UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EFFECTS OF LATE CRETACEOUS AND CENOZOIC FAULTING ON THE GEOLOGY AND HYDROLOGY OF THE COASTAL PLAIN NEAR THE SAVANNAH RIVER, GEORGIA AND SOUTH CAROLINA

By Robert E. Faye and David C. Prowell

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CONVERSION FACTORS

For readers who may prefer to use the International System (SI) of units, rather than inch-pound units, the conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain SI (metric unit)
ft (foot)	0.3048	m (meter)
ft/s (foot per second)	0.3048	m/s (meter per second)
ft^2/d (feet squared per day)	0.0929	m^2/d (meters squared per day)
mi^2 (square mile)	2.590	km^2 (square kilometer)

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ABSTRACT

Geologic and hydrologic investigations by the U.S. Geological Survey have defined stratigraphic and hydraulic anomalies suggestive of faulting within Coastal Plain sediments between the Ogeechee River in east-central Georgia and the Edisto River in west-central South Carolina. Examination of borehole cuttings, cores, and geophysical logs from test wells indicate that Triassic rocks and Upper Cretaceous and lower Tertiary Coastal Plain sediments near the Barnwell-Allendale County line near Millett, South Carolina, are offset by a northeast-trending fault downthrown to the northwest. The location of this suspected Coastal Plain fault generally coincides with the location of an inferred fault in basement rocks as interpreted from aeromagnetic surveys. Apparent vertical offsets range from about 700 feet at the base of Upper Cretaceous sediments to about 20 feet in strata of Late Eocene age. As a result, the Upper Cretaceous Middendorf Formation which directly overlies crystalline and Triassic rocks updip (northwest) of this fault, is absent immediately downdip of the fault. The thickness of Upper Cretaceous sediments is also sharply reduced from about 700 feet to about 180 feet across the fault.

Sediments of the basal Coastal Plain aquifer are largely truncated by uplifted Triassic rocks at the fault near Millett, South Carolina. Lateral ground-water flow near the Savannah River is consequently disrupted updip of the fault and ground water is transferred vertically into overlying sediments and possibly into the Savannah River. At several locations, abrupt changes in potentiometric head occur across this fault. Computed transmissivity of the basal Coastal Plain aquifer is also radically reduced downdip of the fault, sharply reversing a downdip trend of rapidly increasing aquifer transmissivity.

Other anomalous potentiometric data along a northeast-trending line between Statesboro, Georgia, and Fairfax, South Carolina, suggest the possibility of similar faulting in correlative geologic units. The location of the suspected fault near Statesboro, Georgia, generally coincides with the eastward extension of the Gulf Trough, a regional potentiometric anomaly in central Georgia.

INTRODUCTION

Investigations undertaken as part of the U.S. Geological Survey's Southeastern Atlantic Coastal Plain Regional Aquifer Systems Analysis (RASA) have defined anomalous geologic and hydraulic data suggestive of recurrent faulting within Coastal Plain sediments in east-central Georgia and west-central South Carolina. The general area of study is bordered to the west and east by the Ogeechee and Edisto Rivers, respectively (fig. 1). Potentiometric anomalies and radical changes in

Figure 1.--(Caption on next page) belongs near here.

aquifer transmissivity and in aquifer discharge to area streams were observed within parts of two regional Coastal Plain aquifers comprised of sediments of Late Cretaceous and early Tertiary age. Site-specific investigations of subsurface lithology were consequently undertaken to determine the origin and nature of the observed anomalies. Detailed analyses of borehole cuttings, geophysical logs, and palynological data at well sites adjacent to and along a line generally parallel to the Savannah River indicated the presence of faulting of Triassic rocks and Coastal Plain sediments near Millett, S.C. Cretaceous sediments are vertically offset approximately 700 ft, probably by en echelon reverse faulting similar to that previously observed along the Belair fault zone near Augusta, Ga., by Prowell and O'Connor (1978). Northeast-trending potentiometric anomalies and limited geologic data imply the presence of another fault which offsets correlative Coastal Plain sediments between Statesboro, Ga., and Fairfax, S.C.

Figure 1.--Location of study area.

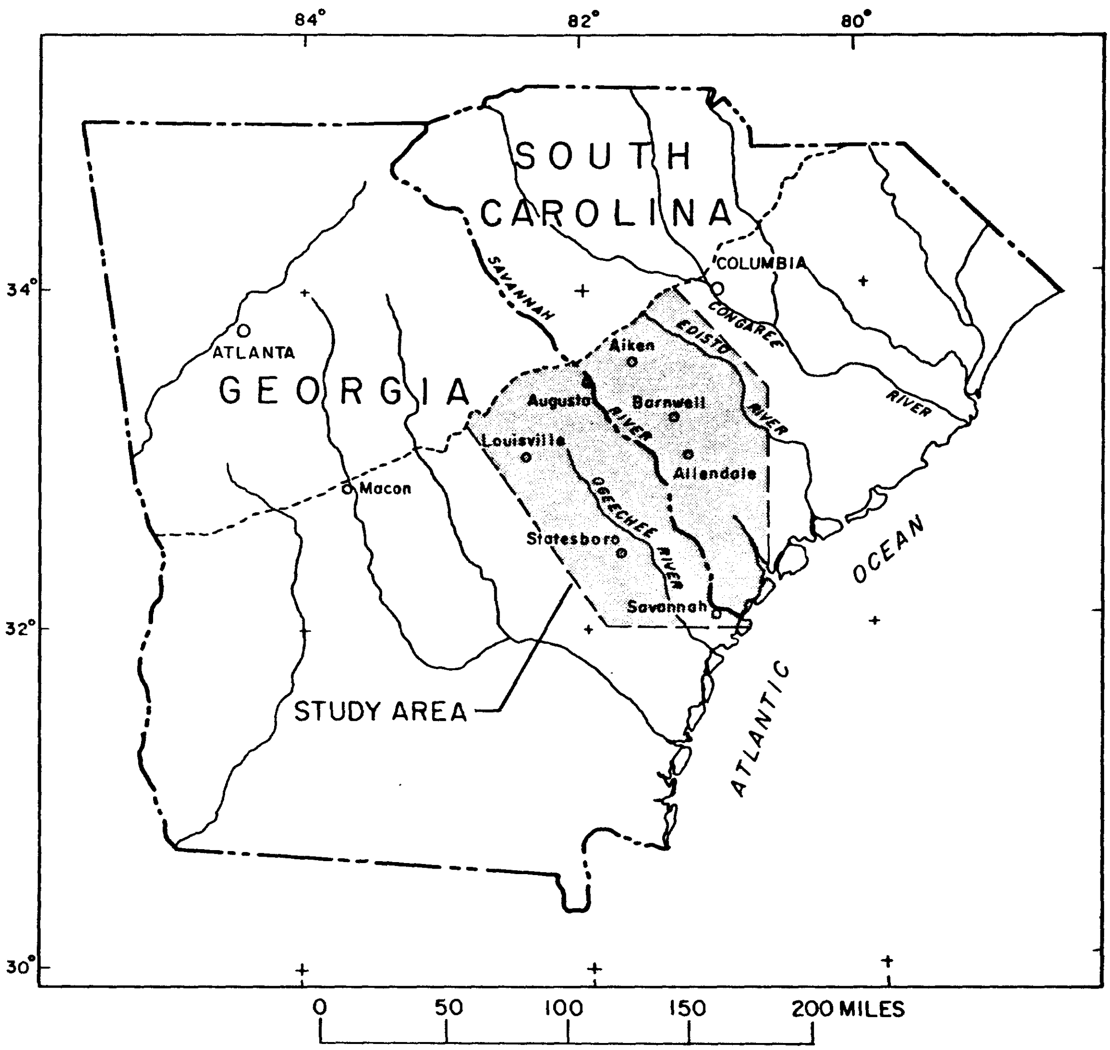

Figure I.—Location of study area.

The purpose of this paper is to describe and, where possible, quantitatively document the geologic, hydrologic, and hydraulic effects of faulting of Coastal Plain sediments within the study area. The geology and hydrology of regional aquifers are briefly described to provide bases for interpretation. Data sources and interpretive methods unique to various aspects of this study are discussed selectively in the text. Methods pertinent to the map location of well-data points are described in the Supplemental Information section at the end of the report.

Acknowledgments

The authors extend their thanks to I. Wendell Marine of the E.I. duPont de Nemours Company, Savannah River Laboratory, and gratefully acknowledge the use of data, borehole cuttings, and facilities at the Savannah River Plant (SRP). We similarly acknowledge the use of facilities and cuttings at the South Carolina Geological Survey and the Georgia Geologic Survey. The authors particularly acknowledge the palynological identifications contributed by Raymond A. Christopher and Norman O. Frederiksen of the U.S. Geological Survey. Appreciation is also extended to Ralph F. Crawford for cartographic organization, Rebekah Brooks for final map compilation, and Patricia J. Bentley and Mary D. Ballew for assistance in preparation of this manuscript.

GEOLOGY

The emerged Coastal Plain in the vicinity of the Savannah River is a southeastward thickening wedge of semiconsolidated to unconsolidated strata of Cretaceous to Holocene age. The strata, in general, dip gently to the southeast; hence, "down dip" as used in this report means "southeastward". Outcrop areas of Cretaceous through middle Eocene sediments critical to this study are shown in figure 2. The inner margin of the Coastal

Figure 2.--(Caption on next page) belongs near here.

Plain noted in figure 2 is the updip limit of Upper Cretaceous and lower Tertiary sediments and is defined by the exposed unconformable contact between crystalline rocks and Coastal Plain sediments. The stratigraphic correlation of Coastal Plain sediments within the study area to contemporaneous sediments of the Atlantic and Gulf Coastal Plains is illustrated in table 1. Lithologic units described in table 1 pertinent to

Table 1.--(Caption on page 8) belongs near here.

the Savannah River area refer to the geologic section of Coastal Plain sediments shown in figure 3.

Figure 3.--(Caption on page 9) belongs near here.

Figure 2.--Outcrop areas of Upper Cretaceous through middle Eocene sediments and critical data-collection sites.

Table 1.--Generalized correlation of stratigraphic, lithologic, and aquifer units

Table I.—Generalized correlation of stratigraphic, lithologic, and aquifer units

Series	European Stage	Provincial Stage	New Jersey	North Carolina	Clubhouse Crossroads core South Carolina	This Report: Savannah River area Georgia and South Carolina	This Report: Lithologic unit 1/ (see fig. 3)	This Report: Aquifer-confining unit 1/	Chattahoochee River area Georgia and Alabama
OLIGOCENE	Chattian	Chickasawhayan		Trent Marl (part)	Upper part of Cooper Formation				
	Rupelian	Vicksburgian		?					
	Lattorfian			?					
EOCENE	Bartonian	Jacksonian		Castle Hayne Limestone	Lower part of Cooper Formation; Santee Limestone	Barnwell Formation	E_6, E_5		Ocala Limestone; Moodys Branch Formation
	Lutetian	Claibornian	Shark River Formation	?	Santee Limestone	McBean Formation; Huber (?) Formation	E_2, E_3, E_4; E_1	A_2	?; Lisbon Formation; Tallahatta Fm.
	Ypresian	Sabinian	Manasquan Formation		Black Mingo Formation	? Black Mingo Formation	P_2	A_2	Hatchetigbee Formation; Tuscahoma Fm.
PALEOCENE	Thanetian		Vincentown Formation		Black Mingo Formation	Black Mingo Formation	P_2	A_2	Nanafalia Fm.; ?
	Danian	Midwayan	Hornerstown Sand; ?	Beaufort Formation	Beaufort (?) Formation	Ellenton Formation	P_1	C_1	Clayton Formation
UPPER CRETACEOUS	Maestrichtian	Navarroan	Red Bank Sand; Navesink Formation; Mount Laurel Sand	Peedee Formation	Peedee Formation	?; Black Creek (?) Formation	UK_3	A_1	Providence Sand; Ripley Fm.; Cusseta Sand Member
	Campanian	Tayloran	Wenonah Fm.; Marshalltown Fm.; Englishtown Fm.; Woodbury Clay; Merchantville Formation	Black Creek Formation	Black Creek Formation	Black Creek (?) Formation; ?	UK_3	A_1	Blufftown Formation
	Santonian	Austinian	Magothy Fm.	Middendorf Formation / Cape Fear Formation; ?	Middendorf Formation / Cape Fear Formation; ?	Middendorf Formation; ?	UK_2, UK_1	A_1	Eutaw Fm.
	Coniacian								
	Turonian	Eaglefordian							
	Cenomanian	Woodbinian	Raritan Formation	Unnamed Tuscaloosa equivalent	Unnamed Tuscaloosa equivalent				Tuscaloosa Formation; ?

1/ Tentative age correlation

Modified from Hazel and others, 1977

Figure 3.--Geologic section along line A-A'.

Regional Stratigraphy and Lithology

Crystalline Rocks

Paleozoic crystalline rocks that include gneiss, schist, quartzite, and granites of the Kiokee belt and metavolcanic rocks of the Little River Series of Crickmay (1952) underlie Coastal Plain sediments within the updip parts of the study area (LeGrand and Furcron, 1956; Siple, 1967; Prowell and O'Connor, 1978; Marine, 1979). The age of the Belair belt of the Little River Series was established as Paleozoic (probably Cambrian) from a trilobite found near Augusta, Ga. (Maher, 1981). The ages of the Kiokee belt and the remaining Little River Series are also considered Paleozoic. Crystalline rocks crop out within the study area north of the inner margin of Coastal Plain sediments and downdip in the channels of larger streams (fig. 2). Crystalline rocks unconformably underlie Cretaceous Coastal Plain sediments downdip to a line extending approximately from Wadley in southern Jefferson County, Ga., to Williston in Barnwell County, S.C. The upper 10 to 100 ft of the crystalline rock both in the exposed Piedmont and in the subsurface northwest of this line is typically saprolite. Saprolite is formed by the in place weathering of crystalline rock with the preservation of the relict texture of the parent rock. Saprolite can be distinguished from the overlying poorly consolidated Coastal Plain sands and gravels by mineralogy and texture and commonly by abrupt changes in the trends of electrical resistivity and spontaneous potential curves of bore-hole geophysical logs.

South of the line from Wadley to Williston, drill-hole data defining the nature of the crystalline rocks are unavailable. Drill holes penetrating the Cretaceous strata in this region bottom in unmetamorphosed red beds.

Triassic Rocks

Moderately to well-indurated interlayered dark-red claystones, siltstones, sandstones, and fanglomerates are present in the subsurface between the crystalline basement and the Cretaceous Coastal Plain strata generally southeast of the line between Wadley, Ga., and Williston, S.C. These rocks are interpreted as river and lake deposits formed in a continental environment. The fanglomerate layers, particularly those in the cores from well P5 and the cuttings from well AL-66 (fig. 3), contain an assortment of rock fragments that have been derived from other rock units. Greenschist clasts similar in lithology to the rocks labeled Pz_3 on figure 3 have been found in the samples from AL-66 and they indicate the presence of an exposed crystalline terrane during erosion and deposition. No fossils have been recovered from these red beds but by analogy with similar rocks in the Eastern United States, they are probably of Triassic to Early Jurassic age. In this report, these red beds are referred to as Triassic rocks, or rocks of Triassic age.

A weathered zone typically less than 50 ft thick is commonly present at the top of the Triassic red beds. The contact between Triassic rocks and overlying sediments can be distinguished by lithologic changes and is commonly characterized on electric logs by a relatively sharp reduction in electrical resistivity and spontaneous potential compared to the poorly consolidated overlying Cretaceous sands and gravels.

The geology and hydrology of Triassic rocks which underlie the SRP (Savannah River Plant) have been extensively investigated to evaluate their storage potential for radioactive wastes. Results of these studies are described by Christl (1964), Marine (1973; 1979), and Marine and Siple (1974). Lithologic and geophysical drill-hole data in U.S. Geological Survey files from South Carolina and Georgia were examined by the authors to determine the altitude of the base of Cretaceous Coastal Plain sediments. Individual data points with designation of pre-Cretaceous rock type in the drill holes are shown in figure 4.

Figure 4.--(Caption on next page) belongs near here.

Coastal Plain Sediments

Coastal Plain sediments within the study area range in age from Late Cretaceous through early Tertiary and form a seaward thickening, wedge-shaped section of poorly consolidated lithologic units. Successively

Figure 4.--Altitudes at the base of Coastal Plain sediments.

younger sequences of sediments crop out generally seaward of older sediments and generally dip at a correspondingly smaller angle. Only Upper Cretaceous through middle to upper Tertiary sediments are considered in detail in this study.

Upper Cretaceous fluvial and marine sediments of Santonian to Maestrichtian age unconformably and continuously overlie Paleozoic crystalline or Triassic sedimentary rocks throughout most of the study area. These sediments were formerly considered contemporaneous with the Tuscaloosa Formation of Alabama and southwest Georgia (LeGrand and Furcron, 1956; Siple, 1967), but are now known to be younger and contemporaneous with the Middendorf, Black Creek, and Peedee Formations of South Carolina (Raymond A. Christopher, U.S. Geological Survey, written commun., 1980-81). Sediments of Campanian and Maestrichtian age correlative with the Black Creek and Peedee Formations are subsequently termed the Black Creek (?) Formation in this report. Sediments of the Upper Cretaceous Middendorf Formation (table 1) comprise the basal part of the Coastal Plain downdip to approximately the southern boundaries of Burke County, Ga., and Barnwell County, S.C., where they are abruptly terminated (fig. 3). Downdip from this area, for an undetermined distance, the basal Coastal Plain is probably comprised of sediments correlative with those of the Black Creek Formation of eastern South Carolina.

Sediments of the Middendorf and Black Creek(?) Formations are difficult to differentiate updip of the SRP and are characterized by poorly consolidated, kaolin-rich, fine- to coarse-grained sands and gravels. These sediments are irregularly crossbedded and commonly contain discrete, generally discontinuous layers of kaolin and lenses of well-rounded quartz gravel. A zone of oxidation and weathering marks the Middendorf-Black Creek(?) contact. Sediments of the Black Creek(?) Formation are typically marine and are comprised of well-bedded, fine- to coarse-grained, clayey sand containing significant quantities of carbonaceous material. This unit is generally a fining-upwards sequence of sands and silty clays the upper part of which contains thin commercial grade kaolin deposits.

Basal sediments of the Middendorf Formation at the SRP and probably elsewhere consist of a semiconsolidated sandy clay overlying a tan to buff-colored indurated silty to sandy clay (Marine and Siple, 1974). The entire basal section of semiconsolidated clay ranges in total thickness from about 40 to 150 ft and is characterized on electric logs as a zone of low electrical resistivity which contrasts sharply with overlying highly resistive, poorly consolidated coarse sands. The basal and upper units of the Middendorf Formation and the sediments of the Black Creek(?) Formation are designated UK1, UK2, and UK3, respectively, in table 1 and in figure 3.

Unconformably overlying the Upper Cretaceous sediments throughout most of the study area is a continuous dark-gray to black, sandy, lignitic micaceous clay. The basal part of this unit consists of gray to bluish-gray, clayey quartz sand and gravel. Downdip of the SRP, these sediments change facies to a carbonaceous marl. Siple (1967) formally named this unit the Ellenton Formation and suggested that it is probably contemporaneous with youngest Upper Cretaceous or lower Paleocene sediments observed elsewhere in South Carolina. Core samples of what is probably the Ellenton Formation were obtained from the site of Georgia Power Company's Plant Vogtle in Burke County, Ga., near TW-1 (figs. 2 and 3). Palynological analyses of these samples establish the age of the sediments as early to middle (Midwayan) Paleocene (Norman O. Frederiksen, U.S. Geological Survey, written commun., 1980) which is the age assignment used for the Ellenton Formation in this report.

Lower to middle Paleocene sediments occur only in the subsurface within the study area, generally seaward of a line between Louisville in Jefferson County, Ga., to Jackson in Aiken County, S.C., and range in thickness from a few feet to more than 150 ft. The upper contact of these Paleocene sediments is distinguished lithologically by the generally massive, lignitic clay in the upper part of the unit and on geophysical logs as a zone of low electrical resistivity and relatively high natural gamma radiation. Sediments of early to middle Paleocene age are labeled P1 in table 1 and in figure 3.

Sediments of late Paleocene to early Eocene(?) age occur only in the subsurface, generally seaward of a line between Perkins in Jenkins County, Ga., and Barnwell in Barnwell County, S.C. These sediments are characterized by calcareous, partially glauconitic, fine- to coarse-grained quartz sand within a matrix of light-gray to off-white calcareous clay.

Downdip these sediments undergo a facies change to sandy limestone and limestone. The maximum thickness of this unit within the study area is about 100 ft. Sediments of late Paleocene and early Eocene(?) age are designated P2 in table 1 and in figure 3 and are possibly contemporaneous with the Black Mingo Formation described by Siple (1975).

Sediments of middle Eocene (Claibornian) age unconformably and discontinuously overlie Upper Cretaceous sediments throughout updip parts of the study area and continuously overlie Paleocene sediments downdip in the subsurface. These sediments are contemporaneous with the Hatchetigbee, Tallahatta, and Lisbon Formations of southwest Georgia (Cederstrom and others, 1979, table 1), the Huber Formation of central Georgia (Buie, 1978), and the "Claiborne undifferentiated" unit and the McBean Formation in South Carolina described by Siple (1955; 1967). The McBean Formation as defined by Herrick and Counts (1968) is contemporaneous only with the uppermost outcropping sediments of middle Eocene age. Updip of McBean Creek (Burke County, Ga.), sediments immediately underlying the McBean Formation of Herrick and Counts (1968) were formerly considered part of the Upper Cretaceous. They are now known to be middle Eocene and are assigned to the Huber Formation. Sediments of youngest middle Eocene age (McBean Formation) crop out in eastern Georgia in the valley of McBean Creek near its confluence with the Savannah River in Richmond County and in the valley of Brier Creek in northern Burke County. Older sediments of middle Eocene age (Huber Formation) crop out within a belt extending from northern Jefferson County, Ga., to northern Aiken County, S.C. (fig. 2). Undifferentiated sediments of middle Eocene age crop out in South

Carolina in the valleys of Holley Creek, Upper Three Runs Creek, Town Creek, Tims Branch, and Tinkers Creek in Aiken and Barnwell Counties (fig. 2).

Within updip parts of the study area (fig. 2) the lowermost sediments of middle Eocene age are lithologically similar to the underlying Upper Cretaceous sediments and consist of fine- to medium-grained, unconsolidated kaolinitic quartz sand, clayey silt, and beds and lenses of commercial grade kaolin. The uppermost middle Eocene sediments consist of green glauconitic, sandy marl and beds of impure and silicified, fossiliferous limestone. Downdip in the vicinity of the SRP, sediments of middle Eocene age are comprised largely of calcareous sands and sandy limestones. Generally south of Burke and Jefferson Counties, Ga., and Barnwell County, S.C., middle Eocene sediments undergo abrupt facies changes to a sandy limestone and limestone, reaching a maximum thickness of about 300 ft. Where possible, sediments of middle Eocene age are subdivided lithologically in table 1 and in figure 3 into units E1 and E2, E3, and E4.

Sediments of late Eocene (Jackson) age overlie middle Eocene sediments in most of the study area. These upper Eocene sediments are contemporaneous with the Ocala Limestone (Herrick and Counts, 1968; Siple 1955, 1967: Huddleston and Hetrick, 1979) and the Santee Limestone (Hazel and others, 1977) and have traditionally been called the Barnwell Formation. Upper Eocene sediments updip are characterized by red to tan clayey sands, green to gray carbonaceous clay, and calcareous sands containing thin fossiliferous limestone beds. Updip the calcareous sands and limestones which form the basal part of the upper Eocene sequence are lithologically distinct from the underlying green sandy marl of youngest middle Eocene age. Downdip this distinction is less apparent as both middle and upper Eocene sediments undergo facies changes to sandy limestone and limestone. Upper Eocene sediments are designated E5 and E6 in table 1 and in figure 3.

Geologic Section

Borehole cuttings, cores, and geophysical logs from selected control wells were analyzed to delineate the lithologic and stratigraphic characteristics of geologic units along the line A-A' shown in figure 2. The geologic section shown in figure 3 illustrates the stratigraphic and structural relationships derived from the data analyses. Control wells not directly on the line of section were projected to the line over the shortest horizontal distance. Structure contour maps by Siple (1967) and Prowell and O'Connor (1978) indicate that the Coastal Plain strata strike northeast and the line of section is generally parallel to true dip in the Coastal Plain strata northwest of well P5. Southeast of well AL-66, however, beds strike more easterly reflecting the influence of the Cape Fear arch (not shown in fig. 2). This change in strike and the northward divergence of control wells AL-19 and AL-23 from the section line results in an apparent but false flattening of sedimentary units seaward of well AL-66.

Geologic units of similar lithology, texture, and age are represented on the section by informal letter and number designations. This method of classification designates specific geologic units without the geologic connotations of regional formation names. For purposes of comparison, however, the names of correlative geologic formations have been included in the geologic section explanation and in table 1. Various geophysical logs used in conjunction with the examination of the borehole cuttings and in the extrapolation of geologic contacts between wells are shown with the control wells on the section. In the preparation of the geologic section, lithologic logs of borehole cuttings were compared with the corresponding geophysical logs to better establish the position of lithologic contacts and to provide information about sample contamination due to downhole caving. The inaccuracy of the samples, however, may result in a + or - 10-foot error in the position of any contact shown in figure 3. Paleontologic control points are shown on well columns P-1 and TW-1 in the section but evidence of the age of other units is commonly derived by extrapolation of data from surface outcrops and other drill holes.

Two previously reported faults and their related lithologic discontinuities are shown in figure 3. The Belair fault, previously described by Prowell and O'Connor (1978), is a zone of reverse faults which vertically offset Santonian (Upper Cretaceous) sediments about 40 ft near well MZ-1 (fig. 2). At this locality, Piedmont crystalline rocks are faulted over Coastal Plain strata along a high angle reverse fault trending to the northeast. Subsequent erosion has removed the Coastal Plain strata from the upthrown block exposing metavolcanic crystalline rocks. The crystalline rock - Triassic rock contact in the subsurface at the SRP was described by Christl (1964), Siple (1967), and Marine and Siple (1974) as a normal fault of undetermined total displacement. This fault forms the northwestern border of the "Dunbarton" Triassic basin (Marine and Siple, 1974) but it displaces only pre-Cretaceous rocks. Therefore, the line on the geologic section representing this fault terminates at the base of the Cretaceous Coastal Plain strata. The following section of this report contains a more detailed discussion of structural features within the study area.

The positions of correlative sedimentary contacts at control wells P5 and AL-66 (fig. 3) initially indicated anomalous dip changes in the Coastal Plain strata. Well AL-66 is 3.5 mi southeast (downdip) of well P5 and both wells bottom in Triassic rocks. The Triassic rocks in these wells have a distinctive dark red color from oxidation and contain distinctive clasts of crystalline greenschist (probably from unit Pz_3 in fig. 3) in the fanglomerate layers. The presence of these fanglomerates distinguishes the Triassic rocks from highly weathered overlying Cretaceous strata, which also could be highly oxidized. The Cretaceous-Triassic contact northwest of well P5 dips about 50 ft/mi to the southeast and is at a depth of 1,056 ft below sea level in well P5. The depth of the correlative contact in AL-66, however, is 485 ft below sea level. A straight-line connection of these points requires that the contact dip northwest at 163 ft/mi between wells P5 and AL-66. Similarly, the Cretaceous-Paleocene contact in well P5 is 350 ft below sea level, whereas in well AL-66 it is 310 ft below sea level. This contact typically dips about 40 ft/mi to the southeast but a straight-line connection of these points between wells P5 and AL-66 requires that it dip 11 ft/mi to the northwest. Similar anomaleous dips would result from straight line extrapolations of younger sedimentary units deposited in different sedimentary environments. Although dip reversals in sedimentary environments are not uncommon, dip reversals of this magnitude and extent are highly unlikely. The anomalous stratigraphic conditions between wells P5 and AL-66 are more reasonably explained by faulting which has uplifted the landmass downdip of well P5. For this reason, a previously unreported fault (the Millett fault in fig. 3) is postulated between wells P5 and AL-66.

The exact position of the Millett fault between wells P5 and AL-66 is not known, but its position in figure 2 was determined by available potentiometric data (figs. 6 to 9) and the abrupt change in the meander pattern of the Savannah River. The proposed Millett fault displaces the Triassic-Cretaceous contact approximately 700 ft vertically and is shown as a reverse fault suggesting a geometric similarity to the Belair reverse fault at Augusta, Ga., and the Cooke and Helena Banks reverse faults reported near Charleston, S.C. (Behrendt and others, 1981). The amount of displacement suggested by correlative geologic contacts has been estimated by projecting the contacts to the fault line at the same dip recognized in the equivalent contacts updip of well P5. As discussed previously, the dip of the Coastal Plain strata southeast of well AL-66 is not true dip and, therefore, the slope of the contacts could not be used in the extrapolation of units from AL-66 to the fault plane. Localized changes in the dip of the Coastal Plain strata may shift the position of the intersections of the geologic contacts with the suggested fault plane and the value of any displacement measurement may vary by 10 to 20 ft.

The correlation of units between wells P5 and AL-66 suggests that successively younger strata are displaced to a lesser degree. Unit UK_1 on the geologic section (fig. 3) and probably all of unit UK_2 are not represented in the sedimentary sequence on the southeast (upblock) side of the Millett fault. This suggests that these units either never existed on the upblock or they were eroded after some stage of Cretaceous faulting. Similarly, subsequent movement along the fault has resulted in the thickening of some units on the northwest (downblock) side of the fault, but the displacements were too small to completely exclude their upblock counterparts. These conditions suggest that the Millett fault was active spasmodically, if not continuously, from the Cretaceous through the late Eocene.

Structure

Contour maps by Siple (1955, figs. 4 and 9: 1967, pls. 4 and 5) and Prowell and O'Connor (1978, figs. 2 and 3) show the configuration of the unconformity at the surface of "basement rocks" and the top of Upper Cretaceous sediments in most of Aiken and Barnwell Counties, S.C., and Richmond County, Ga. The strike of the basement rock surface in this region is about N. 66° E. and the dip is about 30 to 35 ft/mi to the southeast. The top of Upper Cretaceous sediments strikes similar to the basement surface but dips at a rate of about 15 to 20 ft/mi to the southeast.

Altitudes of the base of Cretaceous Coastal Plain sediments and designations indicating underlying rock types are shown in figure 4. Many of the irregularities shown in figure 4 are probably the result of erosion and deposition. However, abrupt changes in the altitude of the basal Coastal Plain unconformity provided a basis for Prowell and O'Connor (1978) to delineate the Belair fault zone near Augusta, Ga. Similar abrupt changes in the altitude of this unconformity near the Barnwell County-Allendale County line in South Carolina provided initial evidence for the existence of the Millett fault.

Faulting

The Belair fault zone near Augusta, Ga. (Prowell and O'Connor, 1978) is a zone of northeast-trending, high angle, en echelon reverse faults that displace Upper Cretaceous and younger sediments near the inner margin of the Coastal Plain (fig. 2). A segment of the Belair fault zone is shown on the geologic section near well MZ-1 (fig. 3). Southwest of this locality, Prowell and O'Connor (1978) reported that the fault displacements reach a maximum of about 100 ft in Upper Cretaceous strata and about 40 ft in upper Eocene strata. This evidence suggests at least two episodes of fault movement. Prowell and O'Connor (1978) also reported that the fault plane dips about 50° to the southeast and is marked by a thick, clayey gouge zone.

Southeast of the Belair fault zone, Marine and Siple (1974) described the northwest contact of Triassic and crystalline rocks at the SRP as a Triassic basin border fault and reported seismic reflection data which indicated no offset of the basal Cretaceous unconformity. The seismic data substantiated previous examinations by Marine (1973) of lithologic and geophysical data from boreholes across the fault. Seismic reflection data on the southeast side of the SRP, however, were reported by Marine (1973) to show some apparent discontinuities at the Cretaceous-Triassic unconformity.

Siple (1967) considered the radical changes in natural gamma radiation levels shown on the aeromagnetic map of Petty and others (1965) at the southern end of the SRP to be indicative of faulting at the southeastern border of the buried Dunbarton Triassic basin of Marine and Siple (1974). Based on essentially the same aeromagnetic data supplemented with seismic refraction data, Daniels (1974) inferred the location of a basement fault in the same general location. The fault noted by both Siple and Daniels is generally coincident with the proposed Millett fault.

Unlike the northwestern border fault of the Dunbarton basin, the Millett fault offsets Cretaceous, Paleocene, and Eocene strata overlying the Triassic red beds. Evaluation of the drill-hole samples of these sub-horizontal Coastal Plain units provides evidence related to the vertical movement of the fault but there are no critical markers to define amounts of horizontal movement. Measurement of the vertical displacement of the dated geologic units shown in figure 3 indicates that movement has diminished through geologic time. The 700-foot offset at the base of the Santonian (80 m.y. old) unit UK_1 suggests a displacement rate of about 8 or 9 ft per million years, whereas the 220-foot offset at the base of the late Campanian (70 m.y. old) unit UK_3 suggests a displacement rate of about 3 ft per million years. Similarly, the suggested 20-foot offset of the upper Eocene (40 m.y. old) unit E_6 suggests a displacement rate of only 0.5 ft per million years. These rates are very similar to rates calculated for other Cretaceous and younger faults in the Southeastern United States (Wentworth and Mergner-Keefer, 1981).

The Cooke fault and the Helena Banks fault (not shown on figures) of Behrendt and others (1981) are northeast-trending reverse faults near Charleston, S.C. The Cooke fault has been recognized by seismic reflection profiling northwest of Charleston and the Helena Banks fault has been recognized in offshore seismic surveys. The geometry of these faults and the reported characteristics of the Belair fault zone (Prowell and O'Connor, 1978) provided a basis for describing the geometry of the Millett fault, which is shown in figure 3 as a reverse fault steeply dipping to the southeast. The Millett fault strikes about N. 50° E. and probably exceeds 40 mi in length. If the Millett fault is similar to the Belair fault zone, the Coastal Plain strata should be drag-folded adjacent to the fault plane, particularly in units UK_1, UK_2, UK_3, and P_1 (fig. 3).

By analogy, the Millett fault plane in these units is probably marked by a clayey gouge zone 0.5 to 1.5 ft thick. The characteristics of Cretaceous and younger reverse faults in carbonate rocks are unreported.

The position of the Millett fault at the southeastern margin of the Dunbarton Triassic basin suggests that it may be a reactivated zone of weakness that formed in pre-Cretaceous time. However, the margins of Triassic basins, such as the northwest border of the Dunbarton basin, are characteristically normal faults and the evidence from regional fault studies mentioned previously would strongly suggest that the Millett fault is a reverse fault. Reverse reactivation of a normal fault at the southern margin of the Dunbarton basin would require that the area be downthrown to the southeast whereas the geologic section (fig. 3) indicates that the area is upthrown to the southeast. Therefore, simple reactivation of an old normal fault seems unlikely. An alternate explanation would be that the Dunbarton basin was a half-graben during the early to middle Mesozoic with a fault at the northwest border. Subsequent Cretaceous and Cenozoic reverse fault movement along the Millett fault would have resulted in the present basin geometry as a full graben.

Anomalous potentiometric data in Bullock and Screven Counties, Ga., and in Hampton County, S.C., (figs. 6 to 9) seem to be extensions of and coincident with a northeast-trending band of potentiometric anomalies extending across most of the Georgia Coastal Plain. This feature was first recognized as part of the principal artesian aquifer of Georgia by

Herrick and Vorhis (1963) and was referred to as the Gulf Trough. Geologic investigations of the Gulf Trough by Gelbaum (1978) and Cramer and Arden (1980) described the trough as a narrow, fault-bounded, excessively thick, belt of Cretaceous and younger sediments characterized through most of its length by abrupt, downdip changes in potentiometric head and to some degree by downdip changes in ground-water quality (Zimmerman, 1977).

Downdip projection of the base of the Coastal Plain sediments shown in the geologic section (fig. 3) to the vicinity of the potentiometric anomaly described above suggests that the top of pre-Cretaceous rocks in the vicinity of the Screven-Effingham County line in Georgia should be approximately 2,100 ft below sea level. Examination of borehole cuttings from test well GGS-855 (fig. 2) in southern Screven County, Ga., indicates that the well was drilled to a depth of 2,547 ft below sea level but did not bottom in "basement" rocks as reported. The hole probably bottomed in the indurated unit UK_1 shown in figure 3. This increase in thickness of the Coastal Plain strata and the similarity of the potentiometric data to that along the general strike of the Gulf Trough suggests that at least one side of the Gulf Trough may extend as far east as Hampton County, S.C.

Such an extension implies that geologic conditions near the Screven-Effingham Co. line in Georgia are similar to those at the Millett fault and suggests that a similar fault is present in this area with the southeast block downthrown. This proposed fault is informally named the "Statesboro" fault in this report for its proximity to the town of Statesboro in Bulloch County, Ga. The Millett and Statesboro faults thus border a relatively upthrown block approximately 40 mi wide and of unknown length. The upward motion of this block from the Cretaceous through the Eocene has affected both the distribution and lithology of strata overlying the block. Such effects, in turn, should influence aquifer hydraulics and regional patterns of ground-water flow.

HYDROLOGY

Aquifer Definition

The sediments described previously can be subdivided into regional aquifers and confining zones based on lithology, areal extent, and stratigraphic and lithologic continuity. Regional aquifers of interest to this study include a basal Coastal Plain aquifer comprised almost entirely of Upper Cretaceous sediments of the Middendorf and Black Creek(?) Formations and an overlying aquifer comprised of sediments of late Paleocene through middle Eocene age. The basal Coastal Plain aquifer is, to a large degree, spatially equivalent to the occurrence of Upper Cretaceous sediments and is bounded at the bottom by contact with crystalline rock saprolite, the weathered Triassic rocks, or the semi-consolidated and indurated silty clay of the basal Middendorf Formation. The upper boundary of this aquifer is generally coincident with the occurrence of lower Paleocene sediments. In the vicinity of the SRP, basal sands and gravels of early Paleocene age are considered part of the basal Coastal Plain aquifer.

The relatively thick lignitic clay of early Paleocene age is an areally continuous confining zone which separates the basal Coastal Plain aquifer from the overlying aquifer comprised of upper Paleocene through middle Eocene sediments. This overlying aquifer is, in turn, partially confined at the top by the glauconitic clay and marl of youngest middle Eocene age (McBean Formation).

Where sediments of middle Eocene age directly overlie Upper Cretaceous sediments in updip parts of the study area, the basal Coastal Plain aquifer is discontinuously confined by thick beds and lenses of kaolin and other clays near the base of the middle Eocene sediments. The aquifer comprised of middle Eocene sediments in this area is locally confined by basal clays of the upper Eocene Barnwell Formation.

For discussion purposes, the regional aquifers and confining zone will be designated as A1, A2, and C1. Correlation of this nomenclature with defined lithologic units is listed below and shown in table 1.

Aquifer and Confining Unit	Description	Lithologic correlation [Refers to table 1 and figure 3]
A2	Regional Coastal Plain aquifer, lower Tertiary sediments of late Paleocene to middle Eocene age	P2, E1
C1	Regional confining zone, lower Tertiary sediments of early and middle Paleocene age	P1
A1	Basal regional Coastal Plain aquifer, largely sediments of Late Cretaceous age	UK2, UK3, basal P1

Aquifer Parameters

Aquifer-test data pertinent to the A1 aquifer in Richmond and Burke Counties, Ga., were reported by Bechtel Corporation (1973), J. E. Sirrine Co. (1980), and W. G. Keck and Associates (1965). Corresponding data for Aiken and Barnwell Counties, S.C., were reported by Mayer (1972) and Siple (1955; 1967). Hydraulic parameters pertinent to the A2 aquifer and younger lower Tertiary sediments at the SRP are described by Siple (1975), Marine and Root (1976; 1978), and Root (1977). Additional time-drawdown data pertinent to wells in both Georgia and South Carolina were obtained from U.S. Geological Survey data files. Hydraulic characteristics of Paleozoic and Triassic rocks at the SRP are described by Christl (1964) and Marine (1979).

Point values of transmissivity of the A1 aquifer are shown in figure 5. All values were computed using time-drawdown or time-recovery data. Although these data are pertinent only to discrete parts of the

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Figure 5.--(Caption on next page) belongs near here.

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aquifer they are considered representative of relative spatial changes in transmissivity within the study area. In Georgia, A1 aquifer transmissivity increases rapidly downdip from about 3,000 ft^2/day in northeastern Richmond County to about 30,000 ft^2/day in east-central Burke County. Similarly, in South Carolina, A1 aquifer transmissivity changes from about 12,000 ft^2/day in Aiken Co. to about 30,000 ft^2/day at the SRP.

Figure 5.--Point transmissivity of the A1 aquifer.

Transmissivity of the A1 aquifer seems to be greater than 20,000 ft^2/day throughout most of the SRP. Transmissivity of the restricted A1 aquifer downdip of the Millett fault is about 6,000 ft^2/day based on measurements near Martin and near Millett in Allendale County. Thus an established downdip trend of rapidly increasing aquifer transmissivity is sharply reversed across the Millett fault; probably due, in large part, to the observed "fining upward" character of the Black Creek (?) Formation and the 60-percent reduction in aquifer thickness which occurs across the fault (fig. 3).

Results of aquifer tests pertinent to the A2 aquifer at the SRP are reported by Siple (1955) and by Root and Marine (1978). Transmissivity of this aquifer seems to be variable and ranges from about 8,000 ft^2/day to about 13,000 ft^2/day. The larger transmissivities were observed in wells open to limestone and sand. Transmissivity of the McBean Formation, which comprises the upper zone of confinement of the A2 aquifer, is probably less than 100 ft^2/day.

Potentiometric Surfaces

Potentiometric maps in this report are intended to portray predevelopment or unstressed conditions. Potentiometric data actually used were collected during 1945 to 1981. Where data were available for multiple time periods, only the earliest data or data otherwise believed to be most representative of predevelopment conditions were used in this study. Additionally, the authors believe that, with minor exceptions caused by local pumping or long-term natural stress, potentiometric heads changed little or not at all within the study area during 1945 to 1981. Unpublished water-level records which indicate that A1 aquifer potentiometric heads within Georgia have changed little from 1945 to present (1981) support this belief. Similarly, in South Carolina, long-term water-level hydrographs published by Marine and Routt (1975) and Root and Marine (1978) indicate annual water-level fluctuations of about 5 to 10 ft occurred in the A1 aquifer from 1951-77 due to local pumping and seasonal stress, but no long-term water-level changes were observed in the vicinity of the SRP or near Williston, S.C. These published hydrographs are considered indicative of seasonal and long-term A1 aquifer potentiometric changes in the vicinity of the SRP in South Carolina and Georgia and are probably indicative of A1 aquifer head changes throughout most of the study area. Local water-level changes within the A1 aquifer at the SRP observed in production wells or in wells near production wells ranged only from about 5 to 30 ft and were generally less than 15 ft from 1952-60 (Siple, 1967). The SRP is probably the major single user of ground water within the study area.

Local declines in potentiometric heads related to the industrial use of ground water have been recognized within the A1 aquifer, near the cities of Hampton and Varnville in Hampton County, South Carolina. Similar water-level declines within the A1 aquifer have likely occurred near the city of Allendale, S.C.

Potentiometric heads pertinent to the A2 aquifer also have remained generally constant with time. Continuous water-level hydrographs published by Siple (1967) and Root and Marine (1978) indicate that seasonal water-level changes of about 10 ft occurred in sediments of middle Eocene age at the SRP during the periods 1951-60 and 1973-77. Siple (1967) indicates that local pumping and long-term natural stress from 1952-60 resulted in total water-level changes within the A2 aquifer ranging from about 10 to 18 ft. Unpublished water-level records for eastern Georgia also indicate generally constant A2 aquifer potentiometric heads. However, since 1979 local water-level declines have occurred west of Waynesboro in Burke County and northwest of Louisville in Jefferson County, probably in response to the use of ground water for crop irrigation.

Potentiometric data for both aquifers within and immediately downdip of their respective outcrop areas indicate that direct or nearly direct hydraulic continuity exists between the aquifers and larger streams. Consequently, in these areas, stream altitudes determined from 7 1/2-minute topographic maps were utilized to provide additional definition of the potentiometric surfaces.

A1 Aquifer

The altitude of the A1 aquifer potentiometric surface at individual control wells is shown in figure 6. These data suggest that the A1 aquifer regional potentiometric surface within and proximate to the outcrop areas of aquifer sediments (fig. 2) is generally symmetrical to the axis of the Savannah River and is, to a large degree, a subdued expression of surface topography. Potentiometric heads within this area range in altitude from about 500 ft near the inner margin of the Georgia Coastal Plain to about 150 ft near the Savannah River. Corresponding values in South Carolina range in altitude from about 300 to 150 ft, respectively. Potentiometric gradients are consistently toward the larger streams and are generally greatest within the outcrop areas and proximate to the larger streams. Lateral potentiometric gradients toward the Savannah River northwest of the Millet fault only gradually decrease downdip toward the fault and range from about 30 ft/mi in the outcrop area to about 5 ft/mi at the SRP.

The configuration of the inferred predevelopment potentiometric surface shown in figure 6 is based entirely on control well data and the

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Figure 6.--(Caption on next page) belongs near here.

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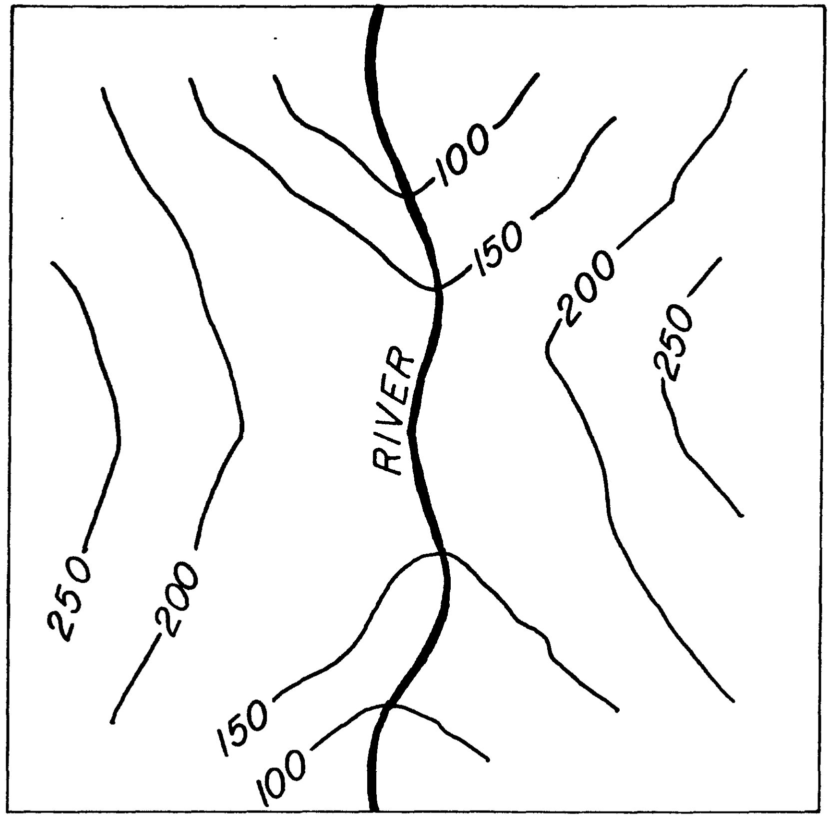
observed sensitivity of potentiometric altitudes to the proximity of the rivers and streams. Potentiometric contours were drawn disregarding geologic evidence of faulting and aquifer truncation described previously, and the Millett and Statesboro faults are shown on the map only for reference purposes.

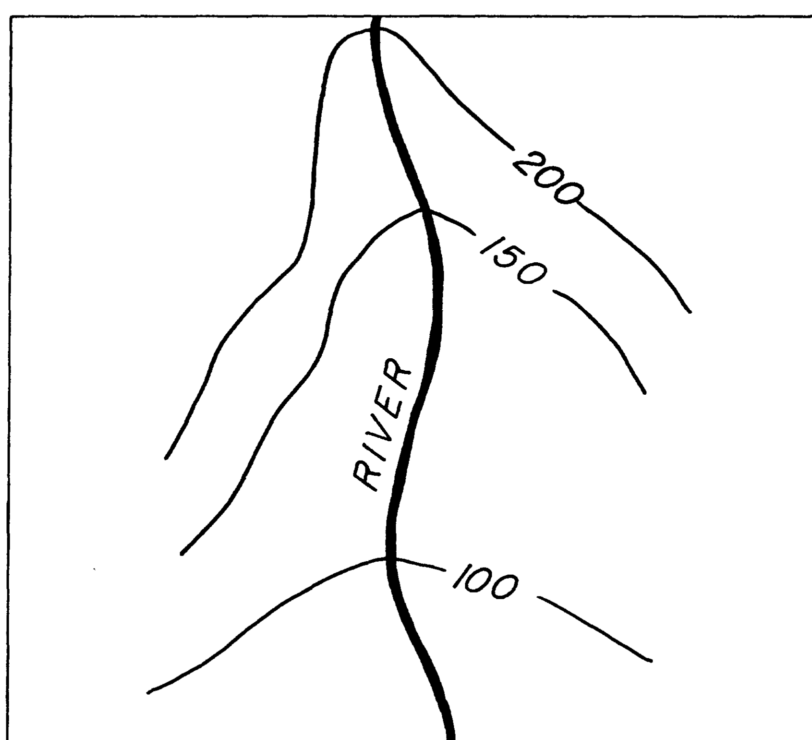
Figure 6.--Inferred predevelopment potentiometric surface of the A1 aquifer disregarding effects of faulting on ground-water flow, based on 1945-81 water-level data.

The potentiometric surface near the Savannah River northwest of the Millett fault is not well defined by point potentiometric data. Available data do, however, indicate a downdip narrowing of contours in the vicinity of central Burke County, Ga., that requires the 150-foot contour to either cross the Savannah River near the Millett fault or closely parallel the river channel to the southeast. Potentiometric contours less than 150 ft cross the river upstream of the Millett fault and form a distinctive "V" pattern symmetrical to the river. Downstream, potentiometric contours less than 150 ft cross the Savannah River and form an inverted "V" pattern also generally symmetrical to the river. This distinctive contour pattern near the Savannah River is shown diagrammatically below and was first described by Siple (1960; 1967) as a "saddle" pattern. More recently, LeGrand and Pettyjohn (1981) utilized the same description of a potentiometric "saddle" (Siple, 1960) to demonstrate a model of confined groundwater flow through undisturbed, homoclinally arranged Coastal Plain sediments and postulated the widespread existence of "saddles" within Coastal Plain aquifers of the Southeastern United States and elsewhere.

Potentiometric maps of the principal artesian aquifer in Georgia have been compiled by Mitchell (1981) and Johnson and others (1980; 1981). Pollard and Vorhis (1980) published potentiometric maps of the Cretaceous aquifer system in Georgia. Unpublished potentiometric maps pertinent to aquifers comprised of sediments of Late Cretaceous and early Tertiary age in eastern Alabama, Georgia, and western South Carolina have been compiled by ongoing Southeastern Coastal Plain RASA investigations. With the exception of the Savannah River area, the potentiometric contour configuration delineated



"SADDLE" PATTERN



INVERTED "V" PATTERN

by each of these maps near large rivers and streams is an inverted "V" pattern, shown in a generalized form in the drawing below. These maps and related potentiometric data suggest that the A1 aquifer contour configuration along the Savannah River valley southeast of Augusta is atypical with respect to corresponding patterns pertinent to correlative and lithologically similar aquifers along other large rivers within and proximate to the study area. Particularly atypical are the narrowing of potentiometric contours near the Savannah River and the resulting relatively large lateral potentiometric gradients toward the river northwest of the Millett fault.

The anomaleous A1 aquifer potentiometric contour patterns southeast of Augusta may be associated with the suggested fault displacements near Millett, S.C. The truncation of aquifer sediments by the suggested uplift of Triassic rocks (fig. 3) probably affects both the lateral and vertical flow of ground water through the A1 aquifer near and updip of the fault. A steeply-dipping clayey gouge zone in the clastic sediments along the Millett fault plane similar to that observed at the Belair fault zone (Prowell and O'Connor, 1978) could also influence the lateral and vertical movement of ground water. Similar conditions may also exist along the proposed Statesboro fault but the geologic evidence regarding this fault is very limited.

The potentiometric data shown in figure 6 were reevaluated by the authors to indicate the suggested effects of faulting on lateral ground-water flow within the study area. The authors' interpretation of the predevelopment A1 aquifer potentiometric surface is shown in figure 7.

Figure 7.--(Caption on next page) belongs near here.

Rather than extend potentiometric contours continuously across the Millett and Statesboro faults, the contours were offset at both faults. Displacement of contours across the Statesboro fault was suggested by pairs of potentiometric data points indicating abrupt lateral changes of potentiometric head ranging from about 25 ft near Fairfax, S.C., to about 40 ft near the Savannah River. Although disruption of the potentiometric surface directly across the Millett fault is not well-defined by point potentiometric data, changes in head of as much as 30 ft are implied by the paired data northwest of Millett, S.C.

Given the suggested effects of faulting on ground-water flow, the steepness and possibly the orientation of A1 aquifer potentiometric gradients between the Millett and Statesboro faults are somewhat changed from updip areas. In South Carolina, southeast of the Millett fault, potentiometric heads seem to be lowest near the fault and toward the Savannah River (figure 7). Potentiometric gradients near Barnwell are about 1.0 ft/mi to the southwest and toward the river. Near the west-central part of Allendale County potentiometric gradients seem to be generally to the north and to the northwest, toward the Millett fault and the Savannah River. Although data are incomplete, potentiometric gradients northwest of the Statesboro fault seem to be small and oriented only from the southwest toward the northeast. Potentiometric data between

Figure 7.--Map showing inferred predevelopment potentiometric surface of the A1 aquifer indicating suggested effects of faulting on ground-water flow, based on 1945-81 water-level data.

Fairfax, S.C., and the Savannah River are not available, however, and gradients may alternatively be oriented toward the Savannah River in South Carolina as well as in Georgia. Potentiometric gradients southeast of the Statesboro fault seem to be small and generally oriented only toward the Savannah River.

A2 Aquifer

The inferred predevelopment potentiometric surface of the A2 aquifer shown in figure 8 is contoured without regard to effects of faulting on ground-water flow. Regional potentiometric symmetry and subdued topographic expression are also common to this surface and characterize the potentiometric surfaces of both the A1 and A2 aquifers (figs. 6 to 9). Updip of the Millett fault in Georgia, potentiometric heads range in altitude from about 400 ft in the most updip areas to about 100 ft near the Savannah River. Corresponding values in South Carolina range in altitude from about 300 ft to 100 ft. Compared to the A1 aquifer, A2 aquifer potentiometric gradients seem to be somewhat lower updip of the Millett fault and greater within the wedge of sediments between the Millett and Statesboro faults. The A2 aquifer potentiometric surface within this wedge is characterized by a subdued expression of topography and by pronounced regional symmetry axial to the Savannah River, which sharply contrasts with the corresponding A1 aquifer surface.

Figure 8.--(Caption on next page) belong near here.

Figure 8.--Inferred predevelopment potentiometric surface of the A2 aquifer disregarding the effects of faulting on ground-water flow, based on 1945-81 water-level data.

The authors consider ground-water flow through the A2 aquifer to also be affected by faulting, although to a lesser degree than corresponding flow through the A1 aquifer. The authors' interpretation of the inferred predevelopment potentiometric surface of the A2 aquifer indicating suggested effects of faulting on ground-water flow is shown in figure 9.

Figure 9.--(Caption on next page) belongs near here.

Abrupt changes in potentiometric head ranging from about 20 to 30 ft are indicated across the Millett fault near Perkins, Ga., and in South Carolina near the Savannah River. Corresponding changes across the Statesboro fault are about 50 ft near Statesboro, Ga. The drop in A2 aquifer potentiometric head across the Statesboro fault between Statesboro and Brooklet in Bulloch County, Ga., supplements and reinforces the corresponding A1 aquifer potentiometric data, which originally led to the suggestion of this fault.

Hydraulic differentiation between the A1 and A2 aquifers is caused, to a large degree, by the confining characteristics of the carbonaceous clay of Paleocene age designated previously as C1. In updip areas, C1 is discontinuous or nonexistent and, depending on local confinement, A2 aquifer potentiometric heads may be similar to or greater than A1 aquifer heads.

Hydraulic differentiation between the aquifers generally increases downdip with the occurrence and increasing areal extent of C1 and is probably greatest near the Savannah River and other large streams.

Figure 9.--Inferred predevelopment potentiometric surface of the A2 aquifer indicating suggested effects of faulting on ground-water flow, based on 1945-81 water-level data.

North of Midville in southwest Burke County, Ga., observed potentiometric heads in adjacent wells screened individually in the A1 and A2 aquifers are offset 11 ft in altitude, with the A1 aquifer head being greater. In east-central Burke County, Ga., at the site of Plant Vogtle near TW-1 (fig. 2), A1 aquifer potentiometric heads are about 170 ft in altitude and A2 aquifer heads range from about 80 to 120 ft. Within the central part of the SRP southeast of Jackson in Aiken County, S.C., A2 aquifer potentiometric heads seem to be similar to or slightly less than A1 aquifer heads. Similar relations generally occur to the southeast, across the central part of the SRP to near the Millett fault.

Generally southeast of the SRP, sediments of the A2 aquifer and overlying sediments of late Eocene and younger age are comprised largely of limestone and sandy limestone. Such lithologies facilitate the vertical movement of ground water and direct or nearly direct hydraulic continuity exists between the A2 aquifer and ground water within overlying sediments. Consequently, surface recharge to the A2 aquifer is direct or nearly direct in interstream areas and A2 aquifer potentiometric heads in these areas may be greater than corresponding A1 aquifer heads. Relatively high A2 aquifer heads at the SRP, near Sardis in southeast Burke County, Ga., and near Swainsboro in Emanuel County, Ga., may be the result of interstream surface recharge to the A2 aquifer.

Generally south of the Millett fault in South Carolina and the Statesboro fault in Georgia, reversal of vertical potentiometric gradients seems to be everywhere complete and hydraulic differentiation between the aquifers is pronounced. At Statesboro in Bulloch County, Ga., measurements at various depths in a single test well indicate that potentiometric heads in the A1 and A2 aquifers are at altitudes of 201 ft and 117 ft, respectively. Similar measurements at AL-27 (fig. 2) near Martin in Allendale County, S.C., indicate corresponding altitudes of 171 ft and 133 ft. At Savannah, predevelopment head differentials between the A1 and A2 aquifers probably were about 100 ft.

Ground-Water Flow

Lateral Flow

The directions of lateral flow within aquifers are indicated by their respective potentiometric maps (figs. 7 and 9). Lateral flow within the A1 and A2 aquifers northwest of the Millett fault is down gradient from interstream areas of recharge (fig. 2) toward large streams and rivers. In Georgia, Brier Creek and the Ogeechee and Savannah Rivers are shown to be major regional flow boundaries, receiving water directly from both aquifers in updip areas and indirectly by leakance through overlying sediments where the aquifers are deeply buried. Similar flow conditions exist in South Carolina with respect to Upper Three Runs Creek and the Savannah River. The A1 aquifer discharges directly into Horse Creek and Hollow Creek in Aiken County, S.C. Lateral flow in the vicinity of the Savannah River is generally directly toward the river in both aquifers. The A1 aquifer potentiometric configuration northwest of the Millett fault, particularly the narrowing of contours near the Savannah River, has been previously described as a possible manifestation of faulting. The potentiometric gradients suggested by these contours and the A1 aquifer transmissivities described previously (fig. 5) indicate that lateral flow through the A1 aquifer toward the Savannah River between Augusta and the Millett fault is probably relatively large.

Although a significant component of lateral ground-water flow through the A1 aquifer near and northwest of the Millett fault is somewhat parallel to the fault, there is also a smaller component of lateral flow generally toward or against the strike of the fault. As indicated in figure 3, the downdip continuity of sediments within the A1 aquifer has been disrupted at the Millett fault such that thick sections of aquifer sediments are juxtaposed directly against relatively impermeable Triassic rocks. Thus, lateral flow toward the fault must move vertically upward through C1 into the A2 aquifer, or flow into the restricted part of the A1 aquifer southeast of the Millett fault. In the vicinity of the Savannah River, about 60 percent of total A1 aquifer thickness is truncated at the Millett fault (fig. 3) and lateral flow that would otherwise move as underflow down the potentiometric gradient must move vertically upward. In addition, the Savannah River is a potentiometric sink and ground-water movement toward the fault is increasingly vertical with proximity to the river. Thus, significant vertical as well as lateral flow components probably occur within the A1 aquifer northwest of the Millett fault near the Savannah River. As a result, any large-scale lateral transfer of ground water within the A1 aquifer from the northwest to the southeast across the Millett fault probably occurs largely in this area.

Consider that the transmissivity of the A1 aquifer is significantly and immediately reduced downdip of the Millett fault (fig. 5). A complete lateral transfer of water across the fault (no vertical discharge through C1), therefore, would require a large increase in potentiometric gradient near the fault and for some distance downdip. The A1 aquifer potentiometric gradients seem to increase significantly across the fault in South Carolina in the vicinity of the Savannah River; however, this increase is local and generally reverses downdip. In addition, A1 aquifer potentiometric gradients within the wedge of sediments between the Millett and Statesboro faults were described previously as very small and trending north to northwest in the west-central part of Allendale County, directly opposite to the direction expected if ground water was moving laterally across the fault from the northwest. Thus, large quantities of lateral flow are probably not transferred across the Millett fault, near the Savannah River. Rather, most ground water within the A1 aquifer approaching this fault is probably discharged vertically through C1 into the A2 aquifer and, to some degree, into the Savannah River. Prowell and O'Connor (1978) observed 10-inch wide gouge zones in unit UK_2 at the Belair fault (fig. 3). The likelihood that a similar gouge zone of low lateral hydraulic conductivity has formed at the Millett fault restricting lateral ground-water flow, further reinforces the argument that lateral flow through the A1 aquifer across the Millett fault is minimal.

The disruption and truncation of aquifer sediments and the probable occurrence of gouge at the Millett fault indicate that ground-water flow through the A1 aquifer within the wedge of sediments between the Millett and Statesboro faults is probably hydraulically discontinuous from flow within contemporaneous sediments updip. Thus recharge to the A1 aquifer within this wedge probably occurs largely at the northeast and southwest extremities of the Millett fault and at the southwest extremity of the Statesboro fault.

The sediments that comprise the A2 aquifer are offset only slightly at the Millett fault relative to the A1 aquifer (fig. 3) and the hydraulic effects of this offset are consequently probably less severe. Most flow within the A2 aquifer near the fault probably continues laterally across the fault, with some degree of interruption caused by fault gouge and the juxtaposition of offset limestones, sands, and clays.

Within the wedge of sediments between the Millett and Statesboro faults, lateral flow through the A2 aquifer seems to be largely toward Brier Creek and the Ogeechee and Savannah Rivers in Georgia and toward the Savannah and Salkehatchie Rivers in South Carolina.

Vertical Flow

Vertical flow conditions within and between the A1 and A2 aquifers in the vicinity of the Millett fault have been described. Where faulting does not significantly disrupt ground-water flow, the potential for vertical leakance between aquifers is largely dependent on sediment lithology and the direction and size of the vertical potentiometric gradient. Thus, within most of the study area vertical potentiometric differentiation suggests that some water is transferred vertically upward from the A1 aquifer, through C1, and into the A2 aquifer. Such transfers are probably relatively large in the vicinity of potentiometric sinks, particularly near the Savannah River northwest of the Millett fault.

Similarly, within updip parts of the study area, some ground water probably is transferred vertically downward from the A2 aquifer, across or around local confining zones, and into the A1 aquifer. The replica relation of each aquifer to topography has been described previously and also implies some degree of continuity of vertical flow.

Data describing vertical hydraulic differentiation within the A1 aquifer are available at several sites within the SRP and at AL-27 near Martin in northeastern Allendale County, S.C. Christl (1964) reported potentiometric heads in observation wells at the SRP where three clusters of three wells each are individually screened across a 10-foot section of sediments near the bottom, center, and top of the A1 aquifer. Differences in potentiometric head between the bottom and top of the aquifer (about 600 ft) were less than 3 ft in each cluster, indicating only a slight vertical hydraulic gradient within the aquifer. Similarly, at AL-27 (fig. 2) potentiometric heads changed only about 4 ft across the lower two-thirds of total A1 aquifer thickness (about 200 ft). Thus, flow through the A1 aquifer seems to be predominantly lateral at the two sites where definitive data are available. Whether these data are regionally representative presently cannot be determined. Vertical hydraulic gradients within the A1 aquifer near the Savannah River and other large streams updip of the Millett fault probably trend upward and probably are relatively large.

Data describing vertical hydraulic gradients within the A2 aquifer are not available. Vertical flow, however, probably is insignificant within the study area except near regional flow boundaries such as Brier Creek or the Savannah River. This concept is reinforced by a large suite of potentiometric data for Screven County, Ga., which indicates nearly direct hydraulic continuity between the limestones of the A2 aquifer and overlying limestones of late Eocene age. Data reported by Warren (1945) indicate similar continuity near Savannah in Chatham County, Ga.

Based on data from observation and pumping wells located near Fourmile Branch and the Aiken-Barnwell Co. line, Siple (1967) reported the possibility of downward vertical leakance from the A2 aquifer in response to nearby long-term pumping from the A1 aquifer. Mayer (1972) reported little or no leakance between the aquifers as a result of long-term aquifer tests near Snelling in Barnwell County, S.C.

Aquifer Discharge to the Savannah River

The Savannah River has previously been described as a regional potentiometric sink for both the A1 and A2 aquifers. The atypical A1 aquifer potentiometric contour configuration near the Savannah River northwest of the Millett fault and the resulting, relatively large lateral flow toward the river have been described previously as a possible manifestation of faulting. The truncation of A1 aquifer sediments by the Millett fault at the Savannah River and the probable vertical upward transfer of ground water from the A1 aquifer to overlving A2 aquifer sediments have also been described. Northwest of the Millett fault the A2 aquifer is in direct hydraulic continuity with the Savannah River. Consequently, lateral flow from the A1 aquifer toward the Savannah River combined with vertical upward discharge from the A1 aquifer near the Millett fault and the river could contribute anomalously large quantities of ground water to river discharge upstream of the Millett fault. The Ogeechee River, Brier Creek, and the South Fork of the Edisto River are also potentiometric sinks relative to both aquifers.

Contemporaneous gaging-station data have been routinely collected on the Savannah River at Augusta, Ga. (station 02197000), at Burtons Ferry Bridge, Ga. (station 02197500), and near Clyo, Ga. (station 02198500). Corresponding data were collected on Brier Creek near Thompson, Ga. (station 02197520), and at Millhaven, Ga. (station 02198000). Ogeechee River stations of interest to this study are near Louisville, Ga. (station 02200500), at Scarboro, Ga. (station 02202000), and near Eden, Ga. (station 02202500). Data from gaging stations on the South Fork of the Edisto River near Montmorenci, S.C. (02172500) and near Denmark, S.C. (02173000) were also utilized (fig. 2).

Table 2 lists 30-day, 2-year (30-day Q_2) low flows for each station during the indicated period of record. Although the 30-day minimum flow probably does not occur simultaneously at each of the stations of interest, differences in streamflow between the stations are considered indicative of average, predevelopment rates of aquifer discharge to the given reach.

Baseflow is computed as aquifer discharge per square mile of drainage area. Baseflow to Brier Creek and between the two most upstream stations on the Savannah, Ogeechee, and South Fork of the Edisto Rivers is largely contributed from drainage updip of the Millett fault.

Aquifer discharge is contributed to the Savannah River between Augusta and Burtons Ferry Bridge at the rate of 0.74 $(ft^3/s)/mi^2$, which exceeds by a factor of 4 the corresponding discharge to the Ogeechee River between Louisville and Scarboro and exceeds by a factor of 1.6 and 2.0 the corresponding discharges to the South Fork of the Edisto River and to Brier Creek. Within their defined reaches, each of the streams receive discharge from contemporaneous sediments of similar lithologies. The Savannah and Ogeechee Rivers receive discharge from about the same incremental drainage areas (1,200 mi^2). Although the Savannah River is slightly more incised into Coastal Plain sediments than the other streams listed in table 2, differences in incisement are probably not significant where discharge to the river occurs from deeply buried aquifers. Thus, aquifer discharge to major rivers and streams within the study area contributed largely updip of the Millett fault from contemporaneous and lithologically similar sediments is shown to increase both eastward and westward to a maximum at the Savannah River.

Table 2.--Thirty-day, 2-year low flows at selected stations on the Savannah River, Brier Creek, and Ogeechee River, Ga., and the South Fork of the Edisto River, S.C.

U.S. Geological Survey Station No.	Station name	Drainage area (mi^2)	Period of record	30-day Q2 (ft^3/s)	Baseflow ($(ft^3/s)/mi^2$)
02197000	Savannah River at Augusta, Ga.	7,508	1960-70	6,300	
					0.74
02197500	Savannah River at Burtons Ferry Bridge, Ga.	8,650	1960-70	7,150	
					.33
0198500	Savannah River near Clyo, Ga.	9,850	1960-70	7,540	
02197520	Brier Creek near Thomson, Ga.	55	1970-80	2.35	
					.37
02198000	Brier Creek at Millhaven, Ga.	646	1960-70 1970-80	260 220	
02200500	Ogeechee River near Louisville, Ga.	800	[1]1937-49	170	
					.17
02202000	Ogeechee River at Scarboro, Ga.	1,940	1937-71	360	
					.11
02202500	Ogeechee River near Eden, Ga.	2,650	1938-74	440	
02172500	South fork of Edisto River near Montmorenci, S.C.	198	1939-65	117	
					.46
02173000	South fork of the Edisto River near Denmark, S.C.	720	1931-65	358	

[1] Adjusted to 1937-71, see Carter and Putnam (1978).

Aquifer discharge to the Savannah River downstream between Burtons Ferry Bridge and Clyo occurs at the rate of 0.33 $(ft^3/s)/mi^2$ or about 45 percent of the baseflow contributed between Augusta and Burtons Ferry Bridge. Baseflow to the corresponding reach of the Ogeechee River between Scarboro and Eden is 0.11 $(ft^3/s)/mi^2$ and amounts to about 65 percent of the flow contributed between Louisville and Scarboro. More than half the flow contributed to the Savannah River between Burtons Ferry Bridge and Clyo is contributed by Brier Creek (table 2) and is derived largely from sediments updip of the Millett fault (fig. 3). Baseflow to the lower reach of the Savannah River without the contribution from Brier Creek is 0.23 $(ft^3/s)/mi^2$, about twice the rate of baseflow contributed to the comparable reach of the Ogeechee River and only 32 percent of the baseflow contributed to the Savannah River between Augusta and Burtons Ferry Bridge. Thus, downstream trends of baseflow contributed along similar reaches of the Savannah and Ogeechee Rivers indicate that anomalously large aquifer discharges to the Savannah River occur generally upstream of the Millett fault. Similar east-west trends were discussed previously. Thus both east-west and downstream trends indicate anomalously high aquifer discharges to the Savannah River upstream of the Millett fault. Such discharges are possibly an indirect manifestation of the lateral truncation of aquifer sediments by the Millett fault (fig. 3) and the resulting atypical ground-water flow patterns northwest of the fault as well as the suggested vertical movement of ground water updip of the fault near the Savannah River.

SUMMARY AND CONCLUSIONS

Structural, lithologic, and hydraulic data strongly indicate faulting of Coastal Plain sediments near Millett in Allendale, County, S.C. Analysis of cuttings from boreholes immediately updip and downdip of the fault indicate that Upper Cretaceous and lower Tertiary sedimentary contacts show increasing displacement with increasing depth. Vertical offsets range from about 700 ft at the base of Upper Cretaceous sediments to about 20 ft in beds of late Eocene age. In addition, the Upper Cretaceous Middendorf Formation which comprises the basal 500 ft of Coastal Plain sediments on the downblock side of the fault seems to be entirely missing on the adjacent upblock.

Hydraulic discontinuities across the Millett fault include abrupt, large reductions in aquifer transmissivity and local decreases in potentiometric head. Transmissivity of the basal Coastal Plain aquifer is reduced about 75 percent across the fault, largely due to changes in sediment lithology and large reductions in aquifer thickness. Linearly aligned potentiometric anomalies beteen Statesboro, Ga., and Brunson, S.C., and the unusual thickness of Coastal Plain sediments in southern Screven County, Ga., are evidence of the suggested Statesboro fault. Ground-water flow within the basal Coastal Plain aquifer between the Millett and Statesboro faults is probably largely hydraulically discontinuous from contemporaneous sediments updip. Ground-water flow southeast of the Millett fault, is largely toward the Savannah River and to the north and northwest. Near the Statesboro fault, potentiometric gradients are small but flow seems to be from the southwest in Georgia toward the northeast to South Carolina. Lateral ground-water flow within the basal Coastal Plain aquifer is largely disrupted at the Millett fault because of the juxtaposition of hundreds of feet of aquifer sediments against relatively impermeable Triassic rocks. Thus vertical flow probably occurs within the basal Coastal Plain aquifer updip of the fault, especially near the Savannah River and may contribute to the anomalously large quantities of baseflow noted in the Savannah River between Augusta, Ga., and Burtons Ferry Bridge, Ga.

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SUPPLEMENTAL INFORMATION

Map Location of Well-Data Points

Potentiometric, lithologic, and structural data described in this report pertain almost exclusively to well-data points. Location of well-data points in Georgia and South Carolina utilized original source material, when availale, from which described locations were transferred to 7 1/2-minute or 15-minute topographic maps. Such material, for Georgia, consisted largely of well-location maps and well schedules and a drawn and(or) written description of the well location. Wells listed by LeGrand and Furcron (1956) were located using a published well-location map in combination with well-schedule data. A large number of well locations for Georgia were transferred directly from corresponding locations shown on county road maps, topographic maps, and municipal street maps. Well-location maps printed in consultants' reports were utilized extensively in Richmond and Burke Counties. To some degree the accuracy of well locations in Georgia is dependent upon when the well was drilled. The locations of most wells drilled during 1960-81 are known with a high degree of accuracy, and data pertinent to these wells comprise the majority of the data base. The locations of many of the wells listed by LeGrand and Furcron (1956) are known less accurately. Field checks of a representative sample of such wells have indicated, however, that location transfers from the published map and well schedules to quadrangle maps were generally accurate.

The transfer of well-location data to quadrangle maps for South Carolina largely paralleled corresponding efforts for Georgia. The accuracy of well locations in South Carolina, based on U.S. Geological Survey file data, is compromised to a large degree because of the nearly total lack of suitable well-location maps. Consequently, written location descriptions and Army Map Service coordinates listed on well schedules were utilized conjunctively to locate a large number of wells in Aiken, Barnwell, and Allendale Counties. Army Map Service coordinates and given land-surface altitudes were utilized almost exclusively to locate the large number of wells within the SRP listed in Siple (1955) that could not be found in U.S. Geological Survey data files. Well-data points in Orangeburg County were located using well schedules and a published well-location map from Siple (1975). Well-data points in Bamberg and Hampton Counties were located exclusively from well schedules and other pertinent information obtained from U.S. Geological Survey data files. Modern (post-1960) well data pertinent to the SRP are located with a high degree of accuracy based on reported latitudes and longitudes and SRP grid coordinates.

The accuracy of well locations in South Carolina is also somewhat dependent upon the period of time a particular well reconnaissance was conducted. Historical (pre-1960) data are the least accurately located. The lack of well-location maps has been compensated for in this study by carefully applying location descriptions written on well schedules or other original source data to comtemporary county maps and modern quadrangle maps. These efforts in conjunction with Army Map Service coordinates, which commonly are listed on original source materials, have provided locations of historical well-data points of sufficient accuracy to be utilized in this or similar studies. If considered doubtful, the locations of critical well-data points were field checked in both Georgia and South Carolina, wherever and whenever possible.