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Editor in Chief: S. Duncan Heron, Jr.

Abstract

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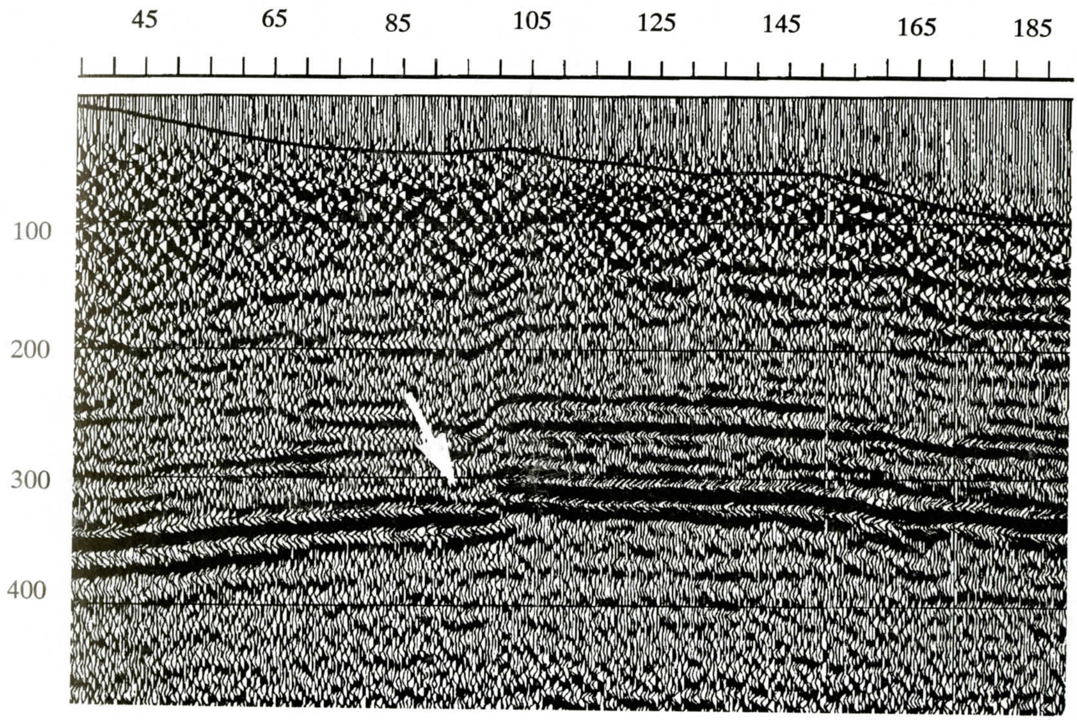

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2) Cite references and prepare bibliographic lists in accordance with the method found within the pages of this journal.
3) Submit line drawings and complex tables reduced to final publication size (no bigger than 8 x 5 3/8 inches).
4) Make certain that all photographs are sharp, clear, and of good contrast.
5) Stratigraphic terminology should abide by the North American Stratigraphic Code (American Association Petroleum Geologists Bulletin, v. 67, p. 841-875).

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SOUTHEASTERN GEOLOGY

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EDITOR'S PAGE

From time to time I will use this space to provide information that may be of interest to our readers.

The first issue of Southeastern Geology was published in the spring of 1959. One might question why the current volume (number 35) is not number 37. The reason is that we do not publish on a set schedule. We sell the journal by the volume (4 issues), not by the year. A volume might take more than 12 months. Because of this, we are known in the trade as an irregular publication.

Over 600 articles have been published in this journal, but only one index and that was for the first 10 volumes. During 1995, I hope to have a searchable index of titles and authors available on the World Wide Web. The journal's Web address is:

http://www.geo.duke.edu/seglgy.htm

You must have access to the Internet and a graphic viewer such as Mosaic. Currently available is information about the journal and the table of contents of volume 34 and this issue of volume 35.

This issue contains two articles on the Savannah River Site. These are the third and fourth articles published since October 1992 on some aspect of SRS. As many readers know, SRS like all of the early atomic bomb sites is severely polluted. In addition it is a temporary storage site for high level waste. It is important to know all that we can of the structure, stratigraphy and hydrology of this area. We are proud that Southeastern Geology has been able to publish these data about SRS.

If you are preparing a manuscript on any phase of the geology and hydrology of the southeast, I encourage you to submit it to this journal. The manuscript will be given a fair review by two peer critical readers as promptly as possible.

Duncan Heron

SOUTHEASTERN GEOLOGY
V. 35, No. 1, March 1995, p. 1-20

GEOPHYSICAL EVIDENCE FOR POST LATE CRETACEOUS REACTIVATION OF BASEMENT STRUCTURES IN THE CENTRAL SAVANNAH RIVER AREA

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ABSTRACT

Interpretation of several generations of seismic reflection data and potential field data suggests the presence of several crystalline blocks in the basement beneath the Coastal Plain in the Central Savannah River Area (CSRA). The seismic reflection and refraction data include a grid of profiles that capture shallow and deep reflection events and traverse the Savannah River Site (SRS) and the vicinity. Potential field data includes aeromagnetic, ground magnetic surveys, reconnaissance, and detailed gravity surveys. Subsurface data from recovered core are used to constrain the model.

Interpretation of these data characteristically indicate a southeast dipping basement surface with minor highs and lows suggesting an erosional pre-late Cretaceous unconformity. This surface is interrupted by several basement faults, most of which offset only early Cretaceous sedimentary horizons overlying the erosional surface. The oldest fault is perhaps Paleozoic because it is truncated at the Basement/Coastal Plain interface. This fault is related in timing and mechanism to the underlying Augusta fault. The youngest faults deform Coastal Plain sediments of at least the Priabonian age (40-36.6 Ma). One of these young faults is the Pen Branch fault (PBF), identified as the southeast-dipping master fault for the Triassic Dunbarton basin. The Cenozoic faults are probably related in time and mechanism to the nearby, well-studied Belair fault.

The study area thus contains a set of structures evolved from the Alleghanian orogeny through Mesozoic extension to Cenozoic readjustment of the crust. A metamorphosed crystalline terrane with several reflector/fault packages exists to the north of a reactivated Triassic basin. A mafic terrane separating the Dunbarton basin from the large South Georgia basin is interpreted to the south of SRS, and an overprint of reverse faults, some reactivated, and some newly formed are found throughout the study area.

INTRODUCTION

Near-continuous geological and geophysical investigations have been performed at Savannah River Site (SRS) and in the general Central Savannah River Area (CSRA) (Figure 1) for more than 40 years. The majority of the studies concentrate on the sediments of the Coastal Plain. The data on the underlying basement are much more limited and depend upon the interpretation of a few deep borings and geophysical surveys. Standard seismic and high-resolution, shallow seismic reflection and refraction data, in conjunction with potential field data and constrained by the available geologic data from deep cores, were used to develop a model of structure within the basement complex.

Interpretation of these data characteristically indicate a southeast dipping basement surface with some minor highs and lows suggesting an erosional surface (pre-Cretaceous unconformity). This surface is interrupted by several basement faults, most of which offset only early Cretaceous sedimentary horizons overlying the erosional surface (Figure 2). The oldest fault is Mesozoic, or perhaps late Paleozoic, because it is truncated at the Basement/Coastal

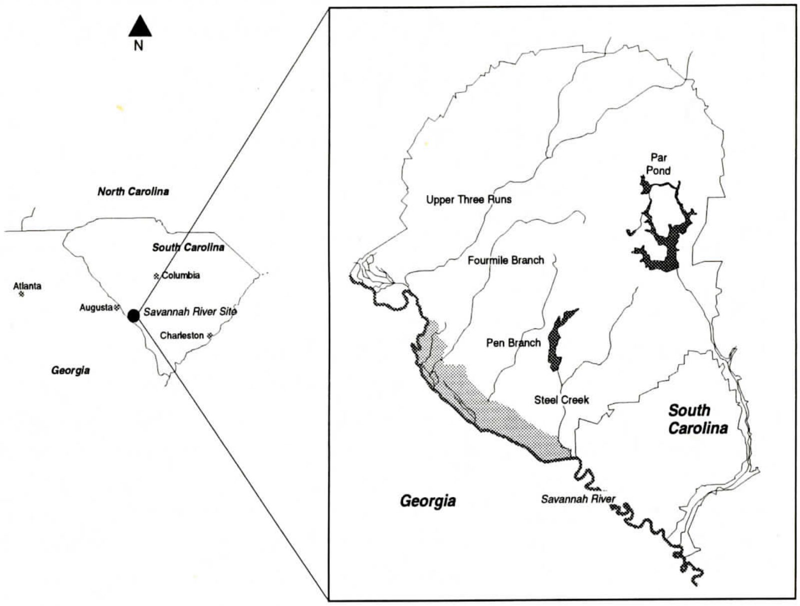


Figure 1.Location of study area.

Plain interface. The youngest fault may be Tertiary-age because deformed sediments of that age in the Coastal Plain are observed directly overlying this fault. The faults form the boundaries to zones with different seismic reflections and potential field characteristics.

Geologic Background

Coastal Plain Section

The CSRA is located on the Atlantic Coastal Plain, which is an essentially flat-lying, undeformed wedge of unconsolidated marine and fluvial sediments. The sediments are stratified sand, clay, limestone, and gravel that dip gently seaward and range in age from Late Cretaceous to Recent. The sedimentary sequence thickens from zero at the Fall Line to more than 1.2 km at the coast. Several investigations have provided a great deal of data and insight into the evolution of the southeastern United States Coastal Plain including: Cook (1936), Siple (1967), Huddlestun and Hetrick (1978), Colquhoun and Steele (1985); Prowell and others (1985), Dennehy and others (1988), Fallaw and others (1990 and 1992), Nystrom and others (1990), Aadland and Bledsoe (1990).

Two lithologic settings occur beneath the Coastal Plain sedimentary sequence at SRS, below a pre-Cretaceous unconformity: (1) the Dunbarton basin, a Triassic-Jurassic Rift basin, filled with lithified terrigenous and lacustrine sediments with minor amounts of mafic volcanic and intrusive rock (Marine 1974a and 1974b; Marine and Siple 1974); and (2) a crystalline terrane of metamorphosed sedimentary and igneous rock that may range in age from Precambrian to late Paleozoic. The Paleozoic rocks and the Triassic sediments were leveled by erosion, forming the base for Coastal Plain sediment deposition. The erosional surface dips southeast approximately 8m/km.

Metamorphic Basement

The metamorphosed crystalline rock is similar to that found in the Piedmont Province immediately northwest of the fall line, 20-25 km northwest of SRS. Preliminary work on drill core lithology suggests that Kiokee Belt and Belair Belt rock may be found in core sample taken at SRS. Probable greenschist facies volcanic rock exists in the Deep Rock Boring

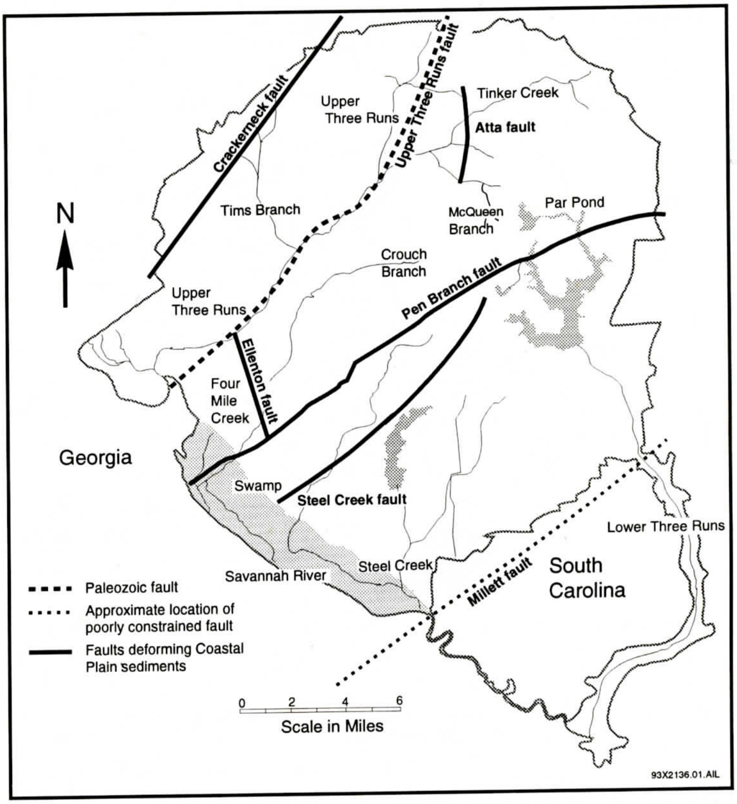


Figure 2. Location of faults in the subsurface at Savannah River Site.

well series (Marine 1974a and 1974b), and the PBF wells contain biotite gneiss and amphibolite. Between New Ellenton and Aiken, South Carolina, granite and granitic gneiss have been identified in core.

Dunbarton Triassic Rift Basin

The Dunbarton basin has been the subject of investigation since Siple (1967) identified the basin from aeromagnetic and well data. Marine (1974a and 1974b) and Marine and Siple (1974) described the subsequent seismic reflection surveys and additional well data. The structure was interpreted as an asymmetric graben approximately 50 km long and 10-15 km wide with normal faults to the northwest and southeast.

Additional investigations were conducted at SRS from 1985 to 1991, such as standard seismic reflection, potential field surveys, in situ stress measurements, and high-resolution, shallow seismic reflection surveys. These studies were initiated to better understand the deformational history of Coastal Plain material and to determine the cause of two micro-earthquakes that occurred in 1985 (local magnitude of 2.6) (Talwani and others, 1985) and 1988 (local magnitude of 2.0) (Stephenson, 1988).

DATA

Seismic Reflection Programs

Since 1969, four seismic reflection surveys were conducted at SRS. Seismograph Service Corporation obtained digital, single-fold data as part of the Bedrock Waste Storage Program. This was the first onsite survey that provided a preliminary indication of basement faults buried beneath the Coastal Plain section of this region. The survey lines were shot in Barnwell

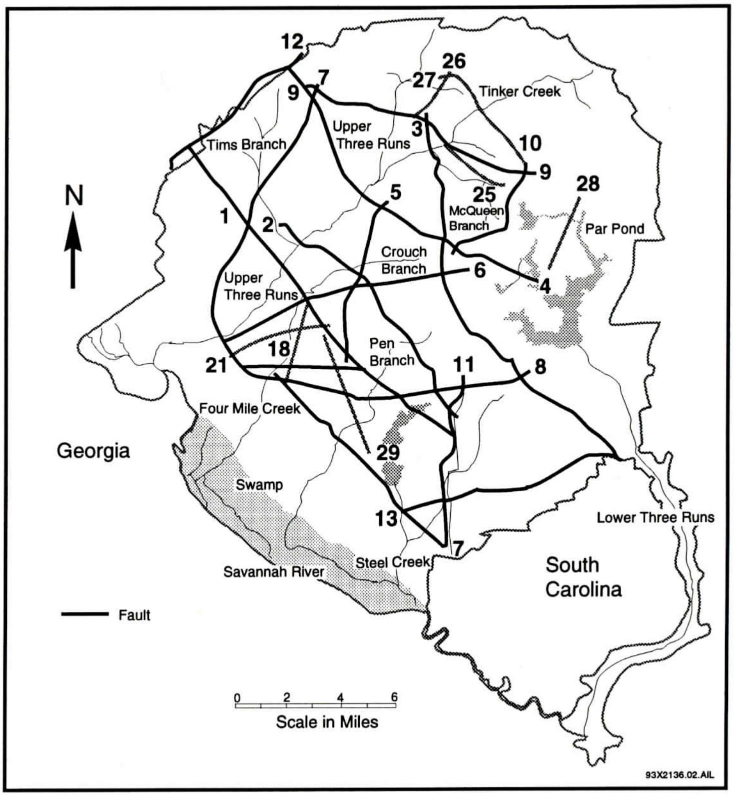


Figure 3. Conoco Inc. seismic reflection survey index map.

County on SRS over the buried Triassic basin. The purpose of this survey was to constrain the position of the basin, the strike of the faults, and the attitude of the bedrock surface. Seismograph Service Corporation obtained 139 line km of surface coverage in three field programs using a 24-channel digital recording system, 278 m between shot points (75 ft near offset), and about 0.45 kg of high explosives per shot.

Conoco Inc. conducted a vibroseis seismic reflection survey at SRS in 1987-88 (Chapman and DiStefano, 1989) (Figure 3). The primary objective of the program was to define basement structure and previously identified faults and to identify any other faults that may exist. A secondary objective was to image shallower or deeper structures that appeared on the seismic records. These data capture energy from 0.1 seconds to about 13 seconds.

An initial 216 line km of seismic reflection data were acquired over the central part of SRS. Initial parameters were selected to provide data for reflection and refraction analysis. The initial seismic acquisition parameters listed in Column A of Table 1, were used on the first five lines recorded (Lines 1, 4, 6, 7, and 8). Initial processing indicated that the reflection data quality was sufficient to satisfy the objectives and that the longer refraction geometries were not necessary. For this reason, the parameters listed in column B of Table 1 were used on the remainder of the lines recorded. The Column B parameters were more singly focused for mapping the shallow basement reflector with 24-fold CDP stack. Preliminary interpretation results highlighted areas that required additional definition. An additional 45 line km (eight lines) were acquired to fill in these specific areas with greater detail. Three shallow vertical velocity surveys were also conducted to provide time-

Table 1: Acquisition Parameters for the Conoco ReflectionSurvey

	A	B	C
Flag spacing	55	40	20
CDP Stack (fold)	48	24	20
Near offset (ft)	137	140	50
Far offset (ft)	2722	2020	990
Sweep frequencies (Hz)	20-120	20-120	30-150
Length (sec)	10	10	8
Source	3 × 6	3 × 6	1 × 4
Array length (ft)	90	90	0
Geophones	1 × 14	1 × 14	1 × 14
Array length (ft)	55	55	0
Record time (sec)	14	14	10
Sample rate (milliseconds)	2	2	2
Alias filter	2	2	2
Low cut filter	18	18	30
Slope	18	18	18
60 Hz notch	out	out	out
COS box	in	in	in

depth calibration for the seismic reflection data. Geophysicists from the Regional Geophysics Laboratory at Virginia Polytechnic Institute recently reprocessed these data. Details of various kinds of structures are revealed from as deep as the Moho (33 km) to as shallow as 50 milliseconds (Costain and others, 1992a and 1992b; Dormoracki and others, 1992; Sen and Coruh, 1992; Dormoracki, Ph.D. dissertation pending).

In general, the seismic reflection data show features that reflect a current understanding of the regional geology of the Coastal Plain. Survey profiles demonstrate a seaward thickening section with a regional dip to the southeast. The reflectors in the upper 305 m of the seismic data are interpreted to be predominantly sand/clay interfaces and clastic/carbonate interfaces. Some are believed to be caused by impedance contrasts across regional unconformities. Interpreted structures observed in the seismic data (e.g., low- and high-frequency undulations, truncated and offset reflectors, and intermittent reflectors) are interpreted to be faults, possible folding or deformation, sedimentary facies changes, and narrow to wide stream channels, point bars, or overbank deposits. Below the Coastal Plain crystalline metamorphic and Triassic/Jurassic-age rock, the basement complex contains structures and characteristics that provide additional insight into the geologic framework of the area.

Gravity Surveys

Long and Talwani (1975) conducted regional gravity surveys for Georgia and South Carolina. The Birdwell Division of Seismograph Service Corporation collected gravity data at SRS in 1971. Anderson (1990) and Madabhushi and Talwani (1991) conducted the most recent surveys. The objective of these surveys was to map basement and other deep-seated structures.

In 1971, the Birdwell Division performed a gravity survey in conjunction with a ground magnetic survey of the southern portion of SRS as part of the Bedrock Waste Storage Program.

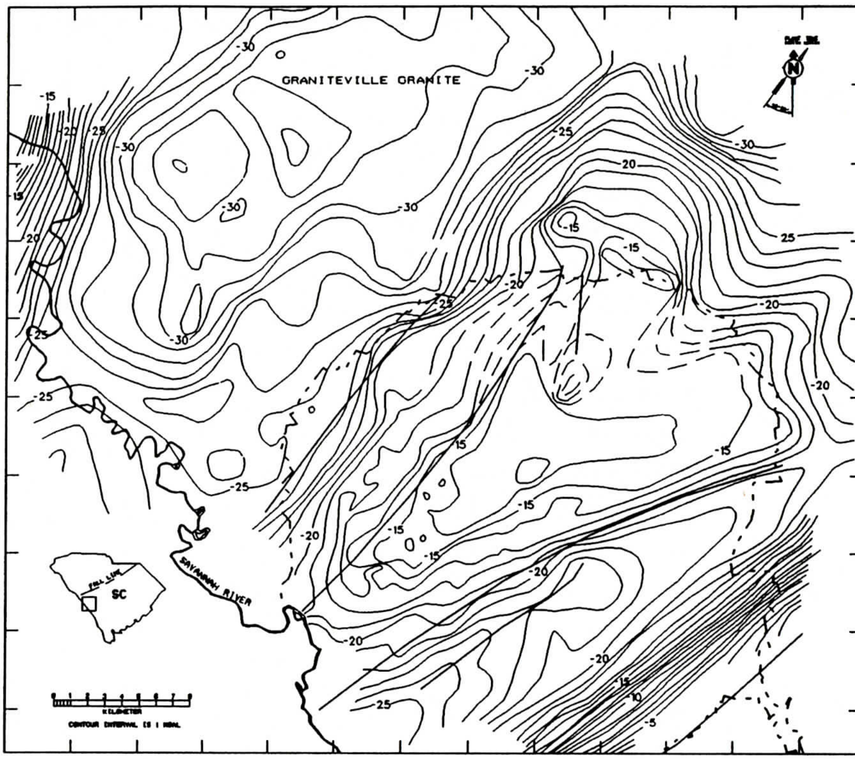


Figure 4. Gravity map of central Savannah River area.

The objective of this survey was to determine the depth and lateral extent of the Triassic Dunbarton basin and the apparent dip of basement faults recognized on the seismic reflection survey. The data obtained in this survey are relative values because the lines were not tied to base stations of the existing gravity networks. Modeling of these data, by the Birdwell Division, indicated the Dunbarton basin to be approximately 2 km deep and contain a number of fault blocks with approximately 0.6 km of displacement on the northwest border fault. The Triassic sediments are underlain by dense crystalline rock.

A second detailed gravity survey was performed by Anderson (1990) (Figure 4). During this investigation, Anderson obtained gravity data with a Worden gravimeter, Model 112, occupying 1134 stations at approximately 0.46 km spacing, mostly on SRS, but also in the surrounding area. The survey established 79 overlapping loops, and base stations were reoccupied at less than 2.5 hour intervals. The maximum local relief was 50-250 m. Within SRS, repeatability of data at the stations was less than 0.2 mgals and in the surrounding region, less than 0.5 mgals. Bouguer gravity maps were constructed to detail the deeper seated features in the bedrock (1 mgal and 0.5 mgal maps). A regional gravity survey (Madabhushi and Talwani, 1991) incorporated a larger portion of the middle state region, but it was taken at a lower station density.

Magnetic Surveys

The United States Geological Survey (USGS) conducted an aeromagnetic survey of the SRS region (1958) at the request of the Atomic Energy Commission. The survey covered a 160-km^2 area, centered on the site. Northwest-southeast flight lines were spaced at 1.6 km intervals and flown at 152 m above ground surface (Petty and others, 1965).

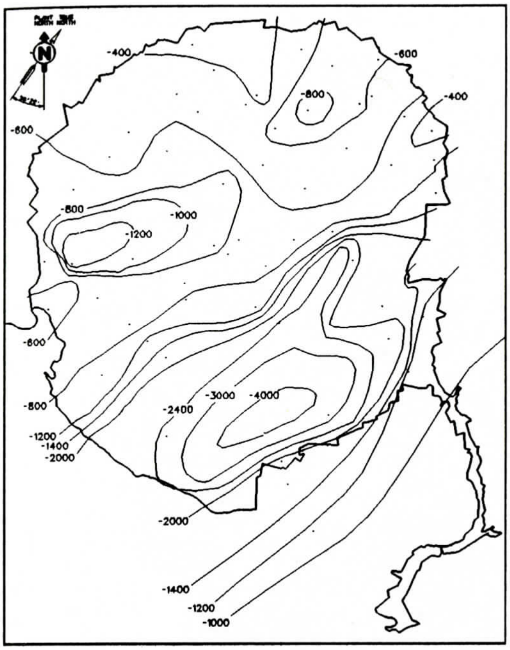


Figure 5. TDEM structure contour of the crystalline basement.

Daniels (1974) reanalyzed these data and modified the map of Petty and others, (1965) by combining geologic data from core.

In 1972, the Birdwell Division performed a surface magnetic survey of the southern portion of SRS following seismic lines and extending to the southeast (Fairfax, South Carolina). No data were obtained in the northwestern portion during this survey.

Time Domain Electromagnetic Survey

Blackhawk Geosciences Inc. conducted a survey at SRS in 1989 to determine the depth and geometry of the Dunbarton basin (Figure 5). Out of 124 total stations, 80 time domain electromagnetic (TDEM) stations detected basement with an aerial distribution of 1/4 mi^2. Three different systems were used to maximize different depth determinations: Geonics EM-42, EM-37, and EM-47. A non-grounded loop transmitter was used with a center loop array. Blackhawk Geosciences Inc. concluded, based on the TDEM survey, that the bottom of the Triassic basin was approximately 1.8 km deep.

INTERPRETATION OF FAULTS

We compiled and integrated this data and developed a geologic model of the subsurface, including the shallow Coastal Plain and the shallow portion of the crust (Figure 6). The following faults were corroborated or newly identified:

- Branch fault (PBF)—initially identified as the northern boundary fault of the Triassic basin
- Steel Creek fault—a fault southeast of the PBF within the Triassic basin and forming a horst with the PBF
- Atta fault—the north, northeast trending fault in the north-central portion of SRS
- Ellenton fault—a north-south trending fault east of D-Area that may intersect the

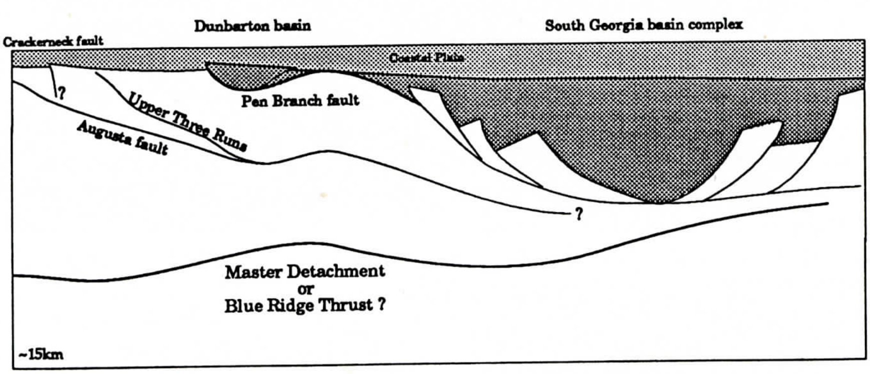
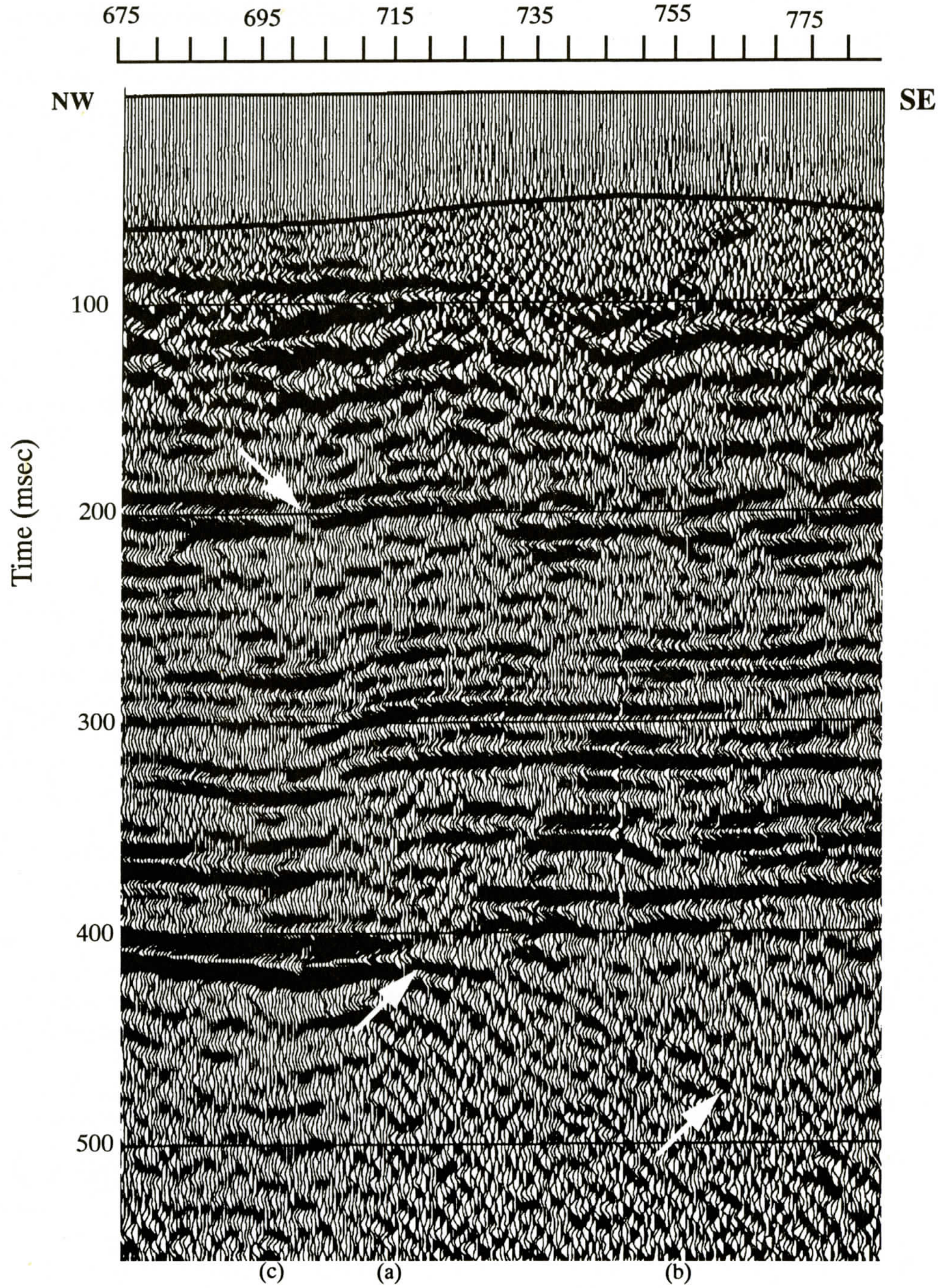


Figure 6. Cross-Section of transect from just north of plant boundary to the southeast to include the south Georgia rift complex.



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[a] offset strata at the basement–Coastal Plain Contact

[b] shallow dip of fault in basement rock

[c] shallowest clean deformation on fault

Figure 7. Conoco seismic reflection profile Line 2 Exp, detailed view of Pen Branch fault.

PBF

- Crackerneck fault—a northeast trending fault located in the northwest portion of SRS
- Upper Three Runs fault—a northeast trending fault that underlies the current Upper Three Runs drainage

Pen Branch Fault

The PBF (Figure 2) was first identified in the subsurface at SRS in 1989 based upon interpretation of earlier seismic reflection surveys and other geologic investigations (Marine and Siple 1974; Chapman and DiStefano, 1989; Snipes and others, 1993; Stieve and others, 1993). This fault constitutes a possible upward propagated segment of the northern boundary fault of the Triassic Dunbarton basin and strikes northeast across the middle of SRS, parallel to the boundary of the Triassic Dunbarton Rift basin. It is the longest and one of the shallowest of the faults in the study area and it dips to the southeast. In the crystalline basement, normal slip direction was originally down to the southeast, resulting in the formation of the rift basin. However, reverse movement during Cretaceous and into Tertiary time is up to the southeast (Stephenson and Chapman 1988; Snipes and others, 1993). Based on drill core data, Triassic rock is known to be structurally higher than the crystalline basement (Snipes and others, 1989; Stieve and others, 1991). Based on focal plane solutions, a component of strike-slip movement could also occur on the fault (Stephenson and others, 1985).

The 1974 seismic survey (Seismograph Service Corp.) crossed the fault with five lines. The data suggested a zone of disturbed layers in the vicinity of the currently mapped trace of the PBF. In the Conoco survey (1987-88), nine lines cross the border fault, clearly showing the fault and providing good control for mapping its location.

Three lines from the Conoco survey, reprocessed by Virginia Polytechnic Institute and State University, serve to illustrate current understanding of the seismic expression of the PBF. Conoco line 2 exp displays typical PBF geometry and the shallowest data collected during this survey (Figure 7, Shot Point 715). The fault dips ~50° southeast in the Coastal Plain section and shallows to ~40° in the basement. The basement reflector is offset at 400 msec and reflectors up to 250 msec show offset across the fault. The top of the Peedee Formation is interpreted at 200 msec, expressed as a continuous recognizable reflector. The slight undulation observed in this layer is due to tectonic deformation (Shot Points 700-715). Continuous reflections up to 40 msec of the datum exists, however, this does not capture the upland unconformity, which is shallower. Details of the shallow seismic profile (200 msec and shallower) are the subject of an ongoing study. Conoco Line 4 shows PBF in Coastal Plain sediments up to approximately 250 msec (Figure 8). The 200 msec reflector is not well expressed over the fault in this line. Conoco Line 1 shows a complicated and more regional context for the PBF (Figure 9). There are perhaps two small splays to the northwest of the main fault. The proximity of the Steele Creek fault to the southeast illustrates a horst structure in conjunction with the PBF in Triassic rock.

The character of the fault below the Coastal Plain sediments is distinguished by the contrast between crystalline basement and Triassic basin sediments from one side of the fault to the other. Triassic strata are clearly imaged in a rollover structure in contrast to the featureless crystalline rock immediately adjacent to the northwest (Figure 8). This aspect of the structure is further exemplified in Line 4 (Figure 10), a profile-enhancing, deeper portion of data. The dip on the fault becomes shallower in basement rock and we have interpreted it as wrapping around beneath the basin (Figure 8). The Pen Branch fault is thus a sole fault forming the boundary between Crystalline and Triassic rock everywhere. The seismic reflection data do not show the shallow portion of the PBF to directly connect to any of the deeper structures (Figure 10). The southern side of the Dunbarton basin (Figure 11) images reflectors in the basin dipping northwest. The deepest

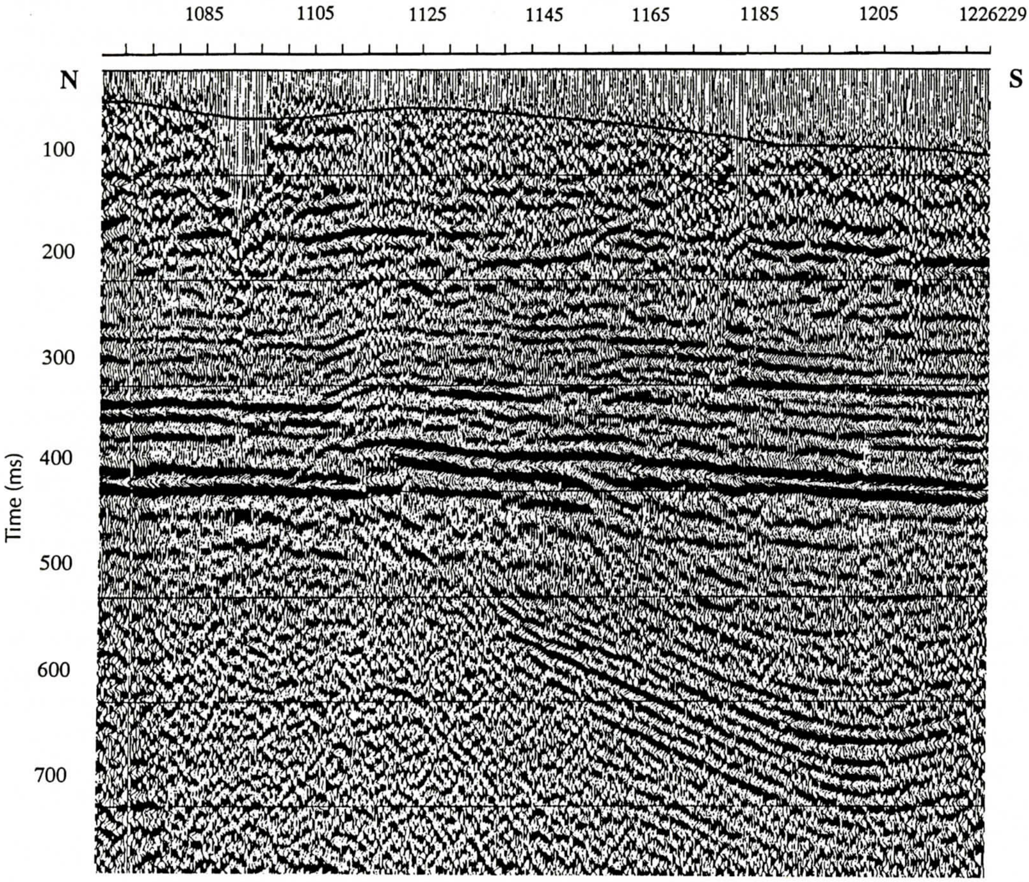

Figure 8. Conoco Line 4 showing Pen Branch Fault and inclined strata of the Dunbarton Basin.

reflector may represent the Pen Branch boundary fault shallowing toward the southern end of the basin, as interpreted in Figure 6. An alternative interpretation could be that the bright reflectors are mafic sills concordant with the Triassic sedimentary layers.

The evidence for the PBF in the gravity, aeromagnetic, and TDEM data are secondary inferences based on a well-defined northwest boundary to the Dunbarton basin seen in those data (Figures 4 and 5).

Steele Creek Fault

The Steele Creek fault, located southwest of PBF and within the Dunbarton basin, trends generally northeast. The offset of this fault is down to the southeast and thus forms a horst with the PBF (Figures 2 and 9). Above the Triassic rock, the fault offsets some Cretaceous horizons, but the shallowest extent of the fault is under investigation (Coruh and others, 1992b). It is located on fewer seismic reflection lines than the PBF. Conoco Line 1 demonstrates the Steele Creek fault in relation to the PBF (shot point 1025). In this profile, the horst is easily observed and the Steele Creek fault can be traced up to approximately 250 msec two-way travel time. The Seismograph Service Corporation seismic reflection data located the Steele Creek fault on four survey lines.

Anderson's (1990) detailed gravity survey shows a second order structure within the Dunbarton basin. This feature appears as a shelf on the contour map to the northwest of the deeper portion of the basin (Figure 4) and is thought to be the Steele Creek fault.

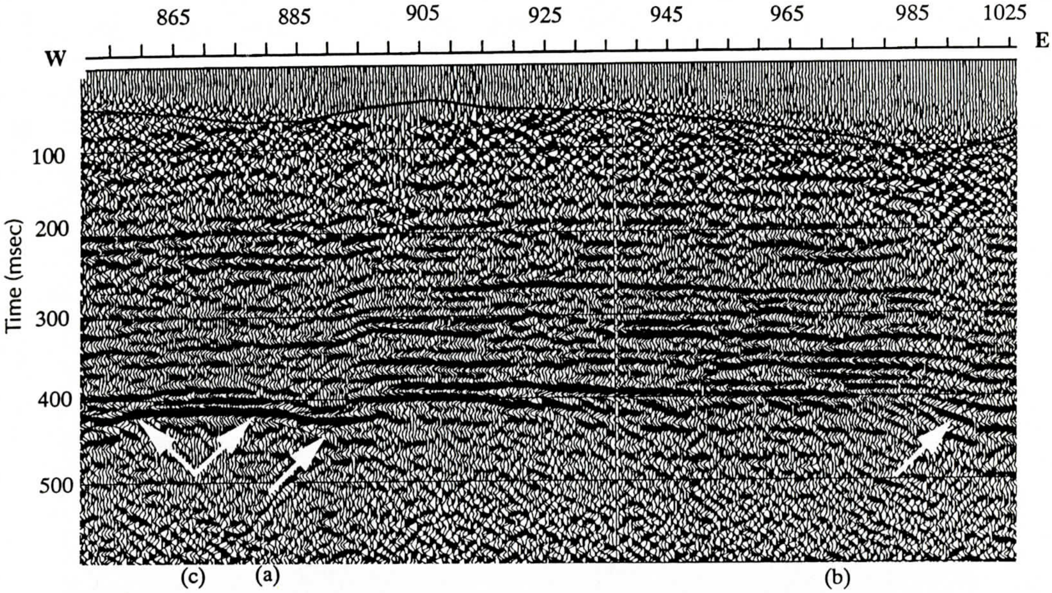

Figure 9. Conoco Line 1 showing Pen Branch (a), Steel Creek (b), and two small splays (c) to the northwest of main fault.

Atta Fault

The Atta fault is located in the northeast quadrant of SRS and strikes north-south. The attitude of the fault appears to be near vertical with marker horizons up to the east relative to the west. Reprocessed Conoco Line 27 (Figure 12) indicates offset reflectors at approximately 250 msec and draping reflectors up to approximately 150 msec (Shot Point 100). The offset at basement is 25 msec. This line is the northern most seismic reflection data obtained for this feature and it also contains the largest offset expression of the Atta fault. Conoco Line 9 is the southern most reflection data that captures this fault.

The upward penetration of the Atta fault is uncertain because there are no good reflectors over the fault in the shallow section. The characteristic 200 msec reflector from other lines in this survey would be expected at about 150 msec in this area of SRS. However, it does not appear to be well developed or even present. This may be due to thinning or a facies change in the interval that effectively erases the reflector. The shallowest extent of this fault is still under investigation (Coruh and others, 1992b).

Because other seismic lines south of Conoco Line 9 does not show faulting, we think that this line may be the southern terminus of the Atta fault. These data suggest that the Atta fault neither intersects nor soles into the PBF. However, it may extend further to the north beyond Conoco Line 27.

Bouguer gravity (Anderson, 1990) may suggest the presence of the Atta fault by a disruption of a northeast-trending gradient. At the interrupted southern extent of the fault is a closed contour gravity high of -12 mgal. To the north and northeast are two other small gravity highs that, taken together, disrupt the general northeast trend in the contour fabric. The Blackhawk TDEM survey exhibits a similar disruption in a northeast trending trough-like feature (Figure 5). In the northeast quadrant of the site there is a closed contour low (-995). This low is coincident with a Bouguer gravity high in the same location on Figure 4. The location of the Atta fault is immediately west of these features.

Crackerneck Fault

The Crackerneck fault is located in the northwestern part of SRS. This fault, which

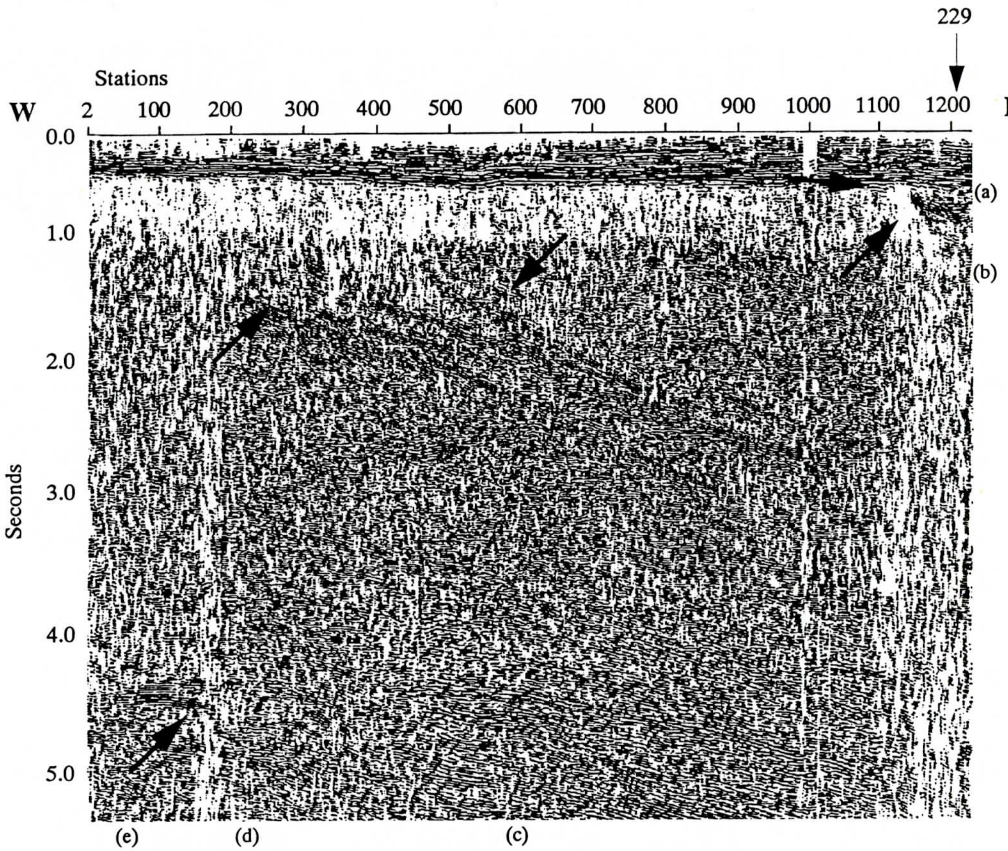

Figure 10. Conoco Line 4; 6 second record showing Pen Branch fault, Dunbarton Basin, Upper Three Runs and Augusta faults.

strikes north-northeast and is down to the northwest, was recognized on Conoco Lines 1 and 4; however, the lateral extent was not determined from the seismic reflection data. The reprocessed Conoco data indicate the Crackerneck fault at Shot Point 140-145 on Line 1 (Figure 13). The basement reflector at approximately 300-350 msec is clearly offset approximately 20 msec. Some deformation may exist in the shallow section up to 250 msec. However, no marker horizons are developed in this area of the profile to indicate the shallowest extent of the fault. The Crackerneck fault does not appear to penetrate through the Cretaceous section. A single seismic line from Seismograph Service Corporation ran to the northwest of the site and the structure contour map prepared from that data indicate a fault approximately in the location Conoco later interpreted the Crackerneck fault.

The Crackerneck fault is located at the northwest edge of a descending Bouguer gravity gradient (Figure 4). Deflections in the trend of that gradient may be bends in the fault or a set of en echelon faults in that line. The Crackerneck fault may be interpreted in the aeromagnetic data of Daniels (1974).

Ellenton Fault

The Ellenton fault is located in the southeast quadrant of SRS and can be observed in Conoco Lines 6, 21, and 23. This fault strikes north-northwest, the dip is thought to be near vertical, and the block to the east is down relative to the west. The Ellenton fault is not known to intersect the PBF, but it is suspect.

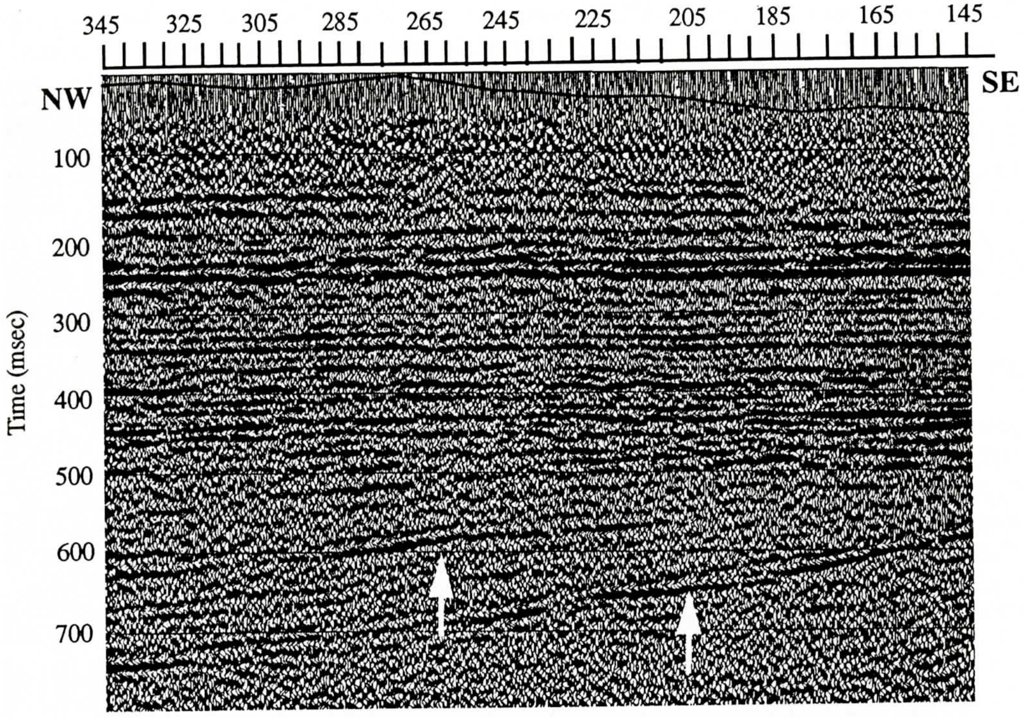

Figure 11. Conoco Line 13, southern boundary of the Triassic basin showing mafic sills or the shallowing expression of the Pen Branch fault. Arrows indicate dipping reflections in the basement rocks.

The fault is not recognized on Line 7, which constrains the southwest extent of the fault and the reprocessed Conoco data does not clearly indicate the presence of this fault. Seismograph Service Corporation seismic reflection data indicate a small fault at the location of the Ellenton fault.

Upper Three Runs Fault

Upper Three Runs fault is located in the northwest quadrant of the study area and trends northeast. As observed in seismic reflection data, this fault is restricted to crystalline basement (Figure 10). The fault dips shallowly to the southeast and may sole into the Augusta fault further to the southeast, beneath the Dunbarton basin. Because this fault has a distinct image in the crystalline terrane, whereas the others except PBF do not, it is thought that this fault might represent the oldest structure in these data. The fault may be initially of the Paleozoic age. The youngest possible age is constrained to at least Jurassic time. The 6 second seismic section from the reprocessed Conoco Line 4 is a useful line to integrate the previously discussed faults with respect to relative age and tectonic setting.

The Upper Three Runs fault can be traced to the basement/Coastal Plain surface just beyond Upper Three Runs Creek data gap at Station 385. Another package of dipping reflectors that project to the Basement/Coastal Plain contact north of SRS immediately underlie this structure. This structure is interpreted as the Augusta fault. The Augusta fault is imaged as a collection or package of strong reflectors and it is believed that it is represented by a thick zone of shearing and faulting, hence the multitude of reflectors. The Upper Three Runs fault soles into the underlying Augusta fault beneath the Dunbarton basin; because of the geometric relationship, an age and kinematic relationship is implied. Reflectors from the Augusta/Upper Three Runs system is interrupted by vertically oriented bright zones beneath the Dunbarton basin believed to be a series of basalt/diabase

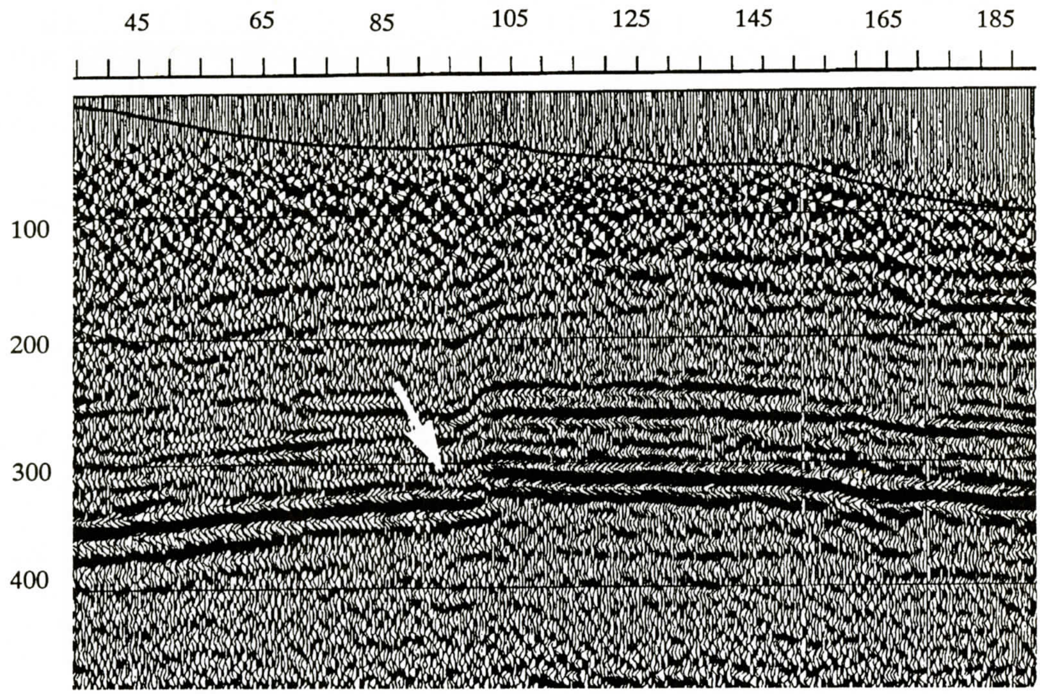

Figure 12. Conoco Line 27 Atta Fault, northern line. Arrow points to basement—Coastal Plain reflector offset.

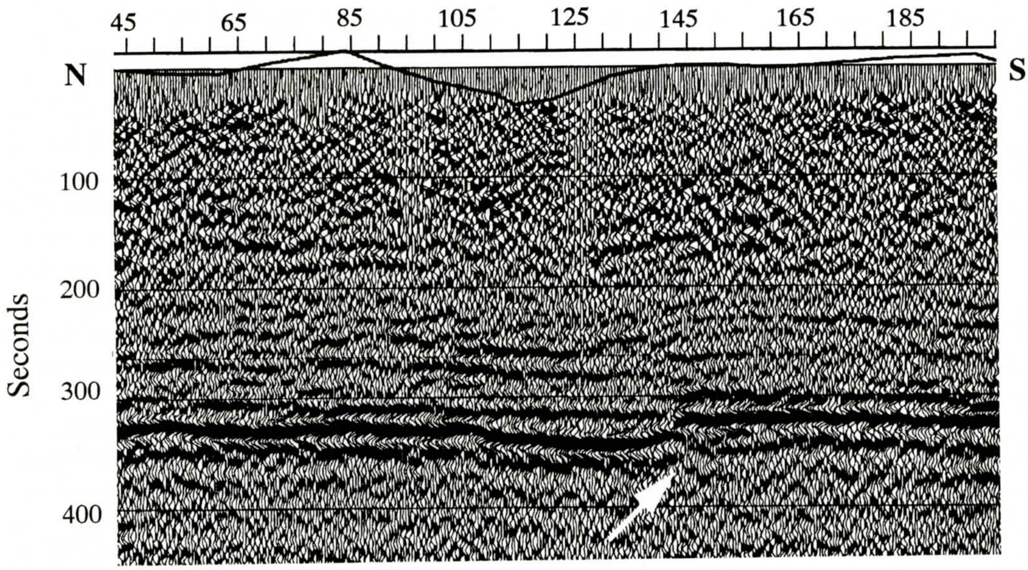

Figure 13. Conoco Line 1; Crackerneck Fault. Arrow points to fault offset at the basement—Coastal Plain reflector.

dikes and sills related to the extensional tectonic regime active during the initiation of the last cycle of rifting on the continental margin (Costain and others, 1992a and 1992b; Dormoracki and others, 1992; McBride and others, 1989).

Dunbarton Basin

The northern boundary of the Dunbarton basin is located at station 1100 and the PBF can be observed disrupting Coastal Plain strata at this point. The rift-related strata beneath the Coastal Plain, proximal to the PBF, dip southeast. Furthermore, the PBF is not observed to sole into the Augusta/Upper Three Runs system. On the southeastern side of the basin, observed on Conoco Line 13 (Figure 11), strata in the basin dip northwest. These layers are interpreted to be basalt sills that intruded along earlier formed strata in the rift basin (Dormoracki and others, 1992). These bright reflectors may point to the border of the Dunbarton basin. The presence of basalt is corroborated by potential field data.

The southeastern boundary of the Dunbarton basin is not well understood. Faye and Prowell (1982) interpreted the presence of the Millett fault (Figure 2) based on two drill holes located just beyond the southern boundary of SRS. Potential field data suggest a southeastern terminus to the basin in the approximate location where Faye and Prowell placed the Millett fault. However, the exact nature of this boundary is yet to be determined.

The thickness of the Dunbarton basin is not well constrained. DRB-9 core entered crystalline rock beneath Triassic sedimentary, measuring 488 m in thickness for the basin. DRB-10 did not reach crystalline rock and recovered 914 m of Triassic rock. The recent seismic reflection data indicate the northwest side of the basin to be about 2 seconds, two-way travel, or approximately 2.5 km deep.

Southeast of the Dunbarton basin aeromagnetic and gravity data indicate a terrane heavily influenced by basalt flows and sills. The magnetic data contain numerous high-frequency, closed-contour features indicative of shallow structures and lower frequency features indicative of deeper seated features. The host rock is perhaps crystalline metamorphosed rock similar to what is found further to the northwest beneath SRS. In addition, Madabhushi and others (1992) suggest that this terrane separates the Piedmont crystalline rocks from crust of a different affinity further to the southeast. In effect, the mafic intrusions define the southeastern boundary of the Dunbarton basin and the northern boundary of the South Georgia Rift basin.

Beneath the Augusta/Upper Three Runs system are other packages of reflectors being truncated by or splaying off of the Augusta fault (Figure 10), some of which dip northwest. At 4.0 seconds, a reflector package is interpreted to be a décollemont surface for the Blue Ridge thrust or perhaps the master detachment from the Mesozoic separation of North America from Africa.

REGIONAL CONTEXT

In a regional context, the upper crust beneath SRS shows similar structures and relationships seen in other crustal sections in the southeastern Atlantic margin. These are rift or collision-related structures with faulting of various ages associated with plate movement.

Northwest of SRS, the Augusta fault crops out in Georgia and South Carolina and is offset 23 km in left-lateral movement by the Cenozoic Belair fault (Prowell and O'Connor 1978). Bramlett, Secor, and Prowell, 1982 concluded that most of the movement on the Belair fault was pre-late Cretaceous. In post-late Cretaceous time, the Belair fault was reactivated as a high angle reverse fault that moved about 30 meters. Geologic mapping indicated the Augusta fault was a late Alleghanian, northeast-striking thrust fault. The fault coincides with a string of magnetic anomalies (Hatcher and others, 1977); there is also an early ductile shear fabric overprinted with brittle fabric (Bramlett, Secor, and Prowell, 1982). COCORP data (Cook, Brown, Kaufman,

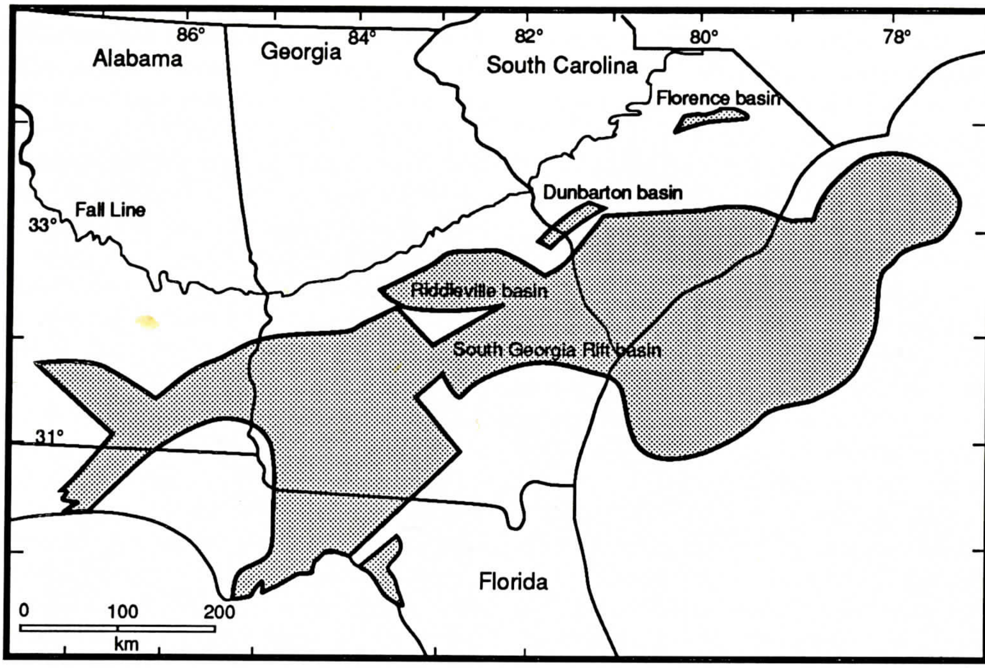

Figure 14. Southeastern regional map of subsurface Triassic basins (modified from Figure 1 of McBride and others, 1989). Heavy lines outline the Triassic-Jurassic subcrop.

Oliver, and Peterson, 1981) traced the shallow southeast dipping fault 60 km to the south. Bramlett, Secor, and Prowell concluded that the fault was a reverse or thrust-type fault. More recent data (Maher, 1987; Maher and others, 1994) indicate that the ductile movement was normal sense displacement (down to the southeast) based on extensive shear sense indicators dated at 275 Ma (latest Alleghanian orogeny). Normal fault movement is also supported by the position of greenschist facies Belair belt rocks are in the hanging wall of the fault and amphibolite facies Kiokee Belt rocks are in the foot wall. Based on its image beneath SRS, the Augusta fault is clearly connected with the Upper Three Runs fault. This connection has implications for similar displacement on the Upper Three Runs fault. Both faults may be originally thrust-type features with reactivation in the Permian as normal faults. These faults are not expected to be associated with Mesozoic normal faulting because Upper Three Runs is not associated with a structural basin, as is the PBF. Furthermore, the Upper Three Run and Augusta faults present no evidence of reactivation after the pre-Cretaceous unconformity.

The Augusta/Upper Three Runs system does not apparently connect with the PBF system within the constraints of our data. This is a significant observation because of the Cenozoic reactivation issue associated with the PBF. As indicated in Figure 6, it is suggested that the Augusta/Upper Three Runs system connects with the master detachment of the South Georgia Rift basin further to the southeast or, in fact, is truncated by that fault system (Stephenson and Stieve, 1992). For further information, refer to Figure 13 (Luetgert and others, 1994).

The PBF and its associated Dunbarton Triassic Rift basin are younger than the Augusta/ Upper Three Runs system. Fault-bounded basins of Triassic-Jurassic age occur throughout the eastern North American continental margin. Many of the basins underlie the Atlantic Coastal Plain and offshore regions (Figure 14). Structurally, the basins are grabens or half grabens, formed by crustal extension during Late Triassic-Early Jurassic rifting that preceded the Middle Jurassic opening of the

Atlantic Ocean (Manspeizer, 1978; Petersen and others, 1984; McBride and others, 1989; McBride, 1991).

Geophysical data, including regional COCORP seismic reflection data, and drill hole data show a large Mesozoic Rift complex beneath Coastal Plain strata from southwestern Georgia to southeastern South Carolina to offshore North Carolina (Figure 14) (McBride and others, 1989). The South Georgia Rift basin covers an expansive area beneath the southeastern Coastal Plain and comprises a complex system of interconnected basins containing variable thicknesses of Mesozoic strata (Chowns and Williams, 1983; McBride and others, 1989; Daniels and others, 1974; Nelson and others, 1985). Drill hole and seismic reflection data indicate the presence of extensive basalt flows and diabase sills (McBride and others, 1989). McBride (1991) presented evidence from COCORP seismic reflection data that major sub-basin border faults within the South Georgia basin dip northward in antithetic relation to the predominantly northward vergence of the Alleghanian suture zone. The sub-basins developed mostly over the upper plate of the Alleghanian suture of North America and Africa. Most basins formed far south of the suture, but some formed north of the suture in eastern Georgia. From these observations, McBride concluded that the border faults do not necessarily activate antecedent structures.

The smaller basins forming to the north of the South Georgia basin (i.e., the Dunbarton and the Riddleville basins) show a slightly different picture. The Riddleville basin is a larger half graben to the southwest of the Dunbarton. Riddleville basin is bounded on the north by a major south-dipping master normal fault. This master soles into the Augusta fault to the south (Petersen and others, 1984). This is similar to observations for the Dunbarton basin, where the PBF is the southeast-dipping master fault to the Dunbarton basin. However, current data suggests that the PBF does not sole into the Augusta fault as the Magruder fault of the Riddleville basin does. Rather, the fault shallows to the southeast on the far side of the basin and then, perhaps, soles directly into the South Georgia basin complex.

Geometric and kinematic arguments from other study areas along the eastern continental margin suggest that early Mesozoic normal faults may be reactivated Alleghanian thrust faults (Peterson and others, 1984; Hutchinson and Klitgord, 1986; Ratcliffe, 1974; Lindholm, 1977; Glover and others, 1980). Other investigators demonstrated a lack of coincidence between location of Triassic basins and earlier formed Alleghanian faults (McBride, 1991). Studies of the exposed and buried rift basins show that the faults controlling basin formation are complex, with border faults of variable dip, antithetic faults of variable magnitude, and cross or transfer faults that fragment the basin into sub-basins (McBride and others, 1989). The same may be true for the Dunbarton basin.

Mesozoic normal faulting initiated the formation of the PBF. More displacement occurred on this fault after the rift-drift period during the opening of the Atlantic basin. After tectonic extension, with the formation of down-dropped blocks over a thinned continental crust, there was a period of erosion during the late Jurassic and early Cretaceous age that planed off the continental margin surface and made the Triassic sediments level with the crystalline basement surface. The Atlantic ocean advanced onto the continental margin and began the deposition of Coastal Plain sediments during the middle to late Cretaceous. The PBF began moving again with very low rates of displacement in a reverse sense movement. This slow, intermittent movement continued through the Tertiary period. Other nearby faults, such as the Belair, also show reverse sense displacement offsetting Coastal Plain sediments from Cretaceous through Tertiary time (Bramlett, Secor, and Prowell, 1982). However, the Belair fault does not capture any Triassic sediments; therefore, this fault may not be a reactivated normal fault. Bramlett, Secor, and Prowell (1982) suggest that the Belair fault may originally be a tear fault of the Augusta sheet. Likewise, the Crackerneck and Atta faults offset young Coastal Plain sediments. The sense of displacement is interpreted to be reverse separation, although it can not be demonstrated with stratigraphic age constraints at this time. The period following extension was perhaps followed by an episode of crustal relaxation whereby the shallow crust flexed or moved upward and created local zones of compression resulting in the formation of these reverse faults. While the Pen Branch and Belair faults contain evidence for reactivation, there is no evidence to suggest the Atta and Crackerneck faults are reactivated antecedent structures; therefore, these faults may be new structures that formed sometime after the rifting in Triassic through Jurassic time.

CONCLUSION

Many studies and investigations over several years at SRS provided a data set that enables us to form a restricted regional model of the shallow crust. A local dip of the shallow crust toward the Savannah River channel that is broken by several basement faults that penetrate Cretaceous through at least Tertiary horizons. The faults break the basement into discreet blocks with unique geophysical characteristics and include the Pen Branch, Steele Creek, Crackerneck, Atta, and Ellenton faults. A block, or terrane, that separates the Dunbarton basin from the South Georgia Rift complex to the south of SRS, is predominantly a zone of mafic extrusion and intrusion. North of the Dunbarton basin, another block is characterized by several fault/reflector packages that are broken up underneath the basin by the mafic intrusions associated with the Triassic basin. These faults can be related to the Alleghanian orogeny. Even further to the northwest, the metamorphosed crystalline rock is influenced by granitic intrusions.

The Upper Three Runs fault is an Alleghanian fault that forms a block boundary and is peneplained at the pre-Cretaceous unconformity. No evidence suggests reactivation in Cretaceous through Tertiary time. The fault soles into the Augusta fault beneath the Dunbarton basin and is related in age and mechanism to the Augusta fault.

The PBF is a reactivated fault that forms a block boundary and shows reverse separation between crystalline basement and Triassic sedimentary rock. It forms the northwest boundary of the Dunbarton basin, dipping southeast and apparently does not sole into the Augusta-Upper Three Runs system. This is in contrast to the Magruder fault of the Riddleville basin. The PBF, which may be the master fault for the Dunbarton basin, perhaps soles into one of the antithetic faults of the South Georgia Rift complex further southeast.

The PBF formed under extensional stress during Triassic time and reactivated during Cretaceous through Tertiary time under a compressive stress resulting in a reverse fault geometry. Fault geometry in the Coastal Plain section is observed as a complex of fault splays to the north and south of the master fault (e.g., PBF forming horst with Steele Creek fault). The Coastal Plain material may have behaved in a passive manner during displacement on the basement fault. The up-section limit of PBF as seen in seismic data is clearly offset up to 250 msec and deformed up to at least 200 msec.

The nearby Belair fault is a reactivated tear fault showing reverse separation. It offsets young Coastal Plain sediments and suggests a corresponding age and mechanism for the PBF. However, the Belair fault is not obviously connected to Triassic rifting, as is the PBF. Other interpreted, young reverse faults in the area include the Crackerneck, Atta, and Ellenton. Their relationship to the Cenozoic reverse fault system is unclear because of a lack of data. However, similar mechanisms and timing may relate them all.

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STRATIGRAPHY OF THE SAVANNAH RIVER SITE AND VICINITY

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ABSTRACT

The Savannah River Site (SRS), operated by the Department of Energy, covers approximately 300 sq mi (780 sq km) in the updip Coastal Plain of southwestern South Carolina. Coastal Plain quartz sands, clays, calcareous sediments, and conglomerates, approximately 1000 ft (300 m) thick in the center of the SRS, overlie Paleozoic (and Precambrian?) igneous and metamorphic rocks of the Appalachian orogen and Triassic sediments of the Dunbarton basin. Approximately two-thirds of the Coastal Plain section consists of Cretaceous quartz sands and clays of Santonian, Campanian, and Maestrichtian ages which have the characteristics of fluvial and deltaic deposits. These sediments have been assigned to the Cape Fear Formation, the Middendorf Formation, the Black Creek Group, and the Steel Creek Formation.

Paleocene deposits are composed of quartz sands and clays of the lower Paleocene Sawdust Landing Formation and the upper Paleocene Lang Syne and Snapp formations. They appear to be deltaic and lagoonal. The lower Eocene Fourmile Branch Formation, consisting of quartz sands and clays, overlies the Paleocene and appears to be marine and transitional marine. It is overlain by quartz sands of the Congaree Formation, most of which is early Eocene. Congaree sediments are interpreted as shallow marine.

Lower middle Eocene quartz sands and clays of the Warley Hill Formation, interpreted as marine and transitional marine, are overlain by quartz sands and clays of the Tinker Formation and by calcareous sediments of the Santee Limestone and the "Blue Bluff" unit, all middle Eocene. These three units were deposited in marine and transitional marine environments. The overlying Clinchfield Formation consists of quartz sands and of calcareous sediments of the Utley Limestone Member, both shallow marine deposits. The spiculitic Albion Member was tentatively assigned to the Clinchfield by Huddlestun and Hetrick (1986). The Clinchfield is probably middle Eocene and was deposited in littoral and lagoonal environments.

The upper Eocene Dry Branch Formation is composed of quartz sands and clays of the Irwinton Sand Member and calcareous sediments of the Griffins Landing Member; these deposits have marine and lagoonal characteristics. The muddy quartz sands of the upper Eocene Tobacco Road Sand overlie the Dry Branch and were deposited in shallow marine and transitional marine environments.

Poorly sorted muddy quartz sands, clays, and pebbly and cobbly beds overlying the Tobacco Road are assigned to the Miocene Altamaha Formation. They were deposited by fluvial systems. Oligocene or Miocene quartz sands and silica-cemented quartz sands, interpreted as channel deposits, occur sporadically in the area. Sediments of alluvial, colluvial, and eolian origin are present in places, and terrace deposits occur along the Savannah River.

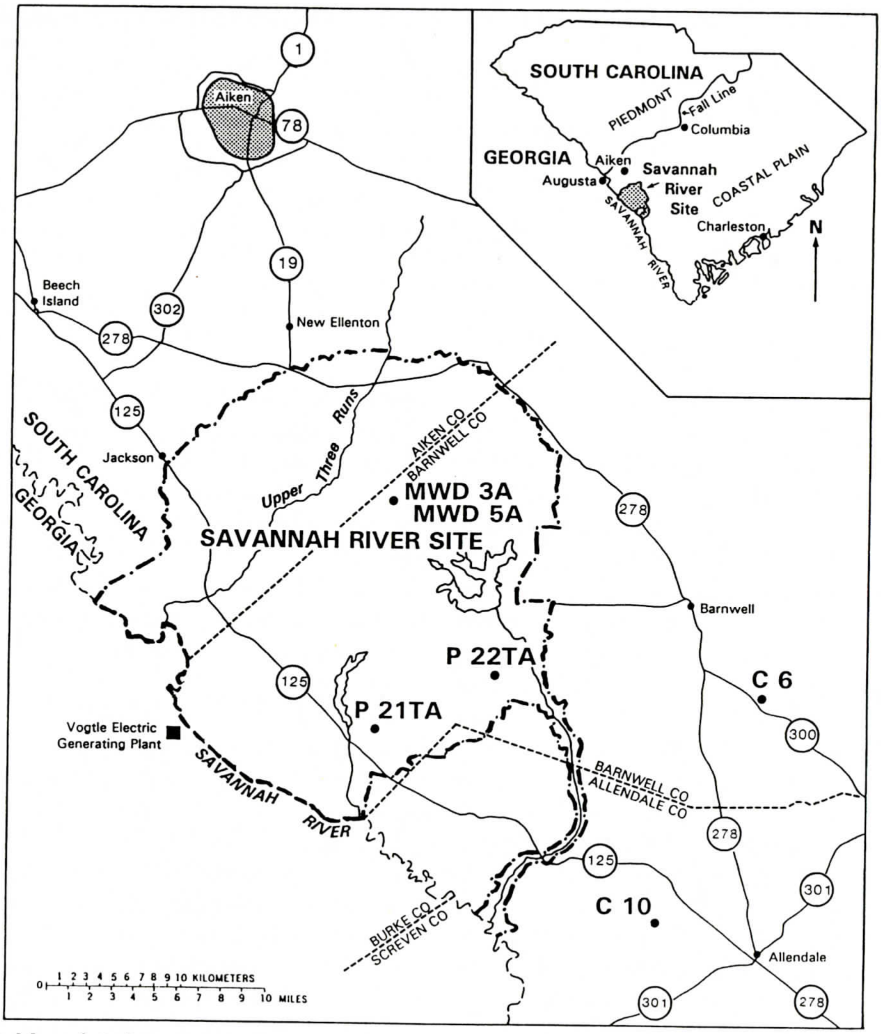

Figure 1.-Map of study area.

INTRODUCTION

The Savannah River Site (SRS), a Department of Energy facility operated by the Westinghouse Savannah River Corporation, occupies about 300 sq mi (780 sq km) in Aiken, Barnwell, and Allendale counties, South Carolina (Figure 1). Numerous cored and geophysically logged wells, some of which were drilled to basement, provide abundant subsurface stratigraphic data. Coastal Plain sediments at the SRS are quartz sand, silt, clay, limestone, and conglomerate ranging in age from Late Cretaceous to Holocene. They thicken from about 700 ft (210 m) at the northwestern border of the Site to about 1400 ft (430 m) at the southeastern border. Composed of siliciclastics along the Fall Line, the section becomes partly calcareous at the SRS and vicinity. Regional dip is to the southeast and south-southeast, although beds dip and thicken locally in other directions.

This progress report discusses the stratigraphic framework the authors are now using at the SRS. Sediments updip from the Site, such as the undifferentiated Upper Cretaceous and the undifferentiated lower Tertiary, are only briefly described. This report is intended

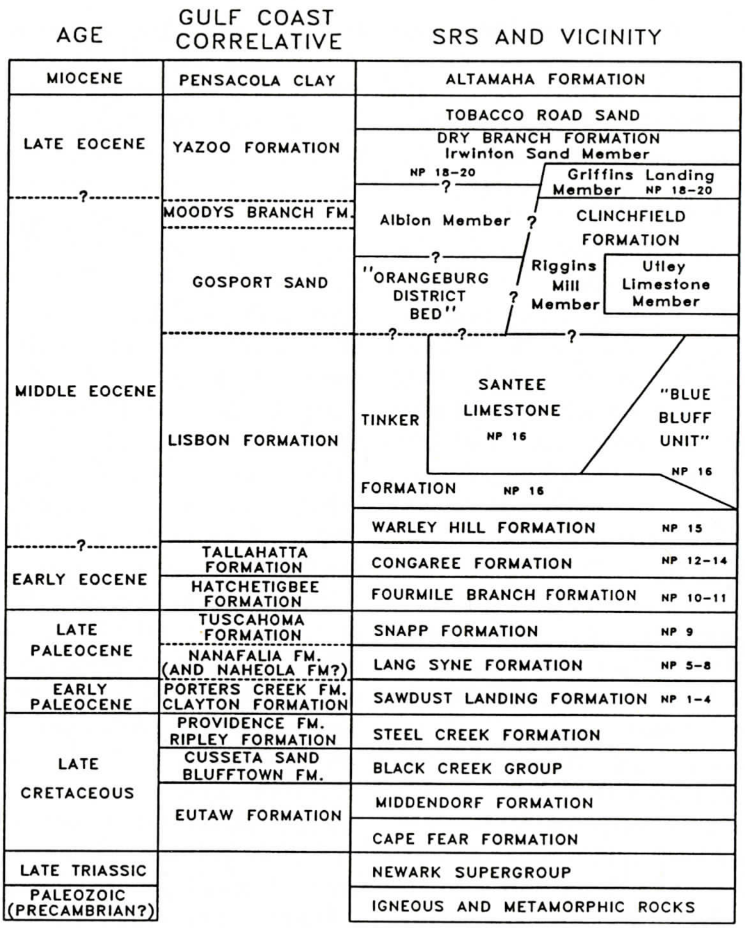

Figure 2.-Stratigraphic column for Savannah River Site and vicinity. NP zones are from most common age calls with some showing a range of possible ages. Tertiary stage boundaries relative to NP zones approximate those of Haq and others (1987). No vertical scale.

to be a summary of the stratigraphy; more detailed descriptions of the stratigraphic units will be published later. A version of this paper, including newly named formations, appeared in a Carolina Geological Society field trip guidebook (Fallaw and Price, 1992). Because the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983) specifies formal description in a widely distributed publication, we regard the names, descriptions, and definitions herein as the formal ones. The newly named formations are the Steel Creek Formation (Upper Cretaceous), the Snapp Formation (upper Paleocene), the Fourmile Branch Formation (lower Eocene), and the Tinker Formation (middle Eocene). Figure 2 summarizes the stratigraphy as currently understood by the authors.

We have found that placing formations into groups as it has been practiced in the South Carolina Coastal Plain does not, in most cases, result in distinct lithologic units at the SRS and have generally avoided the category of groups. We have, however, used the term "Black Creek Group" as explained under that heading below.

PREVIOUS WORK

A stratigraphic framework for updip Coastal Plain stratigraphy in South Carolina was established by Sloan (1908), who examined many outcrops in the study area. Veatch and Stephenson (1911), Cooke and Shearer (1918), Cooke (1936, 1943), and Cooke and MacNeil (1952) included the study area in their investigations of the geology of the South Carolina and Georgia Coastal Plain. Snipes (1965), Smith (1979), Smith and White (1979), Buie and Schrader (1982), Kite (1982), Mittwede (1982), Nystrom (1986; 1990a, b), Nystrom and Willoughby (1982a, b; 1992a, b, c), and Nystrom and others (1982, 1986, 1989, 1991, 1992) investigated outcrop and shallow subsurface stratigraphy in the general area of the SRS. LaMoreaux (1946a, b), Pickering (1970), Carver (1972), Herrick (1972), Huddlestun (1982), and Huddlestun and Hetrick (1978, 1986) helped develop the stratigraphic framework for the upper Eocene. Newell and others (1980), Stevenson (1982), Dennehy and others (1989), and Nystrom (1992b) discussed geomorphological features and post-Miocene stratigraphy in the area.

Siple (1967) initiated detailed subsurface stratigraphic analysis at the SRS. Colquhoun and co-workers (Colquhoun, 1991, 1992; Colquhoun and Muthig, 1991; Colquhoun and others, 1982, 1983; Oldham, 1981; Bishop, 1982; Steele, 1985; McClelland, 1987) presented subsurface data and correlated sediments in the study area with strata in other parts of the Coastal Plain. Faye and Prowell (1982) analyzed structural and stratigraphic subsurface data. Prowell and others (1985a, b) presented lithologic and paleontologic subsurface information and correlated SRS strata with deposits in Georgia and with formations elsewhere in the Atlantic and Gulf coastal plains.

Laws and others (1987, 1992) and Harris and Zullo (1988, 1992) analyzed the Tertiary section from the point of view of sequence stratigraphy, and Harris and Fullagar (1992) discussed radiometric dates. Outcrop and shallow subsurface stratigraphy near the center of the SRS has been discussed recently by Dennehy and others (1989), Nystrom (1989), Nystrom and others (1991, 1992), Nystrom and Dockery (1992), Nystrom and Willoughby (1992b), Snipes and others (1992b), and Fallaw and others (1992d). Thayer and others (1988, 1992), Thayer and Harris (1992), Robertson and Thayer (1992), Robertson (1990), and Smith and others (1992) made detailed lithologic analyses of Coastal Plain sediments from cores at the SRS. Studies emphasizing paleontology in the last few decades include those by Cushman and Herrick (1945), Herrick (1960, 1964), Buie and Oman (1963), Scrudato and Bond (1972), Abbott and Zupan (1975), Hutchenson (1978), Tschudy and Patterson (1975), Zullo (1984, 1988), Zullo and Kite (1985), Lampley (1988), Laws (1988, 1992), Laws and others (1992), Lawrence (1988), Lucas-Clark (1988, 1992a, b, c), Steele and others (1986, 1988), Fredericksen (1991), Edwards (1992), and Edwards and Fredericksen (1992).

Other publications relating to the stratigraphy of the SRS and vicinity include Brantly (1916), Buie and Fountain (1968), Zullo and others (1982), Kite (1982, 1983), Kite and Nystrom (1983), Willoughby (1986), Willoughby and Kite (1987), Willoughby and others (1984), Skinner and others (1988), Spaw and others (1988), Nystrom (1992a), Nystrom and others (1982, 1988), Huddlestun (1992), and Falls and others (1993).

Studies emphasizing structural or geophysical data include those by Petty and others (1965), Daniels (1974), Marine and Siple (1974), Inden and Zupan (1975), Prowell (1982), Prowell and O'Connor (1978), Prowell and others (1976), Bramlette and others (1982), Faye and Prowell (1982), Talwani and others (1985), Fallaw and Price (1987), Maciolek and others (1988), Stephenson and Chapman (1988), Stephenson and Stieve (1992), Anderson (1990), Anderson and Talwani (1988), Coruh and others (1992), Costain and others (1992), Cumbest and others (1992, 1993), Domoracki and others (1992), Madabhushi and others (1992), Snipes and others (1992a), and Steele and Colquhoun (1992). Among hydrologic investigations are those of Siple (1964, 1967), Marine (1973), Colquhoun and others (1982, 1983), Brooks and others (1985), Clarke and others (1985), Gorday (1985), Dennehy and others (1989), Logan (1992), Clarke (1992), Aadland (1992), Aadland and Bledsoe (1992), Aadland and others (1992), Harris and others (1992), Baum (1993), Clarke (1993), Dalaimi and Carver (1993), and Moore and others (1993). Sargent and Fliermans (1989), Logan and Euler (1989), and Gellici and Logan (1993) discussed stratigraphic and hydrologic data.

Numerous studies not in the geologic literature have also been done at the SRS and at Georgia Power Company Plant Vogtle in Georgia. We have presented some preliminary results of our work (Fallaw and others, 1988; 1989a, b; 1990a, b; 1991; 1992a, b, c, d, e; Price and others, 1992).

BASEMENT ROCKS

Igneous and metamorphic rocks of the Piedmont and Blue Ridge provinces are the source of the Coastal Plain sediments. They include slate, phyllite, schist, gneiss, volcanics and metavolcanics, granite, and mafics which are Precambrian and Paleozoic and which formed under the influence of several orogenic episodes in the Appalachians. The rocks are generally rich in feldspar, providing a source for the kaolinite which is abundant in much of the updip Coastal Plain section.

Rocks similar to those exposed in the Piedmont lie beneath the Coastal Plain sediments within most of the SRS. The southeastern part of the Site is underlain by mudstones, quartz sands, and conglomerates of the Triassic Newark Supergroup in the Dunbarton basin (Siple, 1967, p. 22-23; Marine and Siple, 1974; Thayer, 1992). Geophysical data suggest the presence of mafic rocks along the southeastern margin of the basin (Daniels, 1974; Cumbest and others, 1992; Snipes and others, in press). The basement surface, the sub-Cretaceous unconformity, dips at about 50 ft/mi (9 m/km) to the southeast at the SRS.

UPPER CRETACEOUS

Introduction

In the most recent mapping of Cretaceous outcrops in the area, Nystrom and Willoughby (1982a) and Nystrom and others (1986) did not attempt to subdivide the section into formations, a practice we consider desirable until more information becomes available.

The Cretaceous section in the subsurface at the SRS is divided from older to younger into the Cape Fear Formation, the Middendorf Formation, the Black Creek Group, and the Steel Creek Formation. The thickness of the Cretaceous section is about 400 ft (120 m) at the northwestern boundary of the SRS and 800 ft (240 m) at the southeastern boundary. Much of the Cretaceous section from North Carolina to well into the Gulf Coastal Plain has the characteristics of braided stream deposits, suggesting high relief in the Appalachians during this time. Siple (1967) assigned all the Cretaceous strata in the vicinity of the SRS to the Tuscaloosa Formation, the type locality of which is in Alabama. The type Tuscaloosa is now thought to be Cenomanian or Turonian (Christopher, 1982; Faye and Prowell, 1982; Valentine, 1984; Sohl and Smith, 1985). Fossil age determinations from the SRS are younger.

Outcropping Upper Cretaceous

Lithology

Outcropping Cretaceous sediments consist mostly of medium to very coarse grained, poorly sorted, grayish quartz sands with common to abundant kaolinite and muscovite. Pebbly sands and gravel layers are common, as are clay clasts. Bedding is irregular with facies changes occurring over short distances. Cross-bedding is well developed in places. Clay laminae are common within the sands, and large lenses of "soft" kaolin are mined in the area (Buie and Schrader, 1982, p. 5-12). Detailed descriptions of the outcropping Cretaceous are in Nystrom and Willoughby (1982a) and Nystrom and others (1986).

Stratigraphic Terminology

Sloan traced the Middendorf from its type area in northern South Carolina (Sloan, 1908; Heron, 1958; see also Nystrom and others, 1991) to the vicinity of the SRS. The exposed Cretaceous strata have been referred to as "Hamburg" and "Middendorf" by Sloan (1908), "Middendorf" by Cooke (1926), and Snipes (1965); "Middendorf" and "Black Creek" by Colquhoun and others (1983); "Tuscaloosa" by Cooke (1936), Lang (1940), Siple (1967), and Prowell and O'Connor (1978). Christopher (1982) observed that the Cretaceous sediments in the area are younger than the type Tuscaloosa, and the use of the term in the area as a formal formation name has declined. Nystrom and Willoughby (1982a) and Nystrom and others (1986) mapped the deposits as simply "Cretaceous."

Much of what was included before 1970 as Cretaceous strata in Georgia and South Carolina updip from the SRS is now assigned to the Tertiary based on paleontologic data (Buie and Fountain, 1968; Scrudato and Bond, 1972; Abbott and Zupan, 1975; Tschudy and Patterson, 1975; Buie, 1978) and detailed mapping (see Nystrom and Willoughby, 1982a; Nystrom and others, 1986, 1991).

Paleontology, Age, and Correlation

Fossils are rare in the outcropping Cretaceous. Leaves have been found (Berry, 1914), and pollen from an outcrop of dark clay on Interstate Highway 20 near Aiken indicated a late Campanian age (see Nystrom and Willoughby, 1982a, p. 86; Nystrom and others, 1986, p. 7), correlative with the Black Creek Group, which crops out in northeastern South Carolina, and with the Blufftown and Cusseta formations of Alabama. There are probably older and younger sediments within the exposed Upper Cretaceous Series in Aiken County.

Environment

Most the sands were probably deposited in fluvial or deltaic environments. The large clay bodies suggest deposition in interdistributary bays, oxbow lakes, or playas.

Cape Fear Formation

Lithology and Distribution

The basal unit of the Coastal Plain stratigraphic section at the SRS is composed of poorly sorted, muddy quartz sands and interbedded clays. The sands are commonly medium and coarse grained, arkosic in places, and pebbly zones occur in many parts of the section. Gray, yellow, orange, red, brown, tan, and blue colors are common. Many of the sands fine upward into clays, and in most wells the unit appears to be composed of two crudely fining upward supersequences of approximately equal thickness. The Cape Fear Formation is more indurated than the other Cretaceous formations because of high clay content and abundance of cristobalite in the matrix (Prowell and others, 1985a, p. 8). In general, bedding thickness varies from about 5 ft (1.5 m) to 20 ft (6 m), with sands being thicker than clays.

In the northwestern and central parts of the SRS, the Cape Fear lies nonconformably on metamorphic rocks of the Appalachian orogen. In the southeastern part of the Site, it lies on red mudstones, conglomerates, and quartz sands of the Triassic Newark Supergroup. The Cape Fear is about 30 ft (9 m) thick at the northwestern SRS boundary and thickens to about 200 ft (60 m) near the southeastern boundary, with abrupt changes in thickness related to faulting (Snipes and others, 1992a; Cumbest and others, 1992). Regional dip of the upper surface is about 35 ft/mi (7 m/km) to the southeast.

Stratigraphic Terminology

Lithologic similarity, fossils, and stratigraphic position indicate that the sediments at the SRS are part of the Cape Fear Formation, type locality in southeastern North Carolina (Stephenson, 1923; see also Sohl and Owens, 1991). Prowell and others (1985a) assigned the strata at the SRS to their UK1 unit.

Paleontology, Age, and Correlation

Only plant fragments, spores, and pollen have been found at the SRS. A few palynological assemblages have a similar age range as those from the type Cape Fear and suggest a Santonian age. Prowell and others (1985a) correlated palynological assemblages in their UK1 unit with the type Cape Fear, which is probably late Turonian to Santonian (Sohl and Owens, 1991). The unit appears to correlate with the lower part of the Eutaw Formation of Alabama.

Environment

The paucity of marine fossils, the poor sorting, and the high degree of oxidation indicate that the sediments were deposited in fluvial and delta plain environments.

Middendorf Formation

Lithology and Distribution

The Middendorf Formation is composed mostly of tan, gray, and yellow, medium and coarse grained quartz sand. Sorting is generally moderate to good. Pebbly zones are common within the sand, and clay clasts occur in places. Some parts of the unit are feldspathic, and micaceous and lignitic zones occur. Cross-bedding is well developed in the lower part of the section in some areas. Over much of the SRS, a kaolinitic clay or a clay-and-interbedded-sand zone up to 50 ft (15 m) thick forms the top of the unit. In the southeastern part of the Site this clayey interval is micaceous and lignitic. Another clay-rich zone occurs near the middle of the formation in places. Most of the clays are oxidized. In the northern part of the SRS, the formation is highly colored sand with only a few thin clays.

In most wells the contact between the Middendorf and the underlying Cape Fear is sharp and often marked by a pebbly zone. The younger unit has cleaner sands and lacks the repetitive sand-clay sequences of the Cape Fear. It contains less feldspar, is not as well indurated, and the color is less variable. The Middendorf is approximately 100 ft (30 m) thick near the northwestern boundary of the SRS and about 180 ft thick (55 m) near the southeastern boundary.

Stratigraphic Terminology

The Middendorf has been traced from its type area (Sloan, 1908; see also Nystrom and others, 1991) in northern South Carolina by Sloan (1908), Cooke (1926), and Snipes (1965) to outcrops updip from the SRS. Much of the section assigned to the Middendorf by these authors, however, is now known to be Tertiary (Buie and Fountain, 1968; Scrudato and Bond, 1972; Abbott and Zupan, 1975; Tschudy and Patterson, 1975; Buie, 1978; Nystrom and Willoughby, 1982a; Nystrom and others, 1986, 1991). Oldham (1981), Faye and Prowell (1982), and Colquhoun and others (1982, 1983) applied the term "Middendorf" in the subsurface in the study area, as have later workers. Prowell and others (1985a) assigned the sediments at SRS to their UK2 unit and correlated them with the Middendorf.

Paleontology, Age, and Correlation

Wood fragments, spores, pollen, and rare dinoflagellates occur in the unit. A few palynological assemblages suggest a Santonian age, indicating a correlation with the upper part of the Eutaw Formation in Georgia and Alabama.

Environment

The scarcity of marine fossils, the presence of wood fragments, and the discontinuous bedding indicate that most of the Middendorf was probably deposited in fluvial and deltaic environments.

Black Creek Group

Lithology and Distribution

The Black Creek Group consists of quartz sands, silts, and clays. It is generally darker, more micaceous, and more lignitic than the other Cretaceous units. The lower part of the unit is tan and light gray, fine to coarse grained sand with moderate to poor sorting. The sand is micaceous and becomes lignitic in the central and southeastern parts of the SRS. Layers of pebbles and clay clasts are common and feldspathic zones occur locally. A thick, oxidized, kaolinitic clay lens occurs within the lower Black Creek in the western part of the Site, suggesting an unconformity within the formation, at least in the updip part of the SRS. In the central and downdip parts of the SRS, a southeasterly-thickening wedge of dark, fissile, lignitic, pyritic, micaceous clay with dark, interbedded sands and silts occurs in the middle and upper parts of the formation; this facies is slightly calcareous in well C 6 near Barnwell, South Carolina, and well C 10 near Allendale, South Carolina (Figure 1). The upper part of the formation consists mostly of tan and light gray sands.

In many wells tan sands of the Black Creek lie on oxidized clay beds at the top of the Middendorf. Where the clays are missing, it is difficult to pick the contact, but a pebbly zone occurs in some wells. In general, the Black Creek contains more dark clays, lignite, and muscovite than the Middendorf. The oxidized clays at the top of the Middendorf and the presence of an overlying pebbly layer suggest that the contact is unconformable. The Black Creek is about 200 ft (60 m) thick at the northwestern boundary of the SRS and thickens to about 300 ft (90 m) at the southeastern boundary.

Stratigraphic Terminology

Except for the variegated clay bodies, the sediments are lithologically similar to the Black Creek in the type area (Sloan, 1908; see also Nystrom and others, 1991) in northeastern South Carolina, and numerous palynological assemblages from the SRS confirm the correlation. Oldham (1981), Faye and Prowell (1982), Colquhoun and others (1983), and later workers have applied the term in the subsurface at the SRS and vicinity. The strata appear to be the UK4 and UK5 units of Prowell and others (1985a) who correlated these with the Black Creek in the type area.

In 1989, Owens elevated the "Black Creek Formation" of earlier workers to group status and divided the unit into several formations, a revision which has been incorporated into stratigraphic studies in the Carolinas by Owens and Sohl (1989), Sohl and Owens (1991), Gohn (1992), and Prowell (in press). Because the revision has been adopted in the most recent stratigraphic studies, we refer the strata between the Middendorf and Steel Creek formations to the Black Creek Group. Because of uncertainty in correlations at this time, we have not attempted to use the formation names within the Black Creek Group which appeared in the articles cited above.

Paleontology, Age, and Correlation

Wood fragments, some quite large, and pollen and spores are common, as are dinoflagellates. A few mollusks were found in the deep well near Allendale, South Carolina. The Black Creek in and near the type area is early Campanian to early Maestrichtian according to Sohl and Owens (1991). Numerous fossil dates of Campanian and Maestrichtian age have been obtained from palynological assemblages in the unit at the SRS. The Black Creek appears to correlate with the Blufftown and Cusseta formations, and perhaps the lower part of the Ripley formation, of Georgia and Alabama.

Environment

Light-colored sands and large, oxidized clay lenses suggest delta plain conditions in the lower Black Creek in the northwestern part of the SRS. The dark clays and sands abundant in the southeastern part of the Site suggest delta front and prodelta environments.

Steel Creek Formation--
New Formation Name

Lithology and Distribution

Cretaceous beds overlying the Black Creek are light-colored quartz sands and mostly oxidized, kaolinitic clays. The sediments in the lower part of the formation are tan, light to dark gray, orange, and yellow, poorly to well-sorted, fine to coarse grained quartz sand and silty sand, in places very micaceous. Concentrations of feldspar and lignite occur. Pebbly zones are common, as are layers with clay clasts. The upper part of the Steel Creek in most places at the Site is oxidized, kaolinitic clay, with orange, red, gray, purple, and yellow coloring, interbedded with sands in places. The clay is up to 60 ft (18 m) thick but is absent in some wells. Fining-upward sands are interbedded with the clay in some cores. In general, the Steel Creek has more oxidized clays, fewer and much thinner dark clays, and less lignite than the Black Creek.

The Steel Creek is about 60 ft (18 m) thick at the northwestern SRS boundary and 140 ft (40 m) thick at the southeastern boundary. The dip of the upper surface is to the southeast at approximately 30 ft/mi (6 m/km). The unit occurs throughout the SRS and is present downdip in the deep wells near Barnwell (C 6) and Allendale (C 10), South Carolina.

Stratigraphic Terminology and Definition

Steel Creek sediments were assigned to the Middendorf and Middendorf(?)-Black Creek(?) by Oldham (1981) and to the Black Creek by McClelland (1987). Colquhoun and others (1983) and Steele (1985) placed them in the Black Creek updip from Lower Three Runs and in the Peedee Formation downdip. Logan and Euler (1989) and Sargent and Fliermans (1989) included them in the Peedee. The Steel Creek appears to be the UK6 unit of Prowell and others (1985a), who reported Peedee-correlative fossil assemblages.

Stratigraphic position and a Maestrichtian age suggest a correlation with the Peedee Formation or the Black Creek Group. The Peedee in the type area (Ruffin, 1843) in northeastern South Carolina is dark silt and quartz sand, glauconitic in places, with marine fossils. The type Black Creek contains thick, black, lignitic clays. Because neither of these lithologies is common in the Steel Creek at the SRS, a new name is used for the sediments.

The type section of the Steel Creek Formation, a lithostratigraphic unit, is described in the appendix from core from SRS well P 21TA in Barnwell County, South Carolina (Figures 1

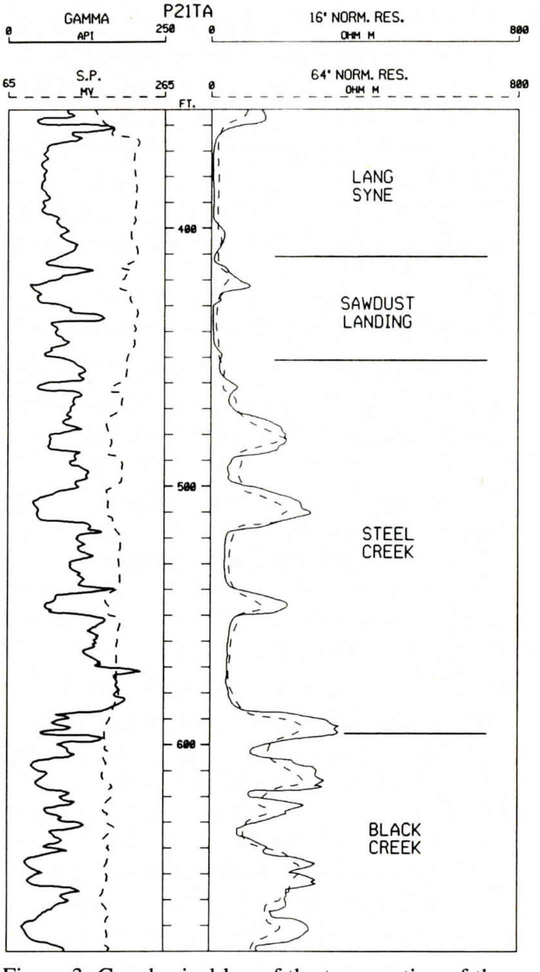

Figure 3.-Geophysical log of the type section of the Steel Creek Formation in SRS well P 21TA.

and 3). Steel Creek is a tributary to the Savannah about 2.4 mi (3.8 km) west of the well. In most wells, the basal contact can be placed at the bottom of a coarse sand below which are sands interbedded with dark clays and above which are sands interbedded with variegated clays. The basal Steel Creek tends to be pebble-rich, suggesting an unconformity. Poorly sorted, pebbly sands of the Sawdust Landing lie with a sharp, unconformable contact on oxidized clays of the Steel Creek in most SRS wells. In general, the Sawdust Landing has more feldspar and iron sulfide than the Steel Creek, is darker, and sorting is poorer. The Steel Creek grades into the calcareous siliciclastics of the Peedee Formation of northeastern and southeastern South Carolina. To the southwest it grades into the calcareous sands of the Ripley and Providence formations of western Georgia (Reinhardt and others, 1980; Prowell and others, 1985a). The lateral limits of the Steel Creek are arbitrarily placed where the calcium carbonate content of the sediments is 5%.

Paleontology, Age, and Correlation

Wood fragments, spores, pollen, and rare dinoflagellates have been found in SRS wells. Dinoflagellates and pollen yield a Maestrichtian age. If the Steel Creek is the same age as the redefined Peedee (Sohl and Owens, 1991), it correlates with the middle and upper Ripley and Providence formations of Georgia and Alabama.

Environment

Scarce marine fossils, irregular bedding, and large bodies of oxidized clay suggest that the sediments were probably deposited in fluvial and delta plain environments.

UNDIFFERENTIATED LOWER TERTIARY

Updip from the SRS, sediments between the Cretaceous strata and the upper Eocene Dry Branch Formation consist of sands and clays which are difficult to correlate with strata to the southeast. The sediments are mostly light-colored, kaolinitic, coarse grained, cross-bedded quartz sands, micaceous sands, and kaolin. According to Nystrom and Willoughby (1982a, p. 88-92) and Nystrom and others (1986, p. 8-10), the lower part of the Tertiary northwest of the SRS consists of fine to medium, moderately well-sorted, loose, micaceous quartz sand interbedded with thinly laminated to thinly bedded clays. Heavy minerals are abundant. Burrows and shark and ray teeth have been found (Kite, 1982; Nystrom and Willoughby, 1982a). The upper part of the undifferentiated Tertiary section is typically orange, cross-bedded quartz sand, fine to coarse grained, poorly sorted, micaceous, and clayey in places. Clay clasts are common. Bedding is not as well developed as in the lower part. A massive, light-colored, "hard" kaolin bed, locally pisolitic, is commonly observed at the top and is mined in the area (Buie and Schrader, 1982; Nystrom and Willoughby, 1982a; Nystrom and others, 1986).

Buie (1978) proposed the term "Huber Formation" for post-Cretaceous, pre-Jacksonian deposits in the districts where kaolin is mined northeast of the Ocmulgee River in Georgia, with the type area in Twiggs County. The "Huber" as defined in Georgia probably consists of Paleocene, early Eocene, and middle Eocene sediments, perhaps including age equivalents of the Warley Hill and Santee or "McBean" formations (see Scrudato and Bond, 1972; Abbott and Zupan, 1975; Tschudy and Patterson, 1975; Buie, 1978; McClelland, 1987). A few molluscan fossils have been found in the upper part in Georgia. Eocene diatoms (Abbott and Zupan, 1975), middle Eocene fossil leaves (Hutchenson, 1978), and lower middle Eocene pollen (Nystrom and others, 1986, p. 8) have been reported. The updip lower Tertiary was probably deposited in fluvial, deltaic, and shallow marine environments.

The term "Huber" has been used in various senses in the study area by Oldham (1981), Buie and Schrader (1982), Kite (1982), Mittwede (1982), Nystrom and Willoughby (1982a), Colquhoun and others (1983), Steele (1985), McClelland (1987), and Nystrom and others (1986, 1991). Nystrom and others (1986, p. 8) restricted the term "Huber" in the updip Coastal Plain of southwestern South Carolina to what they regarded as a single depositional sequence of middle Eocene age. The "Huber Formation" does not appear to us to be a valid stratigraphic concept on the formation level. It has been defined differently in Georgia and South Carolina, and in both places there has been a strong emphasis on time-stratigraphic relationships. We believe that several depositional sequences are included in the "Huber" in both Georgia and South Carolina and prefer to use the term "undifferentiated lower Tertiary."

LOWER PALEOCENE

Sawdust Landing Formation

Lithology and Distribution

In most SRS wells the Sawdust Landing is composed of 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 the 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.

Basal sands, often pebbly, of the Sawdust Landing lie with a sharp, unconformable contact on oxidized clays of the Steel Creek in most SRS wells. In general, the Sawdust Landing has more feldspar and iron sulfide than the Steel Creek, is darker, and sorting is poorer. The clays of the Sawdust Landing are more fissile than those of the Steel Creek. Where the oxidized clay at the top of the Steel Creek is missing, it is difficult to pick the contact. Where the Sawdust Landing in these places is better sorted and lighter in color than is typical, it is similar to tan, moderately to well-sorted sands in the Steel Creek. In some cores, the sands of the Steel Creek are micaceous, poorly sorted, and dark, similar to typical Sawdust Landing sands. A pebbly layer occurs in the base of the Sawdust Landing in some of the problem wells.

The Sawdust Landing is about 10 ft (3 m) thick near the northwestern boundary of the Site and thickens to about 40 ft (12 m) near the southeastern boundary. Sediments dated as Danian (early Paleocene), perhaps Sawdust Landing deposits, crop out about 4 mi (6 km) northwest of the SRS in the valley of Hollow Creek (Prowell and others, 1985b, p. A63; Nystrom and others, 1991, p. 224).

Stratigraphic Terminology

We consider the basal Paleocene quartz sands and clays at the SRS to be a facies of the Sawdust Landing Formation, the type locality of which is to the northeast in the Congaree River valley (Padgett, 1980; Colquhoun and others, 1983; Howell, 1985; Muthig and Colquhoun, 1988; Colquhoun and Muthig, 1991; Nystrom and others, 1991). The Sawdust Landing appears to be the lower parts of: the "Ellenton Formation" of Siple (1967) as used by Prowell and others (1985b) and Logan and Euler (1989); the "Black Mingo Formation" as used by Oldham (1981); the "Ellenton Formation" and the "Rhems Formation" as used by Colquhoun and others (1983); the "Ellenton member of the Rhems Formation" as used by Steele (1985); and the "Rhems Formation" as used by McClelland (1987). The Sawdust Landing is the lower part of unit P1 of Prowell and others (1985a).

We believe that the term "Ellenton" should be abandoned because the sediments named by Siple (1967) consist of two different sedimentary sequences with different lithologies. An alternative to the use of the term "Sawdust Landing" for the basal Paleocene at the SRS is to restrict the "Ellenton" of Siple to the lower sequence. Most of the type section of the "Ellenton", however, is the upper Paleocene Lang Syne Formation, and the term "Lang Syne" has priority over "Ellenton." The term "Sawdust Landing" for the lower Paleocene strata rather than "Rhems" is used here because the lithology at the SRS is more similar to the type Sawdust Landing in central eastern South Carolina than it is to the type Rhems (Sloan, 1908; Van Nieuwenhuise, 1978; Van Nieuwenhuise and Colquhoun, 1982) in eastern South Carolina.

Paleontology, Age, and Correlation

When Siple (1967) named and described the "Ellenton Formation" from well cuttings at the SRS, he thought the age to be Cretaceous or

Paleocene. Prowell and others (1985b) reported early Paleocene fossils from the lower part of the "Ellenton" but were not able to obtain dates from the upper part. Since that time, late Paleocene palynomorphs have been recovered from the upper part, coming from sediments above a glauconitic sand which appears to be the base of a depositional sequence younger than the Sawdust Landing. Harris and Zullo (1992) also considered the "Ellenton" of Siple (1967) to be both early and late Paleocene. Fredericksen (1991) dated the "Ellenton" at the SRS as late Paleocene.

In its type area, the Sawdust Landing is thought to be early Paleocene (Colquhoun and Muthig, 1991; Nystrom and others, 1991). A few palynological assemblages from the SRS indicate assignment within the calcareous nannoplankton zonation of Martini (1971) of NP 1 through 3 or perhaps NP 1 through 4. The Sawdust Landing at the SRS appears to correlate with the early Paleocene Rhems Formation in central eastern South Carolina (Van Nieuwenhuise and Colquhoun, 1982), a more marine deposit. It also appears to correlate with the Clayton and Porters Creek formations in the Gulf Coastal Plain (lower and middle Midwayan; Danian).

Environment

Light-colored, moderately to poorly sorted, micaceous quartz sands, feldspathic in places, which we interpret as upper delta plain deposits, are common in the northwestern part of the SRS, with darker, poorly sorted, micaceous lower delta plain facies becoming dominant in the southeastern part.

UPPER PALEOCENE

Lang Syne Formation

Lithology and Distribution

At the 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 the 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.

Basal sands which are glauconitic in places lie on dark clays or dark, moderately and poorly sorted sands of the Sawdust Landing, with a pebbly zone common at the contact. In general the Lang Syne contains more glauconite, muscovite, lignite, and iron sulfide than the Sawdust Landing and the clay beds are much thicker. It tends to be darker and to contain less feldspar. It is difficult to pick the contact where the basal sand is not glauconitic. The Lang Syne probably crops out northwest of the SRS but has not been definitely identified. The unit appears to be sporadic in the northwestern part of the SRS and is about 80 ft (24 m) thick near the southeastern boundary, where it becomes calcareous.

Stratigraphic Terminology

The type locality of the Lang Syne is in central eastern South Carolina (Sloan, 1908; Padgett, 1980; Colquhoun and others, 1983; Howell, 1985; Muthig and Colquhoun, 1988; Colquhoun and Muthig, 1991; Nystrom and others, 1991). Nystrom and others (1989, 1991) traced it from its type area to the SRS. It appears to be the upper parts of: the "Ellenton Formation" of Siple (1967) as used by Prowell and others (1985b) and Logan and Euler (1989); the "Black Mingo Formation" as used by Oldham (1981); the "Ellenton Formation" and the "Rhems Formation" as used by Colquhoun and others (1983); the "Ellenton member of the Rhems Formation" as used by Steele (1985); and the "Rhems Formation" as used by McClelland (1987). The term "Lang Syne" for the SRS deposits is used here rather than "Rhems" because of greater lithologic similarity with the type Lang Syne. Our palynological data indicate that the Lang Syne (upper "Ellenton") strata at the SRS and vicinity are Thanetian or Selandian rather than Danian; the Rhems has been dated as Danian (Van Nieuwenhuise and Colquhoun, 1982). The Lang Syne at the SRS is the upper part of unit P1 of Prowell and others (1985a).

Paleontology, Age, and Correlation

The Lang Syne has yielded numerous palynological assemblages at the SRS which indicate an assignment within calcareous nannoplankton zones NP 4-8 or 5-8 (late Paleocene). A nannofossil assemblage from the Lang Syne in the deep Allendale well was given a late Paleocene age by Laws (1992, p. 112). Fredericksen (1991) dated several samples from the "Ellenton" at the SRS as late Paleocene. Muthig and Colquhoun (1988) assigned the Lang Syne in the type area to the lower Paleocene, but Nystrom and Willoughby (1992a, p. 10) believed it to be upper Paleocene, citing age determinations from pollen, dinoflagellates, calcareous nannofossils, and mollusks. It probably correlates with the Naheola and Nanafalia, and perhaps the lower part of the Baker Hill (Gibson, 1982), formations of the Gulf Coastal Plain (upper Midwayan and lower Sabinian; lower and middle Thanetian or Selandian).

Environment

Light-colored, moderately to poorly sorted, micaceous quartz sands are common in the northwestern part of the SRS and are interpreted to be upper delta plain sediments. The thick, dark clays probably accumulated in lagoons or bays. Darker, poorly sorted, micaceous lower delta plain and prodelta facies become dominant in the southeastern part of the SRS. Calcareous deposits in the deep well near Allendale, South Carolina, appear to be shallow shelf sediments. Glauconitic sands probably represent transgressive deposits.

Snapp Formation--
New Formation Name

Lithology and Distribution

The Snapp sediments are typically light gray, tan, orange, and yellow, silty, micaceous, medium to coarse grained quartz sands and pebbly sands interbedded with kaolinitic clays. The micaceous sands have a powdery appearance in some wells. Sorting in the sands is generally poor, but well-sorted sands are present. Dark, micaceous, lignitic sands also occur. The clays are oxidized in some places but dark in others.

The Snapp is well developed in the southeastern part of the SRS, where there are two fining-upward sequences. Only one sequence occurs in the center of the Site and the Snapp appears to pinch out updip in the vicinity of Upper Three Runs. It is about 70 ft (20 m) thick near the southeastern boundary of the SRS and is present downdip in well C 10 near Allendale, South Carolina. A glauconitic sand, much different from the lithology of the Snapp, occurs in this part of the section in well C 6 near Barnwell.

Stratigraphic Terminology and Definition

The Snapp has been referred to in the study area as "Williamsburg Formation" by Colquhoun and others (1983), Steele (1985), and McClelland (1987). It appears to correspond roughly to at least part of the "Black Mingo Formation" as used by Logan and Euler (1989). The Snapp is unit P2 of Prowell and others (1985a).

A new formation name is established here because the lithology is not similar to that of the type Williamsburg and Black Mingo in eastern South Carolina (Sloan, 1908; Van Nieuwenhuise, 1978; Van Nieuwenhuise and Colquhoun, 1982). The precise chronologic relationship between the Snapp and the Williamsburg is uncertain. The type section of the Snapp Formation, a lithostratigraphic unit, is described in the appendix from core from SRS well P 22TA in southern Barnwell County,

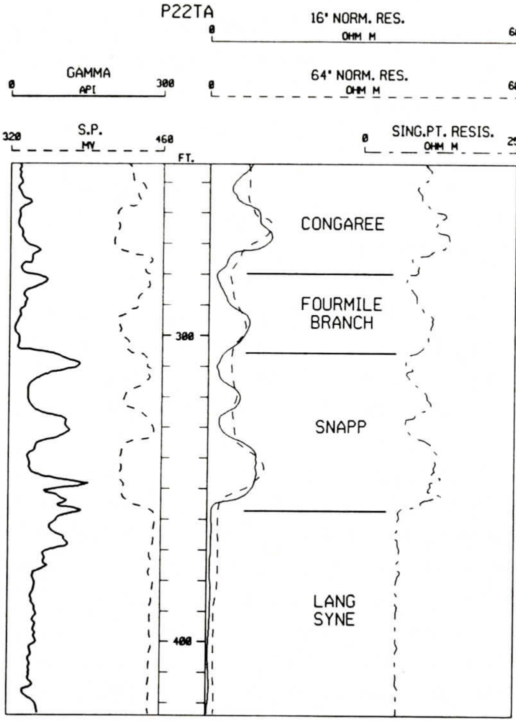

Figure 4.-Geophysical log of the type section of the Snapp Formation in SRS well P 22TA.

South Carolina (Figures 1 and 4). The name is from an old railroad stop in the southeastern part of the Site. In most wells basal, light colored, micaceous Snapp sands lie on dark clays, glauconitic in places, of the Lang Syne. Snapp sands are usually lighter in color than Lang Syne sands, and the unit contains less lignite, iron sulfide, and glauconite. The sharpness of the contact suggests an unconformity. In a few wells, the Lang Syne is light in color, making it difficult to pick a contact. The upper boundary of the Snapp, also sharp and unconformable, is the base of the Fourmile Branch Formation, composed of cleaner, more glauconitic sand. On geophysical logs, the Fourmile Branch sediments have a lower gamma ray count (Figures 4 and 5) than the Snapp.

To the northeast and southeast, stratigraphic relationships are uncertain, but the Snapp probably grades into siliciclastics and limestones of the upper part of the Williamsburg Formation in eastern South Carolina. The boundary between the Snapp and the Williamsburg is arbitrarily placed where the section is 5% calcium carbonate. The glauconitic sand in this part of the section in the deep well near Barnwell may be a transitional unit between the Snapp and the Williamsburg. To the southwest the Snapp probably grades into the glauconitic sands and laminated, carbonaceous silts and clays of the Tuscahoma Sand of western Georgia (Reinhardt and others, 1980). The boundary with the Tuscahoma is defined as where the silts and clays become mostly carbonaceous rather than being mostly oxidized as is typical of the Snapp.

Paleontology, Age, and Correlation

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 in zone NP 9, middle Sabinian, perhaps correlating with the upper part of the Williamsburg Formation (Van Nieuwenhuise and Colquhoun, 1982; Colquhoun and others, 1983; Muthig and others, 1992) 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).

Environment

The near absence of marine fossils, the generally poorly sorted sands, and the oxidized clays indicate that the environment of deposition was probably mostly upper delta plain.

LOWER EOCENE

Fourmile Branch Formation-- New Formation Name

Lithology and Distribution

The Fourmile Branch Formation is composed of quartz sand with some interbedded clays. It is mostly orange, green, gray, yellow, and tan, moderately to well-sorted, fine to coarse grained quartz sand with green and gray clays a few feet thick in the middle and at the top in places. There appear to be two fining-upward sequences in some wells. Glauconite, muscovite, and iron sulfide are common accessories. Dark clays rich in organic matter tend to be more abundant in the northwestern part of the SRS and glauconitic clays more common to the southeast. Clay laminae occur in the sands locally.

Fourmile Branch sediments probably crop out northwest of the SRS, although they have not been definitely identified. The lower surface of the formation dips to the southeast at about 25 ft/mi (5 m/km) across the Site. The unit is about 30 ft (9 m) thick in the northwestern part of the Site and appears to thin to the southeast and toward the Savannah River from the center of the SRS. Edwards and Fredericksen (1992) noted the absence of early Eocene fossils in a well in Burke County, Georgia, near the Savannah.

Stratigraphic Terminology and Definition

The unit seems to be the lower part of the Congaree(?) Formation as used by Siple (1967) and the lower Congaree as used by Logan and Euler (1989). It roughly corresponds to the lower parts of the informally named "Bamberg" and "Neeses" as used by Oldham (1981) and Colquhoun and others (1983) and to the lower parts of the "McBean", "Neeses", and "Aiken" formations as used by Steele (1985). The Fourmile Branch is the E1 unit of Prowell and others (1985a), who noted the presence of beds in the area possibly equivalent to the lower Eocene Fishburne Formation.

A new formation name is used here to refer to a sand-and interbedded-clay unit immediately underlying the Congaree. The type section is described in the appendix from core from well MWD-3A in northwestern Barnwell County, South Carolina (Figures 1 and 5). In the northwestern part of the SRS, the Fourmile Branch overlies the dark clays and sands of the Lang Syne Formation. In the southeast, the underlying unit is the Snapp. The basal contact is sharp in both areas. In general, going upward across the Lang Syne/Fourmile Branch contact,

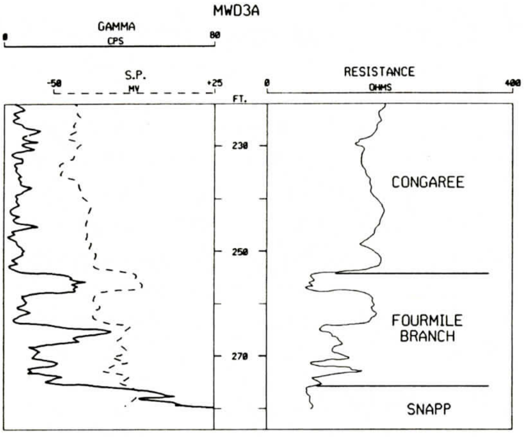

Figure 5.-Geophysical log of the type section of the Fourmile Branch Formation in SRS well MWD 3A.

the sands become cleaner, iron sulfide and lignite content decreases, colors become lighter, and clay bed thickness decreases. Going upward across the Snapp/Fourmile Branch contact, sands become cleaner, glauconite increases, and clay bed thickness decreases. Oxidized clays at the top of the underlying Snapp indicate that the contact is an unconformity. On geophysical logs, there is a marked decrease in gamma ray count going upward across the base of the Fourmile Branch (Figures 4 and 5).

Downdip, the Fourmile Branch grades into the Fishburne Formation (Gohn and others, 1983), a limestone. We arbitrarily define the contact as where 25% of the section is composed of calcium carbonate. To the southwest, the Fourmile Branch grades into a unit composed of laminated and massive clay with interbedded quartz sands in central Georgia (Prowell and others, 1985a). This may be the Hatchetigbee Formation as described by Reinhardt and others (1980). We define this contact as where 50% of the section is composed of clay beds.

Fourmile Branch is a Savannah River tributary which rises in the center of the SRS. Fallaw and Price (1992) have used the term "Fourmile Formation"; "Fourmile Branch Formation" is here adopted to distinguish it further from several other stratigraphic units having "Fourmile" as part of their name.

Paleontology, Age, and Correlation

The only well-preserved fossils recovered from the Fourmile Branch are palynomorphs. Age determinations from dinoflagellates indicate that the formation is within zones NP 10 and NP 11, early Eocene, late Sabinian (early Ypresian), correlative with the Fishburne Formation in southeastern South Carolina and with the Hatchetigbee Formation in the Gulf Coastal Plain.

Environment

The glauconite, the abundant dinoflagellates, and the moderate to good sorting indicate that the environment of deposition was shallow marine, with dark clays in the northwestern part of the SRS probably forming in bays or lagoons, and glauconitic clays in the southeastern part being deposited in neritic conditions.

Congaree Formation

Lithology and Distribution

The Congaree consists of orange, yellow, tan, gray and greenish gray, moderately and well-sorted, fine to coarse grained quartz sands. Thin clay laminae are present in places. In some cores, quartz grains are rounder than in other parts of the section. There appear to be at least two fining-upward sequences. In some places at the SRS, the Congaree sands are slightly calcareous; they are consistently calcareous near the southeastern boundary. The abundant indurated clays which are common in the type area in central eastern South Carolina (Sloan, 1908; Nystrom and others, 1991) are absent at the SRS. The Congaree tends to have lower gamma ray and higher resistivity values than underlying and overlying units (Figures 5 and 6).

The Congaree is similar to the Fourmile Branch. In most wells glauconite decreases, muscovite decreases, clay beds and laminae become less common, sorting becomes better, pebble content decreases, and colors become lighter above the contact. The presence of a silicified zone at the top of the Fourmile Branch in some cores and the occurrence of pisolitic structures near the top in one well suggest that the contact is unconformable.

The Congaree crops out in stream valleys in the northwestern part of the SRS. Updip correlative sediments have been mapped as part of the "Huber Formation" (Nystrom and Willoughby, 1982a). The "Huber" is more micaceous and poorly sorted in places and suggests more fluvial and deltaic influence. The Congaree is about 60 ft (18 m) thick at the northwestern boundary of the SRS and about 80 ft (24 m) thick near the southeastern boundary. Across the river from the SRS in Georgia it appears to be thinner and more argillaceous and micaceous. Sediments downdip from the SRS are more calcareous, and a limestone occurs in this part of the section in the deep Allendale well (C 10), where another formation name would be appropriate.

Stratigraphic Terminology

The Congaree was traced in outcrop from its type area (Sloan, 1908; see also Nystrom and others, 1991) in central eastern South Carolina to the SRS area by Sloan (1908), Cooke and MacNeil (1952), and Nystrom and others (1991), and it has been described at the Site by several authors including Siple (1967), Dennehy and others (1989), Fallaw and others (1992d), Nystrom and others (1992), and Snipes and others (1992b). The unit corresponds in stratigraphic position to some of the lower part of the informally named "Bamberg" and "Neeses" formations as used by Oldham (1981) and Colquhoun and others (1983), and parts of the "McBean Formation" and the informally named "Aiken Formation" as used by Steele (1985). The Congaree appears to be units E2 and E3 of Prowell and others (1985a).

Paleontology, Age, and Correlation

A few molluscan shell fragments, usually silicified, have been found in the Congaree at the SRS. In the type area of the Congaree in central eastern South Carolina, the pelecypod *Anodontia augustana*, an index fossil found in the Tallahatta Formation of the Gulf Coastal

Plain, occurs (Gardner, 1951; Cooke and MacNeil, 1952; Nystrom and others, 1991). We have a few palynological dates at the SRS from the lower and middle parts of the Congaree; judging from these and by age determinations from below and above, the Congaree is probably within zones NP 12 through NP 14, early Claibornian (late Ypresian and possibly early Lutetian), equivalent to the Tallahatta Formation, a correlation also made by Nystrom and others (1992). The latter unit is mostly early Eocene according to Bybell and Gibson (1985). The upper part of the Congaree and the Tallahatta may be early middle Eocene.

Environment

The well-sorted sands, the occurrence of glauconite, and the dinoflagellate assemblages indicate a shallow marine environment.

MIDDLE EOCENE

Warley Hill Formation

Lithology and Distribution

A fine to medium grained, poorly to well-sorted quartz sand and muddy quartz sand, glauconitic in places and a few inches to approximately 15 ft (4.6 m) thick, occurs above the Congaree in many SRS cores. The sand fines upward, and locally a clay, a few inches to 2 ft (0.6 m) thick, occurs at the top. The clay commonly has a high sand content with granules and pebbles present in places. Common colors are brown, green, gray, yellow, tan, and orange. The top of the Congaree is picked at the top of a clean sand sequence. Going upward in many wells, the overlying Warley Hill sands become coarser, then finer, sorting becomes poorer, silt and clay content increases, glauconite becomes more common, and colors are darker. In some cores, the top of the Congaree is cemented with silica, indicating that the contact may be unconformable.

The unit is sporadic and difficult to identify. It appears to be missing from the northwestern part of the SRS. It is most distinct in cores and outcrops in the central part of the SRS and appears to become calcareous in the downdip part, making it difficult to distinguish from overlying carbonates. The possible occurrence of *Cubitostrea lisbonensis* at Blue Bluff on the Savannah River indicates that the unit, or a time-equivalent, may crop out there, although most of that exposure is younger.

Stratigraphic Terminology

The type Warley Hill is in central eastern South Carolina (Sloan, 1908; Cooke and MacNeil, 1952; Pooser, 1965; Nystrom and others, 1991). Sloan (1908) assigned outcrops along Tinker Creek within the SRS to his "Warley Hill phase", correlating with his type area where it is very glauconitic. Most of these Tinker Creek exposures, however, are probably younger than the type Warley Hill (see Nystrom and others, 1991, p. 230-234). Siple (1967) noted the possible occurrence of the Warley Hill at SRS. Fallaw and others (1992d) and Snipes and others (1992b) applied the term to sediments in the center of the SRS. Steele (1985) and McClelland (1987) assigned calcareous facies to the Warley Hill in the downdip part of the study area. At least part of unit E4 of Prowell and others (1985a) may be the Warley Hill.

Paleontology, Age, and Correlation

Dinoflagellates, spores, and pollen have been recovered from the unit at the SRS. Samples from two wells have dinoflagellate assemblages indicating a correlation with zone NP 15 and the lower part of the Lisbon Formation of the Gulf Coastal Plain, which is middle Claibornian (lower Lutetian). Cooke and MacNeil (1952) and Willoughby and Nystrom (1992) correlated Warley Hill outcrops in central eastern South Carolina with the lower Lisbon based on the occurrence of *Cubitostrea lisbonensis*.

Environment

Glauconite and dinoflagellates suggest shallow marine conditions, with the muddier sands indicating lower energy levels than those prevailing when the Congaree was deposited. The high mud content could have also developed by flocculation at the fresh water/salt water interface.

Santee Limestone

Lithology and Distribution

Most of the middle Eocene section consists of three laterally gradational units: the Santee Limestone, the Tinker Formation, and the informally named "Blue Bluff" unit (Huddlestun and Hetrick, 1986, p. 4). Much of the Santee at the SRS is composed of cream-colored, slightly to moderately indurated calcarenite and calcilutite with well-indurated calcareous nodules. Indurated, moldic limestone is also common in many SRS cores and in outcrops. In places the carbonate has been replaced by silica. In most places, the Santee lies on quartz sands and clays of the Warley Hill.

The Santee is best developed in a northeasterly trending zone across the middle of the SRS. It crops out on the Georgia side of the Savannah River, and silicified facies can be seen in a few places along tributaries to Upper Three Runs at the SRS. It is sporadic in the vicinity of Upper Three Runs and rare to the northwest. To the southeast it interfingers with and grades into the "Blue Bluff" unit. Judging from Sloan's (1908, p. 271) lithologic descriptions, the Santee is at least 60 ft (18 m) thick at Shell Bluff in Burke County, Georgia.

Stratigraphic Terminology

The type area of the Santee is in central eastern South Carolina (Lyell, 1845a; Cooke, 1936; Cooke and MacNeil, 1952; Pooser, 1965; Ward and others, 1979; Baum and others, 1980; Powell, 1984). Sloan (1908) used the term "Santee" for calcareous deposits in the vicinity of the SRS, but it appears that he applied it mostly to strata now assigned to upper Eocene units (Paul Nystrom, personal communication). "McBean Formation" of many authors and "McBean member of the Lisbon Formation" (Huddlestun, 1982; Huddlestun and Hetrick, 1986, p. 4) are terms that have been applied to the Santee at SRS and vicinity. The "McBean Formation" at its type locality on McBean Creek in Georgia as defined by Veatch and Stephenson (1911, p. 237-244) consists of carbonates, clays, and quartz sands, a lithologically heterogeneous assemblage. Their concept of the "McBean" included upper Eocene carbonates exposed on the Savannah River (Veatch and Stephenson, 1911, p. 243; Huddlestun and Hetrick, 1986).

In 1952 Cooke and MacNeil (p. 24) restricted the "McBean" to beds equivalent to the Cook Mountain Formation, the *Cubitostrea sellaeformis* zone of the Lisbon Formation in Alabama. They, however, mistakenly included sediments now known to be younger in their descriptions of the stratigraphy (Nystrom and others, 1992). Their definition was adopted by Nystrom and others (1989, 1992). Huddlestun (1982, p. 25) and Huddlestun and Hetrick (1986) concluded that much of the type "McBean" was Jacksonian rather than Claibornian in age. They suggested that the term "McBean" be restricted to calcareous facies below the Jacksonian bed and informally used the term "McBean member of the Lisbon Formation." Nystrom and others (1992) concluded that some of the sands overlying the calcareous "McBean" in the type area, assigned by many workers to the "McBean" and by Huddlestun (1982) and Huddlestun and Hetrick (1986) to the Jacksonian, are correlative with the Claibornian Gosport Sand in Alabama and with the informally named "Orangeburg District bed" (Dockery and Nystrom, 1992a, b) in South Carolina.

Because the "McBean" is not defined as a lithologically homogenous unit and because of confusion involved in the use of the term, we are currently not using "McBean." We concur with Huddlestun (1982) and Huddlestun and Hetrick (1986) that the carbonate below the lowest quartz sands in the sections at McBean Creek and Shell Bluff should be assigned a name different from that applied to the sands. Rather than "McBean member of the Lisbon Formation", however, we are using the term "Santee." The carbonates at McBean Creek and Shell Bluff are more similar to those in the type area of the Santee than they are to the type Lisbon, and we regard them as updip facies of the former. Lyell, generally regarded as the author of the term "Santee" (1845a), concluded that the deposits in the type area of the Santee are ". . . a continuation of the same Eocene deposit which I had seen at Shell Bluff, at Jacksonboro, and other places on the Savannah river . . ". (1845b p. 176, 177). Lyell (1845b), Sloan (1908), and Veatch and Stephenson (1911) included strata now assigned to the upper Eocene in their concepts of the Santee and "McBean."

Although the calcareous facies of the type "McBean" consists mostly of slightly to moderately indurated sediment with a "marly" texture, beds of moderately to well-indurated biomoldic limestone typical of the Moultrie Member of the Santee (Ward and others, 1979) occur in the "McBean" type area (Sloan, 1908, p. 271; Veatch and Stephenson, 1911, p. 242-243). The "McBean" as redefined by Cooke and MacNeil (1952) is a biostratigraphic unit. "McBean" as used in the updip Coastal Plain by Cooke and MacNeil (1952) and Siple (1967) consists mostly of siliciclastics; in some places "McBean" has been used where no calcareous sediments are present. Two names have been used by most workers for this part of the section: "Santee" for calcareous sediments and "McBean" for calcareous sediments and siliciclastics. We believe that it is more logical to have a different name (Tinker Formation) for the siliciclastics. The Santee is part of the E5 unit of Prowell and others (1985a).

Paleontology, Age, and Correlation

Microfossils and megafossils are abundant in the Santee. From the outcrops at McBean Creek, Georgia, Cushman and Herrick (1945) described many species of foraminifers, mostly benthic. The foraminiferal species *Cibicides westi* appears to be a marker for the middle Eocene in this area (Huddlestun and Hetrick, 1986, p. 15). Veatch and Stephenson (1911, p. 239-240) listed numerous species identified by T. W. Vaughan, including gastropods, pelecypods, a coral, and a scaphopod. Zullo (1984, 1988) analyzed barnacle assemblages from the "McBean." *Cubitostrea sellaeformis* and *Pteropsella lapidosa*, characteristic of the upper Lisbon Formation in Alabama, are prominent in the Santee. Among other groups common to abundant are ostracodes, bryozoans, and sponges. Calcareous nannoplankton, palynomorph assemblages, and other fossils indicate a zone NP 16 age assignment (late Lutetian, middle Claibornian).

Veatch and Stephenson (1911, p. 237), citing T. W. Vaughan, suggested a possible correlation for the upper part of the "McBean" with the base of the Gosport Sand of late Claibornian age in the Gulf Coastal Plain, and Toulmin (1977) correlated the upper part of the "McBean" with the Gosport. Ostracodes from Santee carbonates in one well at the SRS indicate the presence of Claibornian strata slightly younger than the *Cubitostrea sellaeformis* zone, probably equivalent to the Gosport (J. E. Hazel, personal communication). According to Hazel, some ostracode assemblages from the type "McBean" and from sediments between the *C. sellaeformis* zone and the *Crassostrea gigantissima* bed at Shell Bluff also correlate with the Gosport. This part of the section appears to be equivalent to strata in the South Carolina Coastal Plain described by Dockery and Nystrom (1992a, b). These deposits contain abundant silicified molluscan shells and are unconformably separated from the underlying *C. sellaeformis* zone. Dockery and Nystrom (1992b) informally named these sediments the "Orangeburg District bed" and correlated them with the Gosport Sand in Alabama. Nystrom and others (1992) described the "Orangeburg District" as being unconformably separated from the underlying Lisbon-equivalent strata and the overlying Jacksonian deposits in the type area of the "McBean."

Gosport-correlative deposits may be an updip facies of the Utley Limestone and other parts of the Clinchfield Formation according to Nystrom and Dockery (1992; see also Harris and Zullo, 1992), and may also correlate with the Cross Member of the Santee Limestone in central eastern South Carolina (see Ward and others, 1979; Baum and others, 1980; Harris and Zullo, 1991; Dockery and Nystrom, 1992a, b).

Environment

The environment of deposition was probably mostly inner to middle neritic, judging from the abundant fossils and calcareous sediments.

"Blue Bluff" unit

Lithology and Distribution

Calcareous strata occur for many miles along the Savannah River valley in the same stratigraphic position as the Santee Limestone but with sufficient areal extent, thickness, and distinctiveness in lithology to warrant recognition as a separate unit, informally named the "Blue Bluff member of the Lisbon Formation" by Huddlestun and Hetrick (1986). The "Blue Bluff" is gray and green, clayey, laminated calcilutite, calcarenite, and calcareous silt and clay, with shell layers, indurated nodules, thin indurated limestone lenses, calcareous muds, and quartz sand laminae in places. Brantly (1916, p. 54) reported an analysis from the exposure at Blue Bluff on the Savannah River with a carbonate content of 56%. Much of the sediment from SRS cores has more than 75% (Thayer and Harris, 1992).

The "Blue Bluff" is a cliff-former and is exposed at several bluffs on the Georgia side of the Savannah opposite the SRS (see Veatch and Stephenson, 1911, p. 249-250). The sediments are widespread in the southern part of the Savannah River Site. They interfinger and are gradational with the cream-colored Santee facies and, in general, tend to be more common in the lower part of the section than the lighter-colored carbonates. The "Blue Bluff" lithology extends as thin beds as far northwest as McBean, Georgia, interfingering with of cream colored calcarenite and calcilutite; it extends to the southeast at least as far as the deep wells near Barnwell and Allendale, South Carolina. "Blue Bluff" sediments lie on poorly sorted quartz sands and clays, calcareous in places, of the Warley Hill. A thin, phosphatic crust in SRS well P 21TA suggests that this contact is unconformable. On geophysical logs, the "Blue Bluff" is characterized by having high gamma ray counts and low resistivities compared to sediments above and below. The "Blue Bluff" is about 90 ft (27 m) thick at the southeastern boundary of the SRS.

Stratigraphic Terminology

"Blue Bluff" sediments have been assigned to the "McBean Formation" or Santee Limestone by most workers in the area. Colquhoun and others (1983), Steele (1985), McClelland (1987), and Logan and Euler (1989) used the terms "Santee" downdip and "McBean" updip for carbonates within the study area. Huddlestun and Hetrick (1986, p. 4) informally used the term "Blue Bluff member of the Lisbon Formation." Because of the extent and thickness of the unit, we believe that when it is formally named, it should be on the formation level. The "Blue Bluff" may be part of the E4 unit of Prowell and others (1985a); most is unit E5.

Paleontology, Age, and Correlation

The benthic foraminiferal species *Cibicides westi* appears to be a marker for the Santee and "Blue Bluff" in this area (Huddlestun and Hetrick, 1986, p. 15). *Cubitostrea sellaeformis* and *Pteropsella lapidosa*, characteristic of the upper Lisbon, occur in the "Blue Bluff" with numerous other molluscan taxa. Calcareous nannoplankton, palynomorphs, and other taxa indicate a zone NP 16 age assignment (late Lutetian, middle Claibornian), correlating with the upper Lisbon of Alabama.

Environment

The fine grain size, the lamination, and fragile molluscan shells in the "Blue Bluff" suggest a lower energy environment than that of the Santee, probably farther out in the neritic zone.

Tinker Formation--
New Formation Name

Lithology and Distribution

The Tinker consists of quartz sands, silts and clays which, in general, occur updip from the Santee. Typically, the sands of the Tinker are finer than the sands above and below, contain more heavy minerals, and are more likely to contain glauconite, although glauconite is often found in the Warley Hill. Yellow, tan, and white sands are common, and pale green sands occur in the center of the SRS. The clays of the formation tend to be illite/smectite rather than kaolinitic as in other parts of the section (Dennehy and others, 1989). Tan clays are prominent in the overlying Dry Branch Formation, while green clays are common in the Tinker. Tinker clays contain less sand than those of the underlying Warley Hill. Silica-cemented zones occur in many cores. Burrows of the *Ophiomorpha* type are abundant in some outcrops. Most burrows are less than 1 inch (2.5 cm) in diameter and have thin walls of white clay.

Small outcrops of the Tinker can be seen along northwesterly-flowing tributaries to Upper Three Runs at the SRS. The section below is on Waterfall Creek (Fallaw and others, 1992d), about 700 ft (210 m) southeast of Upper Three Runs:

Colluvium

Tinker Formation

Dark gray to dark green, very clayey, moderately sorted fine grained sand; moderately indurated 2.0 ft (0.6 m)

Light gray to white, well-sorted fine-grained sand; loose; tan and yellow color bands 3.9 ft (1.2 m)

Warley Hill Formation

Orange and tan, poorly sorted, clayey and silty, fine to coarse-grained sand; quartz granules common; white clay laminae; moderately indurated 4.8 ft (1.5 m)

Although very fine and fine grained sands are typical of some of the Tinker, medium and coarse sands are common in SRS wells, especially updip. What appears to be the fine sand facies can also be found several miles updip. An exposure of very fine grained, well-sorted, burrowed sand on Good Hope Farms Road in Aiken County, about 0.9 mi (1.4 km) west of Silver Bluff Road (South Carolina Highway 302), is very similar to outcrops of the Tinker at the SRS. A similar exposure is in a borrow pit-landfill on the north side of Herndon Dairy Road, about 1.3 mi (2.1 km) west of Silver Bluff Road. The fine, well-sorted, burrowed sand here is topped by massive clay. These sediments were assigned to the "Huber Formation" by Nystrom and others (1982, p. 121) who believe them to be older than the Santee-"Blue Bluff"-Tinker strata. (See also Huddlestun, 1992, p. CGS-92-B-XII-3).

The clay between 187 ft and 190 ft in the type section (appendix) is part of the "green clay interval" (Dennehy and others, 1989; Snipes and others, 1992b), a series of clays and clayey sands ranging from the upper part of the Congaree Formation through the lower part of the Tinker. At the SRS, a fossiliferous section of the Tinker "green clay" several feet thick is exposed in a roadcut on the east side of Upper Three Runs where SRS road 2-1 crosses the creek. Molluscan molds, including *Pteropsella lapidosa*, occur here. In a few cored wells near the center of the SRS, part of the formation consists of light tan to buff, low density silt.

The Tinker Formation grades downdip into the carbonates of the Santee and the "Blue Bluff." Northwest of Upper Three Runs within the SRS, we know of only one well which encountered calcareous sediments. Trending southwest-northeast through the middle of the SRS, the Tinker and Santee are gradational and interfingering. Some wells with calcareous sediments are surrounded by wells a few hundred feet away containing only siliciclastics and vice versa.

The Tinker is about 40 ft (12 m) thick at the northwestern boundary of the SRS and the "Blue Bluff" is about 90 ft (27 m) thick at the southeastern boundary. Dip of the upper surface of the Tinker-Santee-"Blue Bluff" is about 20 ft/mi (4 m/km) to the southeast across the SRS.

Stratigraphic Terminology and Definition

We propose a new name for siliciclastic sediments which occur, in general, updip from the

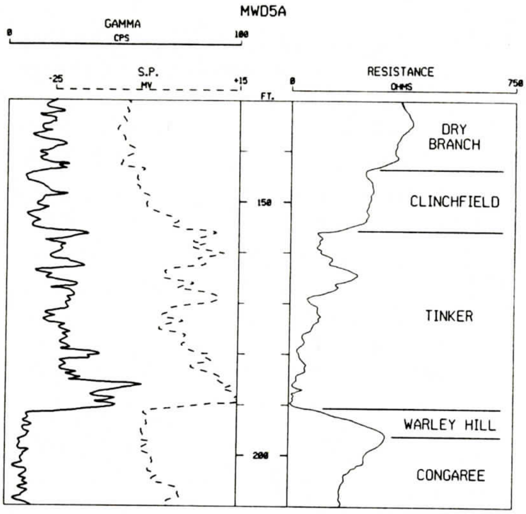

Figure 6.-Geophysical log of the type section of the Tinker Formation in SRS well MWD 5A.

carbonates of the Santee and "Blue Bluff." The Tinker is most of the siliciclastic parts of the "McBean Formation" as used by many workers, and probably is at least some of the upper part of the informally named "Aiken formation" as used by Colquhoun and others (1982, 1983), Bishop (1982), and Steele (1985). It may have been included in the upper part of the "Huber Formation" as used by Nystrom and Willoughby (1982a), and part of the informally named "Neeses formation" as used by Oldham (1981). It is the informally named "Tims Branch formation" of Fallaw and others (1992c).

The type section of the Tinker is described in the appendix from core from well MWD-5A in northwestern Barnwell County, South Carolina (Figures 1 and 6). The transition from the Santee and "Blue Bluff" calcareous sediments to the Tinker is both interfingering and gradational. The boundary is defined as where 25% of the section is composed of calcium carbonate. Where the Warley Hill is missing and the Tinker overlies the Congaree, colors become darker, grain size decreases, sorting becomes poorer, green clay or glauconitic sand become more common, and heavy minerals become more abundant upward in the section. Where the Tinker overlies the Warley Hill, Tinker sands tend to be finer and cleaner than the underlying sand, and the clays have a lower sand content. A pebbly zone occurs at the base of the Tinker in places, and the lower contact is usually sharp. At the upper contact, medium and coarse grained, more poorly sorted sands of the Clinchfield or Dry Branch formations lie with a sharp contact on finer, better sorted sands or on thin clay beds. On geophysical logs, the gamma ray count in the Tinker is usually higher and the resistivity lower than in the overlying and underlying units (Figure 6), especially where the "green clay" facies is well developed at or near the base of the unit.

Along strike to the northeast, the Tinker pinches out on the flank of the Cape Fear arch in northeastern South Carolina. To the southwest in central Georgia, it may be the same unit referred to as the "Perry Sand" downdip and the "Mossy Creek Sand" updip (Hetrick, 1990; Huddlestun and Hetrick, 1991; Huddlestun, 1992). These authors have not yet extended this terminology into eastern Georgia, and we provisionally use the term "Tinker Formation" pending further work on stratigraphic relationships between the SRS and central Georgia.

Tinker Creek flows into Upper Three Runs near the center of the SRS. Fallaw and Price (1992) have used the term "Tinker Creek Formation"; "Tinker Formation" is here adopted to distinguish the formation from units having "Tinkers Creek" as part of their name.

Paleontology, Age, and Correlation

Palynomorphs and silicified shells and molds of mollusks have been found in the Tinker. A few palynomorph assemblages indicate zone NP 16, and *Pteropsella lapidosa*, characteristic of the upper Lisbon (middle Claibornian; upper Lutetian), occurs in the unit. Nystrom and Dockery (1992) considered some of the sands described by Sloan (1908) as his "Barnwell phase", and other sands containing silicified fossils at the SRS in the same stratigraphic position as the Tinker, to be Gosport equivalents. We have found several outcrops at the SRS which contain abundant silicified shells, especially *Turritella* and *Pteropsella* *lapidosa*. The latter is considered to be characteristic of the Lisbon Formation rather than the Gosport. It is possible, however, that the Tinker is age-equivalent to both.

Environment

Most of the sands of the Tinker probably formed in barrier and inner neritic environments and the silts and clays in bays, lagoons, and low energy shelf areas.

Clinchfield Formation

Lithology and Distribution

The Clinchfield consists mostly of quartz sand and clay, calcareous in places, and carbonates. At the SRS the sands are tan and yellow, poorly to well-sorted, and fine to coarse grained. The Utley Limestone Member is an indurated, bioclastic and biomoldic, glauconitic limestone in some places, and in others a calcareous sand and calcarenite. In places the lower contact of the Clinchfield is marked by a change from calcareous sediments of the Santee and "Blue Bluff" to poorly to well-sorted sands. In some wells the sand contains coarse quartz pebbles. The Utley Limestone tends to be more indurated and coarsely glauconitic than the underlying carbonates, and it contains abundant specimens of the sand dollar *Periarchus lyelli*. In general, there are fewer heavy minerals and more manganese-stained sediments above the contact.

A sporadic, lithologically distinctive unit, the Albion Member, with spiculitic (containing sponge spicules) sediments has been encountered in several places in Georgia and in Aiken County, South Carolina (Carver, 1972; Huddlestun and Hetrick, 1986, p. 31). It consists of spiculite, and spiculitic mudstones and sandstones, cemented with opal in places (Carver, 1972). Maximum known thickness is 22.5 ft (6.9 m) in the Windsor Spring roadcut in Augusta, Georgia (Huddlestun and Hetrick, 1986, p. 31).

The Utley is exposed in places on the Georgia bank of the Savannah opposite the SRS at least as far downstream as several hundred feet southeast of Griffins Landing. Approximately 30 ft (9 m) thick in the southeastern part of the SRS, the Clinchfield pinches out or becomes difficult to identify updip in the middle of the Site. Nystrom and others (1992, p. 60) assigned sands in the study area to the informally named "Orangeburg District bed" which they consider equivalent to the Clinchfield.

Stratigraphic Terminology

The type locality of the Clinchfield Formation is in central Georgia (Pickering, 1970). Huddlestun and Hetrick (1986) assigned sediments in the Savannah River valley to the Clinchfield, and defined the Utley Limestone Member there. The quartz sand of the Clinchfield at the SRS may be the Riggins Mill Member, defined in central Georgia (Huddlestun and Hetrick, 1986, p. 26-29, 63-65). The Clinchfield appears to be unit E6 of Prowell and others (1985a). The type locality of the Albion is the Albion Kaolin Mine in Richmond County, Georgia (Carver, 1972). Carver described other occurrences, including the Windsor Spring outcrop in Augusta.

Paleontology, Age, and Correlation

Huddlestun and Hetrick (1986) reported the presence in Georgia of the pelecypods *Chlamys* cf. *C. membranosa* and *Crassostrea gigantissima*, the sand dollar *Periarchus lyelli*, and benthic foraminifers. *P. lyelli* has been identified from the Utley at the SRS. The abundance of *P. lyelli* suggests that the Clinchfield is in the "*Scutella*" abundance zone of the Gulf Coastal Plain, making it a correlative of the Gosport Sand (late Claibornian) and/or the Moodys Branch Formation (early Jacksonian) (Nystrom and others, 1992). Huddlestun and Hetrick (1986, p. 26) discussed the age problem and tentatively assigned the Clinchfield to the Jacksonian. Nystrom and others (1992) favored a correlation with the Claibornian Gosport Sand. Harris and Zullo (1992) correlated the Utley Limestone Member with the lower Moodys Branch and assigned it to the Priabonian.

We do not have precise fossil dates from the Clinchfield. The most common age determinations in the immediately underlying strata are zone NP 16, and in overlying strata, NP 18-20, suggesting that the Clinchfield is zone NP 17 (Bartonian). This would place it in the middle Eocene according to the compilation of Haq and others (1987).

The Albion Member was tentatively placed in the upper Eocene by Carver and in the Clinchfield Formation by Huddlestun and Hetrick (1986), but its precise age is unknown. In addition to marine sponge spicules, some diatoms, radiolarians, and plant fragments have been found in the unit, but no fossils have been found which could be used for accurate age determination (Huddlestun and Hetrick, 1986).

Environment

The concentrations of sand dollars in the carbonates and the sorting of the sands suggest a littoral and inner neritic environment. Carver (1972) proposed an extremely nearshore, perhaps tidal pool, environment for the Albion.

UPPER EOCENE

Dry Branch Formation

Lithology and Distribution

The Dry Branch Formation includes quartz sands, clays, calcareous siliciclastics, and carbonates. Calcilutite, calcarenite, and biomoldic limestone, calcareous sand, and shelly, calcareous clay occur in the Griffins Landing Member. The large oyster *Crassostrea gigantissima*, abundant at Griffins Landing on the Savannah River (Huddlestun and Hetrick, 1986), is found in many SRS cores. The Griffins Landing is less glauconitic than the carbonates of the underlying Utley, Santee, and "Blue Bluff." In places Griffins Landing carbonates overlie quartz sands of the Clinchfield. A thin quartz sand visible on outcrop between the Griffins Landing and the Utley at Griffins Landing is interpreted as a transgressive deposit. A pebbly layer at the contact occurs in some cores. Pisolitic structures were found at the contact in one SRS well.

The Griffins Landing occurs sporadically in most of the Site and is not known to be present northwest of Upper Three Runs within the Site boundaries; Zullo and Kite (1985), however, assigned biomicrudite occurrences north of SRS to the member. The Griffins Landing Member is at least 50 ft (15 m) thick in the southeastern part of the SRS.

The remainder of the Dry Branch Formation within the SRS is made up of the Irwinton Sand Member. It is composed of yellow, tan, and orange, moderately sorted quartz sand, with interlaminated and interbedded clays, typically tan, abundant in places. Pebbly layers and zones rich in clay clasts occur. Glauconite is rare. In general, the Griffins Landing grades updip and upsection into the Irwinton. Irwinton sands are generally coarser than those of the underlying Tinker Formation, and glauconite and heavy minerals are less abundant. Tan clays ["Twiggs clay lithofacies" (Shearer, 1917; Huddlestun and Hetrick, 1986)] are more common above, and green and gray clays are more common below the contact.

Coarse, pebbly quartz sand with *Crassostrea gigantissima* occurs along Hitchcock Parkway in the southern part of Aiken and at the Vale housing development southeast of Aiken. A channel-fill composed of silica-cemented sandstone containing *C. gigantissima* is exposed at Griffins Landing, Georgia. Nystrom and others (1986, p. 17) cited several occurrences of fossiliferous, silicified sand apparently within the Dry Branch, one of which is northwest of Aiken, South Carolina.

The Dry Branch Formation is about 50 ft (15 m) thick near the northwestern SRS boundary and about 80 ft (24 m) near the southeastern boundary.

Stratigraphic Terminology

Siple (1967) assigned some *C. gigantissima*-bearing beds to his "Barnwell Formation", but placed all limestones at the SRS in the lower part of his "McBean." He appears to have assigned the Irwinton and some of the Griffins Landing to his "McBean Formation." The Dry Branch has been correlated in outcrop from its type locality (Shearer, 1917, p. 158-174) in central Georgia to the SRS (Nystrom and Willoughby, 1982a; Huddlestun and Hetrick, 1986, p. 34-46, 66-67), as has the Irwinton Sand Member, type locality in central Georgia (LaMoreaux, 1946a, b; Huddlestun and Hetrick, 1986). The Griffins Landing Member type locality is across the Savannah River from the SRS (Huddlestun and Hetrick, 1986, p. 43-46, 72-73). The Twiggs Clay Member, type area in central Georgia (Shearer, 1917; Huddlestun and Hetrick, 1986), is not a mappable unit at the SRS, although lithologically similar beds occur at various horizons in the formation. The Dry Branch includes unit E7 and probably part of E8 of Prowell and others (1985a).

Paleontology, Age, and Correlation

Aggregations of *Crassostrea gigantissima* in living position are characteristic of parts of the Griffins Landing. Herrick (1960, 1964) described foraminiferal assemblages from Shell Bluff and Griffins Landing. Zullo and Kite (1985) and Steele and others (1986) reported foraminifers, barnacles, crabs, bryozoans, starfish, crinoids, shark and ray teeth, and fish bones from the member at several localities in the vicinity of the SRS. *Ophiomorpha*, palynomorphs, and silicified *C. gigantissima* have been found in the Irwinton Sand Member. Palynological and calcareous nannoplankton assemblages from SRS cores suggest placement within zones NP 18 through NP 20 and with some of the lower part of the Yazoo Formation of the Gulf Coastal Plain, which is middle Jacksonian (Priabonian).

Environment

Common planktonic Foraminifera in one SRS sample from the Griffins Landing indicate some open ocean influence. Some of the *Crassostrea* and *Brachiodontes*-bearing calcareous clay beds contain foraminiferal genera which indicate bay or lagoonal environments. Irwinton sands are probably inner neritic and barrier deposits; the clays probably formed in lagoons or bays.

Tobacco Road Sand

Lithology and Distribution

The Tobacco Road Sand consists of moderately to poorly sorted, red, brown, tan, purple, and orange quartz sands and clayey quartz sands. A few thin clay beds are present in places. In general, the sands of the Tobacco Road are muddier, more micaceous, and more highly colored than those of the Dry Branch. The base of the Tobacco Road is marked in places by a coarse layer that contains flat quartz pebbles. On some geophysical logs, a gamma ray high marks the contact. The upper surface is irregular because of incision that preceded deposition of the overlying Altamaha Formation. The thickness varies considerably because of the eroded upper surface, but it is at least 60 ft (18 m) in places. The formation is exposed in much of the southwestern South Carolina Coastal Plain, including the SRS.

Stratigraphic Terminology

The unit has been traced in outcrop from its type locality in Richmond County, Georgia, to the SRS (Huddlestun and Hetrick, 1978, 1986; Nystrom and Willoughby, 1982a). The "Barnwell Formation" of Siple (1967) seems to correspond roughly to the Tobacco Road. The Tobacco Road is unit O1 and perhaps part of unit E8 of Prowell and others (1985a).

Paleontology, Age, and Correlation

No datable fossils have been recovered from the Tobacco Road at the SRS, but *Ophiomorpha* burrows can be seen in many outcrops and silicified shell fragments are common in places. *Crassostrea gigantissima* has been reported from the sand in Georgia, and the Sandersville Limestone Member in central Georgia contains *C. gigantissima*, *Turritella*, molluscan molds, and the echinoid *Periarchus quinquefarius* (Huddlestun and Hetrick, 1986). Based on evidence in central Georgia, Huddlestun and Hetrick (1986) assigned the Tobacco Road to the Jacksonian (late Eocene), correlating it with the upper part of the Yazoo Formation in the Gulf Coastal Plain, which is upper Jacksonian (upper Priabonian).

Environment

Marine fossils and glauconite have been found in the Tobacco Road in central Georgia, indicating a shallow neritic environment. The abundance of *Ophiomorpha* indicates marine or transitional marine environments. The occurrence of clay laminae, especially in the upper part, suggests that some of the Tobacco Road was deposited in a transitional, low energy environment, such as a tidal flat.

OLIGOCENE (to MIOCENE?)

Zullo and others (1982), Willoughby and others (1984), and Nystrom and others (1991) described partially silicified, barnacle-bearing, quartz sand channel deposits of Oligocene (to Miocene?) age in several localities in Aiken County, South Carolina (*Lophobalanus baumi* beds). The channels cut into the "Huber" and Dry Branch formations. Barnacles, echinoids, Foraminifera, worm tubes, and pectenids occur in the sediments, and the environmental interpretation is a valley-fill sequence or a basal part of the Miocene "upland" unit (Nystrom and others, 1991, p. 236).

Fossiliferous chert of Oligocene age [King's Creek phase of Sloan (1908); Flint River formation of Cooke (1936) and Cooke and MacNeil (1952)] crops out along the Savannah about 5 mi (8 km) downstream from the SRS and 14 mi (22 km) downstream from Plant Vogtle in Georgia.

MIOCENE

Altamaha Formation ("Upland" Unit)

Lithology and Distribution

The "upland" is an informal term applied to deposits that occur at higher elevations in many places in the southwestern South Carolina Coastal Plain. The sediments are red, purple, gray, orange, yellow, and tan, poorly-sorted, clayey and silty, fine to coarse sands, with lenses and layers of gravels, pebbly sands, and oxidized, massive clays. Clay clasts are abundant. Cross-bedding is prominent in places, and muscovite and flecks of weathered feldspar are locally abundant. Clay-filled fissures, probably caused by weathering, are numerous in places. In general, the Altamaha has poorer sorting, larger and more common weathered feldspar grains, more abundant and thicker clay beds, more argillaceous and indurated sands, larger pebbles, and, in places, more muscovite than the underlying Tobacco Road.

The Altamaha occurs at the surface at higher elevations in many places around and within the SRS but appears to be missing at some high elevations. It is up to 70 ft (20 m) thick in parts of the SRS. The lower surface of the unit is very irregular because of erosion of underlying deposits. In a few SRS cores, the Altamaha lies on Dry Branch sediments rather than on the Tobacco Road.

Stratigraphic Terminology

The informal term "upland" has been widely used (Nystrom and Willoughby, 1982a; Nystrom and others, 1986, 1991; Colquhoun and others, 1983; Steele, 1985; McClelland, 1987; Logan and Euler, 1989) for what appears to be an extension of the Altamaha Formation (Huddlestun, 1988; Nystrom and Willoughby, 1992c), type locality in southeastern Georgia (Huddlestun, 1988, p. 101).

Much of the "Hawthorn Formation" of Siple (1967) corresponds to the Altamaha, but the Miocene Hawthorne Group in its type area is phosphatic and dolomitic (Huddlestun, 1988). Siple's "Hawthorn" apparently included some of the underlying Tobacco Road, as he considered the occurrence of *Ophiomorpha* (="*Halymenites*"), common in that formation, to be typical of his "Hawthorn" rather than his "Barnwell Formation." Other terms which have been applied to the Altamaha in the area are "Lafayette" (Sloan, 1908, p. 479) and "Citronelle" (Doering, 1960, 1976; Smith and White, 1979). The Altamaha is unit M1 of Prowell and others (1985a).

Paleontology, Age, and Correlation

Very few fossils have been reported from the Altamaha and its equivalents. *Ophiomorpha* burrows were observed in what appears to be the Altamaha at one locality at the SRS. Siple (1967, p. 61) reported benthic Foraminifera from his "Hawthorn Formation" in an SRS well indicating a correlation with the Duplin Marl, then considered Miocene but now assigned to the Pliocene. In southeastern Georgia, the Altamaha appears to grade laterally into the Parachucla and Coosawatchie formations of the Hawthorne Group, both of Miocene age, according to Huddlestun (1988, p. 30), making it Aquitanian and Serravallian. According to Nystrom and Willoughby (1992c), the Altamaha is late middle to early late Miocene and unconformably overlies the Coosawatchie. Colquhoun (1988, 1992) assigned "upland" sediments to the Oligocene and/or Miocene.

Environment

The conglomerates, poorly sorted sands, and clay lenses have the characteristics of fluvial sediments. The possible occurrence of rare *Ophiomorpha* suggests that there may have been occasional transitional marine influence. If the Foraminifera reported by Siple (1967, p. 61) came from the Altamaha, this would also indicate marine influence.

YOUNGER DEPOSITS

Nystrom and Willoughby (1992b) assigned some surficial sands in the area to the Pinehurst Formation (see Nystrom and Kite, 1988; Nystrom and others, 1991), an eolian deposit which is probably late Miocene to early Pliocene (Nystrom and others, 1991, p. 240; Nystrom and Willoughby, 1992b). Stream terrace deposits, colluvium, and alluvium are common at places (Siple, 1967; Newell and others, 1980; Stevenson, 1982; Dennehy and others, 1989; Nystrom, 1992b).

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APPENDIX--TYPE SECTIONS

Although the North American Commission on Stratigraphic Nomenclature (1983) recommends that a geologic map accompany the definition of newly named units, we have not included one because lithologic characteristics and stratigraphic relationships were determined from well cores. The coring technique which was used requires an adjustment when some lithological changes are encountered; for this reason contacts between formations are sometimes not recovered in the coring operation. Depths of contacts picked in cores tend to differ from those picked on geophysical logs (Figures 3-6) by up to 2 ft.

Steel Creek Formation

The type section of the Steel Creek Formation, a lithostratigraphic unit composed of quartz sand and interbedded kaolinitic clay, is described below from core from SRS well P 21TA (Figures 1 and 3) in Barnwell County, South Carolina, Site coordinates north 24675 and east 40739, or approximately 33° 9' 28" N and 81° 35' 25" W. The ground elevation is 206 feet (62.8 m). The core is stored at the SRS.

Feet below
ground surface

Sawdust Landing Formation

450-452 Sand, coarse, clayey, very poorly sorted, angular; slightly indurated; gray

452-452.3 Sand, very coarse, pebbly, angular; slightly indurated; gray

452.3-453 Missing core, placed in Sawdust Landing based on geophysical log

Steel Creek Formation

453-460 Clay, becoming sandy toward base; micaceous; moderately indurated; mottled grayish red

460-464 Sand and clayey sand, medium, poorly sorted, angular; micaceous; slightly to moderately indurated; light gray

464-472 Clay, sandy at base; moderately indurated; mottled yellowish and tannish gray

472-484 Sand, medium, poorly and moderately sorted; angular and subangular; clayey at top; micaceous; iron sulfides in places; slightly indurated; gray

484-486 Sand, medium, pebbly, clayey, very poorly sorted, subangular; slightly indurated; gray

486-488 Missing core

488-488.4 Sand, coarse, pebbly, very poorly sorted, subangular; slightly indurated; tan

488.4-500 Clay, moderately indurated; gray, yellow, brown

500-518 Sand, medium, clayey at top, poorly sorted; micaceous; slightly lignitic in places; gray, light brown at base

518-540 Clay, sandy at base, moderately indurated; mottled gray, red, yellow, orange

540-552 Sand, medium, moderately and poorly sorted; micaceous; gray

552-574 Clay, moderately indurated; mottled reddish gray

574-575 Missing core

575-577 Clay, moderately indurated; dark gray

577-578 Missing core

578-586 Clay, moderately indurated; dark gray

586-588 Missing core

588-589 Sand, fine, poorly sorted, slightly indurated; micaceous; gray

589-592 Missing core

592-594 Sand, very coarse, somewhat pebbly, poorly sorted; slightly indurated; light gray

Black Creek Group

594-600 Sand, medium, moderately sorted, clayey and lignitic at base; tan and light gray

Snapp Formation

The type section of the Snapp Formation, a lithostratigraphic unit composed of clayey, silty quartz sand and interbedded kaolinitic clay, is described below from core from SRS well P 22TA (Figures 1 and 4) in southern Barnwell County, South Carolina, about 2 mi (3.2 km) west of Lower Three Runs, a tributary to the Savannah River, and 2 mi (3.2 km) south of Par Pond. SRS coordinates of the well are north 20593 and east 73555, or approximately 33° 12' 14" N and 81° 31' 25" W. The ground elevation is 215 ft (65.6 m) above mean sea level. The core is stored at the SRS.

Feet below
ground surface

Fourmile Branch Formation

296-300 Sand, coarse, clayey in places, moderately to well sorted, subrounded; slightly indurated; trace glauconite; light green

300-306 Missing core, placed in Fourmile Branch based on geophysical log

Snapp Formation

306-310 Missing core, placed in Snapp based on geophysical log

310-319 Clay, becoming sandy toward base, micaceous in places; slightly to moderately indurated; light yellowish gray

319-323 Sand, coarse, clayey, poorly sorted, subrounded; slightly indurated; light gray and yellowish gray

323-324 Clay, slightly to moderately indurated; medium gray

324-327 Sand, coarse, clayey, poorly sorted, subrounded; slightly indurated; light gray

327-331 Clay, sandy, micaceous in places; slightly to moderately indurated; pebbly at base

331-337 Clay, moderately indurated; light gray

337-347 Sand, medium and coarse, clayey, poorly sorted, subangular to subrounded; micaceous in places; moderately indurated; light yellowish orange and gray

347-349 Sand, very coarse and coarse, moderately sorted, subrounded; slightly indurated; clayey and darker at base; light yellowish gray

349-354 Missing core

354-357 Sand, coarse, moderately sorted, subangular; heavy minerals common in places; trace lignite; slightly indurated; light yellowish gray

357-358 Missing core

358-360 Sand, very coarse, slightly pebbly, moderately sorted, subangular; slightly lignitic at base; slightly indurated; light gray

Lang Syne Formation

360-364 Clay; moderately indurated; medium gray

Fourmile Branch Formation

The type section of the Fourmile Branch Formation, a lithostratigraphic unit composed of quartz sand with some interbedded clays, is described below from core from well MWD-3A (Figures 1 and 5) in northwestern Barnwell County, South Carolina, near the Aiken County line, southeast of Tinker Creek and west of Mill Creek. SRS coordinates are north 69839 and east 75756, or approximately 33° 18' 9" N and 81° 36' 23" W. The ground elevation is 328 ft (100 m) above mean sea level. In June of 1992, the core was at the University of South Carolina at Aiken.

Feet below
ground surface

Congaree Formation

252-256 Sand, very coarse, slightly pebbly, moderately sorted, subrounded; slightly indurated; orange

Fourmile Branch Formation

256-257 Sand, fine, moderately sorted, subangular; burrowed; lignitic; green and gray clay laminae

257-258 Sand, medium, poorly sorted, subangular; trace iron sulfides and glauconite; light gray

258-259 Sand, very fine, well sorted, subangular; tan clay laminae; somewhat micaceous; slightly indurated; medium gray

259-260 Clay, silty, slightly to moderately indurated; somewhat micaceous; dark gray

260-261 Missing core

261-265 Sand, very coarse, moderately sorted, subrounded; slightly indurated; tan and orange

265-271 Sand, fine, poorly and moderately sorted, clayey in places, subangular; green and gray clay laminae; somewhat micaceous; common heavy minerals in places; some glauconite grains and trace iron sulfide; slightly indurated; green and gray

271-278 Sand, coarse and very coarse, poorly sorted, somewhat pebbly, clayey in places, subrounded; greenish gray clay laminae; sulfides and glauconite becoming more abundant toward base; cemented sands and pebbles at base; grayish green

Lang Syne Formation

278-284 Clay and silty clay, micaceous; lignitic in places; moderately indurated; fissile; dark gray

Tinker Formation

The Tinker Formation, a lithostratigraphic unit consisting of quartz sands, silts, and clays, occurs updip from and interfingers with the Santee Limestone and the Blue Bluff unit. The type section is described below from core from well MWD-5A (Figures 1 and 6) in northwestern Barnwell County, South Carolina, near the Aiken County line, southeast of Tinker Creek and west of Mill Creek. SRS coordinates are north 69235 and east 75491, or approximately 33° 18' 7" N and 81° 36' 10" W. The ground elevation is 322 ft (98 m) above mean sea level. In June of 1992, the core was at the University of South Carolina at Aiken.

Feet below
ground surface

Irwinton Member of Dry Branch Formation

154-158 Sand, medium to coarse, moderately sorted, subrounded; slightly indurated; tan, yellow, orange, white with black oxide stains

Tinker Formation

158-158.5 Sand, fine, clayey, poorly sorted, subangular; slightly indurated; yellowish tan

158.5-159 Interbedded medium sand and clay with lignitic(?) laminae; slightly indurated; dark tan

159-160 Sand, fine to medium, well sorted, subangular; slightly indurated; tan

160-162 Sand, fine to medium, subangular, slightly clayey and with a few clay laminae, moderately to well sorted; slightly indurated; light green and brown

162-165 Sand, fine to medium, moderately and well sorted, subangular; slightly indurated; heavy minerals common; yellow

165-166 Missing core

166-170 Sand, very fine, well sorted, subangular; heavy minerals common; slightly indurated; yellow

170-172 Sand, very fine, well sorted, subangular; slightly clayey and with light green clay laminae; slightly indurated; yellow, orange

172-174 Sand, very fine, well sorted, subangular; nodules of cemented sand; moderately indurated; yellow

174-180 Sand, very fine, slightly clayey, moderately sorted, subangular; heavy minerals common; slightly indurated; yellow, orange

180-181 Missing core

181-185 Sand, very fine and fine, moderately to well sorted, subangular; slightly clayey and with white clay laminae; heavy minerals common; yellow, orange

185-187 Sand, fine, moderately sorted, subangular; many green clay laminae; slightly indurated; orange

187-187.5 Clay with fine sand laminae; slightly indurated; yellow and green

187.5-188 Sand, coarse, very clayey, silty, very poorly sorted; slightly indurated; brown

188-190 Clay, green, with many laminae and thin beds of yellow, fine to coarse sand; slightly indurated

190-190.5 Sand, very fine, slightly clayey; slightly indurated; yellow

190.5-191 Missing core

Warley Hill Formation

191-192 Sand, medium, poorly sorted, subangular, clayey and with green clay laminae; slightly indurated; trace glauconite; orange

192-193 Sand, medium and coarse, slightly clayey, poorly sorted, subangular; slightly indurated; orange

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