lower contacts of the member are present in outcrop at the type locality. In the subsurface of Burke County, the thickness of the Blue Bluff Member ranges from 64 feet (20 m) in TR92-3, to 84.5 feet (26 m) in core VG-1 taken near the community of Girard in Burke County.

Based on benthic foraminiferal faunas that are characterized by high faunal dominance and low diversity, the environment of deposition of the Blue Bluff Member is interpreted to be open marine, inner continental shelf. The scattered, relatively diverse assemblages of planktonic foraminifera, and the diverse flora of dinoflagellates indicate that the member must have had open access to outer neritic and deep ocean water masses.

Age

The Blue Bluff Member of the Lisbon Formation is Middle Eocene, Bartonian, Claibornian in age and is Cook Mountain-equivalent. It occurs in the upper part of the *Cubitostrea sellaeformis* Zone although only juvenile specimens of *Cubitostrea* are present at Blue Bluff and in the past excavation at Plant Vogtle. *Pteropsella lapidosa*, a pelecypod fossil known only from the Cook Mountain and equivalents (Toulmin, 1977) is present at Blue Bluff. Characteristic planktonic foraminifera include:

Truncorotaloides cf. *topilensis*
T. rohri
Globorotalia spinulosa
Acarinina cf. *spinuloinflata* (in part = *G. bullbrooki* of some authors)
A. crassata densa (*sensu* Bandy, 1949)
A. sp.
Globigerina eocaena
G. cf. *senni*
G. sp.
Globorotalia cf. renzi
Globigerinatheka sp.
Globigerapsis sp.
Pseudohastigerina micra

Cibicides westi is a characteristic benthic foraminifer of the Blue Bluff Member. Herrick (1961, p. 173) reported *Asterocyclina monticellensis* from deposits referred to the Blue Bluff Member of this report in well GGS-248 in Dougherty County, Georgia.

Dinoflagellates identified by Edwards of the USGS include the following:

Adnatosphaeridium multispinopsum
Aeriosphaeridium pectiniforme
Cordosphaeridium cantharellum
"*Corrudinium* sp. 1" of Edwards (1984)
Cribroperidinium giuseppei
Glaphyrocysta? *vicina*
Heteraulacacysta porosa
Hystrichokolpoma rigaudiae
Hystrichosphaeropsis sp.
Lejeunecysta sp.
Leninia sp.
Lingulodinium machaerophorum
Operculodinium sp.
Pentadinium goniferum
(including granulate forms)
Pentadinium goniferum/membranaceum
Pentadinium/Impagidinium
Samlandia chlamydophora var. 1
Spiniferites spp.
Systematophora placantha
Tectatodinium pellitum
Thalassiphora pelagica

Edwards concluded that the above "dinoflora is typical of the 'upper Lisbon to Gosport equivalent.' late Middle Eocene, correlative to NP 16 or NP 17." *Welzeliella* was not found in the sample, indicating the environment was offshore, continental shelf.

McBean Limestone Member
(restricted)

Definition

The McBean Formation of past usage (Appendix 4) is reduced in rank to member status in this report. Its geographic extent is limited, occurring only in northern Burke and southern Richmond Counties (Hetrick, 1992). The McBean, in the strict sense of this report, is not known to exist anywhere else in Georgia. The name McBean is retained because the unit is lithologically distinctive.

The McBean Limestone Member of the Lisbon Formation consists largely of soft to hard limestone that is variably calcarenitic, slightly and variably macro-fossiliferous, finely sandy throughout, and variably argillaceous. The limestone is generally thick-bedded, crudely and massive-bedded, and devoid of sedimentary or biogenic structures.

Type Locality

The name McBean was taken from the community of McBean and from McBean Creek. Veatch and Stephenson (1911) did not expressly designate a specific type locality. Their principle concept of the formation is, however, inherent in their list of measured sections (p. 242) and includes the ravines or gullies in the southern valley wall of McBean Creek in Burke County, Georgia. The section of the McBean now exposed in the ravines and gullies, approximately 0.4 to 0.5 miles (0.64 to 0.8 km) southeast to east of the McBean railroad crossing, along the south side of Ga. Hwy. 56 spur, is the principal reference section (neostratotype) of the McBean Limestone Member. Sloan (1908, p. 269-271) however, presented the most thorough measured section of this locality, and the McBean Limestone Member includes beds (f) and (g) of Sloan's section. Other measured sections of the McBean type locality are to be found in Veatch and Stephenson (1911, p. 2420), Cooke (1943, p. 56), LeGrand and Furcron (1956, p. 33), and Herrick and Counts (1968,. p. 54-57).

There is currently little to be seen of the McBean Limestone Member at the type locality, however, most of the McBean Limestone Member section is exposed at Shell Bluff on the Savannah River. Because Veatch and Stephenson (1911, p. 243-247) extensively discussed the McBean section at Shell Bluff, it stands as a reference locality (parastratotype) for the McBean Limestone Member. Shell Bluff is located at Shell Bluff Landing on the Savannah River at the end of Ga. Hwy. 80 in Burke County, Georgia.

The site of the GGS McBean core (Figure 2, Table 1) is here designated a reference locality for the McBean Limestone Member. This site is 1.2 miles (1.9 km) southeast of the exposure of the limestone in the easternmost gully of the type locality. The section from 112 feet to approximately 186 feet is a reference section (hypostratotype) for the McBean Limestone Member. The upper boundary stratotype is at 112 feet where the McBean Limestone Member is disconformably overlain by the Utley Limestone Member of the Clinchfield Formation. The lower boundary stratotype is at 186 feet where the McBean paraconformably overlies the Bennock Millpond Sand.

Lithology

In outcrop and in nearby cores, the lithology of typical McBean is dominantly a finely sandy limestone. In the GGS McBean core, the McBean Limestone Member primarily consists of limestone that is variably calcarenitic, finely sandy throughout, and variably argillaceous. Minor lithic components include variable but minor amounts of fine mica; variable and minor fine lignitic and carbonaceous debris in beds, laminae, and parting surfaces; variable and minor amounts and fine-grained glauconite (most beds are nonglauconitic); some dark minerals; common gypsum bloom on desiccated core surfaces; fine-grained and trace amounts of fine-grained pyrite; some "marl", wad and MnO_2 dendrites; pelletal phosphate and very fine vertebrate bone debris; minute spicules and spicule molds; and scattered, thin, hard limestone beds or lenses.

In the McBean core, the limestone is generally thick- and massively bedded, crudely stratified, and devoid of sedimentary or biogenic structures. Some thin beds or intervals with horizontally oriented, fossil molds and casts can be found. There is some interlayering of soft, sandy limestone with thin layers of hard, indurated, fine-grained, dense, argillaceous limestone.

The limestone tends to be hard to mildly indurated, friable and brittle. In the GGS McBean core, all of the McBean Limestone Member is consolidated to some degree. However, at the type locality of the McBean and in the USGS Millers Pond core, the member consists of unconsolidated finely sandy calcarenite. From 121 feet to 138 feet in the GGS McBean core, the limestone lithology is similar to the Blue Bluff Member in that it is more argillaceous than the rest of the McBean section, more thin- to medium-bedded and shaley, and has minor bioturbation. It differs from typical Blue Bluff lithology in that the bed is conspicuously sandy and indurated.

Typical McBean is slightly and variably macrofossiliferous; some beds are barren of macrofossils but most beds are sparsely fossiliferous. In some beds fossils occur in small concentrations. Most of the macrofossils consist of molds and casts of aragonitic fossils, rare and chalky aragonitic shells and shell fragments in various stages of decomposition, and scattered calcitic fossils (oysters, scallops and barnacles). *Cubitostrea sellaeformis* and rare *Crassostrea gigantissima* (in place) are scattered in the limestone.

The color of unweathered or unoxidized McBean Limestone Member (dry core) ranges from light olive gray through yellowish-gray to very light gray.

We have not yet identified any discrete beds of sand or clay in the McBean Limestone Member. The quartz sand component is interstitial and usually fine- to very fine grained and well-sorted, but some beds contain medium- and coarse-grained, well-rounded, moderately well to poorly sorted sand. Typically, the texture of the McBean Limestone Member is equigranular, calcarenitic, and finely bioclastic.

The McBean Limestone Member is best developed near McBean Creek from several miles above the community of McBean to Shell Bluff. In this area, there are beds or lenses of Blue Bluff lithology within the McBean, although there is no Blue Bluff lithology in the McBean at Shell Bluff.

Stratigraphic Relationships

The areal extent of the McBean Limestone Member of the Lisbon Formation is small. Its northern limit in Richmond County is not currently known but it probably grades laterally a mile or two north of McBean Creek into Oconee Group sediments. The Barnwell Group disconformably overlies Oconee Group deposits a few miles north of McBean Creek in southeastern Richmond County. The McBean outcrop extends about 15 miles (24 km) up McBean Creek from Shell Bluff, and a shorter distance up Boggy Gut Creek (Hetrick, 1992). The McBean Limestone Member grades seaward into the undifferentiated sand in the vicinity of the Pen Branch fault near Hancock Landing.

In northern Burke County, the McBean Limestone Member of the Lisbon Formation overlies the Bennock Millpond Sand with apparent conformity and gradation. In turn the McBean is overlain disconformably by the Utley Limestone Member of the Clinchfield Formation or the Dry Branch Formation. The McBean Limestone Member of the Lisbon Formation grades laterally downdip into the Blue Bluff Member of the Lisbon Formation.

The range of known thickness of the McBean Limestone Member in northern Burke County is from 74 feet (16 m) to 23 feet (7 m) (Table 12). Average total thickness of the McBean Limestone Member in northern Burke County is 52 feet (16 m).

An open marine origin for the McBean Limestone Member is attested to by the presence of planktonic foraminifera and *Cubitostrea sellaeformis*, both of which are restricted to open marine water-mass conditions. On the other hand, the regional distribution of the McBean is small and the lithology is dominated by calcite, a product of biological activity. Based on the above observations, it

Table 12
Thickness variations for the McBean Limestone Member in northern Burke County.

Core site	GGS core number	Thickness in feet
GGS McBean	GGS-3757	74
USGS Millers Pond	GGS-3758	78.5
TR92-1	GGS-3674	23
TR92-2	GGS-3762	23
TR92-4	GGS-3782	62

would appear that the McBean was deposited in an area that was partially cut off from a source of siliciclastics, most conspicuously by the near absence of clay. There is no indication of any sort of barrier to the open ocean because the McBean, Blue Bluff, and undifferentiated Lisbon interfinger and interlense between the vicinities of Shell Bluff and Hancock Landing.

Age

The age of the McBean Limestone Member is Middle Eocene, Bartonian, upper Claibornian, and Cook Mountain-equivalent. Fossils from the McBean useful in correlation purposes include:

Truncorotaloides rohri
T. cf. *topilensis*
Globorotalia spinulosa

among the planktonic foraminifera, and:

Cibicides westi

among the benthic foraminifera.

Barnwell Group

Definition

The Barnwell Group consists of a series of Upper Eocene near shore to coastal marine, sandy deposits in the Fall Line hills area of central to eastern Georgia and western South Carolina. In Burke County, Georgia, the Barnwell Group is subdivided (Figure 3) into the following formations and members (Huddlestun and Hetrick, 1978, 1986; Fallaw and Price, 1992, 1995). The basal formation of the Barnwell Group consists only of the Utley Limestone Member of the Clinchfield Formation. The Dry Branch Formation overlies the Utley Limestone Member either paraconformably or gradationally. In Burke County, the only mappable subdivisions of the Dry Branch Formation are the Irwinton Sand Member, which dominates the Dry Branch section in northern Burke County, and the Griffins Landing Member, which dominates the section in southern Burke County. The Twiggs Clay, a member of the Dry Branch Formation in central Georgia, is represented only by beds or lenses of Twiggs clay lithology scattered throughout the Dry Branch Formation in Burke County. These clay beds are least common in the upper part of the formation, and are most common in the lower part of the formation, especially in the basal part. Other than that, there does not appear to be any systematic pattern to the distribution of the Twiggs-type clay beds between northern and southern Burke County. The Tobacco Road Sand covers most of the upland interfluve surfaces in northern Burke County (Figure 19), but farther south and west, the upland surface is covered by the Altamaha Formation which disconformably overlies the Tobacco Road Sand in that area.

Lithology

The lithology of the Barnwell Group is dominated by quartz sand. Minerals or lithologies that are normally subordinate may dominate the lithology of particular beds or lenses in the group. These include clay (both smectite and kaolinite), limestone, greensand,

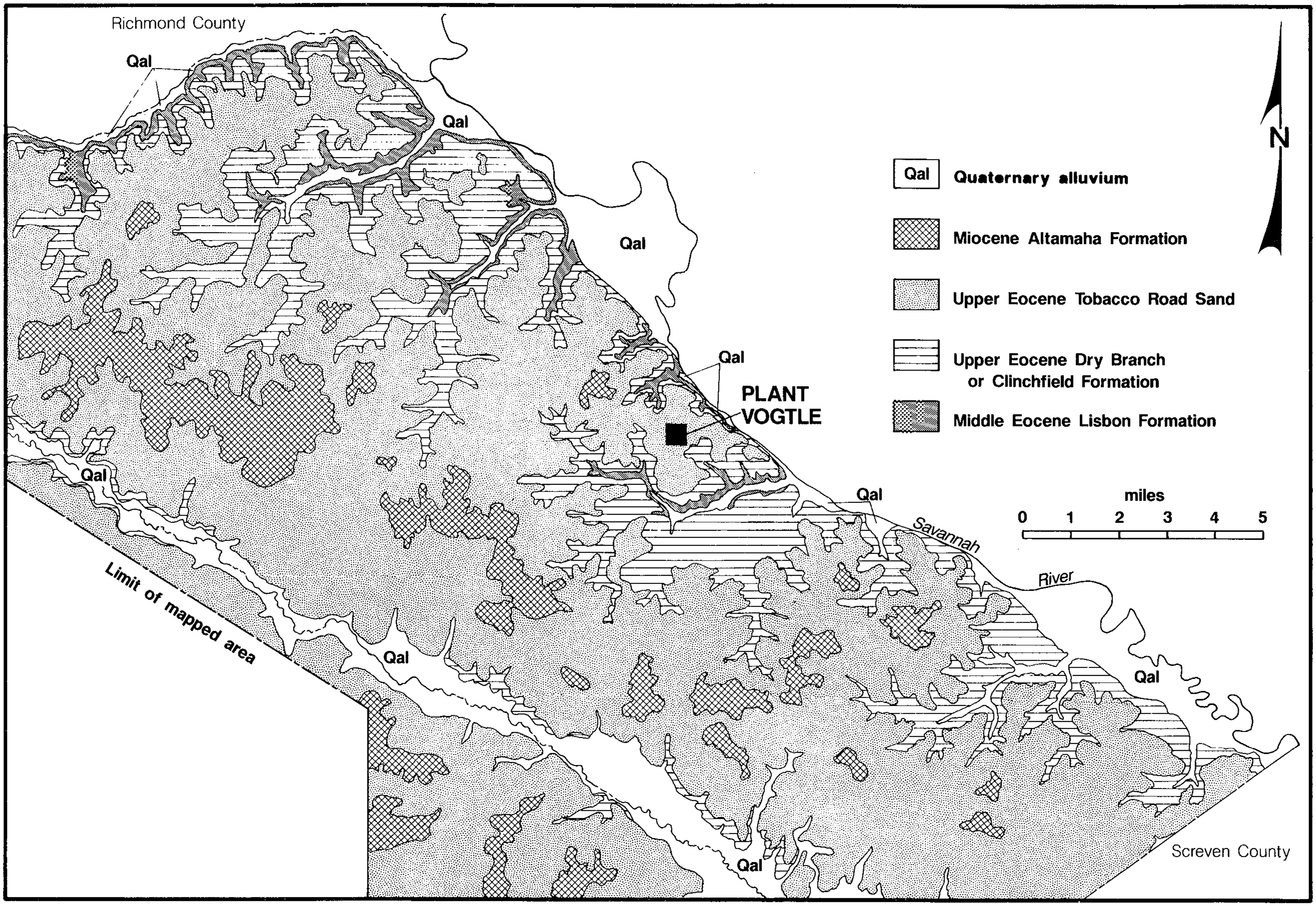

Figure 19. Geologic map showing the extent of the Upper Eocene Barnwell Group in eastern Burke County. From Summerour and others (1994).

lignite, opal-cristobalite, chert, sandstone, and gravel. Shells, mica, hydrated iron oxides, and wad (hydrated MnO_2) may be locally conspicuous. Other accessory lithic components of the Barnwell include aragonitic shells, pyrite, flecks of carbonaceous matter, siliceous microfossils (diatoms and sponge spicules), and generally small marine vertebrate phosphatic bone debris such as fish teeth, scales and bones.

The quartz sand of the Barnwell Group ranges from very fine to very coarse grained and locally contains lenses of gravel and mixtures of sand and pebbles. Sorting ranges from very well to very poorly sorted. In general, very fine to medium-grained sands are well-sorted and lack any appreciable clay component. These sands (and carbonates of the Utley Limestone Member) are highly permeable and constitute the unconfined Upper Three Runs aquifer (Summerour, et al, 1994) in Burke County. With increasing grain size, sorting commonly deteriorates, producing very poorly sorted sediments such as pebbly, coarse-grained sand with a fine-grained or clayey matrix. However, some beds or lenses of well-sorted, coarse to very coarse sand are locally common.

Typical Barnwell lithologies have prominent bedding that ranges from horizontal (thick-bedded, thin-bedded, and laminated), undulatory, and cross-bedded. Some deposits may display little bedding, probably due to bioturbation and complete mixing of the sediments. These include the Griffins Landing Member of the Dry Branch Formation, parts of the Tobacco Road Sand, and parts of the Utley Limestone Member.

Stratigraphic Relationships

The Barnwell Group covers most of the upland surface of eastern Burke County. East and south of the study area in northern and eastern Burke County, the Barnwell Group is overlain by the Miocene Altamaha Formation. The hard, brick-red to reddish brown residuum of the Tobacco Road Sand is most commonly encountered on the upland surface, but in-stream valleys, loose to almost incoherent sands of the Dry Branch Formation cause steep valley sides. Only in northernmost Burke County are older Middle Eocene deposits exposed in the lower parts of stream valleys and along bluffs of the Savannah River.

The Barnwell Group grades downdip into the Ocala Group in Screven County. There are no other stratigraphic equivalents in Georgia. In Burke County the Barnwell Group either occurs at the tops of the sections, as in the study area, or is overlain disconformably by the Miocene Altamaha Formation farther west and south. The Barnwell Group disconformably overlies the Middle Eocene McBean Limestone Member of the Lisbon Formation in northern Burke County and the Blue Bluff Member of the Lisbon Formation in central and southern Burke County. In upland, interfluve areas in Burke County, thickness of the Barnwell Group ranges from 112 feet in GGS McBean core to as much as 252 feet in core VG-2. Because of the erosion of the upper portions of the Barnwell Group, isopach and structure contour maps of the Barnwell Group formations are of questionable value and are not included in this report.

Environment of deposition of the Barnwell Group ranges from littoral to shallow marine, inner neritic, continental shelf. Based on the presence, and local abundance of *Crassostrea gigantissima* in addition to the absence of planktonic foraminifera in all but southernmost Burke County, the salinity of the water-masses probably was slightly brackish.

Age

The Barnwell Group is Jacksonian, Late Eocene (Priabonian) in age (see discussion, Huddlestun and Hetrick, 1986, p. 9-12).

Clinchfield Formation
Utley Limestone Member

Definition

The Utley Limestone Member of the Clinchfield Formation was named by Huddlestun and Hetrick (1986) for a fossiliferous, sandy limestone at the base of the Barnwell Group throughout eastern Burke County. The Utley Limestone was differentiated from the Clinchfield Formation because beds or lenses of Utley Limestone lithology occur within the Clinchfield Formation in central Georgia. Similarly, beds or lenses of Clinchfield sand lithology occur within the Utley Limestone in Burke County.

Type Locality

The name Utley was taken from Utleys Cave at the upper end of Mallards pond in eastern Burke County. The type locality is at Utleys Cave, approximately 0.8 mile (1.3 km) southwest of Hancock Landing and on the property of Georgia Power Company Plant Vogtle. The section exposed at Utleys Cave is the type section, or unit-stratotype for the member (Huddlestun and Hetrick, 1986).

Lithology

The Utley Limestone Member of the Clinchfield Formation typically is a moldic, fossiliferous, variably glauconitic, variably sandy limestone. Some beds consist of calcareous sandstone or, more rarely, unconsolidated calcareous sand. The sand is generally fine-grained and well-sorted, but there are minor occurrences of coarse-grained, well- to moderately sorted sand. Other subordinate lithic components include small, dark grains (heavy minerals?); minor amounts of clay minerals; some unconsolidated calcarenite beds; a trace of pelletal phosphate in southern Burke County; scattered shell fragments and other calcitic fossil debris; and rare foraminifera. In southern Burke County the lower part of the formation consists of a calcareous, glauconitic sand with some calcareous greensand. The associated limestone has a salt and pepper appearance because of the light colored calcarenite and dark glauconite. Clayey, calcareous "marl" is rare in the Utley.

The Utley Limestone Member is typically massive- and thick-bedded but there is some crude stratification. Most shell molds appear to be randomly oriented, but there is a slight tendency toward horizontal alignment in some thin intervals. Some thin bedding occurs in the sandier parts of the limestone. Except where the limestone is sandy, fractures are irregular.

The Utley is variably and finely to coarsely moldic, with varying degrees of secondary porosity and bioclastic texture. Some limestone beds are very fine grained but not lutitic. The limestone exhibits varying degrees of consolidation. Most commonly the Utley is indurated, hard, dense and recrystallized, but some beds are only partially indurated and very friable. The Utley Limestone Member is variably fossiliferous and is subcoquinoid in some beds. Unaltered calcitic shells are locally abundant, but the original aragonitic shells generally have been leached, leaving molds and impressions. There are also some concentrations of the oyster *Crassostrea gigantissima* near the base of the member, similar to concentrations in the Riggins Mill Member (Huddlestun and Hetrick, 1986). Faunal diversity is fairly high. Most of the fossils consist of molds and casts of mollusks but include unaltered bryozoa, barnacles, crab claws and echinoids. Also, the Utley Limestone is the eastern-most known occurrence of the *Periarchus lyelli* bed, and the fragments of the sand dollars are locally common.

The color of the limestone is most commonly very pale orange but other colors include variable shades of yellowish-gray, olive-gray and light-grays.

Stratigraphic Relationships

In Georgia, the Utley Limestone is currently known only from the Savannah River area in Burke and Screven Counties, Georgia (Huddlestun and Hetrick, 1986). However, beds or lenses of Utley-like limestone are present in the Riggins Mill Member of the Clinchfield Formation in the central Georgia Coastal Plain. Fallaw and Price (1992) have identified the Utley Limestone in the southeastern part of SRS in Barnwell County, South Carolina, but report its absence updip in the middle part of SRS.

In eastern Burke County, the Utley Limestone is locally absent due either to solution or nondeposition on topographic highs during the Jacksonian transgression. Where the Utley Limestone is present, it disconformably overlies the McBean Member and undifferentiated Lisbon Formation in northern Burke County, and disconformably overlies the Blue Bluff Member in central and southern Burke County. The Utley in turn is overlain with apparent conformity by the Dry Branch Formation, but the contact is generally sharp.

In northern Burke County, Utley Limestone ranges in thickness from 0 feet (where absent) to 13 feet (4 m) at the type locality. Its average thickness in northern Burke County (based on 8 sites) is approximately 7 feet (2 m). The Utley limestone is systematically thicker in southern Burke County where it ranges from 10 feet (3 m) in core VG-4 to 34 feet (10 m) in core VG-8. Fallaw and Price (1992, 1995) reported 30 feet (9 m) in the southeastern part of SRS.

Age

There is some controversy over the age of the Clinchfield Formation and, therefore, also of the Utley Limestone Member. Paleontologically, it could be late Claibornian in age and correlative with the Gosport Sand of southwestern Alabama. Like the Gosport, the Clinchfield Formation is variable in thickness over short distances in kaolin mines in central Georgia due, apparently, to filling of topographic lows on the top of the Oconee Group (Huddlestun and Hetrick, 1986) during the Barnwell transgression. In most places, the upper contact of the Clinchfield with the overlying Tivola Limestone (or Dry Branch Formation) appears to be conformable, gradational and horizontal in most kaolin mines in central Georgia (in contrast to a basal irregular contact).

Dry Branch Formation

Definition

The Dry Branch Formation was named by Huddlestun and Hetrick (1979, 1986) for a body of deposits that had been previously called members of the Barnwell Formation (Irwinton Sand Member of the Barnwell Formation of LaMoreaux, 1946a, 1946b; Twiggs Clay Member of the Barnwell Formation of Shearer, 1917; or as undivided Barnwell Formation of Veatch and Stephenson, 1911). As defined by Huddlestun and Hetrick (1979, 1986), the Dry Branch Formation consists of three formal members, each one of which constitutes the entire Dry Branch section in the areas where they are typically developed. These are the Twiggs Clay Member, Irwinton Sand Member and Griffins Landing Member. Where these particular lithofacies are not well-developed, the Dry Branch Formation may be composed of any two or three of the member lithofacies. In Burke County, all three lithofacies are present, but only the Irwinton Sand and Griffins Landing can be considered as members. A Twiggs-type clay occurs as thin beds or lenses within Irwinton Sand Member and Griffins Landing Member.

Type Locality

The name Dry Branch is taken from the community of Dry Branch, located on U.S. Hwy. 80 on the Bibb-Twiggs County line. The type locality of the Dry Branch Formation is in Twiggs County, along an abandoned kaolin haul road at the entrance to an abandoned kaolin mine, 0.6 miles (1 km) from the junction of the haul road and U.S. Hwy. 80 at the highway bridge over the Seaboard Coast Line Railroad, 2.3 miles (3.7 km) south of Dry Branch. The section of Barnwell exposed beneath the Tobacco Road Sand is the type section, unit-stratotype (holostratotype) of the Dry Branch Formation (Huddlestun and Hetrick, 1986). The section of Dry Branch exposed in the pit consists of the Irwinton Sand Member with beds or lenses of Twiggs-type clay.

Lithology

The Dry Branch Formation locally consists of three distinct but interfingering lithofacies: 1.) a marine smectitic clay lithofacies (Twiggs Clay); 2.) a prominently stratified sand and sand-clay lithofacies (Irwinton Sand); and 3.) a crudely bedded, thick-bedded and massive, calcareous, fossiliferous, argillaceous sand lithofacies (Griffins Landing Member). In many areas of Georgia, however, a fine distinction between the lithofacies, due to complex interfingering and intergradation, is not possible. In those areas, for mapping purposes and purposes of discussion, it is best to distinguish only the formation and to recognize the facies subdivisions as informal lithofacies, lithosomes or lithostromes.

Stratigraphic Relationships

In northern Burke County, the Irwinton Sand constitutes most of the Dry Branch Formation and, in Richmond County immediately to the north, the Irwinton constitutes all of the Dry Branch. In northernmost Burke County, the Griffins Landing Member occurs at the base of the formation and thickens irregularly southward at the expense of the overlying Irwinton Sand. In southern Burke County, the Dry Branch Formation consists mostly of the Griffins Landing Member with Irwinton Sand occurring only at the top of the formation. Farther south in northern Screven County, the Griffins Landing Member constitutes all of the Dry Branch Formation.

The Dry Branch Formation overlies, with apparent conformity, the Utley Limestone Member of the Clinchfield Sand. Within the Dry Branch Formation in central and southern Burke County, the Griffins Landing appears to grade both upward and laterally into the Irwinton Sand suggesting that, for a brief time, both members were being deposited contemporaneously. During the later phase of deposition of the Dry Branch Formation, the Irwinton Sand was deposited across the entire eastern part of Burke County. In addition, the contact between Griffins Landing Member and Irwinton Sand Member is obscured by deep weathering of the Irwinton sand and the upper part of the Griffins Landing. However, in most cores, there is a clear distinction between weathered Irwinton Sand and weathered Griffins Landing. Bedding characteristics of the two members are different and leaching of the calcareous Griffins Landing commonly results in precipitation of wad on bedding surfaces, joints, or fractures.

Because the Dry Branch Formation is deeply dissected in Burke County, its apparent thickness is quite variable, being absent where stream erosion has completely removed the formation. However, the variation in original thickness of the Dry Branch Formation can be determined where the overlying Tobacco Road Sand is still present. Only three cores in eastern Burke County were taken at sufficiently high elevations for the Tobacco Road to be identified. These three cores are GGS McBean, TR92-2, and VG-6 (Figure 2, Table 1). The Dry Branch is 67 feet (20 m) in the GGS McBean core near McBean Creek, 101 feet (30.8 m) in the TR92-2 core in central Burke County near Hancock Landing, and 163 feet (49.7 m) in the VG-6 core east of Girard in southern Burke County. These three thicknesses suggest that the Dry Branch Formation thickens at the rate of approximately 4 feet/mile (1.2 m/km) to the southeast.

The depositional environment of the Dry Branch Formation was shallow to very shallow water, inner neritic, marine. The abundance of sand, undulatory bedding and cross bedding, and the presence of *Crassostrea gigantissima* suggests a near-shore environment near an influx of fresh water as opposed to normal, open-ocean water. The presence of Twiggs clay and Griffins Landing interfingering strongly suggests a near-shore facies mosaic that includes bays and lagoons, beaches, tidal inlets, and oyster reefs. Water depth during deposition of the Irwinton Sand must have been very shallow subtidal whereas that of the Griffins Landing was only slightly deeper, such that open-ocean, planktonic foraminifera could survive in southern Burke County. However, the presence of *Crassostrea gigantissima* bioherms suggest that the sea water was also slightly brackish at times.

Age

The Dry Branch Formation is Late Eocene, early Jacksonian in age (Huddlestun and Hetrick, 1986).

Twiggs Clay Lithofacies

Lithology

Clay beds within the Dry Branch Formation essentially have the same lithology as the eastern facies of the Twiggs Clay Member of the Dry Branch Formation (Huddlestun and Hetrick, 1986), characterized by a paucity of calcite and glauconite and the presence of opal-cristobalite. No opal-cristobalite has been reported from the Twiggs-type clay beds in Burke County, however.

In general, the Twiggs-type clay is a yellowish gray to light olive gray, dense, silty clay with hackly, blocky, shaley, subconchoidal to conchoidal fracture. Where the clay is almost pure and unaltered by weathering, it commonly displays a combination of blocky and conchoidal fracture. Where it is weathered, its fracture is pronouncedly hackly.

Stratigraphic Relationships

The Twiggs Clay lithology is present in Burke County as clay lenses scattered throughout the Irwinton Sand and Griffins Landing, most commonly at or near the base of either member. Where present, the thickness usually ranges from .3 feet (in core VG-3) to 22 feet (in core VG-5). In core VG-5, the Twiggs Clay unit overlies the Griffins Landing Member.

Griffins Landing Member

Definition

Huddlestun and Hetrick (1986) named the Griffins Landing Member of the Dry Branch Formation for beds exposed at Griffins Landing on the Savannah River in Burke County, Georgia. The Griffins Landing Member is relatively well exposed in the Savannah River area, both in Burke County, Georgia, and Barnwell County, South Carolina. The Griffins Landing Member is distinguished from the rest of the Barnwell Group in being typically calcareous, micro- or macrofossiliferous, thick- to massive-bedded, and devoid of sedimentary or biogenic structures.

Type Locality

The type locality of the Griffins Landing Member of the Dry Branch is at Griffins Landing on the Savannah River, 1.4 miles (2.3 km) north of the junction of Griffins Landing Road and River Road, and 5.2 air-miles (8.4 km) north of Girard in Burke County. The section exposed at Griffins Landing is the type section, or unit-stratotype of the Griffins Landing Member. Neither lower nor upper boundaries are exposed at the landing but Price (personal communication, 1993) identified the top of the Utley Limestone several hundred feet south of the landing.

Lithology

In general, the Griffins Landing Member is a fairly well sorted, massive to vaguely and rudely bedded, calcareous sand. In the updip areas of Burke County, thin limestone beds, clay beds or lenses, local oyster (*Crassostrea gigantissima*) beds and bioherms, and chert and silica-cemented sandstone (as at Stony Bluff Landing) are common. Subordinate lithic components include smectite clay, calcite, shells, zeolite, chert, mica, glauconite and wad.

In many outcrops and cores, the Griffins Landing Member shows few primary sedimentary or biogenic structures, especially in the downdip, shallow subsurface where it consists of a thick-bedded, uniformly structureless, somewhat argillaceous, calcareous, microfossiliferous, well-sorted, medium-grained sand. Vague stratification can be seen in outcrop on etched surfaces, as at Griffins Landing, and in some cores from the shallow subsurface.

Stratigraphic Relationships

The Griffins Landing Member at this time appears to be restricted to the Upper Eocene outcrop belt in the vicinity of the Savannah River. Other than minor lenses of Griffins Landing lithology in the Dry Branch Formation in central Georgia, we know of no certain occurrences of the Griffins Landing

Member west of Burke County in Georgia (see Huddlestun and Hetrick, 1986).

The Griffins Landing Member is in the lower part of the Dry Branch Formation where it grades laterally and vertically into the Irwinton Sand (Huddlestun and Hetrick, 1986). The Griffins Landing is absent farther north in Richmond County where the Irwinton Sand Member directly overlies either the Albion Member of the Clinchfield Formation or the underlying Oconee Group. Farther south in Screven County, Georgia, the Griffins Landing Member composes the entire Dry Branch Formation.

The Griffins Landing Member thickens southeastward in Burke County. In northern Burke County, its thickness is variable, ranging from 0 feet where it is locally absent due to non-deposition, to as much 96.5 feet in the core TR92-5. Average thickness of the Griffins Landing Member in northern Burke County is 34 feet (11 m). Where the Griffins Landing Member is absent, either the Irwinton Sand directly overlies the McBean Member of the Lisbon Formation or undifferentiated Dry Branch Formation directly overlies the Utley Limestone. In southern Burke County, where the Griffins Landing Member is consistently present, thickness ranges from 36 feet (12 m) in core VG-3 to 123 feet (40 m) in core VG-2. Average thickness of the Griffins Landing Member in southern Burke County is approximately 74 feet (23 m).

The environment of deposition of the Griffins Landing Member was shallow, inner continental shelf. The common occurrence of *Crassostrea* suggests that the salinity of the sea water may have been slightly brackish or variable.

Age

The age of the Griffins Landing Member of the Dry Branch Formation is Late Eocene, early Jacksonian (Huddlestun and Hetrick (1986).

Irwinton Sand Member

Definition

The Irwinton Sand was named by LaMoreaux (1946a, 1946b) for a soft, commonly loose and incoherent, fine to medium, stratified, noncalcareous sand that contains thin beds, lenses, laminae, or clasts of Twiggs-type clay (see Huddlestun and Hetrick, 1986).

Type Locality

The name Irwinton is derived from the town of Irwinton in Wilkinson County, Georgia. The type locality of the Irwinton Sand is in gullies, now overgrown, on the west side of U.S. Hwy. 441 (Ga. Hwy. 29), 0.3 mile (0.5 km) south of the courthouse in Irwinton. The type section, unit-stratotype (holostratotype), of the Irwinton Sand is the section of sand overlying the Twiggs Clay in the gullies at Irwinton. When LaMoreaux (1946a, 1946b) described the type section, there was 44 feet (13 m) of Irwinton Sand overlying 20+ feet (6.1+ m) of Twiggs Clay and underlying about 12 feet (3.7 m) of weathered clay that LaMoreaux (1946a, 1946b) described as colluvium but Huddlestun and Hetrick (1986, p. 40) considered to be a deeply weathered bed or lens of Twiggs-clay lithofacies.

Lithology

The Irwinton Sand typically consists of fine- to medium- grained, well-sorted, almost pure quartz sand that shows well-developed small-scale, horizontally bedded, undulatory bedded, and cross-bedded sand. Accessory lithic components include mainly smectitic clay and minor amounts of illite and kaolinite. Some weathered beds of clay in the Irwinton are composed entirely of kaolin, apparently altered from smectite. All Irwinton clay beds (smectite) we know of are of Twiggs Clay-type lithology. Other accessary minerals in the Irwinton Sand include chert, locally conspicuous dark minerals, and very minor mica.

Sand in the Irwinton is fine- to medium-grained and well-sorted. Coarser beds are more poorly sorted. Typically, the Irwinton Sand is soft and unconsolidated, in some places even incoherent. Therefore, the Irwinton is a "slope-former". There are some poorly sorted sand beds within the Irwinton, especially in the far updip areas. Some sections are dominated by medium to coarse, rarely pebbly, moderately well to poorly sorted sand.

Most exposures of the Irwinton Sand contain some beds, lenses, and laminae of disrupted clay clasts of Twiggs-type smectitic clay. In general, all the clay beds in the Irwinton probably are lenses, but the thicker clay beds are more areally extensive than the thin beds, and the clay laminae are especially discontinuous. The clay beds and lenses within the Irwinton Sand produce locally perched water tables.

Stratigraphic Relationships

The Irwinton Sand Member of the Dry Branch is present throughout Burke County. It is thickest in the northern part of the county, especially in the study area where its thickness can be as much as 80 feet (24 m). In some exposures, the Irwinton/Tobacco Road contact appears to be slightly gradational. In other exposures, it appears that the basal flat pebble bed of the Tobacco Road disconformably overlies the Irwinton Sand.

The Irwinton Sand gradationally overlies the Griffins Landing Member. In addition, the lower part of the Irwinton appears to grade laterally into the upper part of the Griffins Landing. The vertical gradation between the Irwinton and Griffins Landing is rarely seen in outcrop and, because of deep weathering and poor core recovery across the Irwinton-Griffins Landing boundary, it is rarely seen in cores. Where there is poor recovery in cores, we arbitrarily place the Irwinton-Griffins Landing contact near the lowest occurrence of prominent bedding, and the highest occurrence of wad (hydrated MnO_2), chert, or calcium carbonate. The Irwinton is most easily identified where the sand is conspicuously and thinly stratified and noncalcareous.

Age

The age of the Irwinton Sand Member of the Dry Branch Formation is Late Eocene, early Jacksonian (Huddlestun and Hetrick, 1986).

Tobacco Road Sand

Definition

The Tobacco Road Sand was named by Huddlestun and Hetrick (1978) for upper Jacksonian deposits that previously had been called the upper sand member of the Barnwell Formation by LaMoreaux (1946a, 1946b).

Type Locality

The name Tobacco Road was taken from the Tobacco Road highway in southern Richmond County. The type locality of the Tobacco Road Sand is located on the east side of Morgan Road, 0.3 miles (0.6 km) north of the intersection of Morgan Road and Tobacco Road, Richmond County, Georgia. The type section, or unit-stratotype (holostratotype) of the Tobacco Road Sand is that section of the formation exposed at the type locality (Huddlestun and Hetrick, 1978, 1979, 1986).

Lithology

Tobacco Road is predominantly a sand, all other lithic components (clay minerals, chert, calcite, limestone, mica, glauconite, dark minerals and wad) are only locally significant. The most characteristic lithology of the Tobacco Road Sand is a burrowed and bioturbated, massive-bedded, moderately poorly sorted, medium- to coarse-grained, pebbly, weathered sand. This particular lithofacies of the formation is more prevalent in the downdip areas of the outcrop belt such as Burke County. Although most exposures show little or no bedding, vague, rude bedding and disrupted thin bedding are probably the norm for the formation as a whole. For example, at Stop 3 of the 1992 Carolina Geological field trip (Fallaw and Price, 1992), most of the 35 feet (11 m) of Tobacco Road Sand section consists of crudely bedded, very broadly cross-bedded to horizontally bedded sand with massive-bedded, variably sorted, medium-grained sand in the lower part. The characteristic burrowed and bioturbated sand occurs only in the upper 6 feet (2 m) of the formation. In most places, however, crude bedding can be observed only on close inspection.

A zone of flat pebbles occurs at the base of the Tobacco Road Sand in many places in central and eastern Georgia. Although discontinuous, this bed is very useful for locating the base of the Tobacco Road and the top of the underlying Dry Branch Formation (Huddlestun and Hetrick, 1978, 1986). The flat pebble bed is common in northern Burke County but becomes less common southward as average siliciclastic grain-size decreases. Where the flat pebble bed is absent, chert, or coarse, granular sand is commonly present at the base of the formation, especially where the formation is unusually fine grained and consists mainly of fine- to medium-grained, well-sorted sand.

Stratigraphic Relationships

The Tobacco Road Sand occurs at the top of upland, interfluve sections in the study area. The upper part of the formation generally is deeply weathered and highly pigmented (most commonly moderate reddish brown), although in some exposed sections or cores the pigmentation is more variegated. Deep weathering of the Tobacco Road Sand has caused it to become case-hardened and resistant to both chemical and physical weathering. Thus, it is a ledge-forming unit, and commonly is eroded by undercutting of the soft sands of the Dry Branch Formation.

The Irwinton Sand Member of the Dry Branch Formation underlies the Tobacco Road Sand paraconformably or with abrupt contact. In the study area in northern Burke County, the Tobacco Road Sand occurs at the top of the stratigraphic section. Elsewhere in Burke County, the Miocene Altamaha Formation overlies the Tobacco Road disconformably.

Based on the local abundance of the ghost shrimp burrow *Ophiomorpha nodosa*, the presence of the sand dollar *Periarchus quinquefarius*, chert with molds and casts of mollusks with *Periarchus quinquefarius*, flat pebbles, and the local occurrence of prominent undulatory bedding and cross bedding, the environment of deposition of the Tobacco Road is inferred to be coastal marine, beach, to back-barrier (Huddlestun and Hetrick, 1978, 1986).

Age

The Tobacco Road Sand is Latest Eocene, late Jacksonian in age (Huddlestun and Hetrick, 1978, 1986).

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APPENDIX 1
DESCRIPTIONS OF
CORE SITE LOCATIONS

GGS-3537 (Burke 5, McBean core)

Location: In northern Burke County, on the north shoulder of Collins Road, 1.4 airline miles (2.2 km) southeast of the Ga. Hwy. 56 bridge over McBean Creek, 1.1 miles (1.8 km) east of the intersection of Ga. Hwy. 56 and Collins Road, and 1.2 miles (1.9 km) southeast of the only remaining exposed McBean Limestone at the type locality. The core site is in the McBean USGS 1:24,000 quadrangle map.

GGS-3758 (Burke 6, USGS Millers Pond)

Location: M. A. Miller property, approximately 0.5 miles south-southwest of the intersection of River Road and Millers Pond Road and approximately 0.5 miles (0.8 km) north-northeast of Millers Pond, a dammed segment of Boggy Gut Creek (a.k.a. McKinney Branch) in northeastern Burke County, Georgia. The core site is in the McBean USGS 1:24,000 quadrangle map.

GGS-3764 (Burke 7, TR92-1)

Location: On Georgia Power Company property, on the shoulder of an unimproved road approximately 1 mile (1.6 km) south of Gobbie Grove Church and 1.75 miles (2.8 km) west-northwest of the intersection of Hancock Landing Road and River Road in eastern Burke County. The core site is in the Shell Bluff Landing USGS 1:24,000 quadrangle map.

GGS-3762 (Burke 8, TR92-2)

Location: In an abandoned trailer park on Hancock Landing Road, approximately 0.15 mile (0.1 km) east of the intersection of Hancock Landing Road and River Road, behind the abandoned Shell station and abandoned Southern Fried Chicken restaurant in eastern Burke County. The core site is in the Shell Bluff Landing USGS 1:24,000 quadrangle map.

GGS-3781 (Burke 9, TR92-3)

Location: On Georgia Power Company property, off Ebenezer Church Road, on the upland surface approximately 0.4 mile (0.6 km) south of Beaverdam Creek, approximately 2.4 miles (3.8 km) north of the intersection of Ebenezer Church Road and Ga. Hwy. 23. It is also approximately 2 miles (3 km) south-southwest of Plant Vogtle in Burke County. The core site is in the Alexander USGS 1:24,000 quadrangle map.

GGS-3782 (Burke 10, TR92-4)

Location: On Robert Mobley property, immediately southeast of Allen Chapel Road near the northwestern valley wall on an unnamed Savannah River tributary, approximately 1 mile (1.6 km) east of the intersection of Allen Chapel Road and River Road, and 2.8 miles (4.5 km) southeast of the intersection of River Road (Ga. Hwy. spur 56) and Ga. Hwy. 80 (Shell Bluff Landing Road) in eastern Burke County. The core site is in the Shell Bluff Landing USGS 1:24,000 quadrangle map.

GGS-3792 (Burke 11, TR92-5)

Location: In DeLaigle Mobile Home Park (A & A Trailer Park), on River Road, approximately 0.5 mile (0.8 km) west of Georgia Power Company Plant Vogtle near the large horizontal water tank. The core site is in the Shell Bluff Landing USGS 1:24,000 quadrangle map.

GGS-3794 (Burke 12, TR92-6)

Location: Thomson Oak Flooring Company property, near the edge of the bluff overlooking the Savannah River flood plain, approximately 1.8 miles (2.9 km) northwest of Hancock Landing on the Savannah River in Burke County, Georgia. The core site is in the Shell Bluff Landing USGS 1:24,000 quadrangle map.

USGS Girard core

Location: Adjacent to a fire lookout tower on Griffins Landing Road, 0.75 mile (0.45 km) north of the intersection of Griffins Landing Road and Ga. Hwy. 23 and approximately 1.8 miles (2.9 km) north of Girard in southeastern Burke County. The core site is in the Girard USGS 1:24,000 quadrangle map.

Bechtel core VG-1

Location: On the northeast shoulder of River Road, approximately 1.1 miles (1.76 km) northwest of the crossing of Sweetwater Creek. The core site is in the Girard USGS 1:24,000 quadrangle map.

Bechtel core VG-2

Location: On the shoulder of River Road near the southeast corner of the intersection of River Road and Brighams Landing Road. The core site is in the Girard USGS 1:24,000 quadrangle map in southeastern Burke County, Georgia.

Bechtel core VG-3

Location: On the northeastern shoulder of River Road, on the northern valley wall of Old Mill Branch valley, immediately northwest of the River Road crossing of this dry creek bed. The core site is in the Girard USGS 1:24,000 quadrangle map, in southeastern Burke County, Georgia.

Bechtel core VG-4

Location: On the northeastern shoulder of River Road, on the southeast valley wall of Little Beaverdam Creek. The core site is in the Girard USGS 1:24,000 quadrangle map, in southeastern Burke County, Georgia.

Bechtel core VG-5

Location: Near the foot of the eastern valley side of Sweetwater Creek and Still Branch, on the shoulder of River Road approximately 0.15 mile (0.25 km) east of the bridge over Sweetwater Creek. The core site of the VG-5 is at the boundary of the USGS 1:24,000 quadrangle maps Girard, Ga.-S.C and Millett, S.C.-Ga in southern Burke County, Georgia.

Bechtel core VG-6

Location: On the shoulder of River Road at the intersection with an unimproved county road, approximately 1.4 miles (2.2 km) southeast of the River Road bridge over Sweetwater Creek, and 3 miles (5 km) from the Burke/Screven Counties line in southern Burke County, Georgia. The core site is located in the Millett, S.C.-Ga., USGS 1:24,000 quadrangle map.

Bechtel core VG-7

Location: On the shoulder of River Road near the northeast corner of the intersection of River Road and Griffins Landing Road. The core site is in the Girard USGS 1:24,000 quadrangle map in southeastern Burke County, Georgia.

Bechtel core VG-8

Location: On the northeast shoulder of River Road bridge, on the northwest site of the pond formed by the damming of Little Sweetwater Creek. Approximately .65 miles (10.4 km) northwest of the intersection of River Road and Stony Bluff Road. The core site is located in the Millett, S.C.-Ga., USGS 1:24,000 quadrangle map.

Georgia Power core B-246

Location: On Georgia Power Company Plant Vogtle property, on an upland spur or lead, overlooking the southern end of Utleys Pond, slightly less than 0.1 mile (1.4 km) west of the end of Utleys Pond (also referred to as Mallards Pond). The core site is located in the Shell Bluff Landing, USGS 1:24,000 quadrangle map. The core was inadvertently destroyed in the late 1970's while in storage at Georgia Power Plant Vogtle, but a log of the core is available at the Georgia Geologic Survey in Atlanta.

CORE SITES OUTSIDE BURKE COUNTY

Bechtel core VSC-3

Location: On shoulder of dirt road, 0.5 mile (0.3 km) north-northeast of St. Marys Church; St. Marys Church is on the north side of S.C. Hwy. 125, 0.4 mile (0.25 km) west of the Barnwell-Allendale County in Barnwell County, South Carolina. The core site of the Bechtel VSC-3 is located in the Girard NE USGS 1:24,000 quadrangle map.

Bechtel core VSC-4

Location; On the northern valley wall of the Savannah River, less than 0.1 mile (0.16 km) north of S.C. Hwy. 125, less than 0.1 mile (0.16 km) west of Barnwell-Allendale County line, 2.2 miles (3.5 km) northeast of Savannah River in Allendale County, South Carolina. The core site of the Bechtel VSC-4 is located in the Millett S.C.-Ga., USGS 1:24,000 quadrangle map.

GGS-3187 (Dougherty 2, USGS Albany core)

Location: Dougherty County, approximately 0.2 mile (0.3 km) east-northeast of the intersection of U.S. Hwy. 19 and a county road, approximately 0.8 mile (0.13 km) south of the intersection of U.S. Hwy. 19 and Holley Highway (Ga. Hwy. 257). The core site is on the Albany East USGS 1:24,000 quadrangle map.

GGS-3366 (Sumter 9A)

Location: Sumter County, approximately 0.75 mile (0.12 km) north of Ga. Hwy. 27 and approximately 0.5 mile (0.8 km) west of the Flint River, near the site of the old Danville Ferry. This site is located in the Drayton USGS 1:24,000 quadrangle map.

GGS-3111 (Pulaski 3)

Location: On the south shoulder of a paved county road, approximately 200 feet northeast of the Pulaski fire tower, 0.35 mile (0.2 km) west of the intersection of the paved county road and U.S. Hwy. 129, 1.9 miles (1.1 km) south of the intersection of Broad Street (U.S. Hwy. 341) and U.S. Hwy. 129 in Hawkinsville, Georgia. The core site is on the Hawkinsville USGS 1:24,000 quadrangle map.

GGS-3511 (Pulaski 5, Pulaski County core, Arrowhead core)

Location: On the top of a hill, approximately 1.7 miles (2.7 km) west of Ga. Hwy. 26 and 0.5 mile (0.8 km) southwest of the Bleckley-Pulaski Counties line in northern Pulaski County. The core site is in the southwestern corner of the West Lake USGS 1:24,000 quadrangle map.

GGS-3545 (Colquitt 11, Doe Run core)

Location: on Harrell farm property, on a valley side between an unimproved county road and a farm pond, 0.25 mile (0.15 km) east of junction of the county road and Ga. Hwy. 133, approximately 2.0 miles (1.2 km) southeast of the intersection of Ga. Hwy. 133 and Ga. Hwy. 270 in Doe Run, Colquitt County, Georgia (also see McFadden and others, 1986, p. 323). The core site is in the Doe Run USGS 1:24,000 quadrangle map.

GGS-3523 (Laurens 1, Laurens County core)

Location: In an east-bound Interstate 16 rest area, 2.8 miles (4.5 km) east of the intersection of Interstate Hwy. 16 and Ga. Hwy. 338. The core site is in the southern part of the Dudley USGS 1:24,000 quadrangle map.

APPENDIX 2
HISTORICAL REVIEW OF BLACK MINGO AND ELLENTON FORMATIONS

The undifferentiated Black Mingo Formation of this report previously, in Burke County, had been referred to the Ellenton Formation of Siple (1967) (Bechtel, 1982; Harris and Zullo, 1990). Prowell and others (1985b) described a core section of the Ellenton Formation from SRS (not at the site of the type locality) and determined that the Ellenton in its type area consisted of a lower, Lower Paleocene part (Midwayan) and an upper, Upper Paleocene part (lower Sabinian). Similarly, early paleontologic observations (Sloan, 1908; Cooke, 1936) of the Black Mingo Formation and recent palynological studies of the Black Mingo Formation and the Ellenton Formation of Siple (1967) (Van Nieuwenhuise and Colquhoun, 1982; Muthig and others, 1990) indicate that the Black Mingo and Ellenton are Early Paleocene to Late Paleocene in age (i.e., two discrete biostratigraphic and chronostratigraphic units). This resulted in questioning or abandoning the name Ellenton and replacing the name Ellenton with names of subdivisions of the Black Mingo Formation (or Group).

The Black Mingo has not been formally recognized in Georgia. The type area of the formation is in the central Coastal Plain of South Carolina where the name has been used since 1908. It is to be noted that in the type area of the Black Mingo Formation, the Black Mingo is an off-shore, fossiliferous, continental shelf deposit. In SRS and northern Burke County. the correlative deposits are inner continental shelf with some coastal marine lithofacies. As a results, there are some differences in the gross lithologies of the correlative deposits.

The historical development of the Black Mingo concept has been restricted to South Carolina but, because the name has been informally used in Georgia, and the Black Mingo is crucial to understanding the Ellenton, the historical usage of the name is of concern in Georgia as well. Sloan (1907, 1908) named the Black Mingo stratigraphic unit but his use of the name was vague. He referred to it as: "Black Mingo Phase", "Lower Black Mingo series", " Lower Black Mingo", "Black Mingo Shale", "Upper and Lower Black Mingo formations", "Upper Black Mingo", "Upper Black Mingo phase or Rhems Shale", "Rhems Shale", "Upper Black Mingo (Rhems and Williamsburg"). "WilliamsburgPseudo-Buhrstone","Williamsburg Pseudo-Buhr", "Lang Syne beds", "Lang Syne?" (Sloan, 1908, p. 449-452).

The Upper Black Mingo formations are observed in Williamsburg County near Rhems, ... (p. 451)...shales and pseudo-buhrstone with Eocene fossils, ...interpreted as the probable equivalent of the Upper Black Mingo (p. 451-452)....The Lower Black Mingo formations afford the first expression of the great land subsidence which caused the shore line to retreat inland at the beginning of the Eocene period. The type exposure is at Perkins Bluff on the Black River near its confluence with the Black Mingo River. (p. 452) The Upper Black Mingo was inaugurated by a renewal of sedimentation which afforded additional gray laminated shales inclosing a small variety of the *Venericardia planicosta* in the form of molds and casts; best exhibited at Rhems Landing on the Black Mingo River (p. 452). At Lang Syne and Warley Hill the Congaree shales rest on fine grained, black, slightly glauconitic, sand and partly indurated gray sands, both of which contain tender casts of small shells. We shall refer to them as the Lang Syne beds. Stratigraphically they belong below the Congaree shales, and are tentatively treated as a part of the Black Mingo, pending further investigations. It is recognized that there is a faunal advance from the Lower to the Upper Black Mingo formations, but in so much as the later are so intimately associated over a large area, without stratigraphic break, it has been decided that the distinction of Upper and Lower will prove satisfactory for the general discrimination of these beds. The Upper Black Mingo comprises: (a) The Williamsburg Pseudo-Buhr consisting of yellow-red sands which inclose a hard silicified ledge about two feet thick, in which casts of *Ostrea arrosis* and the Venericardia planicosta occur ... (p. 452) (b) Rhems Shale. Light gray to black shale interlaminated with thin seams of fine grained sand and mica. ... (p. 453). It is clear that Sloan (1908) recognized lower and upper subdivisions of the Black Mingo, but the distinctions appear to be related more to paleontology (age) and stratigraphic position than to lithology. However, Sloan (1908) considered the type "exposure" of the lower Black Mingo to be at Perkins Bluff and the Upper Black Mingo being best exhibited at Rhems Landing. Both the sections exposed at Rhems Landing and Perkins Bluff are now considered to be lower Black Mingo (Van Nieuwenhuise and Colquhoun, 1982b).

Cooke (1936, p. 41) was the first to describe the formation in a more modern context. He paraphrased Sloan's use of the name Black Mingo as follows: *"The name "Black Mingo shales", taken from Black Mingo Creek, a tributary of the Black River in Williamsburg and Georgetown Counties, S. C., was applied by Sloan in 1907 to laminated sandy shale exposed along the Black River from Brewington Lake, in Clarendon County, to the mouth of Black Mingo Creek, and up Black Mingo Creek to a point between Rhems and the General Marion Bridge. In 1908, he extended the name to a more comprehensive unit, his Black Mingo "phase", which included all the strata of lower Eocene age east of the Santee River."*

Cooke (1936, p. 41) applied the name Black Mingo Formation to all Tertiary strata older than the "McBean" Formation, including the Congaree Formation, and correlated it (Black Mingo) mainly with the Tuscahoma Formation of the eastern Gulf Coastal Plain. However, Cooke and MacNeil (1952, p. 21-21) later correlated the Black Mingo with the lower Wilcox, Nanafalia Formation of the eastern Gulf Coast. Their (Cooke, 1936; Cooke and MacNeil, 1952) correlation was based on macrofossils from the more marine, type area of the Black Mingo Formation.

Siple (1967, p. 28-31) introduced the name Ellenton Formation for what he considered to be an Upper Cretaceous unit that overlay the "Tuscaloosa" Formation in the subsurface of the Savannah River Plant in western South Carolina. The type section of the Ellenton Formation is the interval 310 feet to 385 feet in well 52-C in SRS. A reformatted type description of the Ellenton Formation as given by Siple (1967, p. 29) is as follows: ***Cretaceous (?) System-Ellenton Formation***- *(310-335 feet)-25 foot thick clay, bluish-gray, micaceous, lignitic sandy; muscovite common to abundant; altered pyrite or marcasite fairly common. Subangular to subrounded fine medium quartz grains. Trace of chlorite. Interval from 325-335 feet predominantly clay. (335-345 feet)-10 foot thick sand, coarse, clayey, micaceous lignitic; subangular milky quartz; dark gray clay; minor percentage shows conchoidal fractures. Heavy minerals in rare to trace amounts-may be contamination. (345-365 feet)-20 foot thick sand, same as above except for appearance of colorless acicular crystals of gypsum (selenite) in the dark gray clay. Other gypsiferous forms noted include satin spar. Some of the lignite replaced by pyrite or marcasite; 55 percent of sand coarse to very coarse. Laboratory determination of permeability indicates 66 gpd (Meinzer's units). (365-370 feet)-5 foot thick sand, white to gray, clayey and silty, micaceous and lignitic. Subangular fine to coarse quartz. Driller logged interval as clay.* ***Tuscaloosa Formation***-*(370-385 ft.)-15 foot thick Sand, tan to yellow, clayey, micaceous, kaolinitic; contains scattered red ferruginous sand nodules. Siple (1967, p. 28-29) described the Ellenton as follows: The Ellenton Formation consists of a dark-gray to black sandy lignitic micaceous clay interbedded with medium to coarse quartz sand. Some of the quartz grains contain inclusions of pyrite, others are rutilated. Much of the free pyrite appears to be decomposed. Authigenic gypsum crystals are commonly distributed throughout the formation.*

Generally, the upper part of the formation contains a gray silty to sandy micaceous lignitic clay with which the gypsum is commonly associated. In some wells the clay zone may be overlain by coarse quartz sand. The lower part of the Ellenton consists generally of clayey quartz sand of medium to coarse texture, which in some areas becomes very coarse and gravelly. The quartz grains are bluish gray. Lignite and decomposed pyrite or marcasite fragments, muscovite, and aggregates of kaolinite or other very soft minerals are fairly *common. The Ellenton Formation probably is unconformable with the underlying Tuscaloosa Formation and the overlying Tertiary sediments. The lower contact is characterized by a change in color of the clay and a change in the composition of the sand. The dark-gray to black clay of the Ellenton is readily distinguishable from the variegated clay of the Tuscaloosa. likewise, the quartzose sand of the Ellenton can generally be differentiated from the arkosic sand of the Tuscaloosa. The upper contact is also characterized by a change in the color of the clay above and below the contact. ...The type-locality well for the Ellenton Formation is well 52-C which is 4 miles northeast of the town of Ellenton and 7 3/4 miles southeast of Jackson, Aiken County, S. C. ... The Ellenton Formation was penetrated in the type well at a depth of 310 to 370 feet. ...(Siple, 1967).*

The type section consisted of well-cuttings from 52-C but the cuttings are now lost. In general in SRS and eastern Burke County, the basic criteria for identification of the Ellenton Formation were the consistent presence of carbonaceous and lignitic material in the formation, the prevalence of well-sorted, fine-grained sand, and the unit's prevailingly neutral tones of white to gray to black. Subsequent authors adopted the name Ellenton (Bechtel, 1982; Prowell and others, 1985a; Prowell and others, 1985b; Harris and Zullo, 1990). Others have not (Fallaw and Price, 1992, 1995).

Van Nieuwenhuise and Colquhoun (1982b, p. 52) reintroduced the Rhems and Williamsburg of Sloan (1908) in the type area of the Black Mingo: *"The Black Mingo Shale, Rhems, Williamsburg and Lang Syne subphases of formations of Sloan (1908) comprise what is herein defined as the Black Mingo Group. Elevation of the Black Mingo to group status is actually only recognition of the range implied by Sloan (1908) who considered the "Black Mingo Phase" as an aggregation of several formations or "subphases". However, redefinition of the composite formations of the Black Mingo Group is necessary in order to eliminate a great deal of confusion in the literature and to incorporate the much more detailed stratigraphic data now available."*

Further, Van Nieuwenhuise and Colquhoun (1982b) divided their Rhems Formation into a lower Browns Ferry Member and an upper Perkins Bluff Member. The Browns Ferry (lower) and Perkins Bluff (upper) Members (Fig. v) of the Rhems were considered to grade laterally and vertically into each other. Van Nieuwenhuise and Colquhoun (1982b) also divided the Williamsburg Formation into a lower Bridge Member and an upper Chicora Member. The Lower Bridge Member was also described as grading vertically and laterally, in part, into the overlying Chicora Member.

According to Van Nieuwenhuise and Colquhoun (1982b, p. 54,): *"The Rhems Shale of Sloan (1908) is a distinctive shale containing almost no sand-sized particles and very few calcareous microfossils. ...The type Rhems of Sloan (1908) at Rhems Landing is considered to be the finer-grained end member of the total range of the fine-grained clastics comprising the Browns Ferry Member."* and *"The lithology of the type Black Mingo Shale of Sloan (1908) is characteristic of a greater portion of the Browns Ferry Member and also the overall Rhems Formation than any of the other composite lithologies."*

Van Nieuwenhuise and Colquhoun (1982b) did not fully discuss the lithologies of the Black Mingo formations and their members. They described the Browns Ferry Member, which evidently is the principal concept of their Rhems Formation, as an "arenaceous mud" , clayey sand or, generally, as a silty clay. They (p. 54) described the Perkins Bluff Member of the Rhems Formation as an: *"...imbricated, pelecypod-rich. argillaceous sand ...resistant, partially silicified Perkins Bluff Member forms a prominent ridge that extends along the Black River and overhangs the Browns Ferry Member several feet near river level."* and *"The Perkins Bluff Member lithology is considered somewhat variable but throughout maintains a coarser-grained texture than the Browns Ferry Member. Parts of the Perkins Bluff member are almost "coquina," such as at its type locality, but grade to an argillaceous sand with numerous pelecypods either as fragments, internal molds, or whole shells." (Van Nieuwenhuise and Colquhoun, 1982b).*

Van Nieuwenhuise and Colquhoun (1982b, p. 57) described the Williamsburg Formation, or upper Black Mingo, as: *"...arenaceous shales, "fullers earth," and fossiliferous, argillaceous sands of the Lower Bridge Member and the fossiliferous, argillaceous sands and molluscan-rich bioclastic limestones of the Chicora Member. The Lower Bridge and Chicora members tend to be gradational from the very fine-grained clastics of the Lower Bridge to the coarse-grained clastics and limestones of the Chicora."* and the Lower Bridge Member as: *"...siliceous mudstone and arenaceous shale ..."* and *"...fine-grained clastic unit is predominantly clay-size with some silt and occasional clean sand lenses... Internal molds of pelecypods oriented parallel to bedding planes can be found." Van Nieuwenhuise and Colquhoun, 1982b.*

Finally, Van Nieuwenhuise and Colquhoun (1982b) described the Chicora Member of the Williamsburg Formation as *"...a glauconitic, argillaceous, fossiliferous sand and indurated molluscan-rich limestone... Within the indurated limestone beds large internal and external molds of Turritella are present along with large valves and fragments of Ostrea sinuosa Rogers and Rogers, ..."*

In South Carolina, the Ellenton Formation has been recently subdivided into two chronostratigraphic subdivisions, a lower Midwayan (Danian) Ellenton and an upper Sabinian (Thanetian) Ellenton (Prowell and others, 1985a). This subdivision has resulted in the establishment of a variety of new formations: Rhems Formation (McClelland (1987), Sawdust Landing Formation and Lang Syne Formation (Fallaw and Price, 1992, 1995); or combinations of the Ellenton Formation with other formations in the Ellenton interval defined by Siple (1967): Ellenton Formation and Rhems Formation (Colquhoun and others; 1983), P1 and P2 (Prowell and others, 1985a, 1985b), Ellenton Formation and Black Mingo Formation (?), Ellenton Member of the Rhems Formation (Steele, 1985), Ellenton and Williamsburg Formations (Aadland and others, 1992).

Fallaw and Price (1992, 1995) abandoned the name Ellenton *"because the sediments named by Siple 1967) consist of two different sedimentary sequences with different lithologies deposited during separated cycles of deposition."*

They recognized two formations in the Ellenton stratigraphic position in the subsurface of the Savannah River area south of Aiken, South Carolina and Augusta, Georgia: the Sawdust Landing Formation and the Lang Syne Formation. The Sawdust Landing Formation was described by Fallaw and Price (1992, 1995) from the northwestern part of SRS as *"... gray, poorly and moderately sorted, micaceous, silty and clayey quartz sands and pebbly sands with interbedded dark gray clays. In some wells in the northwestern part of SRS, it consists of yellow, orange, tan, moderately to poorly sorted, micaceous, quartz sands. It is locally feldspathic, and iron sulfides and lignite are common in the darker parts of the section. The clays are fissile in places and contain micaceous silt and fine sand laminae. There appear to be two fining-upward, sand-to-clay sequences in the downdip part of the Site."*

The Sawdust Landing Formation, as it has been lithologically described, does not occur in Georgia. However, some Sawdust Landing-type sediments are present in the Black Mingo Formation in Burke County, indicating physical correlation with the Sawdust Landing of Price and Fallaw (1992, 1995). Most Sawdust Landing lithology is seen in northern Burke County in the basal beds of the Black Mingo. In the Millers Pond core (GGS- 3758) and in the GGS-3764, the lower part of the Black Mingo Formation consists of coarse, micaceous, poorly sorted, coarse-grained, pebbly sand of Sawdust Landing lithology as described by Fallaw and Price (1992, 1995). This updip lithofacies of the Lower Paleocene appears to be the downdip extremity of coastal marine/fluvial sediments that are widespread in the subsurface of western South Carolina.

Fallaw and Price (1992, 1995) described the lithology of their Lang Syne Formation in SRS as follows: *"At SRS the Lang Syne typically consists of dark gray and black, lignitic clays and poorly and moderately sorted, micaceous, lignitic, muddy quartz sands and pebbly sands. Iron sulfides are common in the darker parts of the section. Both sands and clays are glauconitic in places, especially in the* *southeastern part of the Site. The basal unit is a greensand in some wells. The clays tend to be fissile and contain micaceous silt and fine sand laminae. Cristobalite is common in some cores. Deposits composed of yellow, orange, tan, moderately to poorly sorted, micaceous quartz sands are common in the northwestern part of SRS, with darker, poorly sorted, micaceous facies becoming dominant to the southeast. In some wells, clean, moderately to well-sorted sands occur near the top of the unit."*

The Lang Syne Formation of the Fallaw and Price (1992, 1995) in SRS is lithologically more similar to the Black Mingo Formation section in eastern Burke County, than it is to other subdivisions of the formation. However, according to their description of the unit, their Lang Syne has more clay than the Black Mingo of Burke County, and the sand in the SRS is coarser and more poorly sorted. The principal distinguishing lithic character of the Lang Syne of Sloan (1908) is glauconite, and the Lang Syne of Fallaw and Price (1992, 1995) and the upper part of the Burke County Black Mingo does contains scattered glauconite. But there is no consistent Lang Syne lithology in the upper part of the Black Mingo in Burke County. Therefore it is questionable whether the upper part of the undifferentiated Black Mingo Formation in Burke county is the same as the Lang Syne beds of Sloan (1908) from the type area of the Lang Syne plantation 1.5 miles east of Fort Motte in Orangeburg County, South Carolina (see Cooke, 1936, for fuller discussion). Furthermore, the age of the Lang Syne of Fallaw and Price (1992, 1995) is considered to be Late Paleocene (Thanetian or Selandian) (late Midwayan or early Sabinian): *"The term "Lang Syne" for the SRS deposits is used here rather than "Rhems", because of greater lithologic similarity with the type Lange Syne. Our palynological data indicate that the Lang Syne (upper "Ellenton") strata at SRS and vicinity are Thanetian or Selandian rather than Danian; the Rhems has been dated as Danian (Van Nieuwenhuise and Colquhoun, 1982b)."*

Palynological dating of the upper part of the Black Mingo in Burke County indicates that it is mostly Selandian, late Midwayan in age, and not Thanetian (Edwards, personal communication, 1995).

Finally, there appears to be a change in tectonism in the vicinity of the Savannah River. The Williamsburg claystone is relative thick in the SRS Ellenton reference core P-18 and in the cores VSC-3 and VSC-4, but is not present a few miles west in Georgia even though the stratigraphic units overlying and underlying the claystone are present and unchanged on either side of the river.

Discussion

The Ellenton Formation of Siple (1967) consists of two distinct lithostratigraphic units in the Ellenton reference core P-18 from SRS in Aiken County, South Carolina; a lower carbonaceous and lignitic sand unit with virtually the same lithology as the correlative formation in Burke County, and an upper sandy opaline claystone (or mudstone) unit (Williamsburg) (a few inches of the claystone are present in the middle part of the Black Mingo in the core VG-5 in Burke County). The lower sand unit and the claystone unit are also present in the cores VSC-3 and VSC-4 from southern Barnwell and northern Allendale Counties, South Carolina, respectively. Siple (1967) did not identify claystone chips in his type description of the Ellenton.

The lower carbonaceous sand unit is distinct from all named subdivisions of the Black Mingo in that the unit is predominantly a carbonaceous, lignitic, well-sorted, fine-grained sand with some medium- to coarse-grained sand. Of the named subdivisions of the Black Mingo, the Lang Syne Formation as described by Fallaw and Price (1993, 1995) is most similar to the lower carbonaceous sand unit in core P-18 and in Burke County. However, the Lang Syne as described by Fallaw and Price (1992, 1995) should be present only in the stratigraphic position of the Williamsburg? claystone rather than underlying the claystone as is the case in the western SRS. We have seen no lithofacies intermediate to the Williamsburg? claystone and Lang Syne in western South Carolina or in Georgia. Therefore, the stratigraphic position assigned to the Lang Syne by Fallaw and Price

(1992, 1995) is problematic. On the other hand, the upper part of the undifferentiated Black Mingo Formation in Burke County is slightly more glauconitic than the lower part of the formation, adding credence to the stratigraphic position of the Lange Syne assigned by Fallaw and Price (1992, 1995). Yet, the lower and upper parts of the Black Mingo Formation in Burke County are too similar to subdivide and, in most cores, there is no distinctive bed change that could be cited as a upper/lower Black Mingo boundary.

According to the modern codes of stratigraphic nomenclature (American Commission on Stratigraphic Nomenclature, 1961, 1970; North American Commission on Stratigraphic Nomenclature, 1983), and guides to stratigraphic nomenclature (International Subcommission on Stratigraphic Classification, 1976), if a lithostratigraphic unit is subdivided into two or more lithostratigraphic units, the original name of the unit cannot be restricted to a subdivision of the unit. If the old name is to be retained, then the original lithostratigraphic unit must subdivided into members or the unit be raised in rank to group. Because the siliceous claystone in the upper part of the Ellenton Formation of Siple (1967) has always been a critical lithic component of the Black Mingo, we believe that the name of the siliceous claystone, the Williamsburg Formation, be retained in western SRS. As a result, the name Ellenton cannot be retained unless the Ellenton is raised to group rank, in which case the lower carbonaceous sand must be given a new formation name. Or, the name Ellenton be retained at formation rank, the lower carbonaceous sand be given a new name at member rank, and the Williamsburg dropped in rank in the Savannah River area to a member of the Ellenton Formation. The later solution is viable according to Article 25 of the North American Stratigraphic Code (1983).

The course we choose to take in this report is neither of the above because we currently lack critical data from the SRS. We suggest that the name Ellenton be considered a junior synonym of Black Mingo and the formation in question in Burke County be called undifferentiated Black Mingo Formation. The formation in question in Burke County is clearly not Sawdust Landing Formation as applied by Fallaw and Price (1992, 1995). It also is not clearly Rhems lithology of the central South Carolina Coastal Plain. On the other hand, except for its being persistently carbonaceous, the Burke County unit is broadly compatible with Black Mingo lithology. But, the unit is not consistently divisible into lower and upper lithostratigraphic subdivisions as in the type area of the Black Mingo. According to Edwards (personal communication, 1995), on the other hand, maintains that the Burke County Black Mingo is generally biostratigraphically divisible into lower (Danian) and upper (Selandian) parts.

Supporting the biostratigraphy, there are some scattered instances in Burke County where the Black Mingo does have lower and upper lithostratigraphic subdivisions. Out of 15 cores logged in eastern Georgia, we have found 4 inches of Williamsburg-type claystone that is present in the middle part of the Black Mingo at a depth of approximately 410 feet in Bechtel core VG-5. Of the 15 cores, 11 clearly consist of one lithostratigraphic unit. In all of these sections sampled for dinoflagellate biostratigraphy, most were early to middle Midwayan in age with a few samples (from the USGS Girard core) near the top of the formation being of late Midwayan age (Edwards, personal communication, 1995). Therefore we conclude that most of the biostratigraphic evidence indicates that the Black Mingo Formation in eastern Burke County is of early and late Midwayan age (and is correlatable with the Rhems in the type area of the Black Mingo).

In two cores in Burke County the Black Mingo does consist of a lower and upper part. In the core GGS-3757, taken near McBean Creek in northern Burke County, the lower part of the Black Mingo consists of a dark gray to black laminated clay abruptly overlain by an upper glauconitic sand. In the USGS Girard core, the Black Mingo also is divisible into lower and upper parts and the lithostratigraphic divisions are compatible with the Rhems and Williamsburg Formations as described in eastern South Carolina by Van Nieuwenhuise and Colquhoun (1982b). The lower part of the Black Mingo consists mainly of finely sandy clay whereas the upper part consists of glauconitic, calcareous sandstone; glauconitic, calcareous sand; and, at the top of the section, a bed of silty laminated clay. The lower part of the Black Mingo was correlated with the Clayton Formation of the eastern Gulf Coastal Plain and the upper part is in calcareous nannofossil zone NP 5 (Edwards, personal communication, 1995). The upper Midwayan Naheola Formation of the eastern Gulf Coastal Plain occurs in Zone NP 5 (Siesser, 1983). Therefore the glauconitic sand in the upper part of the Black Mingo in the Girard core would be in the upper Midwayan and the lower part of the Upper Paleocene (lower Thanetian), consistent with a Late Paleocene age as determined by many paleontologists for the upper Black Mingo.

To summarize, our conclusion concerning the stratigraphic position and lithostratigraphy on the "Ellenton" in eastern Burke County is that the name Ellenton is a junior synonym of the name Black Mingo in that lithologies and stratigraphic position of the stratigraphic unit in the Savannah River area are all compatible with the Black Mingo Group of South Carolina. In addition, the Paleocene (Midwayan and lower Sabinian) in the Savannah River area in Georgia cannot be assigned to the Clayton Formation, Matthews Landing Member of the Clayton, Naheola Formation or Nanafalia Formation of western Georgia on the basis of lithology.

We do not recognize the Black Mingo as a group in Burke County because most of the cored sections consist of only one identifiable lithostratigraphic unit. There is evidence of an upper glauconitic stratigraphic interval in the Black Mingo in Burke County, but its occurrence appears to be local and shows no systematic pattern of occurrence. Neither the Rhems Formation nor the Williamsburg Formation are present in eastern Burke County, nor are any of the members of the Rhems and Williamsburg Formations present in Georgia.

The absence of mappable, Thanetian, upper Black Mingo in eastern Georgia and its consistent occurrence in South Carolina suggests that during the Late Paleocene, either the Georgia coastal area was tectonically stable and the top of the lower Black Mingo (early to middle Midwayan) was a surface of nondeposition (sediment by-pass), or that the top of the lower Black Mingo was eroded. The variable thickness of the formations suggests the later scenario.

APPENDIX 3
HISTORICAL REVIEW OF CONGAREE FORMATION

Sloan (1907, 1908) named the Congaree Formation but did not designate a type locality for the formation. However, Cooke (1936, p. 59) and Cooke and MacNeil (1952, p. 22) suggested a lectostratotype for the Congaree Formation. The following discussion of Cooke (1936) and Cooke and MacNeil (1952) concerns the type locality problem for the Congaree Formation in South Carolina: *"The type locality of the Congaree shale appears to be on Elmore Williams place at the head of First Creek, 0.8 miles west of Gaston. Sloan reports an 8-foot ledge of fuller's earth containing numerous large casts of* *Venericardia "planicosta"* *and shark teeth, overlain by fossiliferous quartzite, exposed on the south side of a large natural amphitheater. The fuller's earth is provisionally assigned to the McBean Formation." (Cooke, 1936, p. 59-60)* and *"Sloan specified no single locality as the type of his Congaree "shale", "sands", or "buhrstone". The name is evidently taken from the Congaree River, and it has been suggested (Cooke, 1936, p. 59) that Sloan's locality 505 on the Elmore Williams place at the head of First Creek, a tributary of the Congaree River, be regarded as typical. This locality is difficult to find without a guide. However, ledges of similar rock are exposed on the road south of Bull Swamp Creek 2¼ miles west-northwest of Swansea and also at a waterfall north of the east-west county road about 2¼ miles west by north of Swansea." (Cooke and MacNeil, 1952, p. 22).*

Considering that Cooke (1936) and Cooke and MacNeil (1952) were correct in assigning the exposure in the amphitheater at the head of First Creek at Elmore Williams place, then that would be the principal reference locality for the formation but not by original designation. The principal reference section (lectostratotype) is the section of Congaree Formation exposed in the amphitheater. The principal reference locality according to Cooke (1936) is in Lexington County, 0.8 mile west of Gaston in the updip central Coastal Plain of South Carolina.

APPENDIX 4
HISTORICAL REVIEW OF THE MCBEAN FORMATION

Sloan, 1908, p. 269-273, 459, 460) first referred to the limestone exposed along McBean Creek and at Shell Bluff as Santee Limestone. Veatch and Stephenson (1911) subsequently abandoned the name Santee, without explanation, for the limestone exposures at Shell Bluff and McBean Creek in Burke County, Georgia. They referred these exposures to their newly proposed McBean Formation.

Veatch and Stephenson (1911, p. 237-284) named the McBean Formation for Claibornian deposits in Georgia that they believed were equivalent to the Tallahatta, Lisbon, and possibly lower part of the Gosport Sand of Alabama. The reason they gave for proposing a new formation rather than adopting a previously named formation was that: *"Although in a general way the correlatives of these formations [Tallahatta, Lisbon, and Gosport] may be recognized in Georgia, the extension of the use of these terms to this State is inappropriate, since the Claiborne group is not naturally divisible into the same units as in Alabama." Veatch and Stephenson 1911, p. 236*

It is not clear whether they believed that the Alabama formations could not be lithologically discriminated (divisible) in Georgia, or whether the lithostratigraphic sequence was not the same and, therefore, the application of the Alabama names was inappropriate. However, Veatch and Stephenson (1911) did apply the name McBean Formation generally to siliciclastic, marine deposits they believed to be of Claibornian age across the entire state of Georgia.

Although Shearer (1917) and Cooke and Shearer (1918) restricted the McBean to its type area in eastern Georgia, Cooke (1936) subsequently expanded the definition of the unit again to conform to that of Veatch and Stephenson (1911). Later authors, however, recognized only the Lisbon and Tallahatta Formations in western Georgia (MacNeil, 1947a, 1947b; Herrick, 1961; Toulmin and LaMoreaux, 1963; Herrick and Vorhis, 1963; Owen, 1963; Marsalis and Friddell, 1975; Huddlestun, 1981; Huddlestun and others, 1988). Only Pickering (1970) continued the usage of the name McBean rather than Lisbon for upper Claibornian marine deposits in central Georgia. Herrick (1961) and Herrick and Vorhis (1963), however, extended the name Lisbon Formation to the Savannah River, and Huddlestun, Marsalis, and Pickering (1974) questioned the lithostratigraphic validity of the McBean Formation in central and eastern Georgia. Huddlestun (1982) discussed the history of the marine Claibornian and Jacksonian terminology in eastern Georgia and western South Carolina.

Confusion regarding the propriety of the name McBean as opposed to the name Lisbon in Georgia resulted from the original ambiguity of both the type lithostratigraphic concept of the McBean Formation, and the stratigraphy of the type locality of the unit. The only sections cited by Veatch and Stephenson (1911)(the descriptions of the McBean were taken from notes by T. W. Vaughan) from the type area of the McBean Formation were in ravines and gullies approximately: ... *one-quarter of a mile south of McBean Station (Veatch and Stephenson, 1911, p. 242).*

The only "ravines and gullies" that are still exposed in that area occur between 0.4 and 0.5 mile (0.65 and 0.8 km) southeast to east of the railroad crossing at McBean. The distance given by Veatch and Stephenson (p. 242) as one-quarter mile south of the station would place the "gullies" in McBean Creek, and the southern valley wall due south of McBean contains no gullies. However, the precise location of the "gullies" of Veatch and Stephenson (p. 242) is uncertain but appear to be the ravines in the eastern valley wall of McBean Creek approximately 0.5 miles (0.8 km) southeast to east of the railroad crossing in the community of McBean.

At this time, most of these ravines expose only bland Barnwell residuum with rare "nodules", cobbles or boulders of chert. Only the eastern-most ravine still exposes approximately 3 feet (1 m) of McBean (according to the original lithologic descriptions of Veatch and Stephenson, 1911). Based on the lithologic descriptions of

Sloan (1908, p. 270), Veatch and Stephenson (p. 242) and on my own experience in the type area of the McBean, the only lithology that can be clearly attributed to the Claibornian McBean at the type locality is an impure, unconsolidated, mostly massive-bedded, fairly even-textured, calcarenitic, finely bioclastic, finely sandy limestone to very calcareous, calcarenitic sand (calcareous marl and soft, chalky limestone of Veatch and Stephenson, 1911).

The overlying greenish or drab clays and greenish yellow sands included in the McBean Formation by Veatch and Stephenson (p. 242), and which are not presently exposed in the ravines, are more consistent with the lithology of the Dry Branch Formation than with any other lithology known in the McBean. The Dry Branch Formation is exposed at the same elevation as the type McBean, 0.2 mile (0.3 mile south of the junction of Ga. Hwy. 56 and Ga. spur 56) from the McBean type locality. At the type locality of the McBean, approximately 30 feet (9 m) of soft, yellow to white sand, included in the Barnwell Formation by Veatch and Stephenson (p. 242, section 1, bed 4) and LeGrand and Furcron 1956), and in the McBean Formation by Cooke (1943, p. 56), was assigned to the Irwinton Sand by Herrick and Counts (1968, p. 54). Huddlestun (1982) included this sand section in the Irwinton Member of the Dry Branch Formation on lithologic grounds; soft white sand is not known to occur in the McBean Limestone Member in its type area, but does occur in the Dry Branch Formation. Bed (e) of Sloan (1908, p. 270) was reported to rest "on irregular surface of (f)", which is the McBean Limestone Member as we understand it. The "irregular surface" of Sloan (p. 270) may represent the disconformity between the McBean and the Dry Branch or a solution horizon at the top of the McBean. Unfortunately, this contact is no longer exposed in outcrop in the type area. In the nearby McBean core (GGS-3757), unweathered McBean limestone extends to the top of the Claibornian section where it underlies calcareous sands and limestone of the Utley Limestone Member of the Clinchfield Formation. Because of physical resemblance, sands and clays immediately overlying the soft limestone of the McBean at the type locality are here included in the Dry Branch Formation. Finally, The northward projection of the Dry Branch/McBean contact from the McBean core (GGS-3537) should be at approximately 20 to 30 feet above the floor of the McBean swamp, consistent with the altitude of the McBean-Barnwell residuum at the McBean type locality.

As an indication of the lithologic distinctiveness of the McBean, Brantley (1916, p. 44-55) presented seven chemical analyses of samples from the McBean Formation along McBean Creek and in the vicinity of Shell Bluff on the Savannah River. The percent calcium carbonate in these seven samples ranged from approximately 70% to 87%, compatible with the impure limestone lithology of the presently exposed McBean at the type locality and at Shell Bluff.

According to Veatch and Stephenson (1911, p. 239) Earle Sloan made a large collection of fossils: *"... at Sloan's Scarp on McBean Creek, between McBean Station and Savannah River."*

Vaughan identified the fauna and presented a faunal list in Veatch and Stephenson (1911, p. 239-240) and correlated it with the Lisbon Formation of Alabama, the St. Maurice Formation in Louisiana, and the Cook Mountain of Texas (see Veatch and Stephenson, 1911, p. 240, for the extensive list of fossils between McBean station and Savannah River). The shell bed is significant for the concept of the McBean Formation of Veatch and Stephenson (1911) and Cooke and Shearer (1918) as well as many subsequent authors.

Veatch and Stephenson (1911) gave no explanation or precise location for "Sloan's scarp", and it would presumably be the "scarp" mentioned by Sloan (1908) 269-270) as occurring: *"0.3 miles south of McBean station... on the south side of McBean Creek..."*, and exhibiting *"...a series of deeply incised gullies which expose the lower portion of the... section...,"* i.e., the "gullies" mentioned by Veatch and Stephenson (1911, p. 242). Therefore, based on the evidence presented by Sloan (1908) and Veatch and Stephenson (1911), it would appear that the fossil collection reported by Veatch and Stephenson (1911, p. 239-240) came from the near vicinity of the type locality of the McBean, i.e., the soft limestone or "marl" in the lower part of the described sections. However, neither Sloan (1908) nor Veatch and Stephenson (1911) mentioned the presence of richly fossiliferous shelly deposits in their measured sections of the type locality. In addition, calcitic fossils from the soft limestone in the McBean Member at the type locality and at Shell Bluff are rare, and aragonitic shells are absent.

The molluscan assemblage reported by Veatch and Stephenson (1911, p. 239-240) is a diverse, aragonitic, shelly fauna, and has the same delicate shells and preservation as that in the collections of the U.S. National Museum that the senior author examined in 1976. The sediment still adhering to these fossils is not a limestone or finely sandy calcarenite but an olive-gray, argillaceous, very fine sand. Therefore, based on the literature, there is doubt as to the precise location of the shell bed at "Sloan's scarp", and to the precise lithostratigraphic context of the shell bed.

The location given by Veatch and Stephenson (1911, p. 239) "between McBean station and Savannah River" suggests that the source bed of the fossil shells could be exposures along the right bank of McBean Creek below Bennock Millpond at the foot of a steep bluff ("Sloan's scarp"?), where McBean Creek passes into the Savannah River flood plain. This interpretation is supported by a comment of Cooke (1936, p. 56) that: *"The best collection thus far obtained was made by Sloan near the mouth of McBean Creek in Georgia."*

Based on that comment, the fossil assemblage reported by Veatch and Stephenson (1911) did not come from the type locality of the McBean as it must be understood today (the southern valley wall of McBean Creek from 0.3 to 0.5 mile [0.5 to 0.8 km] southeast of the community of McBean). Rather, the shells appear to have been collected from the lower part of the steep western valley wall of the Savannah River (Sloan's scarp), less than 2 miles (3 km) from the confluence of McBean Creek and the Savannah River.

The Bennock Millpond Sand Member crops out in the lower part of this bluff and the McBean Limestone Member crops out in the upper part of the bluff. The McBean is lithologically the same as the section exposed at Shell Bluff and in the McBean and Millers Pond cores. Therefore, it appears likely that the fossil shell assemblage attributed to the McBean did not come from the McBean Limestone Member as we now know it, but from the underlying Bennock Millpond Sand Member that is correlative with the lower part of the Lisbon Formation in Alabama. This interpretation is consistent with the presence of both aragonitic mollusk shells and fine, well-sorted sand that is characteristic of the sands in the fossil shells in the collections of the U. S. National Museum, and with the very well sorted, fine-grained sand in the lower part of the bluff (Sloan's scarp). Currently, the Bennock Millpond Sand Member is largely covered by leaf drift along the face of the bluff but very fine, well-sorted sand with common dark minerals can be seen in small braided rivulets from springs and seeps in the lower part of the bluff. Very fine, well-sorted sand with dark minerals is characteristic of the Bennock Millpond Sand Member, not the McBean Limestone Member. In addition, the structural contour map on the top of the Bennock Millpond Sand Member (Fig. 15) indicates that the top of the formation should be roughly 20 feet (6 m) above the base of the valley wall (Sloan's scarp) or the floor of the Savannah River swamp. This matches the elevations of the seeps and springs in the bluff and the elevation of the McBean Limestone Member in the upper part of the bluff. Finally, based on drilling, LeGrand and Furcron (1956, p. 33) included an incoherent sand, below ground level at the type locality of the McBean Limestone Member, in the McBean formation. The incoherent sand is compatible with the Bennock Millpond Sand Member and not with McBean Limestone Member.

Because the only distinctive Clabornian lithology present at the type locality of the McBean is the soft, "marly", massive-bedded limestone, then clearly the principle lithostratigraphic concept of the McBean must be that of a sandy limestone. This is at variance with the correlative upper Claibornian deposits south of the vicinity of Hancock Landing in Burke County and the rest of Georgia where upper Claiborne Group deposits consist of calcareous clay, or very argillaceous limestone ("marl").

Because of the historic confusion in use of the name McBean, and because Sloan (1908) originally referred the limestones along McBean Creek and Shell Bluff to the Santee, Fallaw and Price preferred the name Santee Limestone to that of McBean Limestone in the type area of the McBean. Based on lithology, we conclude that there is no Santee Limestone in Georgia, unless it is the sandy limestone at the top of the Still Branch Sand in southern Burke County.

We conclude that; 1.) the name McBean be should be changed in lithostratigraphic rank to McBean Limestone Member of the Lisbon Formation. The characteristic lithology of the McBean is a sandy limestone; 2.) In this context, the McBean is restricted to the vicinity of McBean Creek, Shell Bluff and the area north of the projected extension of the Pen Branch fault in Burke County; 3.) The name McBean Limestone should not be extended away from the area of its typical development; 4.) the limestone lithology of the McBean is different from the predominantly moldic and indurated Santee Limestone; 5.) the precise biostratigraphic correlation of the McBean to the type Santee has not been rigorously established; 6.) there is an updip, calcareous, argillaceous, probably nearshore sand referred to in this report as Bennock Millpond Sand Member; and 7.), it has never been demonstrated that the McBean fossil fauna collected by Sloan is from the McBean Limestone Member of the Lisbon Formation. It has only been assumed to be from the McBean.

Editor: Joseph Summerour