LITHOLOGICAL AND HYDROLOGICAL CHARACTERISTICS OF THE TERTIARY HYDROSTRATIGRAPHIC SYSTEMS OF THE GENERAL SEPARATIONS AREA AT THE SAVANNAH RIVER SITE (U)

by

R. K. Aadland¹, M. K. Harris², and T. M. Westbrook²

¹Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

²Dames and Moore
455 E. Paces Ferry Road, Suite 200
Atlanta, GA 30363

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R. K. Aadland¹, M. K. Harris², and T. M. Westbrook²

¹ Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

² Dames and Moore
455 E. Paces Ferry Road, Suite 200
Atlanta, GA 30363

INTRODUCTION

The General Separations Area (GSA) is an approximately 15–square–mile area near the geographic center of the Savannah River Site (SRS) (Figure 1). The SRS is located in the Upper Atlantic Coastal Plain physiographic province of South Carolina on the Aiken Plateau at an elevation of approximately 300 feet above mean sea level. The GSA is dissected by a major surface water divide between two streams; Upper Three Runs Creek (UTRC) to the north and northwest, and Fourmile Branch (FB) to the south. Surface runoff, recharge, and discharge areas are all influenced by the topography, creeks, and drainage areas in the GSA.

The sediments of the GSA comprises unconsolidated sediments ranging in age from Cretaceous to Holocene with isolated zones of consolidated sediments. The sequence is approximately 1000–feet thick and is underlain by a Paleozoic crystalline basement. The sedimentary sequence forms a wedge that dips and thickens towards the southeast.

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The Tertiary sediments are composed of sand, silt, clay, and calcareous materials of varying composition. The sequence is complex with abrupt changes in lithology occurring over short distances reflecting alternating nonmarine and marine nearshore depositional environments.

The alpha–numeric hydrostratigraphic nomenclature proposed by Aadland (1990) is used herein. Hydrogeologically, Aquifer Systems I and II are present under the GSA. The major ground–water–producing aquifers are Aquifer Units IA and IB (Middendorf and Black Creek) and Aquifer Unit IIA (Congaree). Major confining beds are Confining System I (Cape Fear), and Confining System I–II (Ellenton Clays). Minor confining beds are Confining Unit IIA–IIB (“Green Clay”) and Confining Zone IIB1–IIB2 (“Tan Clay”). A discussion of only the Tertiary-age hydrostratigraphic units will be presented (Figure 2).

The Tertiary-age lithostratigraphic sequence at the GSA is composed predominantly of terrigenous clastics interspersed with carbonate–rich clastics and limestones. The clastic lithologies consist of gravel or pebble conglomerate, sand, clayey sand, silt, clay, and sandy clay. The calcareous lithologies consist of calcareous sand, calcareous mud, limestone, sandy limestone, and sandy and muddy limestone.

The calcareous lithologies are discontinuous and divided into a lower and upper zone. The lower zone occurs along a northeast–southwest trend in three separate areas within the GSA. The lower beds thicken and thin rapidly. The lower calcareous zone occurs within Aquifer Unit IIA, Confining Unit IIA–IIB, and Aquifer Zone IIB1. The upper calcareous zone is very discontinuous and is located within the upper portion of Aquifer Zone IIB1 and Confining Zone IIB1–IIB2.

**LITHOLOGICAL AND HYDROLOGICAL CHARACTERISTICS OF THE HYDROSTRATIGRAPHIC UNITS**

**Confining System I–II**

Confining System I–II has been informally referred to as the “Ellenton Clays” in previous SRS reports. This system attains a thickness of over 100 feet within the GSA. Lithologically, clay and silt beds are dominant with lesser interbeds of sandy clay, clayey sand, and sand. Individual beds of clay and silt and sandy clay vary in thickness from 2 to 22 feet. Individual beds of clayey sand and sand vary in thickness from 1 to 15 feet.

The fine–grained clay and silty beds of Confining System I–II consist of buff and light gray to black clay and sandy clay. The clays are generally very fissile, highly micaceous, and often carbonaceous or lignitic. The interbeds of clayey sand and sand are generally fine– to coarse–grained and range from moderately to very poorly sorted. Grains are subangular to angular. Secondary minerals include muscovite, feldspar, sillimanite, iron–bearing minerals (typically pyrite, marcasite, and siderite), garnet, rutilated quartz, and various unidentified minerals (Dennehy and others, 1989).

The predominant clay mineral forming the matrix of the clays, sandy clays, and clayey sands is kaolinite. The quartz sand grains are predominantly cristobalite (Dennehy and
The high mica and kaolinite content of the Confining System I–II sediments results in uniformly distinct, natural gamma-ray curve spikes typical of clays.

Vertical and horizontal hydraulic conductivities of the clays/silts are very similar. Vertical hydraulic conductivities for Confining System I–II range from $7.7 \times 10^{-5}$ feet per day to $2.9 \times 10^{-4}$ feet per day. Horizontal hydraulic conductivities range from $1.0 \times 10^{-4}$ feet per day to $1.1 \times 10^{-4}$ feet per day (Bledsoe and others, 1990). The consistency of the low conductivity values (vertical and horizontal) support the confining capabilities of this system.

**Aquifer System II**

Aquifer System II is subdivided into Aquifer Unit IIA, Confining Unit IIA–IIB, and Aquifer Unit IIB. Aquifer Unit IIB is further subdivided in Aquifer Zones IIB1 and IIB2 that are separated by Confining Zone IIB1–IIB2 (Figure 2).

Aquifer Unit IIA has been commonly referred to as the Congaree Aquifer in previous reports. This unit ranges in thickness from 48 to 107 feet within the GSA. The isopach map indicates a thickening of the unit in the western portion of the GSA with a minor thickening toward the southeast.

Aquifer Unit IIA consists predominantly of sand and clayey sand beds with thin interbeds of sandy clay, clay, and calcareous sand. The sand and clayey sand beds range in thickness from 2 to 84 feet. The sandy clay and clay beds range in thickness from 1 to 9 feet. The calcareous sand beds range in thickness from 2 to 3 feet.

The sand and clayey sand beds of the aquifer are largely yellow to orange in color and consist of fine- to coarse-grained, subangular to subrounded quartz. The sands vary from well to poorly sorted. Small quantities of heavy minerals and mica are common. The heavy mineral assemblage consists of sillimanite, ilmenite, staurolite, rutile, garnet, magnetite, kyanite, monazite, sphene, tourmaline, xenotime, and zircon (Dennehy and others, 1989; Robertson, 1990).

Aquifer Unit IIA typically exhibits a natural gamma-ray curve normally associated with clean sands. The contact between Aquifer Unit IIA and the underlying Confining System I–II is readily apparent as a transition from clean sands to clayey/silty sediments.

Hydraulic conductivity estimates for this aquifer unit are available from slug tests, sieve analyses, and pumping tests. The range in the slug tests values is from a high of 12.0 feet per day to a low of 0.16 feet per day (Sirrine, 1987, 1988; S & ME, 1988). Pumping test results indicate a permeability in the range of 30 to 60 feet per day (Albenesius and others, 1990; CH2M Hill, 1989). Hydraulic conductivity estimates from 42 sieve analyses using the Beard and Weyl (1973) method range from 10 feet per day (3.6 Darcy’s) to 479 feet per day (175 Darcy’s) (Thayer, Westbrook, and Harris, personal communication, 1990).

Confining Unit IIA–IIB is commonly referred to as the “Green Clay” in previous reports. Previous investigators illustrated this unit as one vertically and horizontally continuous clay zone; however, this study revealed the unit to consist of several interfingering lenses of grey-colored clays that thicken, thin, and pinch out abruptly.
The confining unit ranges in thickness from 2 to 30 feet. The unit thins to the west and southeast and thickens to the north. The structure contour on the top of the unit indicates a southeasterly dip with localized lows to the south-southeast and to the north. These structural lows tend to correspond with the thicker accumulations of the overlying carbonates. The clays of the confining unit tend to thin or truncate into the areas of carbonate buildup.

Confining Unit IIA–IIB consists predominantly of clay, sandy clay, and clayey sand beds. Locally, beds of calcareous mud contribute significantly to the thickness of the unit. Minor interbeds of sand are also present. The clay and sandy clay beds range in thickness from 2 to 12 feet. The clayey sand beds range in thickness from 1 to 14 feet. The calcareous mud beds range in thickness from 3 to 11 feet and the sand beds range in thickness from 1 to 6 feet.

The clay minerals that make up the matrix of the units described above consist of illite and smectite (Denneh and others, 1989). The clays, sandy clays, and clayey sands generally have a distinct dark green color due to accessory glauconite. The glauconitic clay facies exhibits a distinct natural gamma-ray signature. A large spike on the gamma curve makes this unit easily distinguishable from sediments above and below the zone.

The calcareous muds are usually light green in color. The clayey sands are generally moderately to poorly sorted with grain sizes ranging from medium to very coarse. They can be locally consolidated within the GSA and are light tan to orange in color, fine- to very-fine-grained, and well sorted. Grains are usually subangular and cemented with silica.

Laboratory analyses of horizontal and vertical permeability on representative undisturbed samples of the clayey portions of Confining Unit IIA–IIB range in values from a low of 3.8 x 10^-6 feet per day to a high of 2.7 x 10^-3 feet per day (Bledsoe and others, 1990; Atlanta Testing and Engineering, 1987, 1988). The bulk densities range from 50.9 to 106.3 pounds per cubic foot (pcf). In general, the higher unit weights indicate that Confining Unit IIA–IIB is a dense and compact clay. The lower values result from lighter organic materials and mica found in some samples of the clay.

Aquifer Unit IIB is divided from the base upwards into Aquifer Zones IIB1 and IIB2 separated by Confining Zone IIB1–IIB2. Aquifer Zone IIB1 has been referred to as the McBean/Barnwell Aquifer in previous reports. This zone ranges in thickness from 39 to 84 feet. The isopach map indicates thinning of the aquifer toward the west and thickening toward the southeast.

This aquifer zone consists predominantly of sand and clayey sand beds with local occurrences of calcareous sand, sandy and muddy limestone, and limestone interbeds. Minor interbeds of clay and sandy clay are also present. The sand and clayey sand beds range in thickness from 2 to 60 feet. Calcareous sands range in thickness from 2 to 33 feet and the sandy and muddy limestones and limestones range in thickness from 3 to 30 feet. The clay and sandy clay beds range in thickness from 1 to 16 feet. The sand and clayey sand beds are generally yellow to tan, and occasionally greenish brown to light brown. The sand is fine- to coarse-grained, moderately to well sorted, and generally subangular.
The calcareous sands are white to buff in color and contain up to 50% calcareous material. Shell fragments (gastropods, pelecypods, echinoderm, bryozoans, and barnacles) and whole foraminifera are the common carbonate constituents. The terrigenous fraction consists of fine-grained, subangular and well to moderately sorted quartz grains. Small percentages of glauconite are common.

The sandy and muddy limestones and clean limestones are white to buff in color and contain more than 80% calcareous material. Glauconite is common in these beds. Many of the limestones are partially to fully consolidated with abundant moldic porosity. Fossils are predominantly pelecypods and gastropods. Unconsolidated limestones are generally a coquina-type shell hash consisting of fragments of pelecypods, gastropods, echinoderms, bryozoans, and barnacles. Small silicified layers of this shell hash (<0.5 feet) are occasionally observed in this unit.

The interbeds of clays and sandy clays in Aquifer Zone IIB\textsubscript{1} are light tan to orange in color. According to Dennehy and others, (1989) the clay minerals are illite/smectite. The sand consists of fine- to medium-grained, subangular, well to moderately sorted quartz grains.

The calcareous sands and limestones are generally not distinct on the natural gamma curves from wells in the GSA; however, a limestone with good moldic porosity is generally distinctive on the resistivity curve. The clastic lithologies of Aquifer Zone IIB\textsubscript{1} are not easily distinguishable on natural gamma curves alone, and correlations with this zone require careful examination and interpretation of both core and geophysical data.

Hydraulic conductivity estimates for this aquifer zone are based on slug tests, sieve analyses, and pumping tests. The slug tests values (46 slug tests) range from a high of 136.10 to a low of 0.13 feet per day (Sirrine, 1987, 1988; S & ME, 1988). Parizek and Root (1986) conducted a series of 51 single-well pump tests from wells screened in Aquifer Zone IIB\textsubscript{1} in and around the GSA. Hydraulic conductivity values as reported from the wells range from 0.17 to 2.6 feet per day with a median value of 0.90 feet per day. Hydraulic conductivities estimated from 42 sieve analyses using the Beard and Weyl (1973) method range from 19.2 feet per day (7 Darcy's) to 397 feet per day (145 Darcy's) (Thayer, Westbrook, and Harris, personal communication).

Confining Zone IIB\textsubscript{1}-IIB\textsubscript{2} is informally referred to as the “Tan Clay” in previous SRS reports. This zone consists of multiple lenses of clay that thicken, thin, and pinch out abruptly within short distances. This zone ranges in thickness from 0 to 33 feet. Structure contours on the top of Confining Zone IIB\textsubscript{1}-IIB\textsubscript{2} suggest that the thinning of the zone to the south-southeast may be attributed to post depositional erosion.

Lithologically, this zone consists predominantly of clay and sandy clay beds with interbeds of clayey sands and sands with occasional calcareous sand beds. Clay and sandy clay beds range in thickness from 1 to 11 feet. The clayey sand and sand beds range in thickness from 1 to 8 feet. The calcareous sand beds are approximately 1- to 2-feet thick.

The clay and sandy clay beds are light tan to light green tan in color and contain thin irregular laminae. According to Dennehy and others, (1989) the clay is predominantly
composed of kaolinite and tends to be sticky and plastic. The quartz sand is angular to subangular and contains mica and dark heavy minerals. The clayey sand and sand beds are light tan to light orange in color. The quartz sands are predominantly medium- to coarse-grained with a moderate degree of sorting. The calcareous sands are composed of shell fragments and quartz sand in a clay matrix. The quartz sand is fine-grained and subrounded.

The thicker clays within the confining zone exhibit a natural gamma-ray spike typical of clays. However, natural gamma-ray spikes may also be related to concentrations of heavy minerals. The heavy mineral suite includes brown ilmenite, zircon, brown hornblende, staurolite, sillimanite, kyanite, and magnetite (Dennehy and others, 1989). Interpretation and correlation of this zone requires close scrutiny of core and geophysical data.

Laboratory analyses of vertical and horizontal permeability on representative undisturbed samples range from a low value of $1.9 \times 10^{-5}$ feet per day to a high value of 0.12 feet per day (Bledsoe and others, 1990; Atlanta Testing and Engineering, 1987, 1988). Dry bulk densities of the samples range from a low of 66.1 pcf to a high of 106.6 pcf. The lower unit weights are indicative of a silty and sandy composition.

Aquifer Zone IIB2 represents the water-table aquifer. The total thickness of the zone ranges from 0 feet at Fourmile Creek to 110 feet. The zone consists predominantly of sand and clayey sand beds with lesser or equal amounts of clay and sandy clay. Gravel and pebble layers occur locally. The sand and clayey sand beds range in thickness from 2 to 107 feet. The clay and sandy clay beds range in thickness from 1 to 18 feet and gravel and pebble layers range in thickness from 1 to 5 feet.

The sand and clayey sands are tan to purple and are often highly variegated in color. The sands are fine- to very-coarse-grained, subangular to angular, and moderately to poorly sorted. The clays and sandy clays are composed predominantly of kaolinite. The sands are fine- to very-coarse-grained and subangular to angular. Clay clasts, mica, and dark heavy minerals are also present in the quartz sand. Brown ilmenite and sillimanite are abundant in the typical heavy mineral assemblage along with zircon, rutile, brown hornblende, and staurolite (Dennehy and others, 1989).

The conglomerate layers consist of gravel and pebble-sized quartz that are set in a matrix of fine to very coarse, clayey quartz sand containing abundant mica and white and purple clay balls. Pebbles range in diameter from 0.5 to 4 inches and are generally well rounded. The quartz sand is generally coarse and angular to subangular.

The unit is difficult to correlate using geophysical data alone. As in Confining Zone IIB1-IIB2 the natural gamma spikes resembling clays may be attributed to localized concentrations of heavy minerals. Both core and geophysical data were used in the interpretation and correlation of the unit.

Hydraulic conductivity estimates for this aquifer zone are based on slug tests, sieve analyses, and pumping tests. Slug tests produced values which range from a high of 45.40 feet per day to a low of 0.05 feet per day for 60 slug tests (Sirrine, 1987, 1988, S & ME, 1988).
Parizek and Root (1986) conducted 38 single-well pump tests in the vicinity of the GSA. Hydraulic conductivity values calculated from these tests were reported to range from 0.30 to 3.6 feet per day with a median value of 0.61 feet per day. Hydraulic conductivities estimated from 48 sieve analyses using the Beard and Weyl (1973) method range from 21.9 feet per day (8 Darcy's) to 493 feet per day (180 Darcy's) (Thayer, Westbrook, and Harris, personal Communication).

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Figure 1. Location of the General Separations Area, Savannah River Site

<table>
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<th>Hydrostratigraphic Units</th>
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<td>Ellenton Formation</td>
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(Aadland, 1990)

Figure 2. Hydrostratigraphic Nomenclature for General Separations Area