GEOLOGY AND GROUND-WATER RESOURCES OF ALLENDALE, BAMBERG, AND BARNWELL COUNTIES AND PART OF AIKEN COUNTY SOUTH CAROLINA

by
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Prepared in cooperation with the
Coastal Plains Regional Council

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GEOLOGY AND GROUND-WATER RESOURCES OF ALLENDALE, BAMBERG, AND BARNWELL COUNTIES AND PART OF AIKEN COUNTY, SOUTH CAROLINA

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ABSTRACT

The area of Allendale, Bamberg, and Barnwell Counties and part of Aiken County, South Carolina, is underlain by crystalline rock and sedimentary units that range in age from Precambrian(?) to Holocene. The crystalline basement complex is composed of metamorphic and igneous rocks that crop out to the northwest in the Piedmont Province. Sandstone, siltstone, and mudstone of Triassic age occupy a graben in the Savannah River Plant area. Directly overlying the older rocks are sedimentary units of Late Cretaceous age. These sedimentary units consist of sand, silt, and clay and were deposited as a transgressive-regressive sequence in predominantly deltaic and fluvial environments.

Overlying the Late Cretaceous units are Tertiary-age sediments. These sediments vary in lithology as sand, silt, clay, and limestone, generally becoming progressively more calcareous in the southeast (downdip) direction. Deposition occurred in deltaic and shallow marine environments during a series of marine transgressions and regressions.

In the study area, all of the pre-Cretaceous and Cretaceous units strike in a northeast direction and dip to the southeast at a rate of 10 to 44 feet per mile. The Tertiary units also strike in a northeast direction, except for the Santee Limestone which strikes almost east in the area. These younger units dip southward and southeastward but with a gentler slope (6-21 feet per mile) than the underlying sediments.

Nine or more aquifers are present in the study area. Because of the variability in depositional environments, the hydrologic character of a single aquifer may vary considerably within a short distance. Although all of the aquifers are utilized to some degree, those of the Middendorf and Black Creek Formations of Cretaceous age and the Santee Limestone and Congaree Formation of Tertiary age constitute the aquifers of principal use. Wells screened in the water-bearing units of the Middendorf and Black Creek Formations are capable of producing more than 3,000 gallons per minute. Wells screened in sand beds of the Congaree Formation generally yield several hundred gallons per minute, whereas wells open to the Santee Limestone produce more than 1,000 gallons per minute.

The chemical quality of ground water varies considerably with locale and depth. Water from the Cretaceous formations is very soft and slightly acidic, making it corrosive to metal. Generally, the water ranges from a sodium chloride to a sodium sulfate type, although all ions present are in very low concentrations. The Tertiary Congaree Formation contains water similar to that of the Cretaceous Middendorf, but locally it may contain objectionable amounts of iron. In a downdip direction, the water becomes a calcium bicarbonate type, is moderately hard, and has a pH of about 8.

Water levels in the Cretaceous formations have declined slightly since the period prior to development. The pumping of approximately 11 million gallons per day at the Savannah River Plant has had only minor effects in localized areas. The Santee Limestone and Congaree Formation have also experienced minor water-level declines. Small cones of depression have developed around areas of heavy pumping.

INTRODUCTION

As a part of the South Carolina Water Resources Commission's continuing program of ground-water studies, the area of Allendale, Bamberg, and Barnwell Counties and part of Aiken County has been the subject of investigations to assess the ground-water resources. These and future studies will provide the information necessary for the proper development, management, and protection of ground water in the area.

Ground water in Allendale, Bamberg, and Barnwell Counties is the major source of water supplies; it accounts for 75 percent of total water supply in the area. Within these counties, all water used for public and domestic purposes is obtained from wells. The need for ground-water information about occurrence, availability, and chemical quality is of primary importance, because dependence on this source is great and will continue to increase with growing population and expansion of agriculture and industry.

PURPOSE AND SCOPE

The purposes of this investigation were to: (1) expand the existing data base of hydrogeologic information to determine the occurrence, distribution, availability, and general quality of ground water in the area and (2) upon evaluation of the resulting data, recommend appropriate studies and/or ground-water management. The information obtained during this investigation has been used to construct the following maps and diagrams for the area: geologic sections, surface-configuration and thickness maps of the formations, water-level maps of various aquifers, and diagrams showing water quality variations areally and vertically.

DATA COLLECTION

Initial work for this study consisted of the compilation of water-well and related data from numerous public supply, domestic, industrial, and irrigation water-supply facilities. The data were obtained from several sources (in addition to previously published reports): well owners, drillers, and files of the South Carolina Water Resources Commission (SCWRC), United States Geological Survey (USGS), South Carolina Department of Health and Environmental Control (SCDHEC), and Department of Geology at the University of South Carolina. Records of 815 wells have been obtained in the three-county area and the part of the Savannah River Plant (SRP) that is in Aiken County.

Geophysical logs of approximately 175 wells were obtained through the cooperative SCWRC-USGS geophysical logging program and from various other sources such as well drillers and engineers, SCDHEC, and the University of South Carolina. These logs were used primarily for the correlation of geologic formations so that geologic sections, surface-configuration maps, and thickness maps could be constructed. The types of geophysical logs used in the geologic sections are natural-gamma, electrical spontaneous-potential, and electrical resistivity.

Other geologic data were obtained through the collection of drill cuttings from several wells, through the analysis of drill cores, and through auger hole descriptions by the South Carolina Geological Survey.

Water level data were collected from wells as part of a continuous program to monitor water levels in various aquifers throughout the State. Measurements of observation wells in the study area were made during July 1985 to permit construction of the potentiometric maps included in this report. Additional wells are continually being incorporated into the monitoring network, and, as funding permits, test wells will be drilled for monitoring water levels and water quality.

In addition to water level information from the monitoring network, several hydrographs were obtained from the Savannah River Plant and were used in determining the effects of increased pumping at SRP on water levels at and near the plant.

Water samples were collected from approximately 100 wells in the area and were analyzed by the SCWRC laboratory in Columbia for chemical constituents. Additional analyses were acquired from the USGS, SCDHEC, and private laboratories. Representative analyses from each major aquifer in the area were used to construct diagrams depicting characteristic water types for each aquifer.

The properties and constituents that were measured by the SCWRC laboratory are alkalinity, acidity, hardness, total dissolved solids, suspended solids, calcium, chloride, fluoride, iron, magnesium, manganese, nitrate, potassium, silica, sodium, and sulfate. Properties determined at the time each sample was collected are pH, conductivity, and temperature.

Four water samples were collected from each well. Of these, one sample was treated with nitric acid to retard oxidation and precipitation of any metals present. This sample was not filtered. Two other samples were filtered through 40-micron filters to differentiate between dissolved and total concentrations of various constituents. One of these two samples was then treated with acid. The remaining sample was not treated.

PREVIOUS AND CURRENT INVESTIGATIONS

The geology of the study area was described, to some extent, as early as the nineteenth century by Tuomey (1848), Darton (1896), and Dall (1898), with Darton and Tuomey including general ground-water information in their descriptions. Later reports discussing geology, stratigraphy, fossil identification, and ground-water information include those by Glenn (1905), Sloan (1908), Veatch and Stephenson (1911), Cooke (1936), Lang (1940), Siple (1946,1967), and Cooke and MacNeil (1952).

The 1960's brought a marked increase in both geologic and hydrogeologic papers. Heron (1962) reported on the limestone resources of several counties in the vicinity of the study area; Callahan (1964) discussed the yields of sedimentary aquifers of the southeastern Coastal Plain river basins; Colquhoun (1965) reported on the terrace sediment complexes of central South Carolina; Siple (1967) discussed the geology and ground water of the Savannah River Plant and vicinity; Colquhoun and others (1969) released a detailed description of the stratigraphy of the Paleocene and Eocene strata in central South Carolina and north-central Georgia; and Swift and Heron (1969) discussed Cretaceous stratigraphy of South Carolina.

The effort to define the complex hydrogeology of the area continued through the 1970's to the present, and numerous reports have been published. Notable reports include: a 1974 report by Marine and Siple on a buried Triassic basin in the Savannah River area; Woolen's 1979 thesis on the structure, lithostratigraphy, and depositional environment of Cretaceous sediments in eastern South Carolina; Oldham's 1981 report on the surface and subsurface geology of portions of Aiken, Orangeburg, Bamberg, and Barnwell Counties; Bechtel's 1982 extensive report for Georgia Power on the proposed Millett Fault; and the report by Colquhoun and others (1983) discussing surface and subsurface stratigraphy, structure, and aquifers of the South Carolina Coastal Plain.

Concurrent with the Commission's study in the SRP area are studies being conducted by other State and Federal agencies, the University of South Carolina, and SRP. The South Carolina Geological Survey is conducting a surface geology mapping project in the area, and the United States Geological Survey is constructing geologic sections through Georgia and South Carolina that transect the SRP area. The Department of Geology, University of South Carolina, is studying the surface and subsurface stratigraphy of Aiken, Allendale, and Barnwell Counties. The Savannah River Plant is proceeding with two hydrogeologic projects: a well-cluster system, consisting of 18 cluster sites, is being constructed on the plant site to correlate stratigraphic sequences and to determine hydraulic characteristics of the various aquifer systems beneath the plant; and hydrogeologic studies are being conducted in the M area of the plant to determine transmissivity and flow velocities of underlying aquifers. SRP has also contracted the services of Geotrans, Inc., to conduct a groundwater flow study of the plant and surrounding area. In addition to these studies, the South Carolina Department of Health and Environmental Control regulates ground water at SRP through its Hazardous Waste, Wastewater, and Water Supply programs.

PHYSIOGRAPHY

Allendale, Bamberg, and Barnwell Counties lie within the western portion of the South Carolina Coastal Plain Province. The three-county area is bordered by Aiken County on the north, Orangeburg County on the east, Colleton and Hampton Counties on the south, and the Savannah River on the west (Fig. 1).

Three major river sub-basins share in draining the study area. The Edisto River sub-basin encompasses portions of Bamberg and Barnwell Counties. Although this basin is drained by four major rivers, only the South Fork Edisto and its tributaries are within the study area (Fig. 2). The South Fork Edisto forms the county lines between Barnwell and Orangeburg Counties and between Bamberg and Orangeburg Counties and thus forms the eastern border of the study area.

The Combahee-Coosawhatchie River sub-basin encompasses a major portion of the study area, with portions of all three counties lying within this sub-basin. Of the major streams draining this sub-basin, the Salkahatchie River, the Little Salkahatchie River, the upper end of the Coosawhatchie River, and their tributaries are those which flow through the study area.

The Lower Savannah River sub-basin includes the western portion of Allendale and Barnwell Counties. The Savannah River and its local tributaries drain the region, with the Savannah River forming the western boundary of the study area. The Savannah River is the largest stream in the study area.

Siple (1967) identified the major landforms in the area as the Aiken Plateau and the coastal terraces. He described the Aiken Plateau, which lies between the Savannah and Congaree Rivers and extends southeastward from the Fall Line to the inland border of the coastal terraces, as a highly dissected upland plain. Dissecting streams have created relief of as much as 300 ft (feet) in some localities.

The coastal terraces extend from the Aiken Plateau to the coast. There are at least five terraces in the study area, each marking the position of previous sea levels and the corresponding offshore bars. These terraces are known as the Brandywine (elevation 270 ft m.s.l. [mean sea level]), the Coharie (215 ft m.s.l.), the Sunderland (170 ft m.s.l.), the Okefenokee (145 ft m.s.l.), and the Wicomico (100 ft m.s.l.).

CLIMATE

The prevailing climate of Allendale, Bamberg, and Barnwell Counties is temperate and is controlled largely by the air masses and pressure systems that move across the Nation throughout the year. Maritime air dominates the summer months, when migrating storms are weakest, and modified continental air dominates the winter months.

Summer temperatures are quite warm, characteristic of the South. There are, on the average, two to four days with temperatures of 100 degrees Fahrenheit or higher. Summer rainfall is about one-third of the annual total and falls mainly in the form of afternoon showers or thunderstorms.

The fall season, being a transition between extremes, is generally considered the most pleasant time of the year. Rainfall is at a minimum (about one-fifth of the annual total) and sunshine at a relative maximum. September is the month with the highest frequency of hurricane occurrence for the western Atlantic and Gulf of Mexico, and these storms occasionally produce large amounts of rain in the area.

The winter season is mild. Cold outbreaks occur but are usually of short duration. Days with maximum temperatures of 32 degrees Fahrenheit or less have been observed about 25 times in the past 30 years. Snow flurries occur in the area, but snowfalls of 1 inch or more occur on an average of only 5 times in each 10-year period.

Spring is marked by rapid changes from windy and cold in March to generally warm and pleasant in May. This is the season when severe thunderstorms and tornadoes are most frequent.

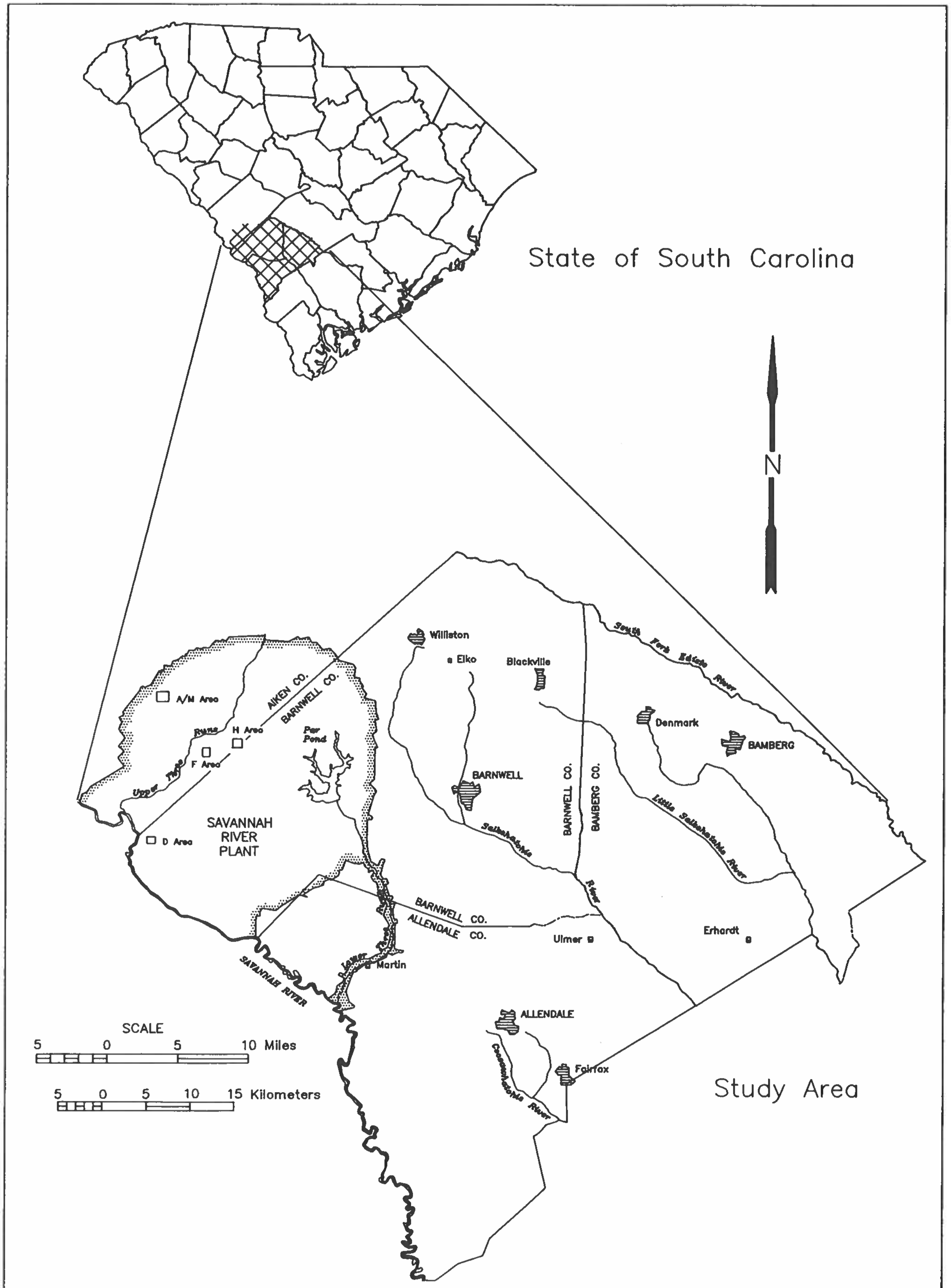


Figure 1. Location of the study area.

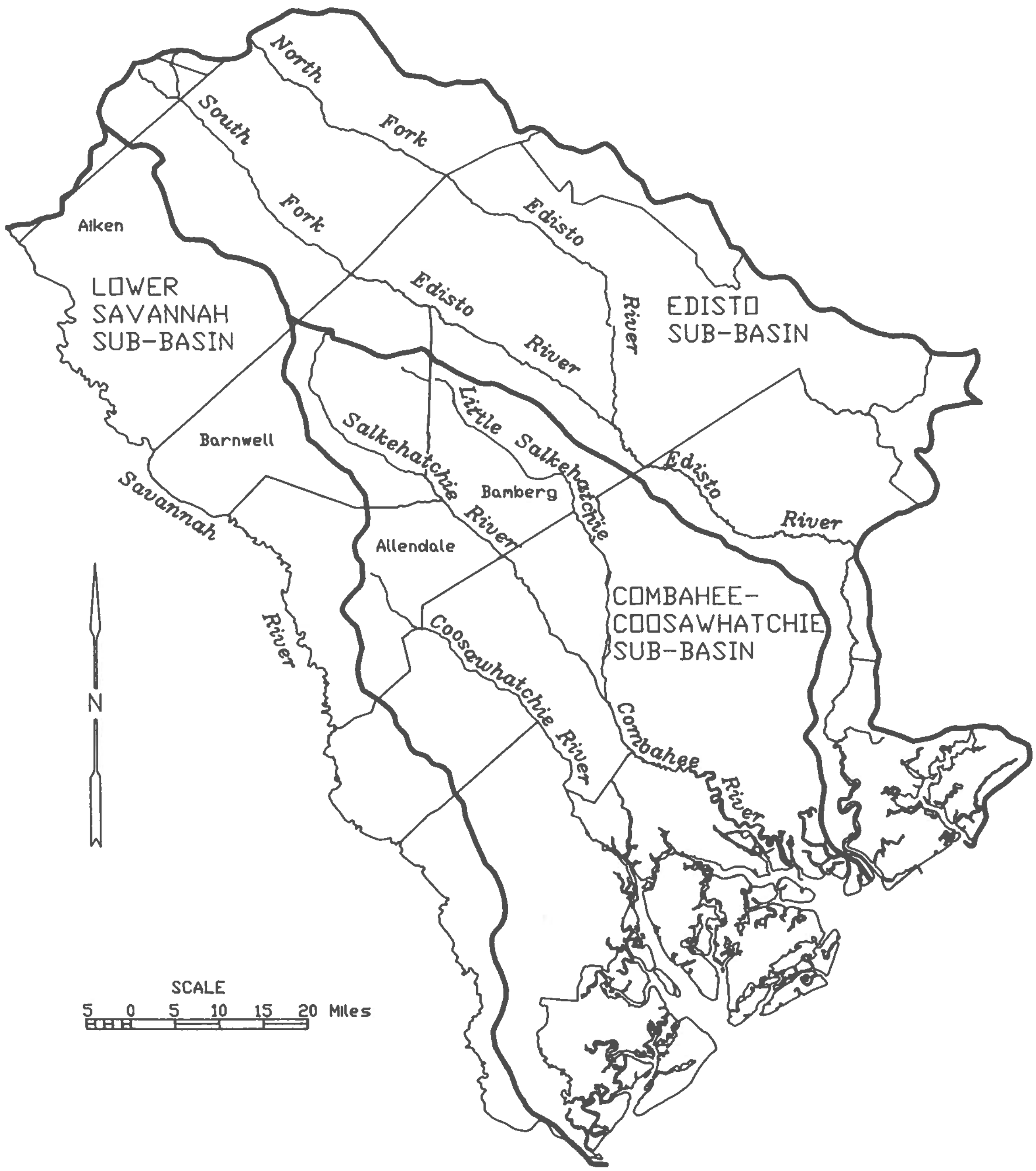


Figure 2. Drainage in the study area and vicinity.

The greatest 24-hour rainfall that, on a 100-year average, may be expected in the area is 8.6 inches, while at least 4 inches or more in a 24-hour period occurs on the average of once every 2 years.

SOCIOECONOMICS

The 1980 population of the three-county area was estimated at 48,800, approximately 1.5 percent of South Carolina's total population. The area is primarily rural in character; the major centers of 1980 population were the cities of Barnwell (5,556), Allendale (4,362), Denmark (4,138), and Bamberg (3,633).

The mean per capita income for the three-county area in 1980 was less than the average for the State. Employment types of nonagriculture wage and salary workers were manufacturing, government, wholesale and retail services, and mining.

WELL-NUMBERING SYSTEM

The South Carolina Water Resources Commission assigns numbers to wells on the basis of their location as determined by use of a latitude-longitude grid system. The entire State is divided into a matrix of grids of 5 minutes of latitude and 5 minutes of longitude. Each of these 5-minute grids has a corresponding number and upper-case letter(s), for example, 36Y. The 5-minute grids are further divided into twenty-five 1-minute latitude-longitude grids, each having a corresponding lower-case letter "a" through "y", for example, 36Y-e. As wells are located within a 1-minute grid, they are numbered consecutively; for example, the first well inventoried in 36Y-e would be assigned the number 36Y-e1. The grid system is illustrated in Figure 3. All wells noted in this report are referred to by their grid number. The location of these wells is shown in Figure 4.

In addition to a SCWRC grid number, each well is assigned a county number. This number consists of a three-letter abbreviation for the county name and a sequentially assigned number. For example, BAM-62 represents the sixty-second well that was inventoried in Bamberg County.

ACKNOWLEDGMENTS

The authors of this report would like to express their gratitude to the staff members of the South Carolina Water Resources Commission, U.S. Geological Survey, South Carolina Geological Survey, South Carolina Department of Health and Environmental Control, the Geology Department of the University of South Carolina, and the Savannah River Plant for their assistance in obtaining information used in this study. Particular thanks go to the former Coastal Plains Regional Council, which provided much of the project funding.

GEOLOGIC FRAMEWORK

The Allendale-Bamberg-Barnwell Counties area is underlain by various rock units representing a variety of depositional environments. At the base of these units is the crystalline and metamorphosed sedimentary rock basement, the surface of which has been tilted to the southeast. The younger sedimentary units overlying this basement form a wedge that thickens from the Fall Line to the coast. Thickness of these sediments is practically zero at the Fall Line and increases to 1,500 ft in the vicinity of Myrtle Beach and more than 4,000 ft in the southern extremity of the State. The sediments vary in lithology, reflecting the alternating non-marine and marine environments that led to the deposition of sand, silt, clay, and limestone. The formations that the authors believe to be present in this area are described in Table 1; however, without paleontological evidence, verification of these formations and their boundaries cannot be made. Until such data become available, the authors are presenting their preliminary correlations in this report.

In the study area, the Upland unit, the Hawthorn Formation, and the Barnwell/Cooper Group can be seen readily in outcrop, with the McBean and Congaree Formations cropping out occasionally in stream channels. All other formations occur only in the subsurface. These stratigraphic sequences are illustrated in geologic sections A-A′, B-B′, and C-C′ (Plate).

Although numerous investigators have described the stratigraphic column and attempted to correlate the geologic formations of western South Carolina, a variety of geologic problems has complicated this task. Scarcity of type localities is a major problem. Not all formations are characterized by a type locality; some occur only in the subsurface, whereas others did not have a type locality designated by the originators of the unit names. Type localities that have been designated and are accessible to the investigator are often difficult to reach (such as undercut creek banks) or are a great distance from the study area. Exposures are often of limited extent and poor quality.

The geologic complexity of the region creates another major set of problems. The area is characterized by deltaic and alternating marine and non-marine depositional features. Abrupt changes in lithology occur, particularly where deltaic sediments and marine sediments meet. Without fossil evidence, similar lithologies of separate delta systems may lead to incorrect correlation of units.

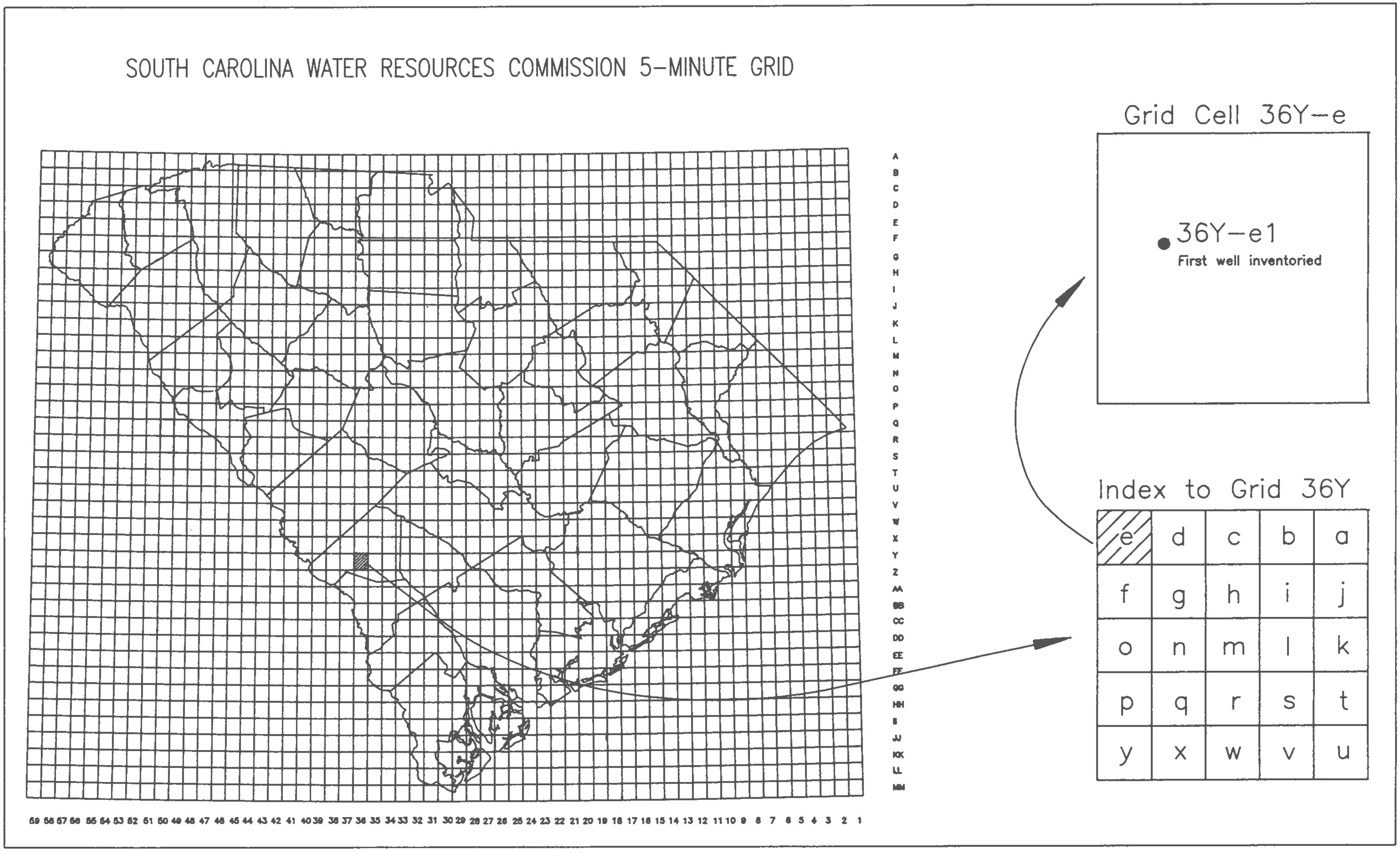


Figure 3. Illustration of the well-numbering system.

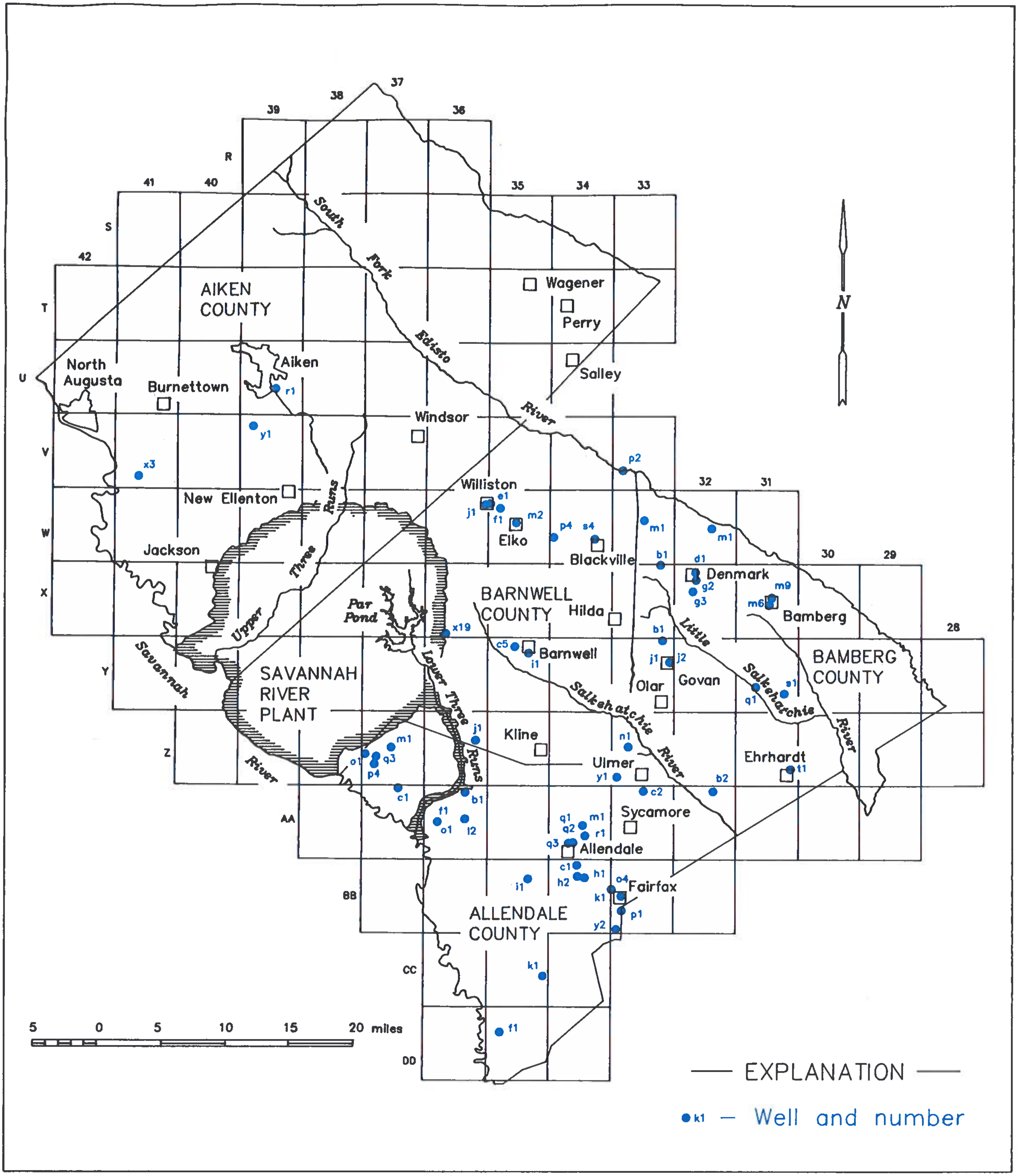


Figure 4. Location of selected wells.

Table 1. Summary of geologic formations and corresponding lithologies

Upland unit	Pink, orange, red, and purple, poorly sorted sandy clay to clay. Quartz cobbles and clay clasts of varying size are common. Sand content is variable, locally micaceous, and contains heavy minerals.
Hawthorn Formation	Updip: pink, tan, or gray, well-sorted, coarse-grained, slightly feldspathic sand containing halymenites. Downdip: gray or green, fine- to coarse-grained clayey sand, sandy clay and clay.
Barnwell/ Cooper	Updip: red, brown, or tan sand, clayey sand, and calcareous fossiliferous sand. Fine to very coarse grained, poorly sorted to well sorted. Heavy minerals, mica, and chert are locally present. Downdip: variable--tan, olive to gray sand, shelly sand, limestone beds, and marl.
McBean Formation	Tan, yellow, or orange, fine to medium sand and clayey sand. May also be olive silt and clay. Lower portion locally calcareous with concentrations of fossils.
Santee Limestone	White, creamy yellow to gray, fossiliferous, occasionally glauconitic limestone with numerous bryozoa. May be interbedded with gray or greenish-gray sand or clay. Very sandy in its updip extent.
Warley Hill Formation	Fine, green to yellow, noncalcareous to calcareous, glauconitic sand.
Congaree Formation	Yellow, brown, green, or gray, fine- to coarse-grained quartzose sand and interbedded silty, sandy, light-green montmorillonitic clay. Locally becomes calcareous in its downdip extent.
Black Mingo Formation	Updip: black, fissile siltstone, light-gray to black clay, commonly micaceous, interbedded with layers of fine to coarse sand and clayey sand. Downdip: unit becomes greenish-gray, glauconitic, sandy limestone and gray, fine to very coarse sand with phosphate.
Ellenton Formation	Updip: light-gray to black, sandy, lignitic, micaceous clay interbedded with medium- to coarse-grained quartz sand. Downdip: unit becomes white, gray to pink, medium- to very coarse-grained sand with quartz pebbles, interbedded with layers of clayey sand and siltstone.
Peedee Formation	Updip: white or light-gray, very micaceous silt and sand. Downdip: becomes gray to pink and tan, medium to very coarse sand interbedded with layers of clayey sand, contains thick sections of dark-gray clay.
Black Creek Formation	Updip: light-gray to black, montmorillinitic, kaolinitic, micaceous and lignitic clay interbedded with layers of medium- to coarse-grained sand and clayey sand. Downdip: becomes dark-gray or brick-red argillaceous, fine- to medium-grained sand.
Middendorf Formation	Updip: light-gray to black, micaceous and lignitic clay interbedded with layers of tan to gray, fine to coarse sand and clayey sand. Locally contains lenses of pink, red, and brown clay. Downdip: section is gray, tan, and brick-red, medium to very coarse, feldspathic sand and clayey sand.
Cape Fear Formation	Olive to greenish-gray to tan, poorly sorted, fine- to very coarse-grained sand with quartz and feldspar pebbles in a matrix of clay. High cristobolite content.

Some formations have been partially to totally eroded in areas, streams have dissected the topography through geologic time, and channels have been filled with sediments foreign to the original depositional environment. Being situated close to the Fall Line in the northern portion of the area, several formations terminate or "pinch out" in the subsurface. As the formations extend farther downdip, they also undergo facies changes, grading both laterally and vertically into different lithologic units. In addition, many of the formations present are non-fossiliferous, making biostratigraphic and chronostratigraphic correlation difficult.

Although geophysical logs from several water wells in the area are available, not all of them are useful in correlating formations. Some are of poor quality and others are from shallow wells, limiting the amount of vertical data. Even logs of good quality are often of little help in correlation, as log signatures vary drastically within the same formation owing to facies changes, mineralogical changes, and changes in the chemical characteristics of the water in the formation.

Another set of problems comes from the previous investigators, many of whom, as they examined the stratigraphic column, approached it with different points of view. Depending upon their interest, different investigators have divided the stratigraphic column on the basis of biostratigraphy or chronostratigraphy or lithostratigraphy, with each column likely to have boundaries different from the others.

In addition to the complexities of the geology, and assuredly a partial result of this problem, the geologic community has conflicting opinions concerning the nomenclature of the formations. Within this study area, a single formation has had as many as three names applied to it. The differences in nomenclature occur not only with a single formation but also with groups of formations as one investigator may combine several formations described by another investigator and apply a single and different formation name. This classification and reclassification results in substantial confusion. For the purpose of this report, the authors are using the stratigraphic units listed in Table 2, modified from Siple, 1967.

Superimposed on the problem of formation nomenclature is the problem of aquifer nomenclature. Many hydrologists are of the belief that aquifer names should reflect the names of the formations in which they occur, which often presents problems when an aquifer transgresses several formational boundaries. Other hydrologists believe aquifer names should be separate from formation names, creating some confusion, particularly to the layman, when trying to associate it with its respective geologic formation.

DEPOSITIONAL ENVIRONMENTS

The types of sediments that were deposited in the study area were controlled by the environmental conditions during the period of deposition. As the depositional environment changed, so did the type of sediments that were deposited. Additionally, with change in sediment type, change in hydrologic properties occurred.

In an area where deposition of sediments occurs, there commonly are numerous depositional environments. These depositional environments reflect variations in physical, chemical, and biological conditions and the distance from the source of sedimentary material. The sediments will have characteristics that are indicative of their depositional environment.

Depositional environments vary from one area to another. Because there is lateral variation in depositional environments, a geologic formation will differ lithologically from one location to another. In addition, depositional environments also shift their position through time. As this occurs, the sediments will succeed one another in a vertical depositional sequence that reflects the sequence of environmental conditions. This concept is known as Walther's Law.

Changes in depositional environment are the result of several factors, but the primary factor is change in sea level. A rise in sea level is termed transgression and a fall in sea level is termed regression. When transgression occurs, adjacent sedimentary units shift landward. Transgressive sediments tend to become finer grained in an upward direction through a vertical sequence of deposits. When regression occurs, adjacent sedimentary units shift seaward. Regressive sediments tend to become coarser grained in an upward direction through a vertical sequence of deposits. During periods of regression, some sediments that were once below sea level are left exposed. These sediments are then subject to erosion.

In the study area, three general types of depositional environments are prevalent: fluvial, deltaic, and marine. In a fluvial environment, the river erodes terrestrial material and transports it downstream. The coarsest material is deposited first as the stream loses energy. As current velocity diminishes in a downstream direction, the river is capable of transporting only the finer material. Gravel and coarse sand are deposited as bedload (channel lag) on the river channel bed. Smaller-grained sand is deposited as point bars on the inside bends of the meandering river. Occasionally, the river will rise over its banks and leave deposits of sand and silt adjacent to the channel, forming natural levees.

Table 2. Stratigraphic units

SERIES	EUROPEAN STAGE	PROVINCIAL STAGE	THIS REPORT
MIOCENE	Undifferentiated	Undifferentiated	Upland unit/ Hawthorn
OLIGOCENE	Chattian	Chickasawhayan	
	Rupelian	Vicksburgian	
EOCENE	Priabonian	Jacksonian	Barnwell
	Bartonian		
	Lutetian	Claibornian	McBean Santee
	Ypresian		Warley Hill Congaree
PALEOCENE	Thanetian	Sabinian	Black Mingo
	Danian	Midwayan	Ellenton
UPPER CRETACEOUS	Maestrichtian	Navarroan	Peedee
	Campanian	Tayloran	Black Creek
	Santonian	Austinian	Middendorf
	Coniacian		Cape Fear
	Turonian	Eaglefordian	

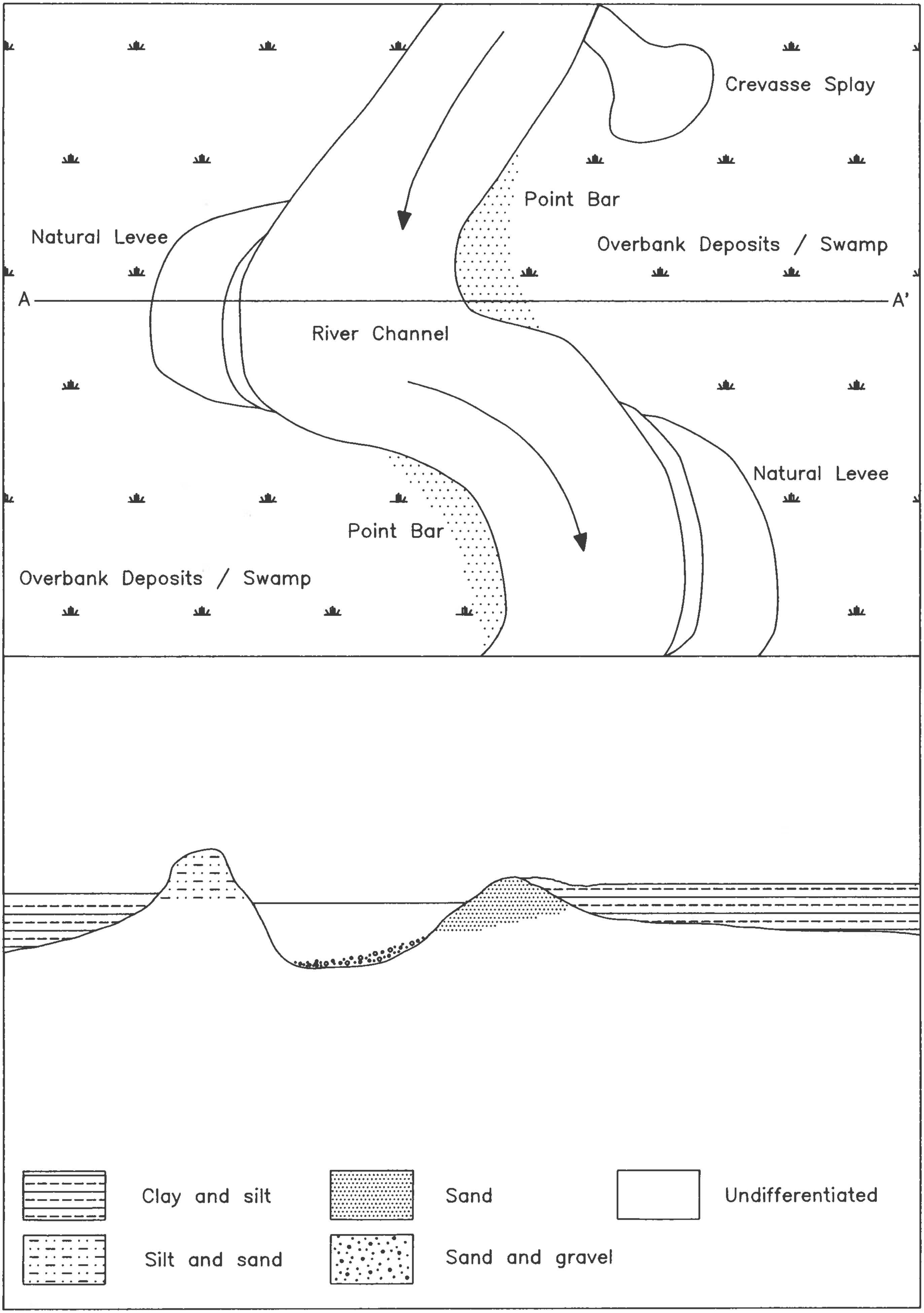


Figure 5. Schematic map and cross section of fluvial-environment deposits.

When natural levees are breached, cravasse splay deposits are left on the lowlands adjacent to the levess. A diagram of a fluvial environment is shown in Figure 5.

In the study area, the majority of sediments that were deposited in fluvial environments were derived from the Appalachian Mountains and adjacent elevated areas of the Piedmont. Physical and chemical weathering of these highlands resulted in erosion. Drainage over these weathered materials caused further erosion and provided a transportation medium for the material to seaward locations.

As with the fluvial environment, the river is also an important transport medium in the deltaic environment. Unlike the fluvial environment, however, the deltaic environment is influenced by the sea. The delta plain, the level or nearly level surface composing the landward part of a large delta, can be divided into the upper delta plain and the lower delta plain (Fig. 6). The upper delta plain receives the coarsest deposits and shows little or no marine influence. The river migrates across the upper delta plain and leaves much the same deposits as in a fluvial environment. Interdistributary bays occur between tributaries of the main channel. Flooding fills these depressions with silt and clay and occasional organic material. The lower delta plain receives marine influence as the sea level fluctuates from high to low tide. Deposits are generally finer grained than those on the upper delta plain and often contain fossil marine organisms. Swamps and marshes occur adjacent to the distributary channels, and interdistributary bays occur between tributaries.

The delta front (Fig. 6) occurs at the effective depth of wave erosion and consists of sandy silt, silt, and clay. Shells, plants, and mud clasts are common. The prodelta, the seaward edge of the delta, occurs below the effective depth of wave erosion and is entirely below the water level. Prodelta sediments consist of silt and clay.

Although several types of marine environments exist, for the sake of simplicity, marine depositional environments will be grouped together and discussed in a general manner. Figure 7 is a generalized diagram of marine depositional environments. The most landward marine deposits occur at the shoreface and on tidal flats and salt marshes. Shoreface deposits consist of material eroded from the land surface. They occur where land meets sea and are therefore subject to the high energy of wave action. The tidal flat deposits vary from sand to mud. Salt marshes are predominantly mud and are rich in organic material.

Seaward of the shoreface is the transition zone. Sediments here are sand and clay. Seaward of the transition zone is the shelf. The shelf can be divided into three parts: the shallow siliciclastic (noncarbonate) shelf, the deep siliciclastic shelf, and the carbonate shelf. Variation among these is based upon the type of sediment that is present. Additionally, the depth of water is an important factor in the type of sediment that will be deposited or precipitated.

The depositional environment affects the hydrologic properties of the sediments that are deposited. Generally, the best aquifers occur where the coarsest and/or most well-sorted sediments are deposited, such as channel and point bar deposits of both upper and lower delta plains; lower delta plain barrier islands, tidal channels, and beach deposits; and shallow siliciclastic shelf sand deposits. Additionally, limestone of deep siliciclastic and carbonate shelf deposition is good aquifer material, particularly limestone that consists of sand-size grains or has interconnected solution openings. Confining beds occur where the finest grained, least permeable sediments are deposited and typically consist of interdistributary-bay and overbank-flood deposits on the upper and lower delta plain; swamp and marsh deposits of the lower delta plain; and silt, clay, and marl of delta front, prodelta, and deep siliciclastic shelf deposits.

REGIONAL UNCONFORMITIES

An unconformity is a substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession, such as an interruption in the continuity of a depositional sequence of sedimentary rocks. Unconformities result from a change that caused deposition to cease for a considerable span of time; it normally implies uplift and erosion with a loss of previously deposited sediments (Bates and Jackson, 1980). It is common practice among stratigraphers to differentiate sedimentary units on the basis of associated unconformities. Sediments occurring between two unconformities are assigned to a single group or formation and represent a continuous sequence of deposition.

Colquhoun and others (1983) suggested that unconformities recognized in the South Carolina Coastal Plain are of regional extent. This is because sediments below the unconformities are eroded, different ages have been assigned to sediments above and below the unconformities, and interruptions in fossil sequences occur at the unconformities. Eleven such regional unconformities were recognized in the South Carolina Coastal Plain by Colquhoun and others (1983). Nine of these occur in the study area between the following units:

1. Piedmont rocks and Middendorf Formation;
2. Middendorf Formation and Black Creek Formation;
3. Black Creek Formation and Peedee Formation;
4. Peedee Formation and Rhems (Ellenton) Formation;

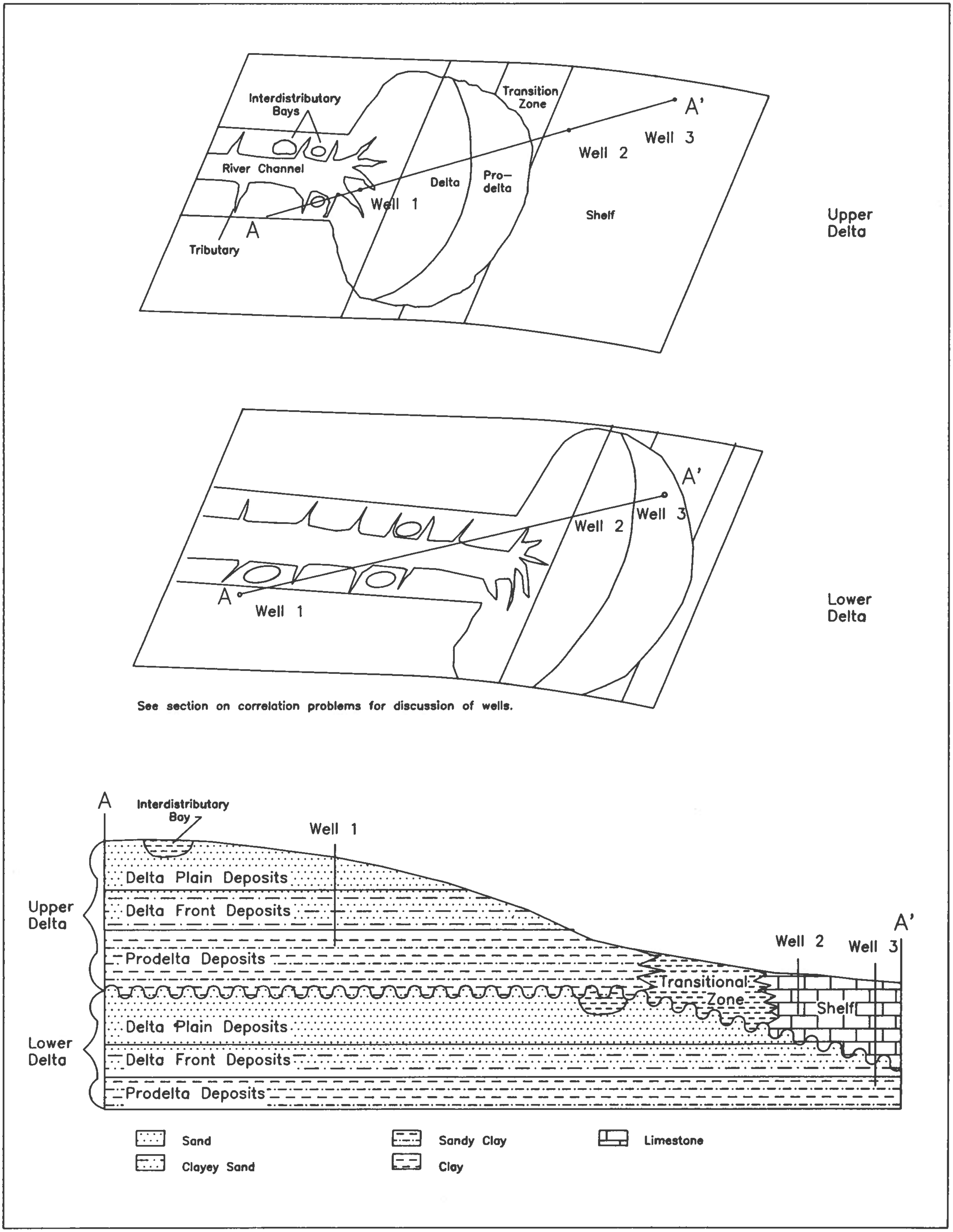


Figure 6. Overriding-delta depositional environment.

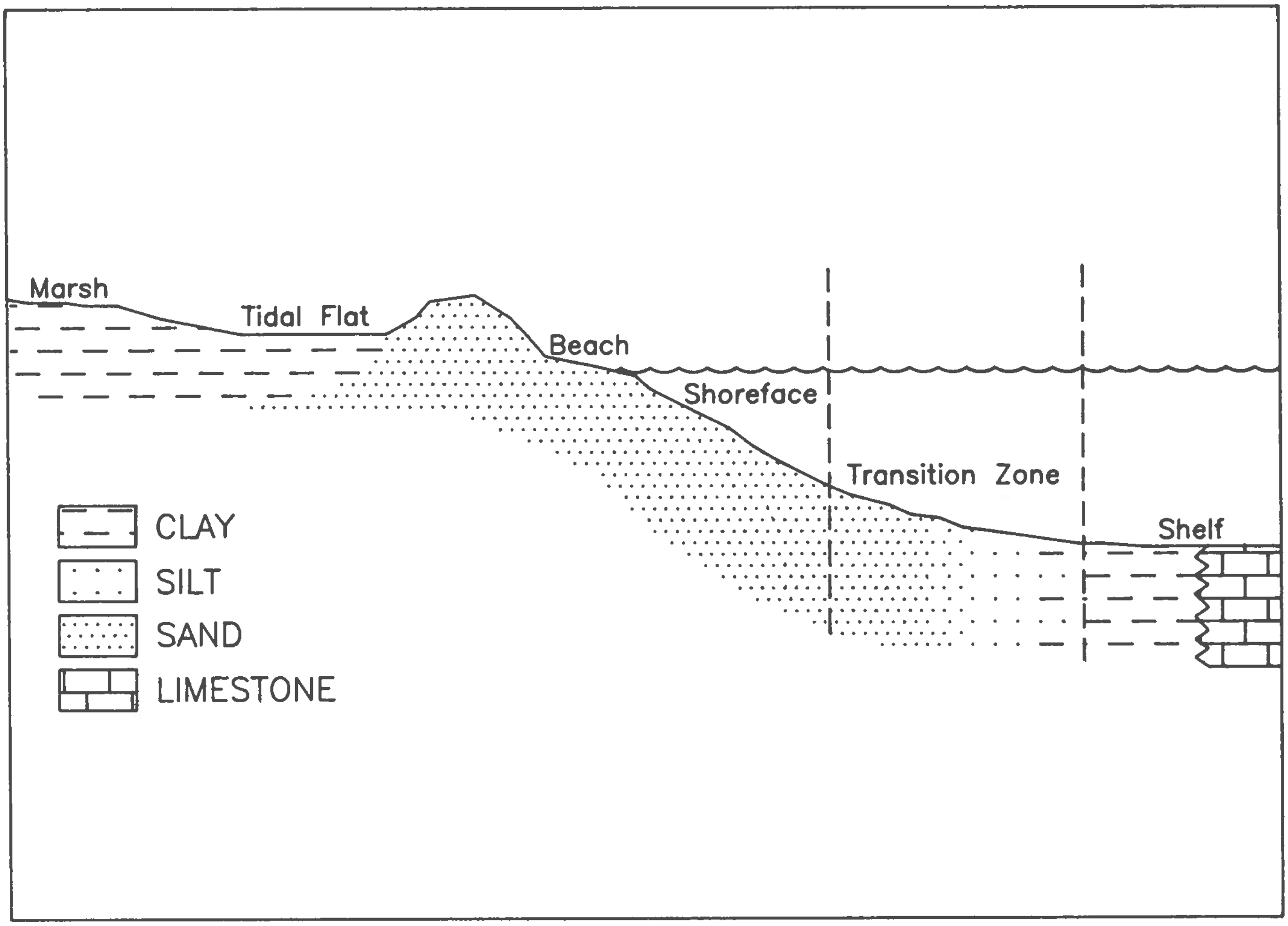


Figure 7. Generalization of marine depositional environment.

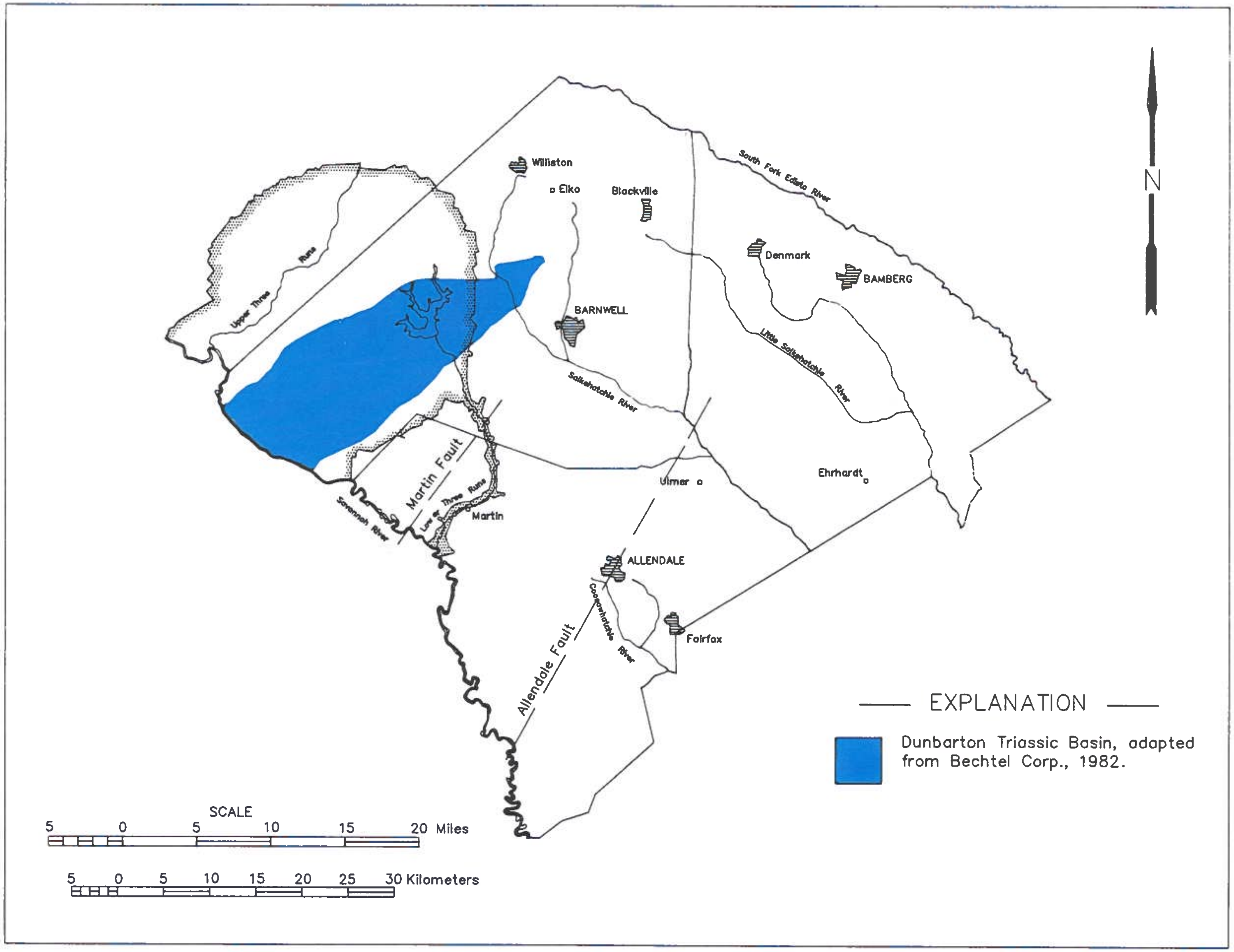


Figure 8. Tectonic features in the study area.

5. Rhems Formation and Williamsburg (Black Mingo) Formation;
6. Williamsburg Formation and Orangeburg Group (McBean and Congaree Formations, Santee Limestone, and Warley Hill Formation);
7. Orangeburg Group and Cooper Group (Barnwell Group updip);
8. Cooper Group and Hawthorn Formation (Upland unit updip); and
9. Tertiary subcrop and Pliocene-Pleistocene section.

TECTONIC FEATURES

The tectonic framework of an area is the combination or relationship in space and time of subsiding, stable, and rising structures or deformational features. Sedimentation is dependent upon tectonic uplift and subsidence, as such movement results in the raising and lowering of sea level and creates sediment source areas and depositional sites.

In the study area, the oldest identified tectonic feature is the Dunbarton Basin, presumably of Triassic age (Fig. 8). The first discussion of the Triassic basin was presented by Siple and Marine (1966). The basin is the probable result of normal faulting, which created a graben. Marine (1976) presented evidence for a northwest border fault and additionally suggested faulting for the southeast border.

Oldham (1981) postulated two faults in Allendale and Barnwell Counties, the Martin and Allendale faults. These faults have been indicated on Figure 8 and the Plate in this report. The Martin fault is located in the northwestern part of Allendale County near the town of Martin. It extends from the Savannah River through Allendale County into the southern portion of Barnwell County. The fault actually may be more extensive, but current information is sufficient only for the extent that is shown. The fault trends N. 35° E.; its dip is not known. Sediments on the northwest side of the fault have been downthrown relative to sediments on the southeast side. The sparse data from the area indicate a maximum vertical offset of 140 ft and a minimum vertical offset of 40 ft. Possible explanations for such a great range are: 1) average dip for each formation was used to calculate offset; 2) formations have different dip; 3) data used to estimate offset were not oriented perpendicular to the strike of the formations; 4) activation of the fault during various periods of deposition; 5) error in identifying the surface of a formation; and 6) thickening of sediments downdip caused by other structural features. Without points of data immediately adjacent on either side of the fault, an accurate value for vertical displacement cannot be determined.

Data indicate that faulting occurred after upper Eocene (Jackson) time or possibly at intermittent intervals between the late Cretaceous (Campanian) and upper Eocene Epochs. Sufficient data are not available to determine whether activation of this fault occurred prior to the Campanian Stage or when movement along this fault ceased.

The Allendale fault extends from the Savannah River through the town of Allendale into the southeast tip of Barnwell County and a small portion of Bamberg County (Fig. 8). As with the Martin fault, the Allendale fault may be more extensive than shown, but sufficient information is not available to make that determination. The fault trends N. 29° E. and its dip is not known. Sediments are downthrown on the northwest side of the fault relative to sediments on the southeast side. Sparse data from the area indicate a vertical offset of 20 to 90 ft.

The Allendale fault may have been activated as early as late Cretaceous (Maestrichtian) time. There are not sufficient data from this study to determine if faulting occurred prior to that time. It is indicated, however, that activation of this fault ceased during the middle Eocene, as displacement is apparent at the base of the Santee Limestone and not at the top.

Although there are not sufficient data from this study to substantiate the presence of the Bamberg Warp, Colquhoun and others (1983) suggested its presence as an abrupt increase in thickness of sediments between the base of the Black Mingo Group (base of the Ellenton Formation) and the top of the Middendorf Formation. The sediments thicken approximately 300 ft from the southwest to the northeast, extending from central Allendale County to central Orangeburg County. As sediments younger than late Cretaceous were not affected, the tectonic activity (faulting or warping) is presumed to have occurred after deposition of the Peedee Formation and before deposition of the Ellenton Formation.

PRE-CRETACEOUS BASEMENT COMPLEX

The basement rock lying below the Coastal Plain sediments ranges in age from Precambrian(?) to Triassic. Rock type varies with location, and in the study area the basement rocks generally consist of granitic intrusives and granite-diorites; metamorphosed sedimentary rocks and associated volcanics of the Carolina Slate Belt; and sandstone, siltstone, and graywacke of Triassic age (Siple, 1967). The surface of the basement rock has been eroded, tilted to the southeast, and subsequently buried by younger sediments. The upper portion of the rock is generally saprolite; that is, weathered rock which still retains the relict structure of the parent rock.

As part of the Bedrock Waste Storage Exploration Program begun in 1962 at the Savannah River Plant, several wells were drilled to the basement rock (Fig.

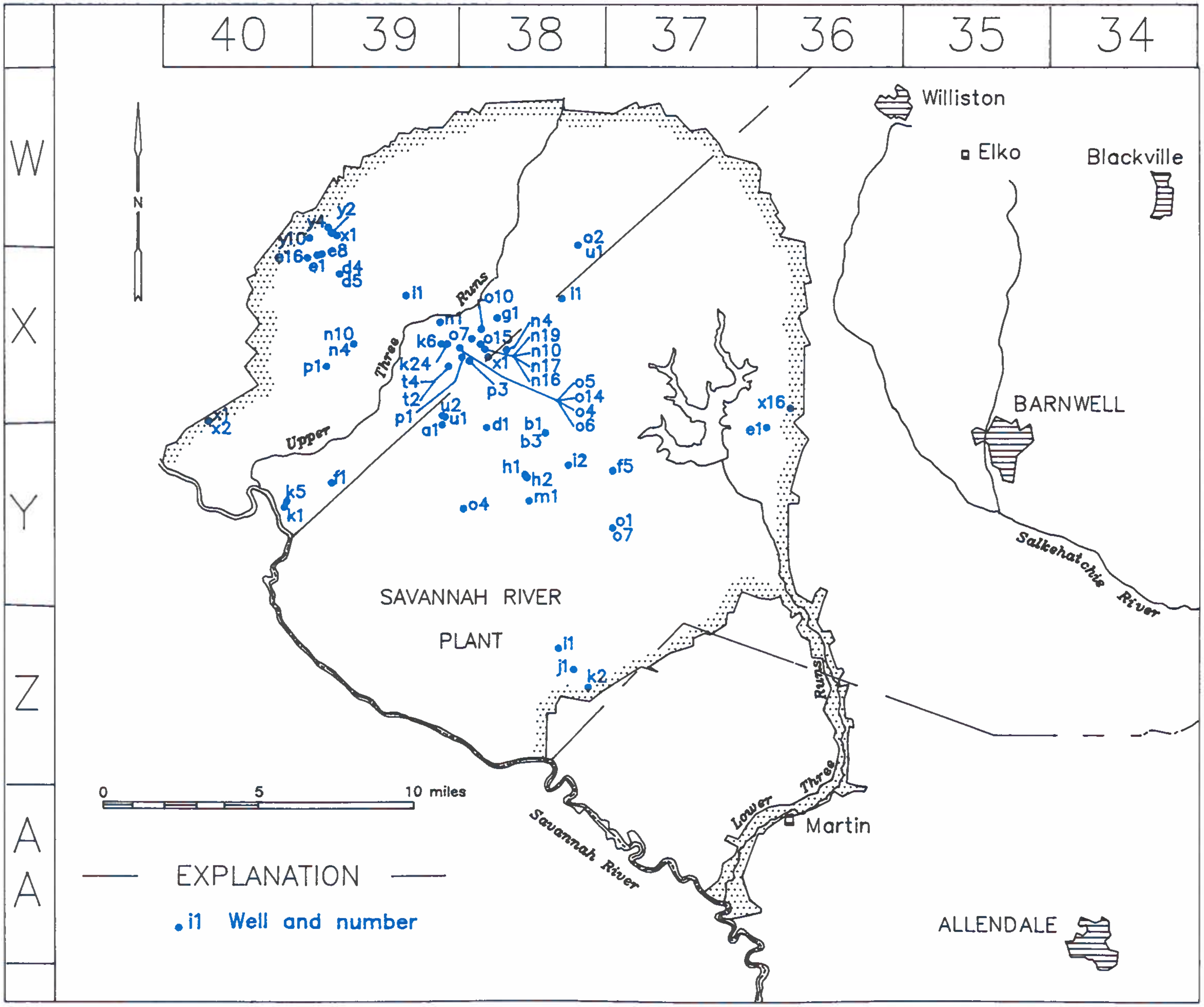


Figure 9. Location of selected wells within the Savannah River Plant.

9). Wells 39X-k24 (DRB 1) through 38X-x1 (DRB 8), located near the Aiken-Barnwell County line within SRP, encountered crystalline rock at depths from -615 to -690 ft m.s.l. (Table 3). However, about 10 miles south of this cluster, well 38Z-i1 (P5R) was drilled through Cretaceous sediments and into sedimentary beds similar to Triassic red beds found in other basins along the east coast of the United States. Other wells drilled in the vicinity intercepted the same type of red sediments. Although no fossils have been recovered from the these red beds to establish age, substantiation of a Triassic basin came from aeromagnetic surveys, seismic reflection surveys, and seismic refraction surveys.

Marine and Siple (1974) named this basin the Dunbarton Basin and described in detail the lithology of its Triassic rocks. Furthermore, they postulated the northeast-trending basin as being 31 miles long and 6.5 miles wide (Fig. 10). Marine (1976) reported that seismic, gravity, and magnetic surveys indicate a thickness of as much as 5,300 ft.

The pre-Cretaceous basement occurs only in the subsurface in the study area and was encountered in only 12 of the wells listed in this report. The surface of the basement in this area strikes about N. 70° E. and dips to the southeast at an average rate of 37 ft/mi (feet per mile). It occurs at -400 ft m.s.l. (about 700 ft below land surface) in the northern part of the area and at -2,000 ft m.s.l. (about 2,200 ft below land surface) in the southern part.

CRETACEOUS FORMATIONS

The Early Cretaceous Epoch was characterized by uplift and erosion (Georgia Power Co., 1982), and consequently Early Cretaceous sediments are not present in the study area. During the Late Cretaceous Epoch, sediments derived from the Piedmont crystalline rocks and possibly felsic volcanic sources (Prowell and others, 1985) were deposited in a seaward direction as seas transgressed landward, constituting the Cape Fear and Middendorf Formations. Superimposed transgressive-regressive cycles during this time resulted in the deposition of both marine and non-marine sediments of the Black Creek and Peedee Formations.

Cape Fear Formation

Until recently, the Cape Fear Formation was not recognized in the Allendale-Bamberg-Barnwell Counties area. Instead, the earliest Cretaceous unit thought to be present was the Middendorf Formation. Recent paleontologic evidence, however, has confirmed the presence of sediments contemporaneous in age with the Cape Fear Formation. Prowell and others (1985) identified microfossils from this unit that are indicative of Pollen Zone V of Late Cretaceous (Santonian) age.

The Cape Fear Formation was probably deposited in an upper delta plain environment, as indicated by great variation in grain size, abundant cristobalite, and sparse marine fauna (Prowell and others, 1985).

Core samples of this formation consist of well-consolidated, poorly sorted fine sand to pebble-size quartz and féldspar in a matrix of pale-olive to grayish-green clay. Small amounts of mica and heavy minerals are also present. The feldspar grains and pebbles are predominantly angular, as breakage occurs along its cleavage planes, while the quartz grains and pebbles are predominantly subangular to subrounded. The feldspar is white or pink and the quartz is colorless, white, gray, or pink.

The few wells that have been drilled deep enough to encounter this formation are at the Savannah River Plant. In that area, the formation strikes N. 70° E. and dips to the southeast at an average rate of 28 ft/mi. It occurs at about -300 ft m.s.l. in the northern part of the plant and about -850 ft m.s.l. in the southern part (Fig. 11) where its thickness reaches 216 feet.

The basal contact of the Cape Fear Formation with the underlying basement complex is represented by very few geophysical logs in the area. This contact is not readily distinguishable on the geophysical logs because the upper portion of the basement rock is weathered and produces log traces similar to the overlying sediments. Therefore, lithologic logs are the only reliable data in the delineation of this contact.

Middendorf Formation

The term Middendorf was first suggested by Sloan in 1908 in his description of sediments occurring in outcrop at Middendorf, S.C. Terminology was changed in 1936 by Cooke when he assigned these sediments to the Tuscaloosa Formation. In 1969, Swift and Heron returned to the name Middendorf. Although there has been considerable disagreement in subsequent years as to proper nomenclature for this formation, the name Middendorf is now the most commonly used among geologists and hydrologists in South Carolina.

Pollen samples from clay zones in this formation are characteristic of Pollen Zone V, indicating a Late Cretaceous (Santonian) age (Christopher, 1982).

The Middendorf Formation was deposited under predominantly transgressive conditions as sea levels rose during the Late Cretaceous epoch (Swift and Heron, 1969). Much of the Middendorf sediments were derived from the Appalachians and deposited in a seaward direction on the eroded surface of the crystalline rock and the Cape Fear Formation. Deposition occurred in a predominantly fluvial and deltaic environment.

The Middendorf Formation can be seen in outcrop

Table 3. Geologic and construction data for basement-complex wells

Well (See Fig. 4 and Fig. 9)	Grid number	Depth (ft)	Elevation of surface	Elevation of crystalline rock	Elevation of red beds
			Elevations are in feet above or below (-) sea level.		
DRB 1	39X-k24	1904	261.6	-615	
2	38X-p3	1982	281.6	-690	
3	38X-o3	1942	285.5	-649	
4	39X-t4	1938	250.8	-673	
5	38X-o7	1933	286.7	-643	
6	38X-o15	1913	269.7	-681	
7	38X-n19	1969	277.8	-682	
8	38X-x1	1965	262.5	-672	
9	38X-b3	2634	295.0	-2331	-765
10	37Y-o7	4206	250.6		-920
11	38Y-i1	3320	274.1		-797
P4R	40X-x2	965	105.3	-585	
P5R	38Z-i1	1313	208.4		-1042
P6R	39X-p1	1042	255.91	-589	
P7R	38X-o2	1178	275.99	-615	
P8R	39X-e2	1025	359.60	-473	
BRN-239	33V-p1	1149	205	-660	
ALL-324	37Z-m1	1354	203		-1143

Adapted in part from Benedict and others (1969) and Marine (1974).

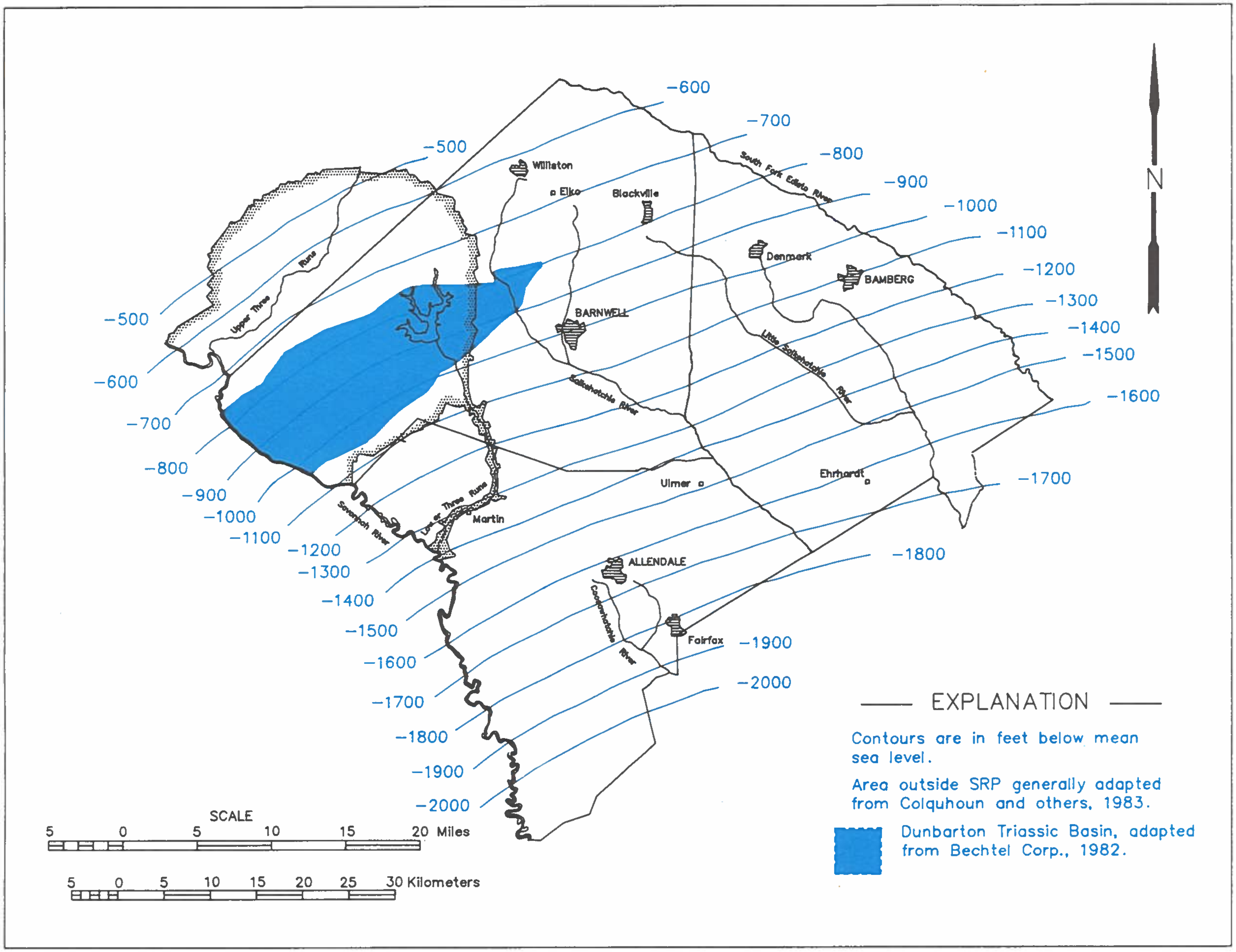


Figure 10. Surface configuration of the pre-Cretaceous basement (Triassic and crystalline).

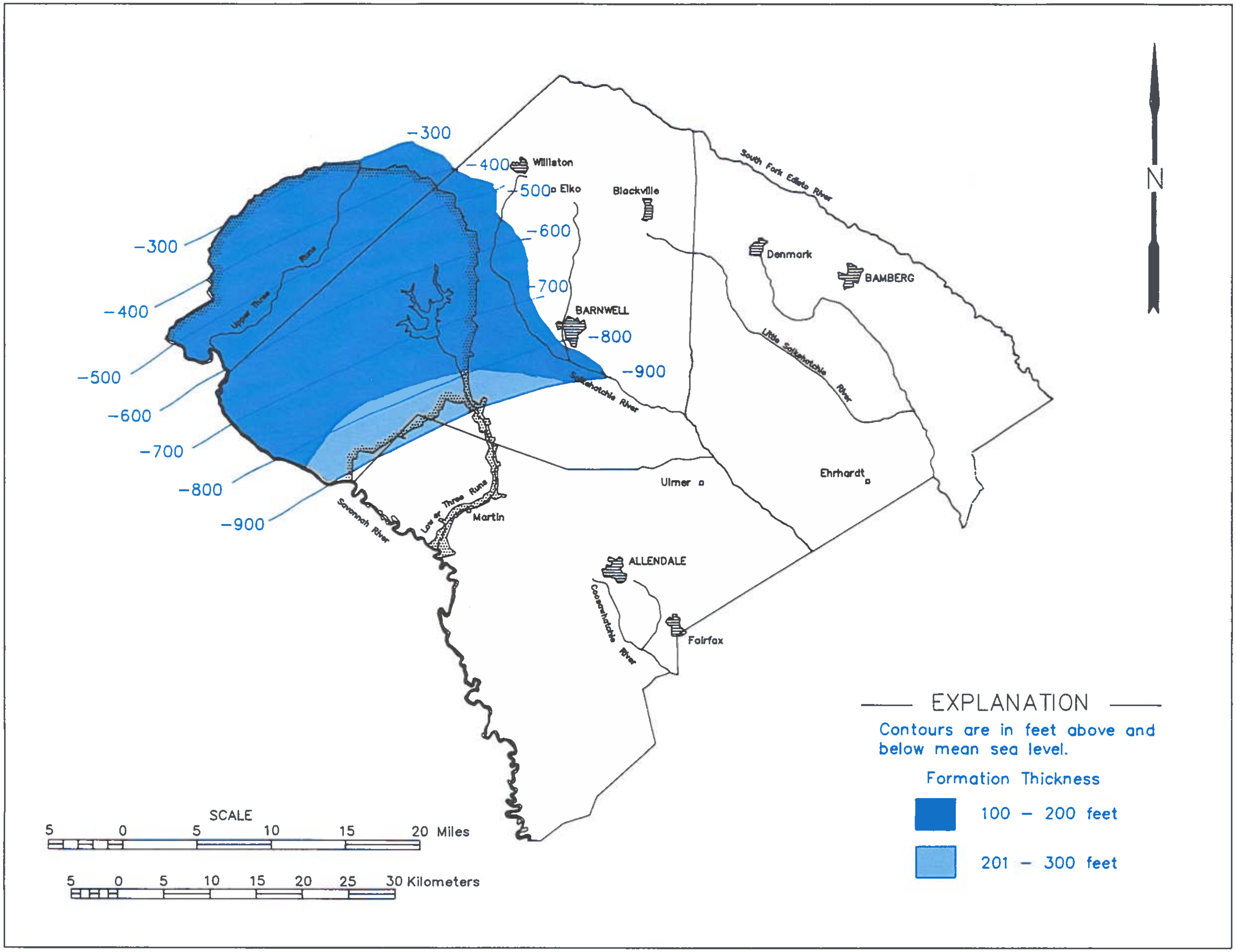


Figure 11. Surface configuration and thickness of the Cape Fear Formation.

in Aiken County. At a pit owned by Augusta Sand and Gravel, Inc., Middendorf sediments are being mined and offer several excellent sections of the formation to view. Gravel deposits at the top of the sections are indicative of fluvial deposition. Below, poorly sorted, cross-bedded sand with clay balls and gravel beds also indicate river channel deposition.

Farther down the dip, Middendorf sediments occur only in the subsurface. In the vicinity of the Savannah River Plant, cores from this formation consist of light-gray to black micaceous, kaolinitic, carbonaceous, and lignitic clay interbedded with tan or gray, fine to coarse sand, and clayey sand. The sand is predominantly quartzitic with occasional isolated zones containing feldspar. Small portions of the upper clay are occasionally red, suggesting oxidation by exposure. Such sediments and depositional features suggest deposition in an upper delta plain environment where interdistributary bays and migrating tributaries would account for the deposition of clay and quartzitic or feldspathic sand.

Eastward, at Bamberg, the Middendorf Formation consists of poorly sorted, gray, medium- to very coarse-grained, angular to subangular quartz sand with quartz pebbles and occasional feldspar grains. Some silt and fine-grained sand are present. The angularity and large grain size of the quartz and the presence of feldspar suggest that deposition occurred relatively close to the source area, most likely in an upper delta plain environment.

Farther down the dip, sediments of this formation become finer grained. In Allendale County, in the vicinity of Millet, the Middendorf Formation consists of light-gray to clear, fine- to coarse-grained quartzitic sand, clayey sand, and silty clay. The sand is unconsolidated and is poorly to moderately well sorted. Trace amounts of heavy minerals and lignite are present. Deposition of these sediments is likely to have occurred on a delta plain.

In the study area, the Middendorf Formation strikes N. 60° E. to N. 70° E. and dips to the southeast at a rate of 25-35 ft/mi. It occurs at -50 ft m.s.l. in the northern portion of the area and at -700 ft m.s.l. near the southern border of SRP (Fig. 12). The formation is approximately 150 ft thick in the northern part of the area and thickens in a southeasterly direction to more than 600 ft along the southeast coast of South Carolina (Park, 1985). Although insufficient information is available from this study to substantiate both the Martin and Allendale faults, offset of Middendorf sediments as a result of these faults was indicated by Oldham (1981) and Colquhoun and others (1983).

North of the study area, the basal contact between the Middendorf and the underlying crystalline rock is difficult to distinguish on geophysical logs and, as with the crystalline rock/Cape Fear contact, it is most easily identified on lithologic logs. The contact between the Middendorf and Cape Fear Formations is more easily recognized on geophysical logs. It is best indicated on spontaneous-potential (SP) and resistivity (R) logs. The underlying Cape Fear Formation is much more consolidated, because of its high clay and cristobalite content, than the overlying, poorly consolidated to unconsolidated sand and clay of the Middendorf Formation. The contact is recognized by a change in SP and R log signatures as they both shift closer to the base line where the less resistive clay of the Cape Fear Formation is intercepted.

Black Creek Formation

Sloan (1908) first described the Black Creek Formation as "Black Creek Shales" which cropped out in Darlington and Florence Counties. Although the formation was later included as part of the "Tuscaloosa" Formation, Swift and Heron (1969) assigned it formational status. Prowell and others (1985), citing Christopher (1978) and Sohl and Christopher (1983), suggested a Late Cretaceous (late Campanian to early Maestrichtian) age for the Black Creek Formation as indicated by various palynomorphs from this unit. The formation was previously considered to be limited to the Campanian stage. Palynomorphs from the type section of the Black Creek in South Carolina have, however, provided early Maestrichtian dates (David Prowell, personal communication).

In the updip portion of the study area, the Black Creek Formation was previously referred to as "Upper Tuscaloosa" (Cenomanian age). Although the lithology is not typical of the Black Creek as it occurs along the coast, recent palynological evidence confirms the age of these sediments as Campanian to Maestrichtian.

The Black Creek Formation was deposited under both transgressive and regressive conditions in the study area (Jordana, 1984). There are at least two submergence-emergence cycles. The basal portion of Black Creek sediments was deposited during transgression, whereas upper Black Creek sediments were deposited under regressive conditions. Some upper Black Creek sediments may have been eroded as regression began. In the vicinity of Millet, the bottommost Black Creek sediments consist of sand and silty clay and are similar to underlying Middendorf sediments. Deposition of both of these units probably occurred on a lower delta plain.

In this same area, upper Black Creek sediments consist of dark-gray to black, clayey silt and silt. The presence of organic material and fossilshell imprints suggests that deposition of these sediments is likely to have occurred on the lower delta plain in a marsh environment. With basal Black Creek deposition occurring slightly farther landward than upper Black Creek sediments, transgressive conditions are indicated. Additionally, erosion of the upper regressive sediments of this unit probably occurred.

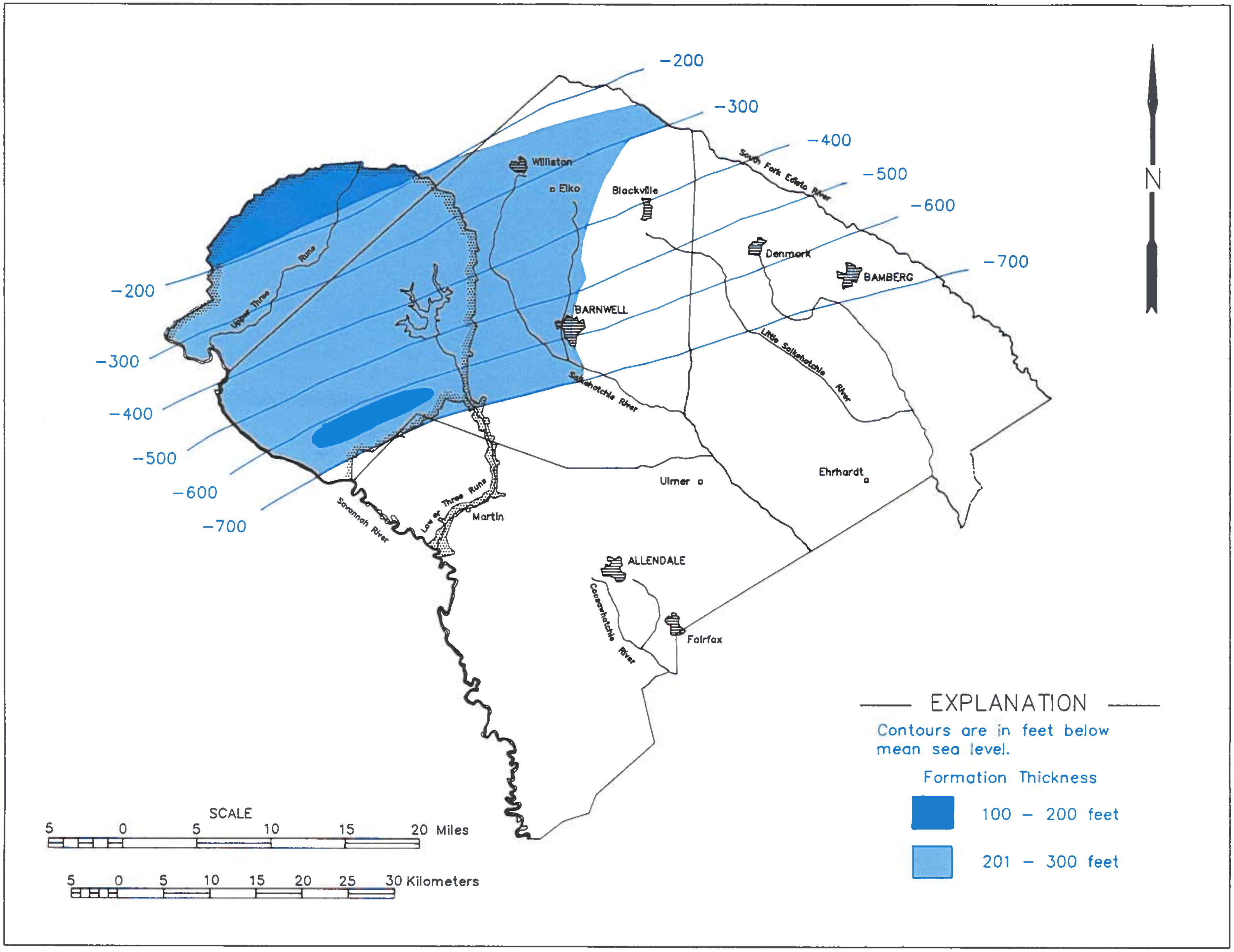


Figure 12. Surface configuration and thickness of the Middendorf Formation.

Around the Langley area in Aiken County, the Black Creek Formation can be seen in outcrop in several places. The best exposures are at the local clay mining pits where the upper portion of the unit is mined for its white or off-white kaolinitic clay. The clay is referred to as "soft clay" in contrast to overlying Tertiary "hard clay". Deposition of the clay occurred on the delta plain in interdistributary bays and marshes, accounting for the discontinuous nature of these deposits (Clarke and others, 1985). Below the minable clay are clayey sand bodies characteristic of lower delta plain deposition.

The commercially minable clay of the upper part of the Black Creek Formation terminates in the northern portion of the study area. Sediments of more seaward environments become prevalent in a southeast direction. At SRP, the formation is characterized by light-gray to black, kaolinitic, micaceous and lignitic clay interbedded with layers of medium-to coarse-grained sand and clayey sand, suggesting deposition in an upper to lower delta plain environment.

At Bamberg to the east, sediments from the Black Creek Formation consist of dark-gray to olive-gray sand, silt, and clay with scattered shell fragments. Samples from a Bamberg well contained oyster-shell fragments and a vertebra. These sediments, combined with the macrofossils, indicate deposition in a tidal flat environment, probably in a subtidal gully or channel. Sand content increases and shell content decreases upward, suggesting a transgressive-regressive cycle. Additionally, Black Creek marine sediments overlying Middendorf upper delta plain sediments further substantiates transgressive conditions for basal Black Creek sediments.

Gohn and others (1977) described Black Creek sediments from a deep corehole (Clubhouse Crossroads) in Dorchester County as abundantly fossiliferous silty clay, muddy sand, and clean sand in alternating 50- to 150-ft sequences with thinly interbedded sand and clay and, less commonly, shelly limestone. The silty clay and muddy sand are typically medium gray or gray-green, calcareous, and fossiliferous. Macrofossils and microfossils vary from scarce to very abundant. Minor constituents include glauconite, phosphate, mica, and pyrite.

The Black Creek Formation strikes generally N. 65° E. and dips to the southeast at a rate of 25-30 ft/mi. The surface of the formation occurs at mean sea level in the northern part of the area and at -500 ft m.s.l. just south of SRP (Fig. 13). The unit thickens from approximately 150 ft in the northern part of SRP to 250 ft in the southern portion of SRP. The Black Creek Formation is the oldest formation for which there is information to suggest the presence of the Martin Fault. Although this study did not produce sufficient evidence to depict the Allendale Fault, Colquhoun and others (1983) presented minimal offset of the formation as a result of this fault.

The contact of the Black Creek with the underlying Middendorf Formation is represented by varying geophysical log signatures, as both the overlying and underlying sediments vary lithologically. In some areas, it was possible to correlate natural-gamma log deflections, especially where they became more "spiky" because of increased clay content of the Middendorf. In other areas, electric-log responses were more useful in delineating lithologic changes, particularly where a basal Black Creek clay overlies Middendorf sand. In some places the contact could be identified solely by samples or lithologic description.

Peedee Formation

The Maestrichtian-age Peedee Formation was named by Ruffin (1843) in his description of beds cropping out along the Pee Dee River in Florence County. This formation was previously considered by some investigators to be absent in the study area; however, recent palynological evidence has provided dates of Peedee age from samples in the southern extremity of SRP. An attempt was made during this study to delineate the Peedee primarily by correlation of geophysical logs.

The Peedee Formation is thought to have been deposited under generally transgressive conditions with subsequent regressive facies being removed by erosion at the end of the Cretaceous (Jordana, 1984). However, Clarke and others (1985) interpreted lithologies of upper and lower Peedee sediments to suggest that regressive facies are present in the formation. There are at least two submergence-emergence cycles.

In the northern portion of the study area, the Peedee Formation consists of white, light-gray to black, kaolinitic to carbonaceous clay. The clay beds, commonly silty and micaceous, are interbedded with light-gray, medium- to very coarse-grained clayey sand. Additionally, layers of tan, medium- to coarse-grained, silty sand are present. The upper 10 to 30 ft of the formation commonly is orange or red, indicating exposure to weathering processes. These sediments probably were deposited on the delta plain where interdistributary bays and marshes were present.

Farther down the dip, in the vicinity of Millett, the formation consists of upward-coarsening quartzitic sand interbedded with layers of multicolored clay and silt. Deposition of this unit probably occurred on the delta plain. The basal sediments were probably deposited farther seaward than the upper sediments as seas retreated.

Farther south at the Sandoz Chemical plant in Allendale County and northeast in Bamberg, the Peedee is represented by pink or buff, upward-coarsening sand. The sand is medium to very coarse grained, angular

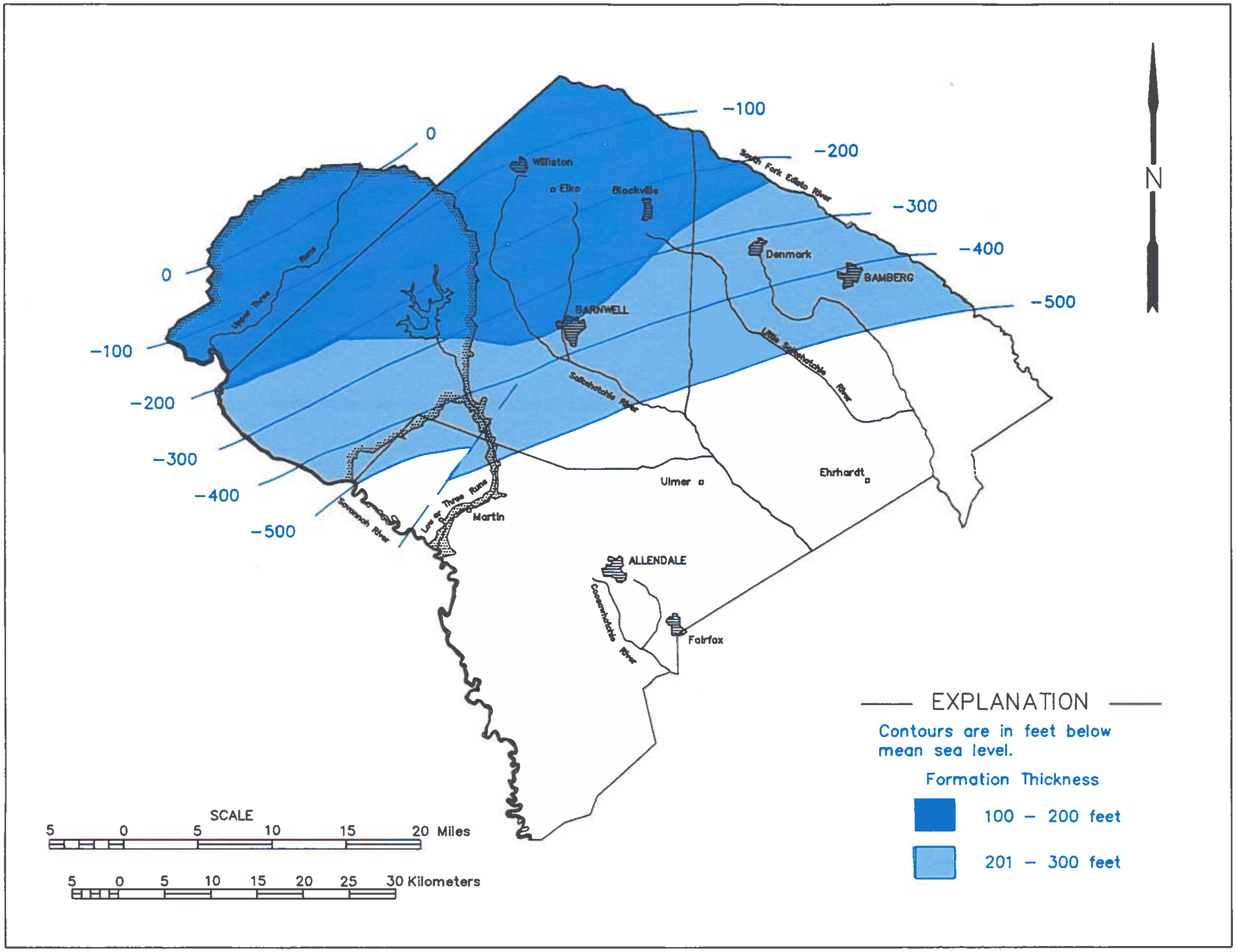


Figure 13. Surface configuration and thickness of the Black Creek Formation.

to subangular, clear, milky, smoky, and with sparse rose quartz. Quartz pebbles and trace amounts of feldspar, mica, and heavy minerals are also present. Grain size and content suggest that these sediments were deposited on an upper delta plain, possibly representing the regressive phase of deposition for this unit.

The strike of the Peedee varies from extremes of N. 55° E. in the northeast portion of SRP to an east-west trend in the vicinity of Bamberg. It dips southeast by south at a rate of 10 to 20 ft/mi (Fig. 14). The Peedee is the only Cretaceous formation for which there is sufficient information to show both the Martin and Allendale faults in Allendale County. The unit occurs at 75 ft m.s.l. in the northern portion of the area where it is approximately 50 ft thick and at -500 ft m.s.l. in southern Allendale County where it presumably exceeds 250 ft in thickness.

Primarily, natural-gamma logs were used to identify the contact between the Peedee and Black Creek Formations. In many areas it is represented by large, spikey deflections of the trace at the top of the Black Creek. These deflections are not always present. Where absent, samples and lithologic descriptions were used.

TERTIARY FORMATIONS

The Tertiary Period is characterized by a series of marine transgressions and regressions upon a gently sloping Continental Shelf. Deposition of sediments was predominantly in shallow water. Uplift and erosion, generally associated with regression, are primarily responsible for chronostratigraphic gaps during this period.

Ellenton Formation

Siple (1967) proposed the name "Ellenton Formation" for a subsurface lithologic unit in the SRP area consisting of beds of dark, lignitic clay and coarse sand. The type section (in this case type well) for the Ellenton Formation is given in Water-Supply Paper 1841. This unit, identified as late Cretaceous in age by Siple (1967) was dated early Paleocene age (Midwayan) by Bishop (1982), Colquhoun and others (1983), and Prowell and others (1985). Van Nieuwenhuise and Colquhoun (1982) proposed the term Black Mingo Group for Paleocene and early Eocene sediments and suggested that the Rhems and Williamsburg be assigned formational status in this group. The Ellenton is considered to be a member of the Rhems Formation by Colquhoun and others (1983).

Within the entire South Carolina Coastal Plain, the Rhems Formation, as named by Van Nieuwenhuise and Colquhoun (1982), consists of five members, each representing a depositional facies. They are as follows: Sawdust Landing Member—an upper delta plain fluvial deposit; Lang Syne Member—a lower delta plain deposit of estuarine and littoral origin (thought to be Ellenton equivalent as described at SRP); Perkins Bluff and Allendale Members—shallow shelf deposits; and Browns Ferry Member—a deep-water shelf deposit. Additionally, there is an unnamed unit which represents the carbonate shelf facies (Jordana, 1984). Although the authors of this report use the name Ellenton in place of Rhems, its relationship to Van Nieuwenhuise and Colquhoun's Rhems Formation should be noted.

In the area of SRP, the Ellenton Formation consists of off-white and light-gray to black clay and sandy clay. The clay is commonly highly micaceous and is often carbonaceous or lignitic. It is interbedded with clayey, medium- to coarse-grained quartz sand. The grains are smoky to translucent and are in a matrix of white or off-white kaolinitic clay. Occasional beds are green, possibly owing to cristobalite content (Prowell and others, 1985). These sediments were probably deposited in a lower delta plain environment as alternating bay and channel-fill deposits. Jordana (1984) considers this unit to be the unaltered equivalent of the Lang Syne Member of the Rhems Formation.

In northern Allendale County, at well VSC-4, the Ellenton is composed of grayish- or greenish-black and light- to dark-gray quartzitic sand. The sand is very-fine to medium grained and poorly to well cemented. The upper portion is clayey and contains abundant mica whereas the lower portion contains occasional beds of silt and clay. Deposition of these sediments probably occurred on the lower delta plain where there was little or no marine influence, as no calcareous material is present in samples from the unit at this locale.

Sediments of the Ellenton Formation, underlying the towns of Denmark, Bamberg, and Allendale, are characterized by shallow siliciclastic shelf deposits (Allendale and/or Perkins Bluff Member of the Rhems). They consist of very fine to very coarse-grained, calcareous, quartz sand with shell fragments and dark green and black shale.

The strike of the unit is northeast and, like the underlying Peedee, ranges from N. 50° E. to N. 88° E. It dips to the southeast at a rate of 12 to 20 ft/mi (Fig. 15). The top of the unit occurs at 100 ft m.s.l. in northern SRP and at -400 ft m.s.l. south of Allendale. Thickness increases in this same direction from about 50 ft at northern SRP to 166 ft at Fairfax. Displacement of the formation is the result of the Martin and Allendale faults.

The contact of the Ellenton with the underlying Peedee is represented by various geophysical log traces as the sand and clay content of each formation varies. Locally, the contact can be recognized by a decrease in resistivity as an upper clay layer of the Peedee is

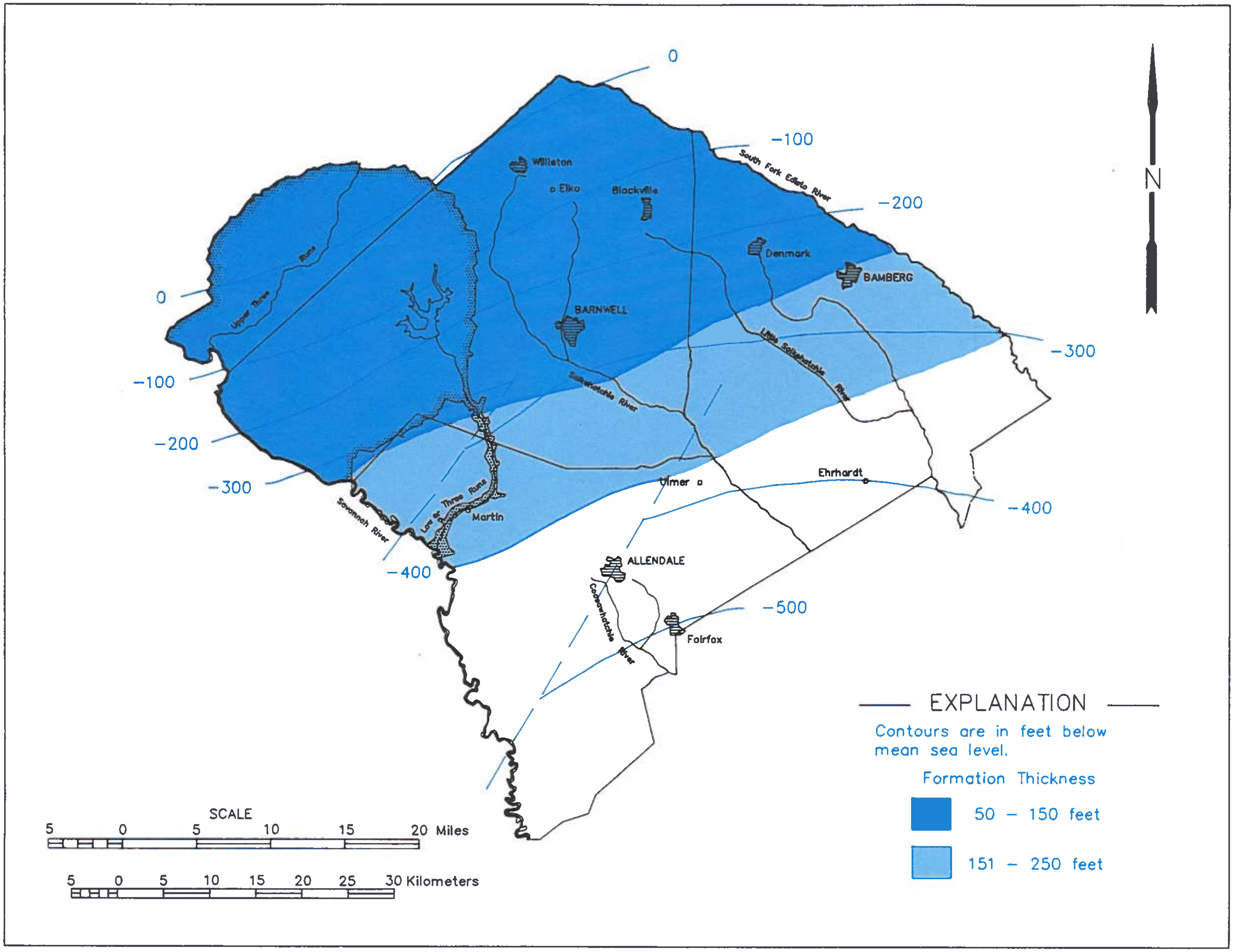


Figure 14. Surface configuration and thickness of the Peedee Formation.

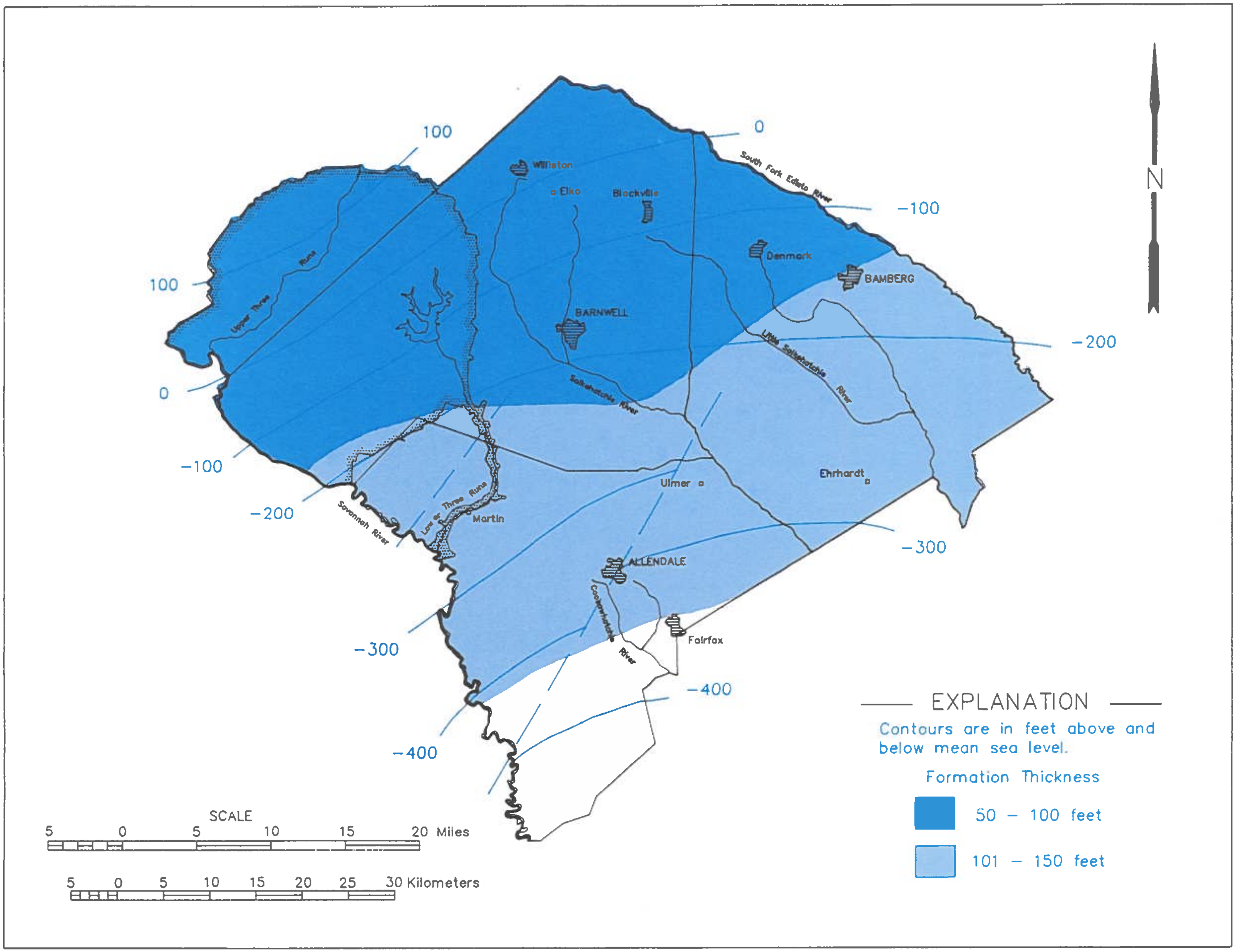


Figure 15. Surface configuration and thickness of the Ellenton Formation.

intercepted. In the downdip portion of the area, where the two formations grade into sandy facies, the contact is much more difficult to recognize. Locally, only subtle changes are observed on the geophysical logs; therefore, additional emphasis is placed on available samples and lithologic descriptions.

Black Mingo Formation

Sloan (1907) first applied the name "Black Mingo" to outcrops of shale along Black Mingo Creek in Georgetown and Williamsburg Counties. The name was later used by Cooke (1936) in reference to all Eocene rocks older than the McBean Formation (early Eocene). As previously discussed, Van Nieuwenhuise and Colquhoun (1982) raised the Black Mingo to group status. The Williamsburg Formation was assigned formational status in this group and is considered by the authors of this report to be the chronostratigraphic equivalent of the Black Mingo Formation. Black Mingo sediments, as described in this report, are considered to be late Paleocene to possibly early Eocene (Sabinian) in age. Prowell and others (1985) have indicated that a thin (approximately 25 feet) unit of early Eocene sediments is present at the southern end of SRP. As no additional information was available to delineate this unit, it was included as part of the Black Mingo Formation.

Black Mingo sediments may represent both transgressive and regressive sequences as sea levels fluctuated during the late Midwayan and Sabinian Stages (Hazel and others, 1977). A major hiatus between the Sabinian and Claibornian Stages may represent large-scale erosion caused by regressing seas. This could account for the absence of regressive facies in drill cuttings samples in the study area.

In the Upper Coastal Plain of South Carolina, the Black Mingo Formation can be seen in outcrop in Calhoun County. In this area, its upper deposits consist of low-density, fissile, dark-gray to black siltstone. Its basal deposits consist of thin layers of black clay interbedded with sand. These and similar sediments in Aiken and Orangeburg Counties were probably deposited in lagoonal or estuarine environments. In the SRP area, Black Mingo sediments consist of off-white or black clay that is commonly carbonaceous and micaceous and interbedded with layers of fine to coarse sand and clayey sand. In adjacent eastern Georgia this unit contains an abundance of marine fauna. Clarke and others (1985) suggest it was deposited in a marginal marine (lagoonal to shallow shelf) environment.

The unit becomes increasingly more marine in a seaward direction. At Denmark, the basal part of the Black Mingo Formation is composed of calcareous, clayey sand representative of a deep siliciclastic shelf environment. These sediments are overlain by medium- to very coarse-grained sand with shell and coral fragments and scattered phosphate, which is representative of a shallow siliciclastic shelf environment.

Across upper Allendale County, lower Barnwell County, and upper Bamberg County, the depositional environment of this unit appears to be open marine-shallow shelf. The sediments are composed of calcareous, glauconitic, or phosphatic sand, silt, and clay and light olive-gray, glauconitic, sandy limestone, locally containing phosphate.

The surface of the Black Mingo Formation occurs at 200 ft m.s.l. in northern SRP and at -250 ft m.s.l. in the vicinity of Fairfax. It strikes in a general northeast direction in the northern part of the area and an east-west direction in the eastern and southern parts of the area. It dips southeast at 20 ft/mi in the northern portion of the area but dips more gently (about 12 ft/mi) in the eastern and southern portions (Fig. 16). This may, in part, be related to faulting; downdip thickening of the formation, a possible result of uplift of the Cape Fear Arch; or downward flexure in the paleo-shelf (Oldham, 1981). The unit thickens from less than 50 ft in the northern part of the area to approximately 120 ft south of Allendale.

In the updip area of this formation, its contact with the underlying Ellenton Formation is best represented on natural-gamma logs as a zone of high activity. Electric logs may exhibit this contact as a low-resistivity zone signifying the upper clay of the Ellenton. This is not always sharply pronounced, since the overlying Black Mingo also contains clayey layers. Farther downdip, natural-gamma log deflections may still be useful in recognizing the contact, but lithologic evidence is much more definitive.

Southeastward, where the formation becomes more sandy and contains limestone units, it is probably connected with overlying sand and limestone units. In this area it may be considered as part of the Floridan/Tertiary sand aquifer discussed later in this report.

Congaree Formation

Sloan (1908) was the first to describe the "Congaree Phase" as shales, sands, and buhrstones of early and middle Eocene age which overlie the "Black Mingo Phase" and underlie the "Warley Hill Phase". Cooke (1936) divided Sloan's Congaree and assigned part to the Black Mingo Formation and part to the McBean Formation. Cooke and MacNeil (1952) reinstated the Congaree Formation as the stratigraphic equivalent of the Tallahatta Formation of Mississippi and Alabama.

The Congaree Formation was deposited under transgressive conditions in estuaries and wide shallow bays (Colquhoun and Johnson, 1968). Pooser (1965) described the unit as "poorly sorted quartzose sands, interbedded sand and silty to arenaceous light-green clays, and hard well indurated siltstone and sandstone layers."

At SRP, the Congaree Formation consists of light-

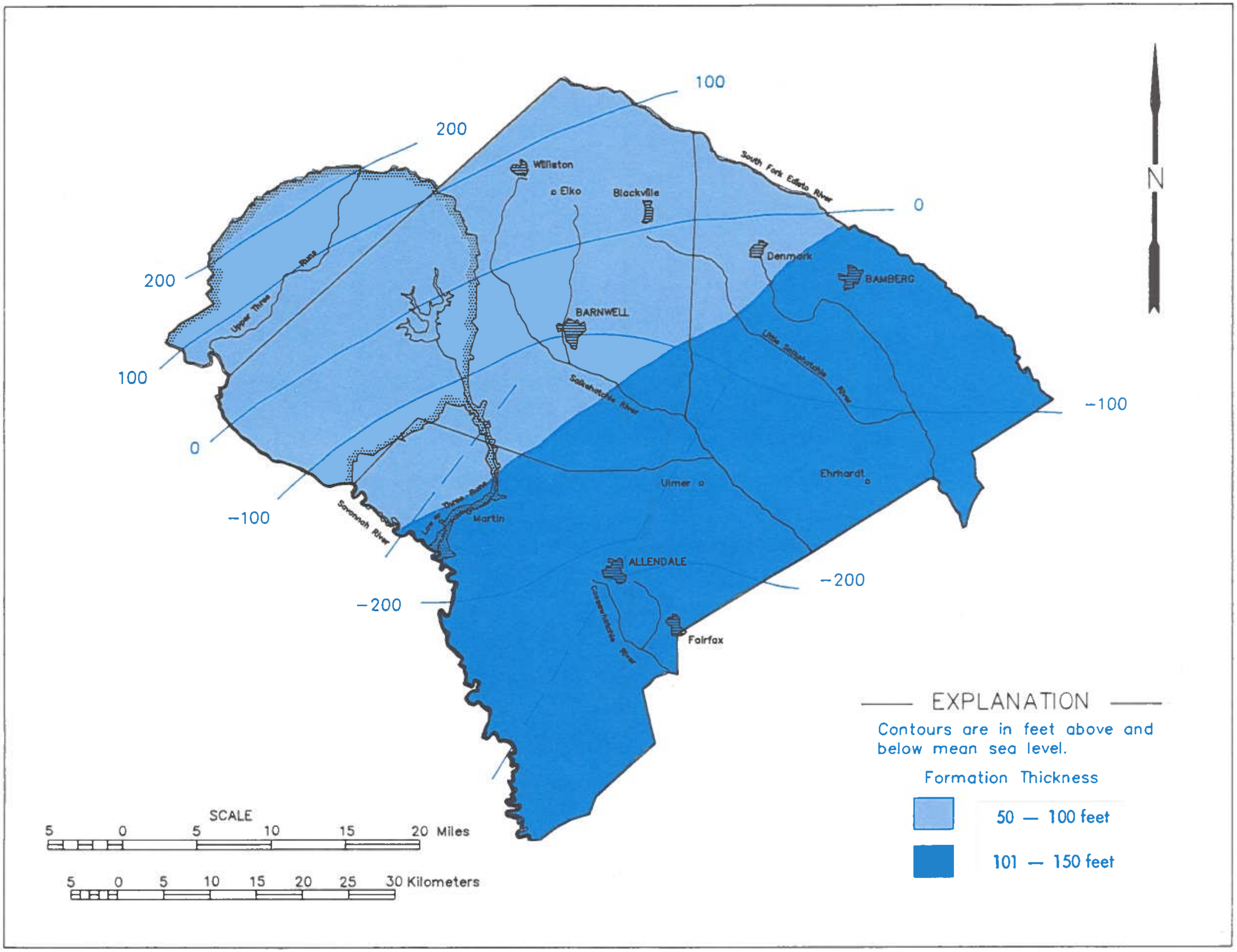


Figure 16. Surface configuration and thickness of the Black Mingo Formation.

to dark-gray and tan, fine to coarse, quartzitic sand and silty or clayey sand. Deposition of these materials probably occurred in a nearshore marine environment. The formation eventually becomes calcareous in its downdip extent.

The surface of the Congaree Formation occurs at 250 ft m.s.l. in the northern end of SRP in Aiken County and at -100 ft m.s.l. in northern Allendale County where the formation terminates (Fig. 17). The unit is approximately 50 ft thick in the northern portion of the area. It reaches a maximum thickness of 140 ft in central to east-central SRP and begins to thin in a seaward direction. The unit strikes generally N. 65° E. and dips to the southeast at a rate of 5 to 20 ft/mi.

The contact between the Congaree and Black Mingo Formations (downdip) can usually be recognized on electric logs as a change from sandy Congaree sediments to more clayey sediments of the Black Mingo.

Warley Hill Formation

The term "Warley Hill Phase" was first used by Sloan in 1907. Cooke and MacNeil (1952) applied the name "Warley Hill Marl" to glauconitic beds occurring between the Congaree and McBean Formations. Pooser (1965) proposed that the name be changed to Warley Hill Formation, as he concluded that the term "marl" was inappropriate to describe the overall lithology of the unit. Ostracode fauna found in this unit are also present in the overlying Santee Limestone and have too broad a range to designate an age more precise than middle Eocene (Pooser, 1965).

The Warley Hill Formation was deposited in a deeper water environment than was the Congaree Formation (Pooser, 1965). Its extent is limited in the study area and, therefore, no surface configuration nor thickness maps have been constructed for this unit. It was recognized in parts of Bamberg and Barnwell Counties as limestone and olive-gray to green, noncalcareous to very calcareous, glauconitic sand, silt, and clay. The glauconite content often exceeded 50 percent in the samples obtained from the unit.

Pooser (1965) described the unit as "noncalcareous, glauconitic quartzose sand which grades both seaward and upward into a calcareous, glauconitic, quartzose sand, and finally into an arenaceous, glauconitic limestone prior to intertonguing with the essentially nonglauconitic Santee Limestone." In that same report he showed the formation to be present in almost all of Calhoun County, northern Orangeburg County, southern Clarendon County, and northwestern Berkeley County.

In the study area, its thickness is generally less than 50 ft. In the area where the Congaree Formation is not present in Bamberg County, the Warley Hill lies directly on the surface of the Black Mingo Formation. The contact of this unit with the underlying sediments is most easily recognized in lithologic descriptions and available samples by the abundance of glauconite in the Warley Hill Formation and lack of glauconite in the units above and below.

Santee Limestone

The term "Santee" was used in many variations by early investigators, but Cooke (1936) was first to use the term Santee Limestone. He considered this name to be most appropriate because the formation's best and most fossiliferous exposures occur along or near the Santee River and because in that area the formation is predominantly limestone. Cooke (1936) assigned the unit to upper Eocene age, but in 1952 Cooke and MacNeil reassigned it to the middle Ecocene as the equivalent of the Gulf States' Cook Mountain Formation of the Claiborne Group.

The Santee Limestone was deposited under transgressive conditions as sea levels continued to rise. East of the Orangeburg escarpment, much of the formation represents the seaward facies of the McBean Formation (Pooser, 1965).

The formation consists of white, creamy yellow or light grayish-green fossiliferous, occasionally glauconitic, limestone. It contains numerous bryozoans, mollusks, and microfossils. Locally, it may be interlayered with gray to greenish-gray sand or clay. In some areas it is a coquina, and in its updip extent the formation becomes very sandy.

The Santee Limestone occurs only in the subsurface of the lower two-thirds of the study area. Its surface is at 150 ft m.s.l. in northern Bamberg County and at -50 ft m.s.l. in northern and central Allendale County (Fig. 18). The Santee Limestone strikes in an almost east-west direction with a dip to the south at a rate of 6 ft/mi. Strike and dip, however, seem to be localized; the strike resumes more of a northeast-southwest trend and the direction of dip shifts to the southeast outside the study area (Colquhoun and others, 1985). The local difference is probably a result of several factors: surface erosion resulting from regression; intertonguing of the formation in its updip extent; faulting in the vicinity of Martin and Allendale; and possible extension of a shallow-water marine environment through the study area. Although strike and dip of the Santee differ from other formations in this area, the unit thickens in the same seaward direction as the other formations. The Santee Limestone is absent in the northwestern one-third of the study area, but it thickens to over 200 ft in southern Allendale and Bamberg Counties.

The contact between the Santee Limestone and underlying formations is represented by various geophysical log traces depending upon the lithology of

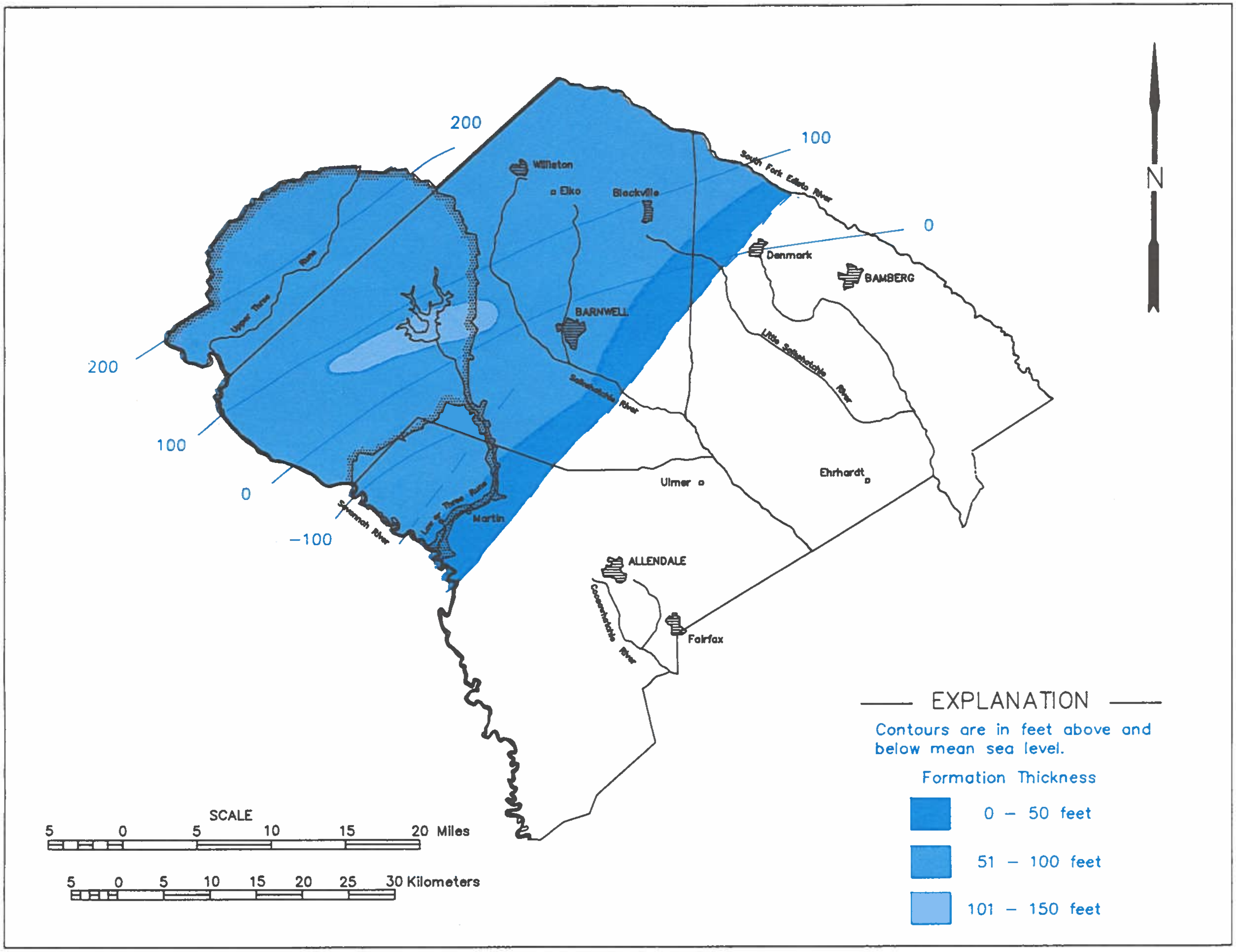


Figure 17. Surface configuration and thickness of the Congaree Formation.

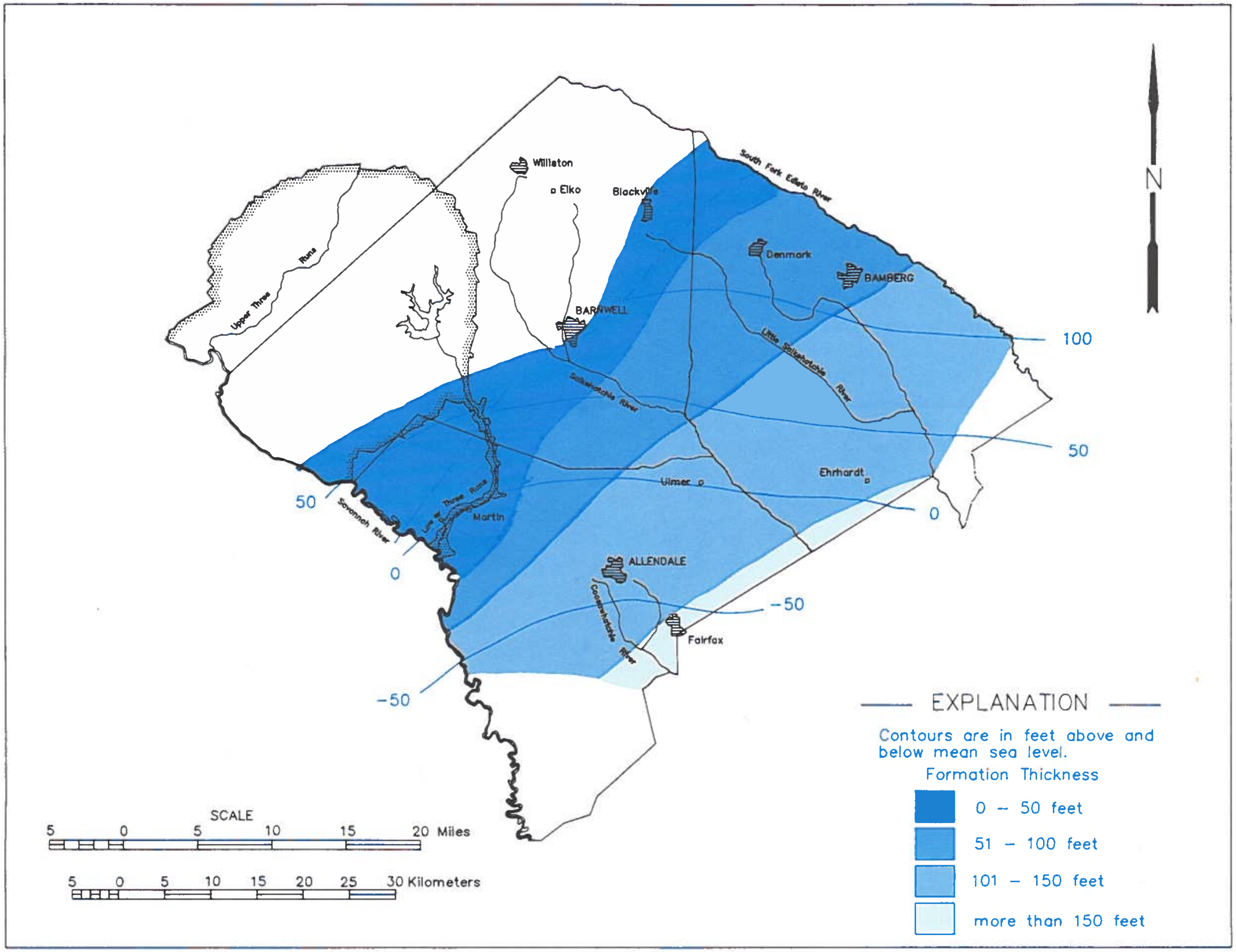


Figure 18. Surface configuration and thickness of the Santee Limestone.

the underlying formation. A deflection on natural-gamma logs (caused by glauconite) is often suggestive of the contact between the Santee and the underlying Warley Hill or Black Mingo. However, the contact is not always readily recognized, especially in the area of the Santee Limestone's updip limit where it grades into its shoreward facies.

McBean Formation

The McBean Formation was originally named by Veatch and Stephenson in 1911 for exposures near McBean, Ga. Cooke (1936) used the term in South Carolina to include all middle Eocene strata. Since that time there has been considerable disagreement about the lithostratigraphic boundaries of this formation. Huddleston (1982) discusses the development of stratigraphic terminology for these sediments and others. The authors of this report refer to the McBean Formation as an upper Claibornian age unit which is underlain by the Congaree and Santee Limestone Formations and overlain by the Barnwell Group.

The McBean Formation was deposited in an open-marine, shallow-shelf environment (Prowell and others, 1985) as seas began to regress.

In the SRP area, the formation consists of mustard-yellow to tan, occasionally greenish-brown or brown, sand and clayey sand. The sand is quartzitic and varies from fine to coarse grained. A lower calcareous zone commonly is present. The zone contains calcareous marl with characteristic fossil molds; silt and sand with a calcareous clay matrix; calcareous sand and clay; and limestone. Additionally, a basal layer of greenish-gray clay or sandy clay is locally present and is referred to as the "green clay" in the SRP area.

At the lower end of the plant and in northern Allendale County, the McBean Formation is represented, in cores drilled for the Vogtle electric generating plant, by greenish-gray to dark grayish-green calcareous siltstone. The unit has near-horizontal and frequently convoluted laminae delineated by small shell fragments. Calcareous streaks, as well as limestone lenses, are also present. The unit is locally clayey or sandy and contains some mica.

The surface of the McBean Formation occurs at 300 ft m.s.l. in northern SRP and at -30 ft m.s.l. southwest of Allendale (Fig. 19). It strikes in a northeast direction, varying from N. 45° E. to N. 70° E. and dips to the southeast at 10-20 ft/mi. Its thickness is less than 50 ft in extreme northern SRP. The unit reaches a maximum thickness of about 140 ft in the vicinity of Barnwell and then it thins in a seaward direction. The unit eventually pinches out as it grades into the Santee Limestone.

The contact of the McBean with the Congaree Formation is represented on both natural-gamma and electric logs in the SRP area as transition from the basal clay of the McBean to the underlying Congaree sand, the clay causing a deflection on the natural-gamma log and a zone of low resistivity on the electric logs. Elsewhere, the contact between these formations is difficult to recognize, especially where there is no basal clay in the McBean Formation. The contact of the McBean with the Santee Limestone is represented by very few geophysical logs in the area. On the gamma-ray logs from the Vogtle wells drilled in southern SRP and northern Allendale County, the contact is characterized by a shift of the log trace closer to the shale base line.

Barnwell and Cooper Groups

The late Eocene of South Carolina is represented by the Barnwell Group and the lower portion of the Cooper Group. The Barnwell Group represents the Jacksonian Stage in the Upper Coastal Plain of western South Carolina and eastern Georgia. The Cooper Group includes sediments of both late Eocene (Jackson) and late Oligocene time. The Cooper Group is recognized in the lower Coastal Plain of western South Carolina. Sediments of the Barnwell Group are chronostratigraphically equivalent to the lower (late Eocene) Cooper Group of Colquhoun and others (1982).

Barnwell Group—This group was previously referred to as the Barnwell Formation, named by Sloan in 1908. The formation was later included in the Orangeburg Group (Siple and Pooser, 1975) and, in 1979, Huddleston and Hetrick proposed raising the Barnwell Formation to group status on the basis of work in Georgia and western South Carolina. In an earlier paper they listed the following reasons for not using "Barnwell" as a formation name: 1) sediments from the reference locality in Barnwell, S.C., are Miocene, not late Eocene, in age; 2) exposures of probable late Eocene age in Barnwell County are residuum or almost residuum and cannot be accurately correlated with other Eocene sediments in Georgia and Aiken County, S.C.; and 3) residuum of the "typical" Barnwell lithology is not stratigraphically useful, as it resembles residuum of many Coastal Plain sediments of various ages (Huddleston and Hetrick, 1978).

The Barnwell Group includes three formations, Clinchfield Formation, Dry Branch Formation, and Tobacco Road Sand. The Clinchfield Formation, although not present in the study area, is the lowermost formation of the Barnwell Group. It generally consists of medium-grained, well-sorted, poorly consolidated, massively bedded quartz sand; however, unit variations of this lithology occur and are considered as separate members (Huddleston and Hetrick, 1979).

The Dry Branch Formation is the middle unit of the

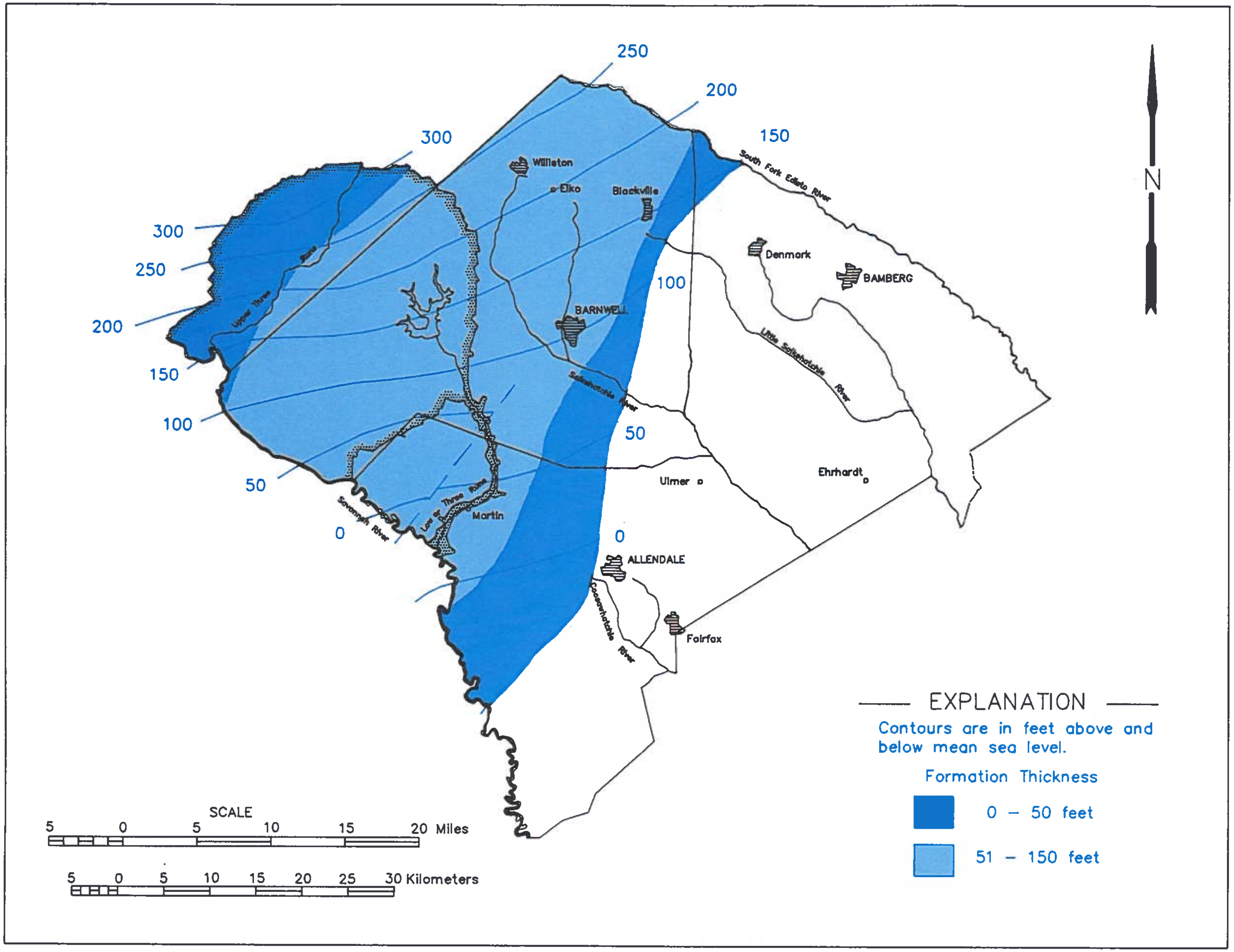


Figure 19. Surface configuration and thickness of the McBean Formation.

Barnwell Group. Huddleston and Hetrick (1979) described three distinct lithofacies of this formation: 1) the Twiggs clay, a marine montmorillonite clay; 2) the Irwinton Sand, a distinctly bedded sand and clay; and 3) the Griffins Landing Sand, a rudely bedded to massive, calcareous, fossiliferous sand. Both the Irwinton Sand and the Griffins Landing Sand have been recognized in the study area (Steele, 1984).

The Tobacco Road Sand is the uppermost unit of the Barnwell Group. It consists predominantly of sand which varies from fine grained and well sorted to pebbly and poorly sorted. Variations of clay, chert, mica, limestone, and heavy-mineral content exist locally (Huddleston and Hetrick, 1979). Massive bedding, bioturbation, and burrowing are characteristic of the formation. Burrows of Callianassa major have been noted in this unit (Siple, 1967) but are most common in the Hawthorn Formation.

Although separate formations of this group have been recognized in outcrop, it is very difficult to recognize the contacts in drill cuttings and geophysical logs. For that reason, the formations in this group were not delineated individually; instead, the group was delineated. The thickness of the group ranges from zero in northern Aiken County to about 150 ft in northwestern Allendale County.

Cooper Group—Since the early 1800's, many names, including Cooper Marl, have been applied to sediments of the Cooper Group. In 1908, Sloan compiled all the data available and assigned an upper Eocene age to the Cooper Marl. Malde (1959) stated that the Cooper Marl contains too little clay and too much sand to be considered a true marl. Pooser (1965) advocated the name, however, because of its extensive use by Coastal Plain geologists. It wasn't until 1977 that Gohn and others referred to the unit as the Cooper Formation. Colquhoun and others (1982) proposed group status for the Cooper and included all strata equivalent to the Cooper Formation lying above the Orangeburg Group and below the Hawthorn Formation or its equivalents. It is thus equal in rank to the Barnwell Group.

The Cooper Group consists of three formations: the Cooper Formation, the Ocala Limestone of Beaufort and Jasper Counties, and an unnamed Oligocene limestone (Colquhoun and others, 1982). The Cooper Formation is divided into three members: 1) the Harleyville Member—a phosphatic calcareous clay and clayey calcarenite; 2) the Parkers Ferry Member—a glauconitic, clayey, fine-grained limestone; and 3) the Ashley Member—a phosphatic, muddy, very fine-grained sand (Ward and others, 1979).

Jordana (1984) recognized the fact that correlation between the Barnwell Group and the late Eocene portion of the Cooper Group is difficult, as time-equivalent sediments have been removed across much of the Middle Coastal Plain. He indicates that the absence of late Eocene sediments below the Citronelle Escarpment prohibits accurate correlation between the upper and lower deltaic deposits of the Barnwell Group and the limestone and deep shelf sediments of the Cooper Group because the connecting shallow shelf sediments are absent.

The surface of the Barnwell Group strikes generally N. 50° E. to N. 70° E. and dips about 9 ft/mi to the southeast. It occurs at about 300 ft m.s.l. in the area of northern SRP and at about 150 ft m.s.l. in northwestern Allendale County (Fig. 20). The unit thickens from less than 5 ft in the northern part of the area to as much as 150 ft in parts of Allendale County. The information obtained during this study is insufficient to construct surface configuration and thickness maps of the Cooper Group.

The contact of the Barnwell Group with the underlying Huber Formation in Aiken County is easily recognized on electric logs as a "tight zone" where the kaolinitic clay of the Huber is encountered. Downdip, the contact between the Barnwell Group and the McBean Formation is more difficult to recognize, although it is locally evident on natural-gamma logs where a deflection away from the shale base line occurs. The contact of the Cooper Group with the underlying Santee Limestone can be recognized on both natural-gamma and electric logs. A strong deflection on the natural-gamma at the base of the Cooper is caused by increased phosphate content. On the electric logs, the contact commonly is indicated by a transition from lower permeability of the Cooper to higher permeability of the Santee.

Hawthorn Formation

The Hawthorn Formation was named by Dall and Harris (1892) for outcrops near Hawthorne, Fla. Use of this name was extended into South Carolina by Cooke (1936). Huddleston (1982) proposed raising the Hawthorn to group status. Four distinct units of the Hawthorn Group are recognized in South Carolina: the Hawthorn Formation, the Coosawhatchie Clay, the Parachucla Marl, and the Marks Head Marl. Of these, only the Hawthorn Formation has been recognized in the study area.

The Hawthorn Formation lies directly over the Cooper Group with its basal unconformity terminating in the vicinity of the Citronelle Escarpment (Colquhoun and others, 1983). Colquhoun and Johnson (1968) described the Hawthorn of the Upper Coastal Plain of northeastern Georgia and southwestern South Carolina as a coarse-grained, well-sorted, slightly feldspathic, littoral sand containing Halymenites. Drill cuttings of this unit, from a well in Ehrhardt, S.C., consist of gray or green sandy clay and clay. The sand is fine- to coarse-grained, translucent to light-gray quartz and becomes increasingly fine in an upward direction.

The contact of the Hawthorn Formation and the

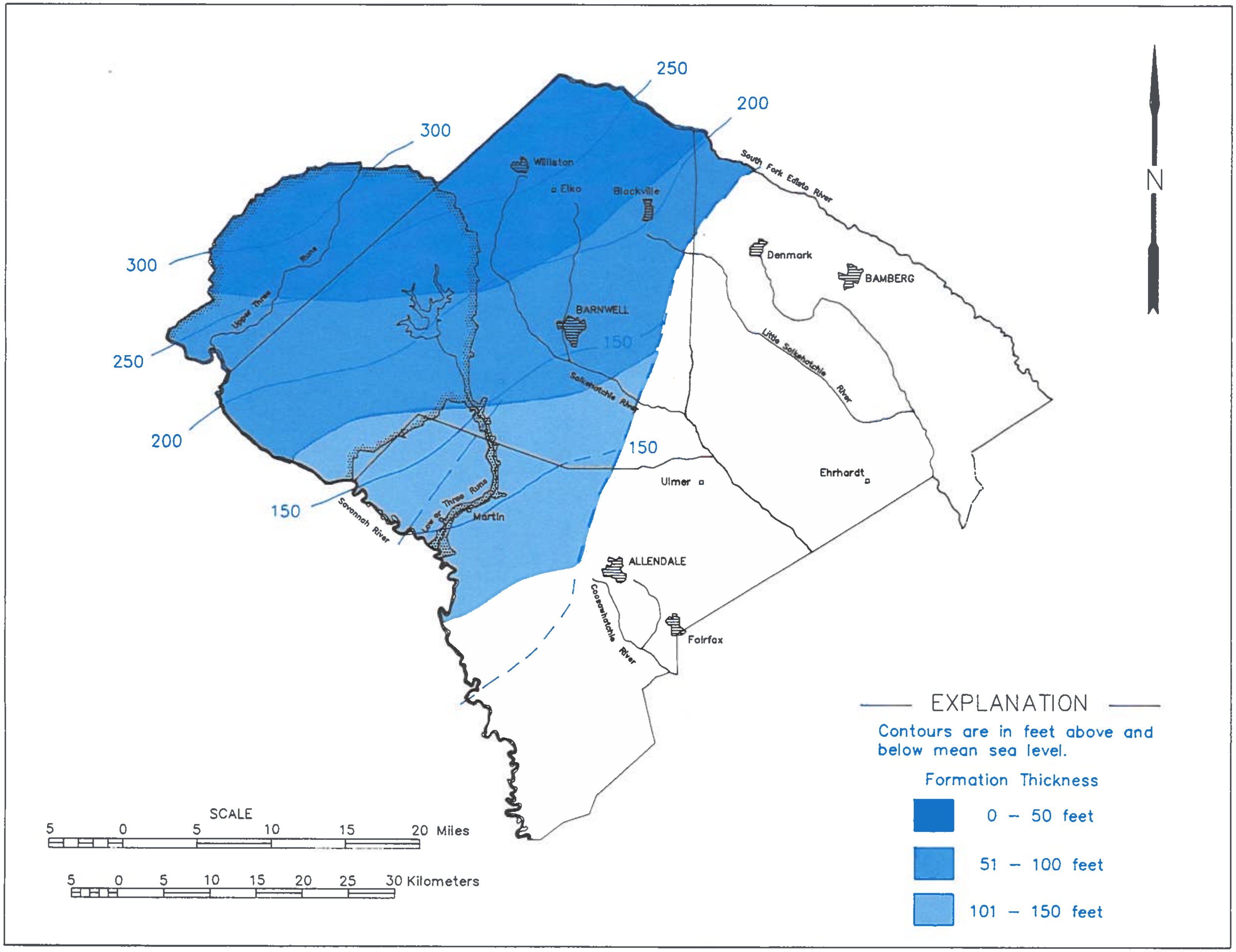


Figure 20. Surface configuration and thickness of the Barnwell Group.

underlying Cooper Group is easily recognized on natural-gamma logs as a deflection at the base of the Hawthorn. Electric log traces often shift closer to the shale base line in moving from the Hawthorn to the Cooper.

Upland Unit

In the western portion of the study area, above the Citronelle Escarpment, the Barnwell Group is overlain by a very clayey, mostly coarse-grained sand referred to as the Upland unit by the South Carolina Geological Survey. Kite (1984) described the unit as "very coarse, commonly pebbly sand, poorly sorted with abundant clay, mostly as interstitial clay, and tiny white clay flecks or sand-sized grains which give the unit a distinctive speckled appearance." She noted clay clasts of varying size along bedding planes and clay-lined burrows (Ophiomorpha nodosa) up to 1 ft in length. In the SRP area, the unit is often mottled and varies in color as white, pink, orange, red, and purple. No age determinations have been made for this unit, but its stratigraphic position suggests that it is younger than upper Eocene.

In the northern part of the study area, the Upland unit occurs immediately below the land surface in topographically high areas and is absent at lower elevations owing to erosion. The contact with the underlying Barnwell Group is often recognized on natural-gamma logs by a deflection at the base of the Upland unit.

HYDROGEOLOGY

GENERAL OCCURRENCE OF GROUND WATER

The occurrence, movement and chemical quality of ground water are directly influenced by the geology. Ground water occurs in aquifers; a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. This water may be under either unconfined (water-table) or confined (artesian) conditions.

Unconfined conditions implies that the upper limit of the aquifer is defined by the water table. The water in the pores of the aquifer at the water table is under only atmospheric pressure. If a well is drilled in an unconfined aquifer, the static water level is at the same elevation as the water table. In some areas, a zone of saturation may exist above the water table and separated from it by unsaturated material. This is caused by an impermeable layer of material interrupting natural percolation and causing ground water to accumulate in an area above this stratum. The upper surface of this water body is referred to as a perched water table.

Where a saturated aquifer occurs between impermeable layers, the aquifer is said to be confined and the water it contains is under artesian pressure. The upper impermeable layer isolates the water from atmospheric pressure; thus the water occurs in the pores of the aquifer under heads that are determined by the elevation of the water level in the recharge area. If a well is drilled into a confined aquifer, the water in the well rises to a point above the top of the aquifer. The level to which the water rises is referred to as the potentiometric level. An imaginary surface representing the levels to which water will rise in wells is called the potentiometric surface. The slope of this surface determines the direction and velocity of ground-water flow in a confined aquifer.

Ground water moves from areas of recharge to areas of discharge. The rate at which it moves is dependent on the hydraulic gradient and the transmissivity of the aquifer. Hydraulic gradient is the change in hydraulic head per unit of distance, usually expressed in feet per mile, and is the slope of the potentimetric surface. Transmissivity (T) is defined as the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient and may be expressed in cubic feet per day per foot, which reduces to feet squared per day (ft^2/d). It can also be expressed in gallons per day per foot, by multiplying feet squared per day by 7.48, the number of gallons in a cubic foot.

Hydraulic conductivity (K) is the basic measure of the capacity of an aquifer to transmit water. It is the rate of flow, commonly expressed in cubic feet per day per square foot, which reduces to feet per day (ft/day), through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 ft per ft at the prevailing water viscosity. The hydraulic conductivity multiplied by the aquifer thickness equals transmissivity.

The ability of an aquifer to store or release water is known as its storage coefficient. The storage coefficient (S) is defined as the volume of water an aquifer takes into or releases from storage per unit surface area of the aquifer per unit change in head and is dimensionless.

A term commonly used by hydrologists, engineers, and well drillers in characterizing a well is "specific capacity". The specific capacity of a well is the rate of discharge divided by the drawdown over a given period of time and is usually expressed as gallons per minute per foot (gpm/ft). For comparable values, it is desirable to measure or project specific capacity on the basis of 24 hours of discharge.

When water is withdrawn from an aquifer by a well, the water level or hydrostatic pressure must be lowered around the well to cause movement of the water toward the well. This results in a depression in the potentiometric surface that has the shape of an inverted cone and is known as the cone of depression. The depth and lateral extent of the cone are dependent on aquifer transmissivity, well discharge, duration of pumping, and existence of hydrologic boundaries (sources of recharge or barriers to flow).

The chemical quality of water contained in an aquifer is dependent on several factors. As rainfall enters an aquifer, minerals from surrounding rocks are dissolved. The type and amount of mineralization depends on the acidity of the water, the composition and solubility of the host rock, and the residence time of the water in the aquifer. Generally, dissolved-mineral concentrations are low in areas of recharge but increase with depth and distance from the recharge area.

HYDROLOGIC SYSTEMS

There are three distinct hydrologic systems in the study area:

- The pre-Cretaceous crystalline metamorphic basement rock, composed of hornblende gneiss and chlorite-hornblende schist, where water occurs mainly in small fractures.

- A buried Triassic basin consisting of consolidated mudstone and sandstone, where water occurs in the intergranular spaces.

- The coastal-plain sediments of Late Cretaceous to Holocene age, where water occurs in sand, clay, and porous limestone.

Pre-Cretaceous Basement Complex and Triassic Rocks

Little information is available on the hydrology of crystalline rocks in the area, except for that obtained in intensive studies made at the Savannah River Plant near Aiken, S.C. An investigation into the feasibility of storing high-level radioactive waste in tunnels excavated in the crystalline rock was made by the E.I. du Pont de Nemours Company at the request of the U.S. Atomic Energy Commission.

The investigation began in 1960 with an exploratory well drilling program. This program consisted of drilling seven wells through the Quaternary, Tertiary, and Cretaceous sediments and 10 to 200 ft into the pre-Cretaceous crystalline rock where casing was set and grouted. The wells were then continuously cored into the rock until approximately 1,000 ft of core had been recovered at each hole. At three of these deep rock boring sites, 38X-03 (DRB-3), 39X-t4 (DRB-4), and 38X-n19 (DRB-7), a cluster of three wells was completed at various depths in the Black Creek and Middendorf Formations. These clusters (P-1, P-2, P-3) were used to determine the ground-water gradients in the sediments. At each of two sites outside the area of investigation, a well was completed in the crystalline rock to determine the static water level in the rock (40X-x2, 38Z-i1). At each of the nine drill sites, a well was drilled to supply water for the deep-drilling operations. These wells were not intended to be a part of the investigation, but they provided information on water levels above the Black Creek and Middendorf Formations. Upon completion of each deep-rock boring, a great variety of geophysical logs was obtained, including neutron porosity, sonic, gamma-gamma density, and microlateral resistivity.

Various sections of the deep-rock boreholes were tested individually, by means of a packer assembly, to determine their hydraulic characteristics (Fig. 21). Packers were emplaced in the section of the hole to be tested and then expanded to isolate that section from the rest of the hole. Various pumping tests, in-hole tracer tests, between-well tracer tests, and sampling for water quality were then conducted.

The investigation was extended in 1967 to include the drilling of two additional deep-rock borings (38X-x1, 38Y-b3) and, in 1969, three deep-rock observation wells (39X-p1, 38X-o2, 39X-e2). In addition to the same tests conducted on the other wells, a 1-year, constant-discharge pumping test was conducted and water samples were collected for Carbon-14 age dating. In 1971 the investigation was expanded to include the drilling of six additional wells to study the character of the Triassic rocks.

Detailed results of all the geologic and hydrologic investigations of this program were published by Marine in October 1979. Only a brief summary of the hydrologic character of the pre-Cretaceous rocks is presented here.

Various pumping and small-volume recharge tests made in isolated sections of the wells indicate two types of fractures in the crystalline basement rock. One type consists of minute fractures that are prevalent throughout the study area but either do not transmit water or transmit water at an extremely slow rate. For practical purposes, rocks that contain this type of fracture are considered impermeable. The second type of fracture consists of larger openings that are horizontally connected and transmit water at a much higher rate, although they may be only poorly connected or unconnected vertically.

An average of values determined for hydraulic conductivity is approximately 4×10^{-5} ft/day for the minute fractures and 10^{-1} ft/day for the larger fractures. Between-well tracer tests on the larger fracture zones indicate a porosity of 0.08 percent.

Similar tests were conducted on the Triassic sand-

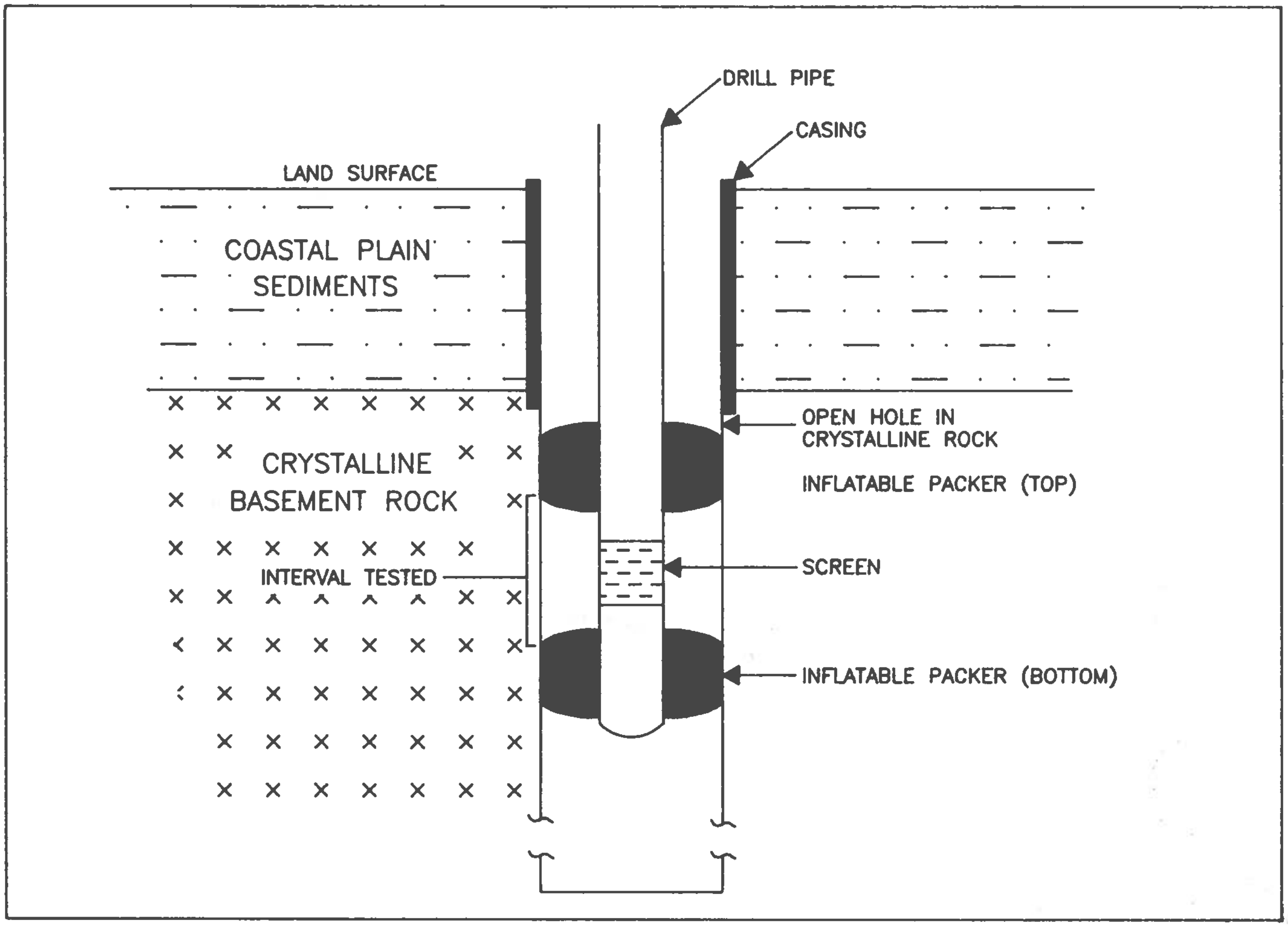


Figure 21. Schematic diagram showing packer assembly.

Table 4. Selected chemical analyses of water from pre-Cretaceous and Triassic rocks

Well	Water source	Dissolved solids (calculated)	pH (S.U.)	Silica	Iron	Cal-cium	Mag-nesium	Sodium	Potas-sium	Bicar-bonate	Sulfate	Chloride	Fluoride	Analyst	Date
38X-o14 DRB-3	Crystalline	2,770	8.1	14	0.05	286	43	629	28	43	1,145	584	2.4	USGS and du Pont	5/9-10/62
38X-o15 DRB-6	Crystalline	6,000	8.3	10	0.05	520	18	1,440		21	2,890	1,090		du Pont	12/4/63
38X-x1 DRB-8 (1082ft)	Crystalline	4,760	6.9	1.8	0.30	483	18	1,100	17	22	2,270	860	2.4	USGS	6/4/69
38X-x1 DRB-8 (1631ft)	Crystalline	5,240	6.6	7.1	0.35	468	12	1,270	13	13	2,490	960	2.6	USGS	6/6/69
38Y-b2 DRB-9 (2701ft)	Crystalline	5,450	7.1	0.7	0.39	475	18	1,430	11	38	2,300	1,290	2.2	USGS	7/18/69
38Y-b2 DRB-9 (2055ft)	Triassic	4,750	6.2	1.0	0.66	522	79	1,080	31	68	428	2,600	.6	USGS	7/14/69
37Y-o7 DRB-10	Triassic	11,100		3.5	0.04	1,990	53	2,100	44	85	110	6,720		) From Vol. 12 No.	
38Y-i1 DRB-11	Triassic	18,200			1.00	3,840	8.5	2,700	22.1	1	1	11,600		) of Ground Water	
39X-p1 P-6R	Crystalline	2,920	7.7	4.0	0.01	342	36	573	24	39	1,320	600	.8	USGS	9/22/67
38Y-o2 P-7R	Crystalline	3,700	7.8	3.6	0.20	374	4.9	880	20	32	1,660	800	.5	USGS	12/6/67
39X-e2 P-8R	Crystalline	574	8.0	3.0	0.12	24	7.9	157	29	135	96	184	4	USGS	12/1/67
38Y-i2 P-12R	Triassic	700			0.05	22	7.6	262	9.3	157	1	330		?	?

NOTE: All constituents are in milligrams per liter unless otherwise noted.

stone and mudstone, where ground water occurs in the primary porosity of the rock. The hydraulic conductivity ranged from 1.3×10^{-8} to 1.3×10^{-5} ft/day, and the porosity was 8.0 percent for sandstone and 3.3 percent for mudstone. Chemical analyses were made for water samples obtained from rock aquifers and the results are presented in Table 4.

Water-level measurements were made in the deep-rock borings and in the wells completed in the overlying sediments. These measurements indicate a head differential averaging about 14 ft between the crystalline rock and the overlying Middendorf and Black Creek Formations, with the crystalline rock having the greater head. This head difference is largely caused by the continuous pumping of process-water supply wells in the area, which has reduced the head in the Middendorf and Black Creek. When compared with static water levels before plant operations began, the head in the crystalline rock is about 2 ft higher than the head in the Middendorf and Black Creek Formations. Even though there appears to be a regional upward gradient, the water in the crystalline rock is separated from water in the sediments by saprolite, formed from the weathering of the rock. This residual clay layer appears to be continuous and is nearly 80 feet thick. Because of its low hydraulic conductivity, it acts as a barrier to ground water flow.

The water in the crystalline rock seems to flow generally toward the northwest at about 2 1/2 inches per year. Because the data are sparse, it is unclear whether this indicates a regional direction of flow or simply an alteration of the flow path because of the local orientation of the fracture zones.

Origins of the pre-Cretaceous crystalline basement and Triassic mudstone and sandstone are different, but their hydraulic properties are similar. The rocks are massive, dense, and practically impermeable except where fracture openings are encountered. Water quality from these units is also similar. Both contain water that is hard, has high levels of calcium, sodium, sulfate, and chloride, and has a pH between 6.2 and 8.3. The low aquifer permeability and poor water quality in the crystalline and Triassic rocks render them undesirable for water supply in the study area.

Coastal Plain Sediments

The most important aquifers in the study area occur in the Coastal Plain sediments of Late Cretaceous to Late Eocene age. These alternating beds of sand, clay, marl, and limestone compose a complex sequence of aquifers and confining units that dip gently to the southeast. Because of facies changes and discontinuity of the geologic units, the aquifer characteristics and the degree of aquifer interconnection can vary considerably with locale. This complex sedimentary sequence is grouped into two geologic ages for discussion purposes: Cretaceous and Tertiary.

Cretaceous Formations

Cape Fear Formation

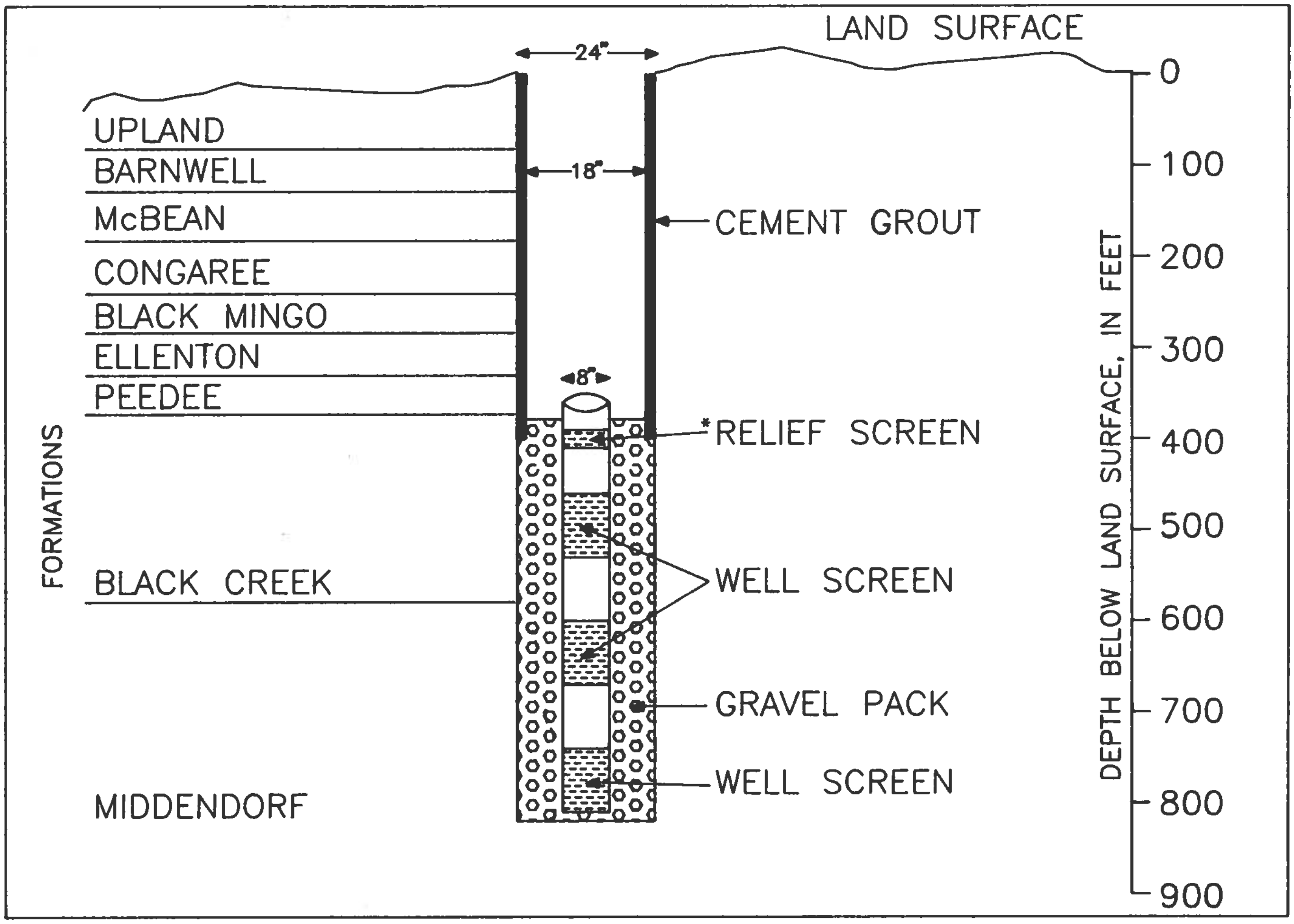
Several wells in the study area have penetrated sediments of the Cape Fear Formation, but no hydrologic data are available for this unit. Where encountered, it is composed mainly of clay or silty clay and probably acts as a confining unit. However, because it was deposited in an upper delta plain environment in this area, the formation presumably would be increasingly sandy in a southeast direction as the depositional environment changed to lower delta plain. It also should yield greater quantities of water. Continuing southeast, the silt and clay content would once again show an increase as the depositional environment changed to pro-delta and open marine.

Middendorf Formation

Occurrence -- The Middendorf Formation occurs in most of the study area and underlies almost all of the Coastal Plain Province from North Carolina to Alabama. It crops out along the Fall Line in South Carolina, except in parts of Aiken County. The Middendorf is the most prolific aquifer in the State and is greatly relied upon for municipal, industrial, and agricultural supplies, especially in the northern part of the study area. The Middendorf occurs at increasingly greater depths toward the southeast (Fig. 12) and is progressively overlain by aquifers that contain water of equal or better quality. Large-capacity wells mostly are screened in:

1) Middendorf Formation in the northern part of the area,
2) Middendorf, in conjunction with the Black Creek, Peedee, Ellenton, and Congaree Formations in Barnwell County, northern Bamberg County, and southern Aiken County,
3) Black Creek Formation and shallower aquifers in Allendale County.

There are several clay layers in the Middendorf, but they are assumed to be discontinuous in the extreme updip area and to not constitute areally extensive confining beds. In the most updip portion of the area (wells 39W-x1 and 39X-k6, Plate), the Middendorf and Black Creek Formations are hydraulically connected. Assuming that clay layers in neither of these units provide effective confinement, together both units would constitute one aquifer. In the area of 39W-x1 (geologic section B-B′) this aquifer would be approximately 500 ft thick. Southeastward, at wells 36W-j1, 36X-x19, 38Y-m1, and 37Z-m1, intervening clay layers are sufficiently impermeable to cause hydraulic heads to be different in units above and below the clay layers. In these wells, confinement is provided by a clay layer in the Black Creek Formation. This clay does not always occur at



***Relief screen installed to relieve pressure during installation of the gravel pack.**

Figure 22. Schematic diagram showing typical production well construction.

the base of the unit; therefore, basal Black Creek sediments may be hydraulically connected with sediments of the Middendorf.

Only a few wells are completed in the Middendorf Formation in the study area and even fewer have geophysical logs or samples associated with them. Until such data become available, delineation of areally extensive confining beds will not be possible.

Middendorf sediments that are most permeable, and therefore are the most productive aquifers in the study area, are those that were deposited in upper and lower delta plain environments. The downdip portions of this formation would be inferior aquifers because the depositional environment changes to delta front, prodelta, and deep marine, with increasing amounts of silt and clay. The best-yielding zones are believed to occur in the northern three-fourths of the area.

Most municipal wells in Aiken County are completed in the Middendorf. Generally, these wells are 8 inches in diameter and less than 500 ft deep. Well 39U-rl, located in the city of Aiken, was constructed with 50 ft of 8-inch screen set between the depths of 240 and 330 ft (240 and 150 ft m.s.l.). When drilled, the well produced 350 gpm (gallons per minute) with a specific capacity of 13 gpm/ft (gallons per minute per foot). A municipal well for the town of Montmorenci (38U-o1) is constructed with 16 ft of 8-inch screen set between 249 and 129 ft m.s.l. and produces 214 gpm with a specific capacity of 5 gpm/ft.

Hydraulic character -- Analyses of pumping tests indicate an average transmissivity for the Middendorf of about 13,000 ft²/day in central Aiken County. As the thickness of the sediments increases toward the south and southeast, the transmissivity also increases.

Pumping tests are usually conducted by the driller to determine well yield, not aquifer characteristics. Measurements made only at the pumping well do not allow for the calculation of the storage coefficient. On the basis of tests at SRP, the values in this area appear to range between 0.0002 and 0.0008, indicative of confined conditions.

Siple (1967) reported an average value of transmissivity for the Tuscaloosa (Middendorf) to be 26,700 ft²/day in and around SRP. This figure was based on 25 pumping tests. Reevaluation of the data indicate that only seven of the pumping wells are completed solely in the Middendorf. The remaining wells are screened in the Middendorf and another aquifer (typical of the production wells) or entirely in another aquifer (Fig. 22). Using data from only the Middendorf wells at SRP, the average transmissivity value is about 32,000 ft²/day. The highest values for transmissivity were observed in the central part of SRP and range from 24,000 to 54,000 ft²/day.

The high degree of variance in the results of different tests within a given area can be attributed to several factors. Among these are partial penetration by some of the wells and differences in the location of the well screens.

The practice of partially screening an aquifer is common for water supply wells; however, for an aquifer test it violates the basic assumption that the well is screened throughout the entire thickness of the aquifer. Depending on the screen setting in the observation well in relation to the screen setting in the pumping well and on the distance between the observation well and pumping well compared to the aquifer thickness, the calculated values for transmissivity may be reliable or misleading representations of the true transmissivity.

A 7-day pumping test was conducted at the Barnwell Nuclear Fuel Plant (BNFP) adjacent to SRP during the spring and summer of 1971. A 10-inch production well and an observation well were completed in the Middendorf. The pumping well produced more than 3,000 gpm during development. For the pumping test, discharge from the well was maintained at a constant rate of 1,400 gpm. Water levels were monitored in the pumping well and indicated a specific capacity of 30 gpm/ft. Water-level data from the observation well indicated a transmissivity of about 19,000 ft²/day and a storage coefficient of 0.00025. Wells completed in the Middendorf aquifer at SRP, only 5 miles west of the test site, commonly have specific capacities between 40 and 60 gpm/ft. The values for transmissivity are also much higher.

Wells screened in the Middendorf are commonly screened in the Black Creek as well. The lack of data exclusively for the Middendorf makes determination of hydraulic characteristics difficult. Because of the similarity in lithology, water levels, and water quality, and the almost identical response of water levels in both aquifers to applied stresses in the updip areas, it may be more practical to treat them together as one aquifer. This will be discussed in greater detail in later sections.

The hydraulic conductivity of the Middendorf aquifer appears to be fairly uniform at about 110 ft/day in the northern part of the study area where coarse-grained sand beds were deposited in an upper delta plain environment. The transmissivity increases toward the southeast as the thickness of the aquifer increases. The transmissivity appears to be greatest near the central part of SRP; however, this observation may be biased by the lack of data southeast of SRP, and the transmissivity of the Middendorf may continue to increase for some distance toward the southeast. A change from deltaic to marginal-marine deposition, however, occurred between SRP and the USGS test well (25Z-b1) at St. George, to the southeast in Colleton County. The occurrence of finer grained sand beds and small amounts of silt and clay associated with this type of environment significantly reduces permeability. An irrigation well (33W-l1) in northern Bamberg County was test pumped at 1,080 gpm with 159 ft of drawdown, for a specific capacity of 6.8 gpm/ft. This is a 14-inch well with 8-inch screen set between -567 and -667 ft m.s.l. Test well 18AA-e2, near Goose Creek in Berkeley County, produced only 135 gpm with a drawdown of 169 ft for a specific capacity of 0.8 gpm/ft. A pumping test indicated the transmissivity of these sediments to be only 600 ft^2/day.

The Middendorf is a prolific aquifer capable of yielding more than 3,000 gpm to properly constructed wells in most of the study area. Because of the high transmissivity, large withdrawals do not result in excessive drawdowns, and cones of depression are not areally extensive.

Water levels -- The potentiometric surface of the Middendorf Formation (Fig. 23) indicates that the outcrops are mainly areas of discharge rather than recharge, as stated by Siple (1967). Some recharge does occur in the interstream areas but most of the water is discharged to nearby streams. Discharge to the Savannah River also occurs, as indicated by the depression in the potentiometric surface at the river. Siple (1960) used this potentiometric map to estimate the amount of discharge from the aquifer to the river. The difference between the potentiometric high of 360 ft in Aiken and the potentiometric low of 160 ft near the Savannah River, 14 miles to the southwest, results in a ground-water gradient of about 14 ft per mile. Using this gradient and a transmissivity value of 27,000 ft^2/day, a discharge of 2.8 million gallons per day (mgd) was calculated to occur through each 1-mile strip of the aquifer. This converts to a total of 170 mgd being discharged into the Savannah River. Substituting the recently calculated transmissivity value of 32,000 ft^2day, the total discharge amounts to 201 mgd.

Ground-water contribution to a stream can also be estimated by using streamflow measurements. By comparing the average flow between points upstream and downstream from the area of interest, and subtracting any inflow from tributaries, the net increase should be the amount of ground-water contribution. Since the data used in constructing the potentiometric map in Figure 23 were obtained in 1954, the streamflow measurements from the 1954 water year (October 1953 to September 1954) were used for the calculations. The average discharge at Augusta was 7,293 cfs (cubic feet per second), and downstream near Milhaven, Ga., it was 7,892 cfs, for an increase of 599 cfs. Subtracting an estimated value of 275 cfs as the portion being contributed by smaller streams, there is a net increase of 324 cfs. This converts to 209 mgd, as compared to 201 mgd by using the previous method. These figures are far from exact; however, they indicate the magnitude of ground-water discharge to the Savannah River.

Most of the water contained in the Middendorf is derived from leakage through overlying sediments, particularly in the updip areas where the Middendorf is overlain by a thin veneer of Tertiary sediments. In these areas, ground water in the Middendorf is under water-table conditions. Very little water moves downdip from the outcrop areas, but rather it moves in an arcuate flow pattern toward the Savannah River. The rate of water movement can be approximated by the equation: .

$$v = KI/n$$

where:

v = average velocity, in feet per day
K = hydraulic conductivity, in feet per day
I = hydraulic gradient, in feet per foot
n = porosity, as a decimal fraction

Hydraulic conductivity and porosity are both fairly uniform in the study area; therefore, the velocity is directly proportional to the gradient. Using a gradient of 0.027 ft/ft (14 ft/mi) and assuming an average hydraulic conductivity of 110 ft/day and an effective porosity of 0.25, the velocity is calculated to be about 480 ft per year. Farther downdip, the aquifer is more deeply covered by Cretaceous and Tertiary beds, and confined conditions prevail. In these areas, the gradients are gentler (0.00076 ft/ft or 4 ft/mi), resulting in a velocity of only about 150 ft per year.

The potentiometric map in Figure 23 was constructed from data obtained in 1954 prior to any significant withdrawals. Several of these data points were rechecked in 1960 and 1963 and substantially reflected the same distribution of potentiometric contours, with the exception of somewhat higher water levels that indicated recovery from the drought of the mid-1950's. Measurements made in 1982 by E.I. du Pont Company and Bechtel Corporation confirmed the major features of the potentiometric surface (Fig. 24). The most notable difference is that the 180-foot contour is roughly parallel to the river rather than being closed. Minor adjustments were made because of the addition of data points and an overall loss of head.

What are now known as the Middendorf and Black Creek Formations were considered until recently to be one unit, the Tuscaloosa Formation. When the original water-level measurements were made, some of the data reflected water levels in the Middendorf, some in the Black Creek, and some were a composite. Aucott and Speiran (1985a and b) noted the similarities in water levels and flow systems of the Black Creek and Middendorf. In the upper Coastal Plain they were treated as one aquifer. In the outcrop areas and the northern part of SRP, the confining bed associated with the base of the Black Creek either does not exist or is relatively permeable. In these areas the water levels in the two aquifers are nearly the same and the water is free to move between aquifers where head differentials are created. Figure 25 shows hydrographs of three wells (38X-n10, 38X-n16, 38X-n17) located near the center of SRP. These wells are screened in the lower part of the Middendorf, the upper part of the Middendorf,

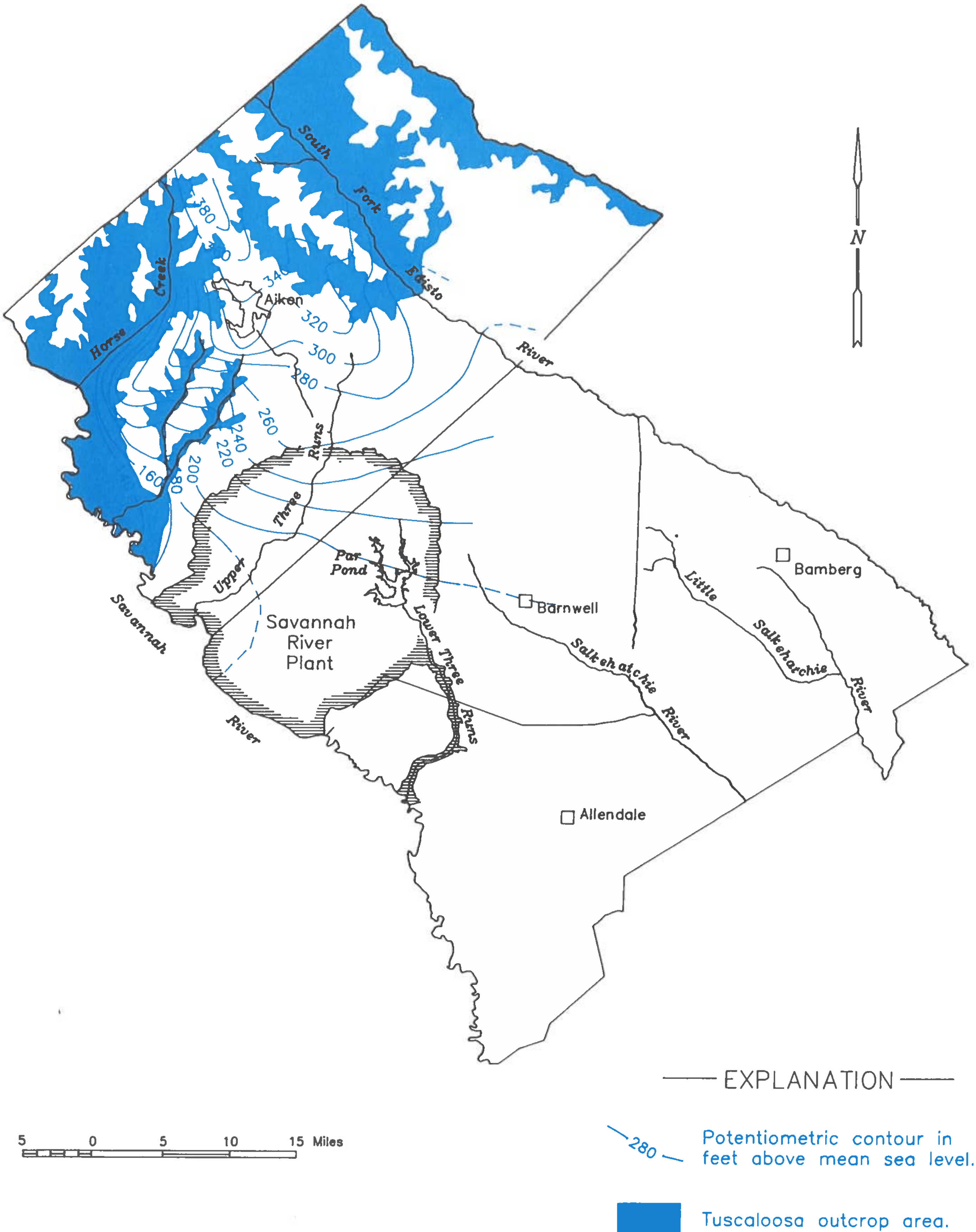


Figure 23. Potentiometric surface and area of outcrop for the Tuscaloosa (Middendorf) aquifer, 1954 (after Siple, 1967).

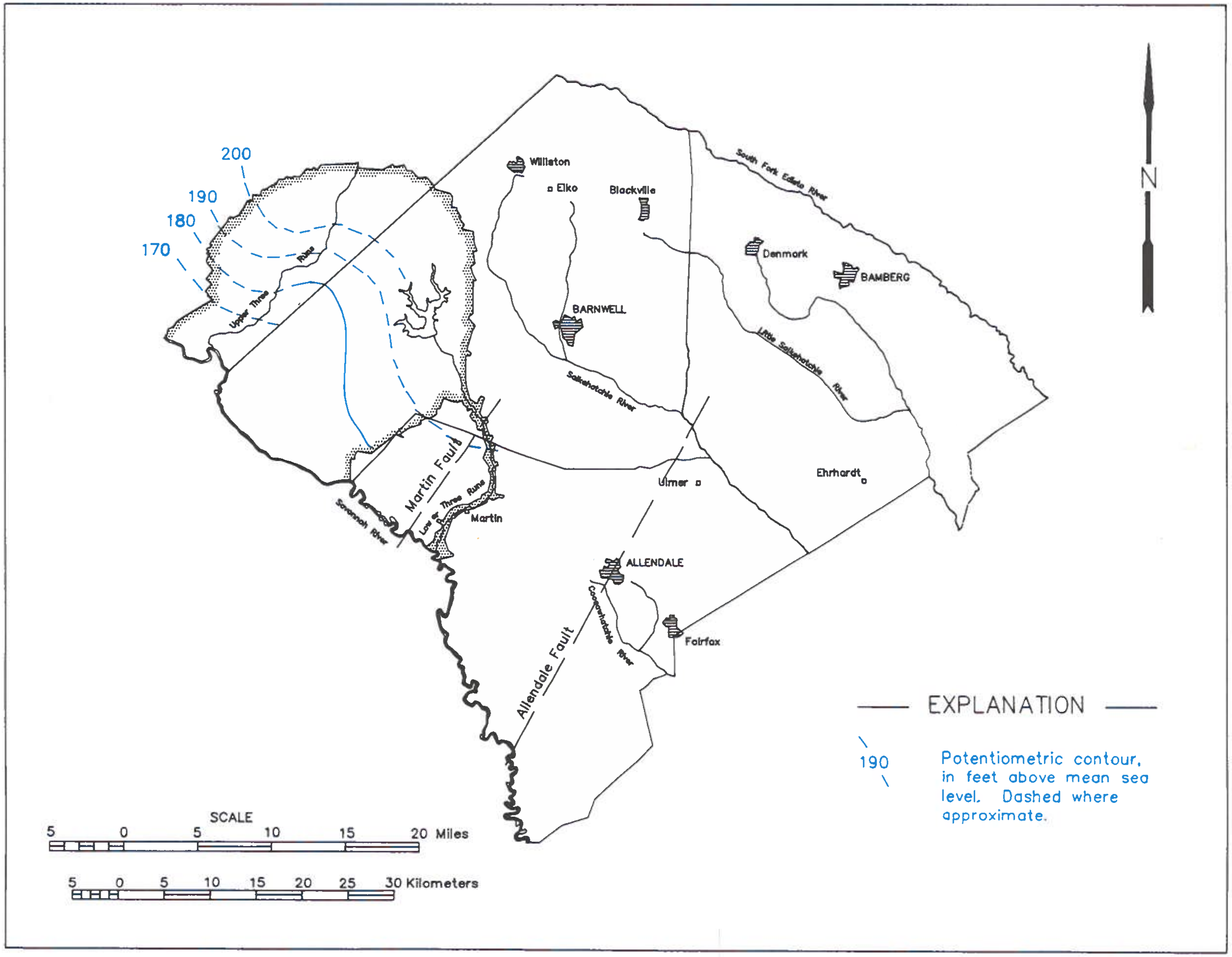


Figure 26. Potentiometric surface in the Middendorf Formation, August 1985.

and the Black Creek, respectively. The change in water levels is probably related to nearby pumping; however, the almost identical response in each well suggests an ineffective confining unit between the aquifers. East and southeast of these areas, the confining unit that separates the two aquifers increases in thickness and becomes less permeable.

The authors separated the 1985 water-level measurements for the purpose of constructing a potentiometric map for each aquifer. The lack of sufficient water-level data exclusively for the Middendorf, except in a few places at SRP, made this difficult. The data collected, however, indicate practically the same potentiometric configuration as originally defined for the Tuscaloosa by Siple, with only a slight decline of head (Fig. 26). This loss in head is a relatively recent development, probably resulting from an increase in pumpage in combination with a deficiency in rainfall. One interesting feature that is not evident on Siple's map (constructed prior to heavy withdrawal at SRP) is the shape of the contours near the center of SRP. This upward bending indicates a depression in the potentiometric surface in the vicinity of F and H Areas (Fig. 1). These two areas combined withdraw about 3,100 gpm continuously for a total daily withdrawal of almost 4.5 million gallons.

Pumping effects — Use of the Theis nonequilibrium formula allows for the calculation of theoretical drawdowns at various times and distances from a pumping well. Among other things, this formula assumes that all the water being discharged by the well is derived from storage in the aquifer. As pumping continues, more water must be derived from storage at greater and greater distances from the pumping well. Therefore, the cone of depression must expand in order for water to move from greater distances toward the well. The cone will deepen and expand at a decreasing rate, however, because with each horizontal foot of expansion, there is a larger increase in volume of water available from storage than from the preceding one. Therefore, water levels will never reach a steady condition but will continue to decline infinitely at a constantly decreasing rate. The aquifer is also assumed to be infinite in areal extent. The results of calculations of ultimate drawdowns to be expected in each of the areas of heavy withdrawals, at various times and at various distances, are plotted in Figures 27 and 28. A/M, F, and H Areas (Fig. 1) have 4 or 5 wells each, with 2 wells being pumped at any time in each area. For the calculations, however, A/M Area was assumed to have one well pumping 1,350 gpm, and F and H Areas were assumed to have one central well pumping 3,100 gpm. As shown in Figure 27, drawdown at a distance of 5,000 ft from A/M Area should have been about 14 ft after 1,500 days of pumping. However, well 39X-e1, located about 4,500 ft from the center of pumping, shows a decline of only 2 1/2 ft. Likewise, well 38X-n4, located about 1,900 ft from any source of initial pumping in H-Area, should show a drawdown of 20 ft (Fig. 28), but it has a decline of only 6 ft, even though an additional well was installed 1,200 ft away and pumped during 1954.

The drawdown calculations are based on drawing all the water from storage, which is probably not the case. Pumping water from an aquifer tends to induce recharge or lessen natural discharge, or a combination of both. In an artesian aquifer, the cone of depression around a pumping well expands rapidly over a large area. The cone will tend to enlarge in an effort to obtain recharge to the aquifer in an amount equal to the discharge from pumping. This recharge may come from several sources:

1. Interception of natural discharge.
2. Vertical recharge from precipitation.
3. Leakage from overlying and underlying formations.

There was an approximate 10-ft fluctuation in head in the Black Creek/Middendorf aquifer during the period 1951-61, primarily because of the onset of heavy pumping and a severe drought in 1954-55 (G.E. Siple, personal comm. 1985). Water levels recovered and remained fairly stable between 1961 and 1978. Since that time, there has been a large increase in pumpage coupled with several years of below-normal rainfall.

Figure 29 shows total ground-water withdrawals (average continuous pumping in millions of gallons per day) at SRP from 1968 to 1985. As can be seen from the graph, SRP increased their water use slightly in 1978 and then quite substantially in 1980. Current ground-water usage is about 11 mgd, as compared to an average of 7.2 mgd during the period 1963-77. Although this is a significant increase, agricultural irrigation has also shown rapid growth. In 1970, the total number of irrigated acres in the study area was 1,065. By 1980, the number had grown to 18,670 and in 1983 was reported to be 25,210 acres. Reliable water-use figures have not yet been received; however, they are probably on the order of 15 mgd. A large percentage of this pumpage is obtained from the Middendorf, particularly in Aiken and Barnwell Counties. In addition to SRP's increase in pumpage, the graph shows several years of above- and below-normal rainfall. An extreme drought was experienced in 1954 (rainfall was 19 inches below normal) followed by several years of continued below-normal rainfall. During the period 1957-63, rainfall was near or above normal for most of the years. Excessive rainfall occurred in 1964, amounting to more than 25 inches above normal.

There appears to be a good correlation between water-level declines and pumping rates, particularly around 1980. Between 1980 and 1983, total pumping rates increased from 6.7 to 10.3 mgd. A corresponding decline in water levels from 180 ft m.s.l. to 174 ft m.s.l. in well 38X-n10 is shown. Well 38X-n10 is located in the center of F and H Areas, the areas of heaviest

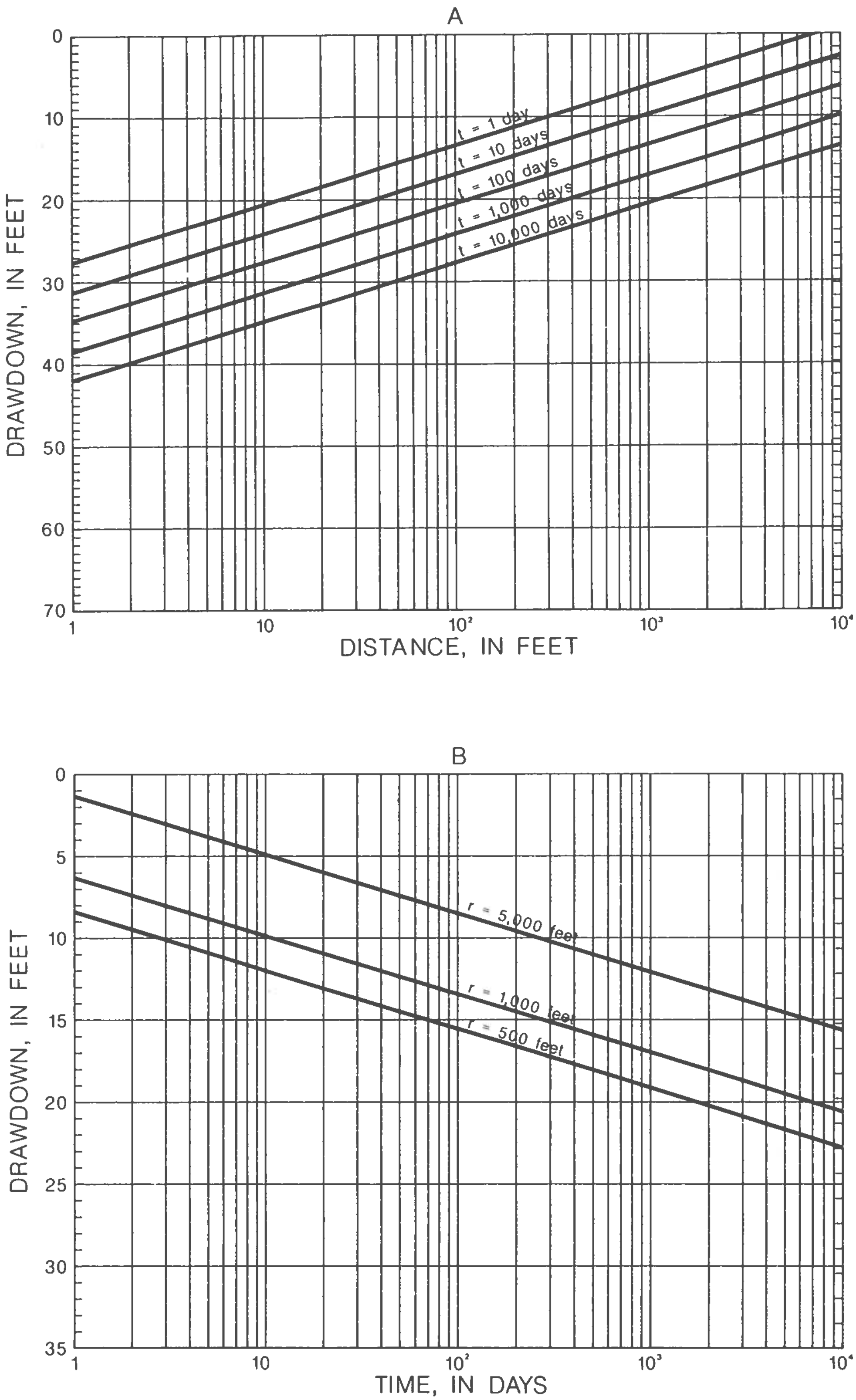


Figure 27. Graph showing theoretical drawdowns, at various times (A) and distance (B), caused by pumping from the Middendorf Formation in A/M Areas.

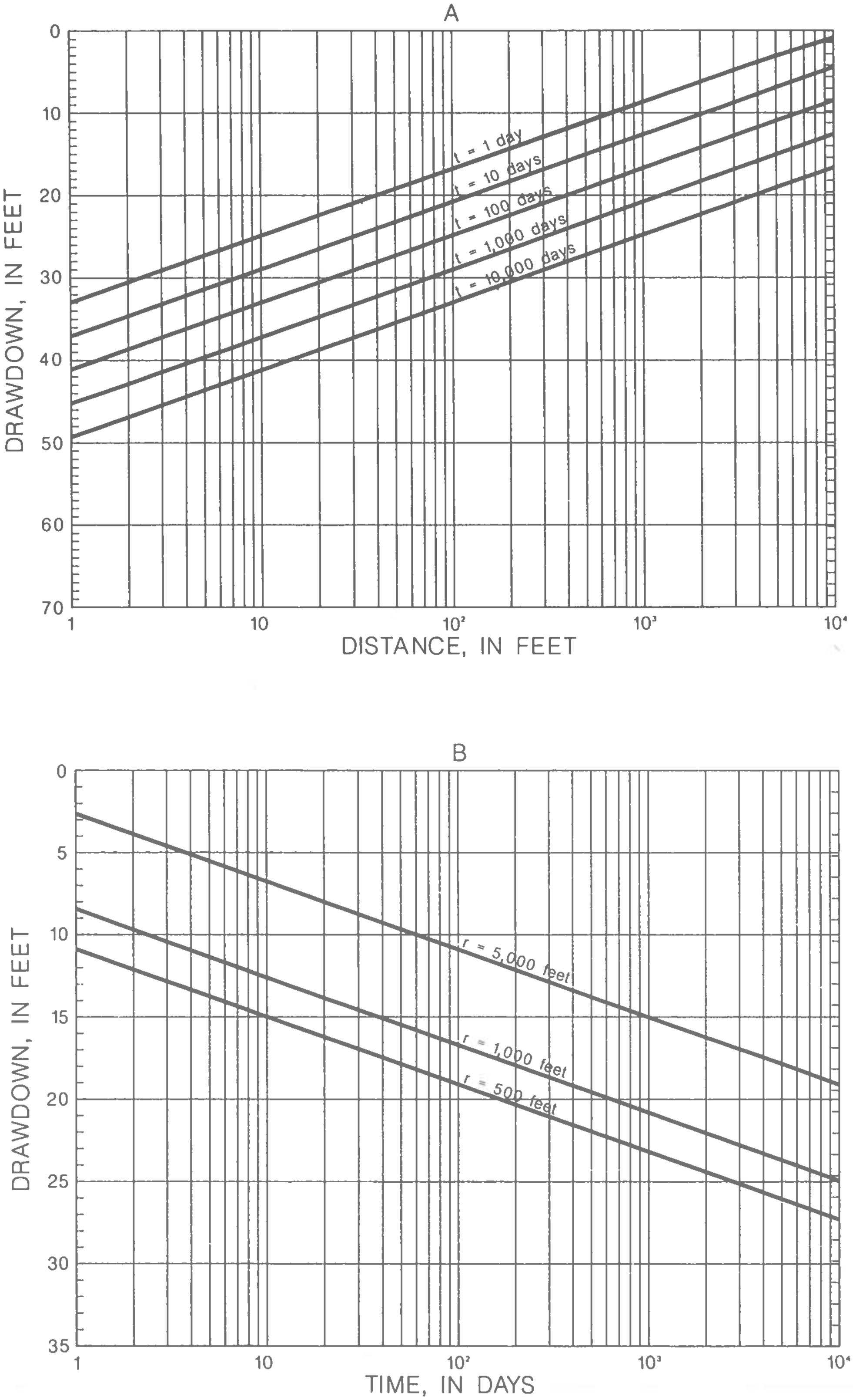


Figure 28. Graph showing theoretical drawdowns, at various times (A) and distances (B), caused by pumping from the Middendorf Formation in F and H Areas.

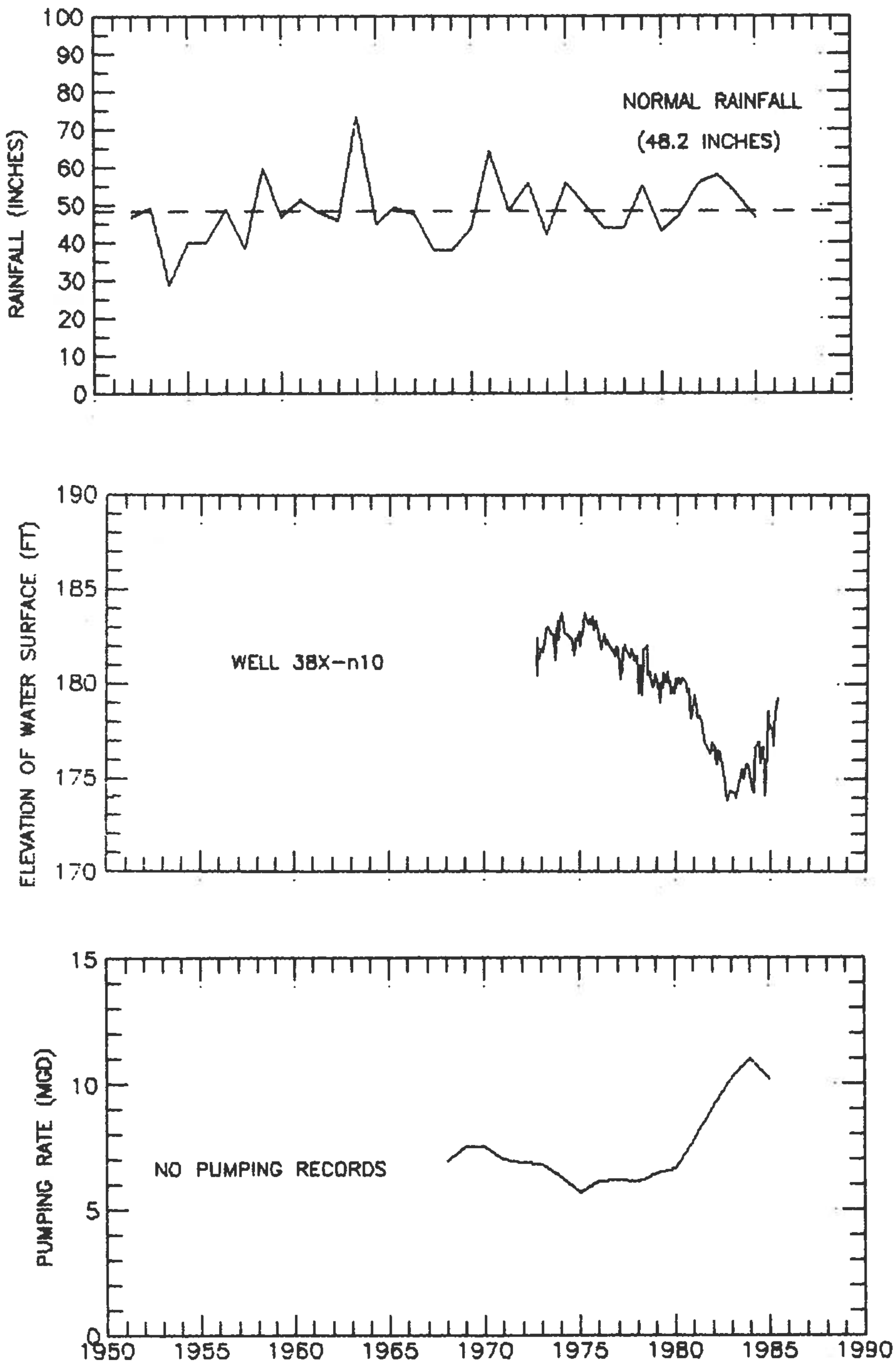


Figure 29. Comparison of rainfall at SRP, total yearly SRP pumpage, and water levels near the center of SRP.

pumping. Since 1983, water levels in F and H Area have recovered and continue to rise. This is probably because of the above normal rainfall that occurred during the period 1982 through 1984 and a decrease in pumpage in 1984.

Cones of depression exist in the vicinity of heavy withdrawals; however, they are not deep or areally extensive. Drawdowns in production wells producing 1,000 gpm range from 20 to 40 ft. Although these depressions in water level probably have little effect on the potentiometric surface for the area around SRP, locally they are adequate to alter the head relationships between the Middendorf and other aquifers. This is an important development in that it may influence the flow paths of potential contaminants that are generally stored in these areas of heavy withdrawal. The potential that exists for interaquifer contamination is discussed in detail in a later section on water quality.

Marine and Routt (1975) developed a computer model of the Tuscaloosa (Middendorf and Black Creek) to obtain an estimate of the amount of ground-water flux through the system. The accuracy of the calculated flux is dependent on the accuracy of the input variables. In this model, the assumptions were that the aquifer had a single average transmissivity and a single average storage coefficient. Using these estimated values, Marine and Routt concluded that the flux through SRP was at least 19.4 mgd and more probably 42.0 mgd. A study underway in 1989 will provide more accurate data and will produce refined estimates. In any event, the continuous average pumping of 6.5 mgd for 22 years (1952-74) had no discernible effects on water levels, and the present pumping of 11.0 mgd shows only minor local effects.

The Middendorf is largely an undeveloped source of ground water except at SRP. Properly constructed wells are capable of producing more than 3,000 gpm of good water. This capacity probably exists throughout the study area, but additional hydrologic information is needed before an accurate appraisal of its water-yielding potential can be made.

Black Creek Formation

Occurrence and hydrologic character - The Black Creek occurs in most of the study area and crops out generally parallel to the Fall Line. The sediments of the Black Creek are similar lithologically to those of the Middendorf. Although not as massive, the sandbeds of the Black Creek have an average hydraulic conductivity, within the study area, approaching that of the Middendorf; 90 ft/day for the Black Creek compared to 110 ft/day for the Middendorf.

Several clay layers are present in the Black Creek Formation; some are easily recognized as thin and discontinuous, but others cannot be delineated owing to the lack of data. In the northern part of the area the upper clay of the formation serves as a confining bed. As this clay pinches out, however, the unit is confined only by clay beds in overlying formations. In wells 36W-j1, 34W-s4, 39X-k6, 38Y-m1, 37Z-m1, and 36AA-f1 (Plate), the Black Creek Formation is confined by clay layers in the Peedee Formation. These clay layers do not always occur at the base of the unit. In such areas (34W-s4 and 37Z-m1), basal sediments of the Peedee are combined with Black Creek sediments as one aquifer. At well 38X-i1, there are no clay layers in the Peedee that are sufficiently impermeable to confine water in underlying sediments. Water levels in wells completed at various depths at the site of 38X-i1 are the same whether the wells are completed in the Peedee or Black Creek. Confinement for both of these units is provided by impermeable clay of the Ellenton Formation. At this location, permeable sediments of the upper Middendorf, Black Creek, Peedee, and lower Ellenton constitute one aquifer that is approximately 350 ft thick.

Wells screened in the Black Creek, in the study area, are generally screened also in other aquifers. Wells at SRP are completed only in the Black Creek where moderate amounts of water (500-600 gpm) are needed. Well 39W-y1 was test pumped at 450 gpm and had a drawdown of about 74 ft, for a specific capacity of 6 gpm/ft; and well 39X-u2 had a specific capacity of 3.5 gpm/ft when pumped at 570 gpm. A well located only 400 ft away (39X-u1), and almost identical in construction, had a specific capacity of 38 gpm/ft at 590 gpm. Pumping tests at these wells indicated an average transmissivity of 12,000 ft^2/day and a storage coefficient of 0.0004. Few data are available on the hydraulic characteristics of the Black Creek outside of SRP. Geophysical and lithologic logs suggest that the transmissivity is probably highest in an area extending northeast from the vicinity of SRP toward northern Bamberg County. Well number 33W-m1, located in northwestern Bamberg County, is a 14-inch well with 8-inch screen set between -165 and -315 ft m.s.l. When drilled, this well produced 1,200 gpm with 50 ft of drawdown, for a specific capacity of 24 gpm/ft. The southernmost well completed in the Black Creek in the study area is irrigation well 35DD-f1 in southern Allendale County. This well is 12 inches in diameter with an 8-inch screen set between -730 and -870 ft m.s.l. When drilled in 1978, the well produced a natural flow of about 1,500 gpm. The static water level was 65 ft above land surface. Pumping the well at 1,000 gpm produced a drawdown of 42 ft and a specific capacity of 24 gpm/ft was calculated. Another irrigation well, 7 7 miles to the northeast (35CC-k1) is 12 inches in diameter with 150 ft of stainless steel screen set between -710 and -860 ft m.s.l. No pumping test was made when the well was drilled in 1980, but the well had a natural flow of 500-600 gpm. This well was later blown with air at 1,750 gpm and had less than 70 ft of drawdown, for a specific capacity of at least 25 gpm/ft. East and southeast of this area, a transition from lower delta plain to pro-delta deposition is evidenced by a decrease in grain size and an increase in clay content. The water-bearing properties of the aquifer tend to deteriorate in a southeasterly direction. Zack (1977) reported values for transmissivity ranging from 390 to 5,350 ft²/day in Horry and Georgetown Counties. In Charleston County, Park (1985) calculated a value of about 1,200 ft²/day. A value of 30 ft/day was calculated to be the average hydraulic conductivity for the Black Creek aquifer in the coastal area of South Carolina, and specific capacities range from 0.8 to 4.8 gpm/ft.

Water Levels — Recharge to the Black Creek is coincident with the Middendorf. In the updip areas, recharge occurs to both as leakage through the overlying Tertiary sediments.

The potentiometric surface of the Black Creek (Fig. 30), indicates discharge mainly to the Savannah River and, to a much lesser degree, the South Fork Edisto River. The sparsity of data makes contour drawing difficult, but there is a general indication of the direction of ground-water flow. The flow pattern is similar to that for the Middendorf. East of SRP, away from the Savannah River, the potentiometric contours are less influenced by stream discharge and flow is to the southeast. A notable feature on the map is the inverse curvature of the contours near the center of SRP, similar to those of the Middendorf.

Large-capacity wells are generally completed in both Middendorf and Black Creek aquifers, as previously discussed. Production wells in the F and H Areas have this type of construction, which probably accounts for the similarity in the shape of the contours. The small cone of depression near Martin is probably related to heavy withdrawals for industrial use. Sandoz Color and Chemical Corporation, located about 2 miles south of Martin, produces about 2.0 mgd (1,400 gpm continuously) from a well completed in Peedee and Black Creek aquifers.

Another feature of the potentiometric surface is the bending of the 150-ft contour in a southerly direction around Allendale. Ground-water flow in the Black Creek had previously been assumed to be toward the south and southeast. Recent data indicate that the potentiometric surface begins to slope toward the east in the vicinity of Allendale and continues in this direction throughout the lower Coastal Plain (Aucott and Speiran, 1985b).

The sparseness of data made it impractical to construct a potentiometric map of the Black Creek for the period prior to development. Because of the similarity in water-level fluctuations with those of the Middendorf in recent years and their similar transmissivity, water-level declines are probably minor, with localized declines around centers of heavy pumping.

Water levels at various locations have fluctuated more than 30 ft in both Cretaceous aquifers since 1951. During this time, the area has experienced periods of severe drought and above-normal rainfall. In August 1985, water levels in many wells were higher than when first measured in the late 1940's and early 1950's. There appears to be a strong correlation between rainfall and water level fluctuation. The potentiometric surface in some areas has declined in recent years as a result of withdrawals that exceed the transmissive or storage capacities of these aquifers. This is a localized condition near centers of pumping and does not reflect an areally extensive condition in the aquifers.

Peedee Formation

The Peedee Formation has long been considered a poor aquifer in eastern areas of the State; however, it appears to be an excellent aquifer in portions of the study area. In the northern part of the area (39W-x1, 39X-k6, 36W-j1, and 38Y-m1 on the Plate), several clay layers in the formation reduce its overall permeability. Southeastward (38X-i1, 36X-x19, 37Z-m1, and 35AA-o1 on the Plate), where upper delta plain deposits of coarse sand characterize the unit, the water yielding capability increases greatly. As discussed in the Black Creek section, the Peedee is commonly hydraulically connected with underlying and overlying sediments. There are areas, such as at well 36AA-o1, where the formation is isolated from overlying and underlying units. At well 36AA-o1 the unit is confined from above by a basal Ellenton clay. A basal Peedee clay isolates the unit from the Black Creek. At this location, almost the entire Peedee Formation can be considered a single aquifer. The high permeability of the Peedee Formation probably extends downdip into sediments of lower delta plain deposition but it decreases as the sediments become finer grained and the clay content increases.

Little hydrologic information is available for the Peedee Formation in the study area. Few wells are known to be completed solely in the Peedee. One well (31X-m6) is 12 inches in diameter and has five 10-ft sections of 12-inch screen set between -301 and -392 ft m.s.l. When drilled for the town of Bamberg in 1978, this well produced more than 1,500 gpm. The static water level was above land surface. After pumping at 1,000 gpm for 24 hours, the water level was 58 ft below land surface. An irrigation well in Allendale County, 34AA-m1, is 12 inches in diameter with 100 ft of screen set between -403 and -588 ft m.s.l. This well was test pumped at 1,650 gpm and had a pumping water level 108 ft below land surface. No measurement of the static water level is available for these last two tests.

The town of Allendale has several municipal wells screened in sandbeds of the Peedee. One such well, 34AA-q1, is 16 inches in diameter with 60 ft of 8-inch screen set between -476 and -536 feet m.s.l. In 1967 this well produced 754 gpm with a drawdown of 81 ft, for a specific capacity of 9.3 gpm/ft.

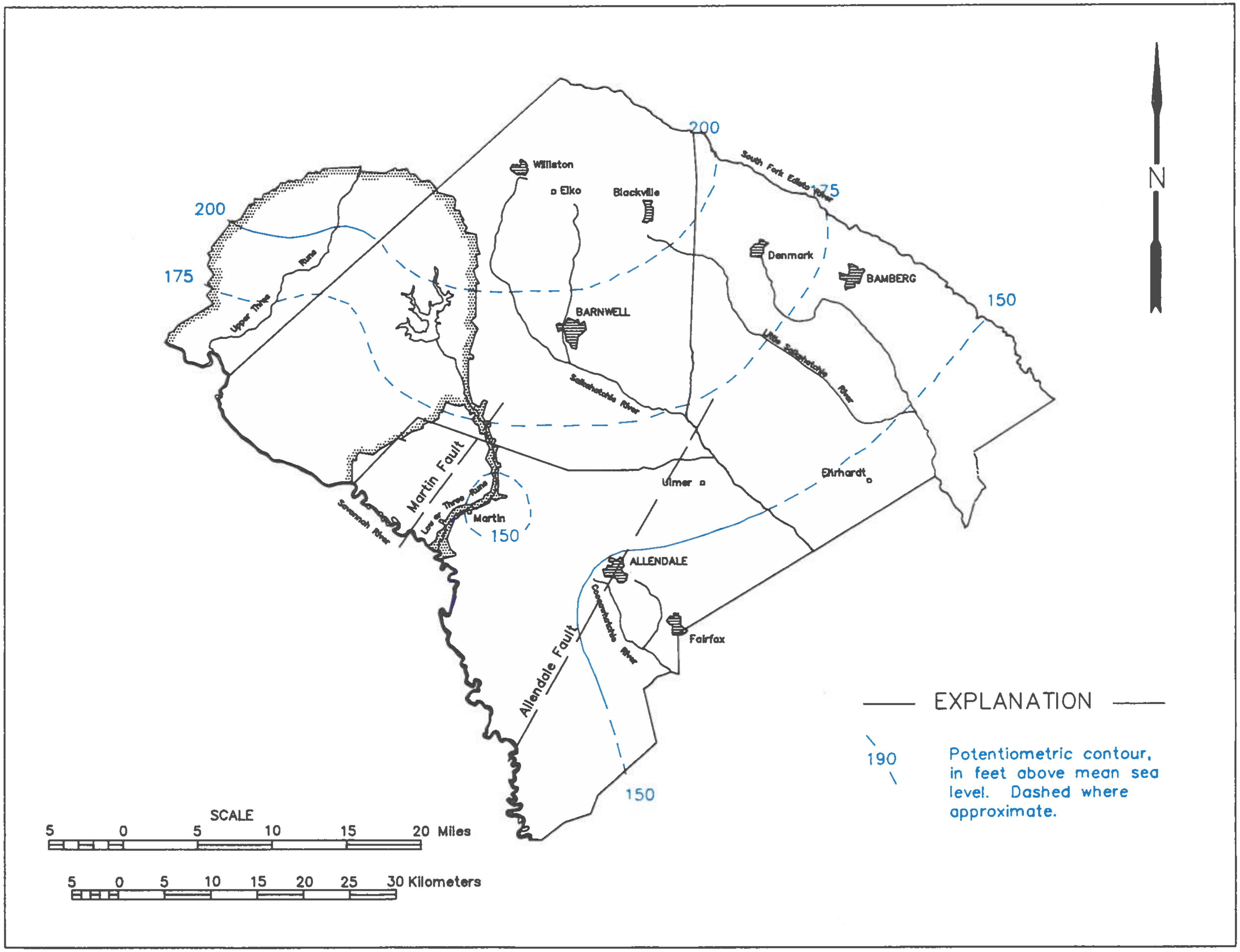


Figure 30. Potentiometric surface in the Black Creek Formation, August 1985.

Siple (1975) noted coarse-grained, well-sorted sand in the Peedee in Orangeburg County. The texture and sorting of this sand suggest a high permeability, and its thickness (over 200 ft) may imply a transmissivity for this aquifer comparable to that of the Middendorf, at least locally. In most of Bamberg County the sand unit is nearly 200 ft thick, and it appears to maintain this thickness throughout southern Barnwell County and across Allendale County to the Savannah River. Few wells are completed in the Peedee because aquifers in the overlying formations are less expensive to develop and are capable of yielding adequate water supplies for most purposes.

Tertiary Formations

Ellenton Formation

The Ellenton Formation is present throughout the study area. In the updip areas it is characterized by an upper clay unit and a basal sand unit. In many areas in the vicinity of SRP, a thick clay layer at the top of the Cretaceous sediments separates the Peedee from the Ellenton sand. Where the upper clay of the Peedee is absent, the sandbeds of the Ellenton and Peedee are hydraulically connected and water is free to move between them.

The Ellenton Formation has several clay layers in its updip extent that are excellent confining beds, and the formation is generally considered to be a confining unit. The clay, however, is interbedded with sand that yields appreciable quantities of water. The confining beds gradually pinch out toward the southeast as the formation becomes predominantly sandy. Owing to the sparseness of hydrologic data, it is only assumed that the basal clay of the Ellenton provides complete confinement to the underlying Peedee in the southern part of the area.

The Ellenton is hydraulically connected with underlying formations in some areas. In other areas, however, it is isolated. At wells 36W-j1, 34W-s4, and 36AA-f1 (Plate), the Ellenton is confined by overlying Black Mingo clay or by an upper clay in the Ellenton and is separated from the underlying Peedee by either a basal Ellenton clay or an upper Peedee clay. In these areas, the Ellenton Formation constitutes a single aquifer with a maximum thickness of about 100 ft. In the southern portion of the area, parts of the unit may be hydraulically connected with the overlying Black Mingo.

Data relating to the hydraulic characteristics of the Ellenton are sparse, but geophysical logs and lithologic descriptions suggest that the most productive zones are in the eastern half of the study area. These sandbeds appear to be as permeable as the Middendorf or Black Creek but are not as thick, commonly being less than 75 ft. The existence of more productive aquifers at shallower depth accounts for the fact that no water wells are known to be completed only in the Ellenton.

No production wells are completed in the Ellenton, but a few wells at SRP are screened opposite the sandbeds to monitor water levels. The sparse data do not allow the construction of a potentiometric map; therefore, little is known about the horizontal flow paths of water in the Ellenton. Because of its apparent hydraulic connection with the Cretaceous aquifers, the flow pattern is probably similar, at least in the vicinity of SRP.

Figure 31 shows long-term hydrographs for wells 39Y-f1 and 38X-n18, screened in the Ellenton; 38X-n17 screened in the Black Creek; and 41V-x3, 38X-n10, and 38X-i7 screened in the Middendorf. Ellenton well 39Y-f1 is located in D Area and shows effects of the nearby pumping of about 0.3 mgd from the Middendorf until 1972, when the wells were discontinued. The response of water levels in the Ellenton to withdrawals in the Middendorf indicates some hydraulic connection. Overriding the fluctuations caused by pumping is the same general trend of water levels as seen in wells completed in other aquifers. The characteristic rise and fall of water levels in the Ellenton are similar to those in the Middendorf and Black Creek. The hydrograph for well 39Y-f1 shows a steady decline of about 12 ft in water level since about 1978. There has been no increase in pumpage from any of the aquifers in this area. The sharp decline in the water level in this well since 1978 may not be indicative of the general trend. The corrosive nature of the water in this area has resulted in the abandonment of wells because of casing failure. Since the water level in the Ellenton Formation is much above land surface (13 ft in 1978), the large decline may be attributed to leaks developing in the casing and loss of head to other aquifers.

Black Mingo Formation

Clay in the Black Mingo Formation in its updip extent limits its water producing capability and acts as confining units. However, as the formation grades into different lithologic facies, its porosity and permeability change. Although there is little hydraulic information available concerning the Black Mingo limestone in this area, it is likely that its calcareous nature has allowed for some solution porosity and has made the unit capable of yielding water. In areas where the formation consists predominantly of sand, its yields are probably greater.

All of the upper part of the Black Mingo is hydraulically connected with overlying sediments in the updip part of the area (39W-x1, 39X-k6, 36W-j1, and 38X-i1 on the Plate). In downdip locations (36W-j1, 34W-s4, and 38Y-m1), an upper clay in the formation may provide confinement. If confinement is continuous

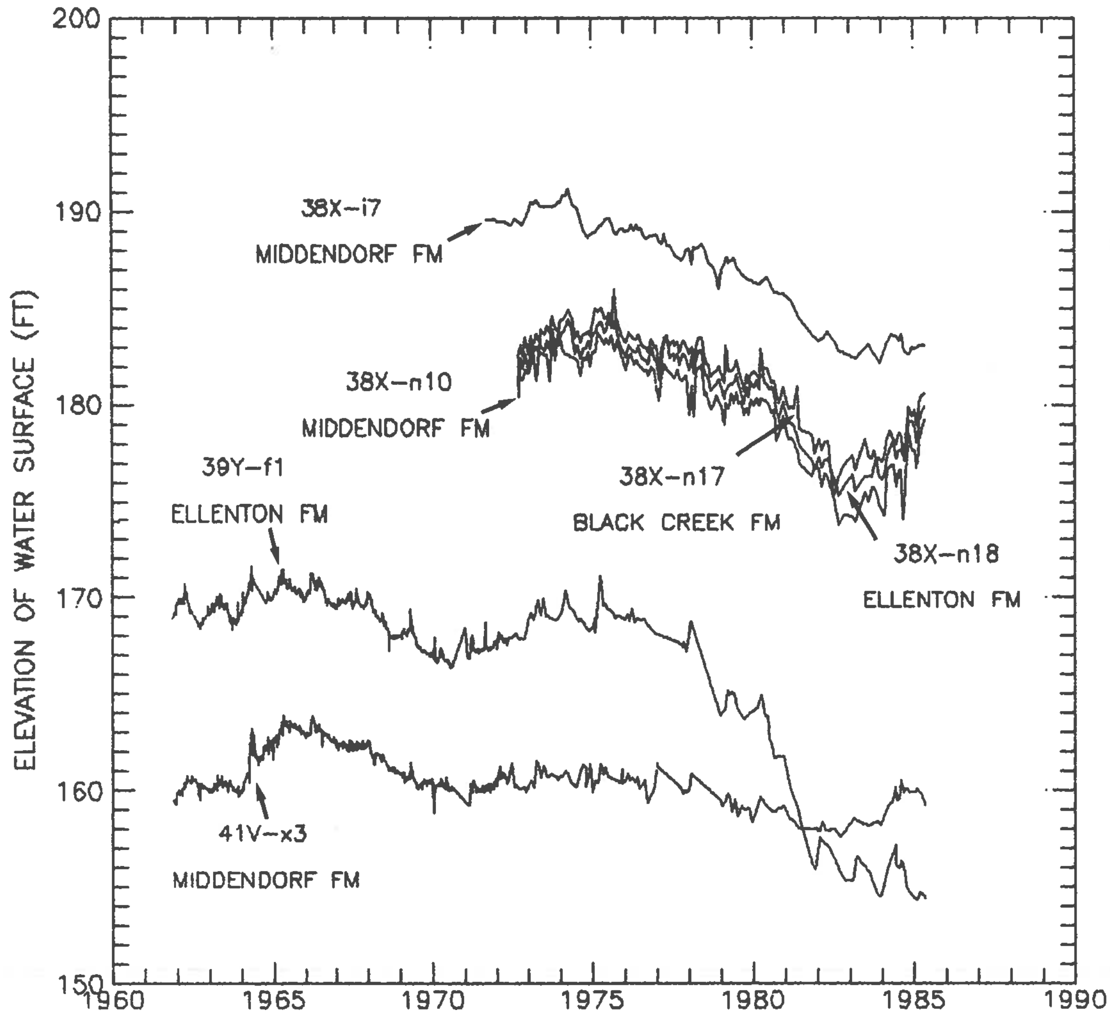


Figure 31. Hydrographs of selected wells at SRP.

in these areas, part of the Black Mingo Formation would constitute a single aquifer, its maximum thickness being about 50 ft.

Black Mingo sediments consist mainly of clay and clayey sand and act as a confining unit in the SRP area. Downdip, the unit grades into different lithologic facies. Across the upper part of Allendale and Bamberg Counties and the lower part of Barnwell County, the sediments are composed of calcareous sand overlain by sandy limestone. One well for the city of Barnwell (35Y-i1) appears to be screened opposite sand of the Black Mingo. The well is 12 inches in diameter and has 30 ft of 12-inch screen set between -63 and -100 ft m.s.l. When completed in 1968, the well was test pumped at 560 gpm and had 70 1/2 ft of drawdown, for a specific capacity of 8 gpm/ft. East of the study area, in Orangeburg County, an irrigation well has 140 ft of 16-inch screen set opposite Black Mingo sand between -74 and -214 ft m.s.l. This well (24v-s2) was test pumped at 2,356 gpm and had 112 ft of drawdown, for a specific capacity of 21 gpm/ft. South of the study area, in Hampton and Colleton Counties, more than 25 wells are open to the Black Mingo Formation and have natural flows of 50-250 gpm (Hayes, 1976). Only limited hydrologic data for the Black Mingo in the study area are available; however, geophysical and lithological data suggest that it could be a productive aquifer in the southern half of the study area. Many wells in Allendale and Bamberg Counties are open to the Black Mingo in conjunction with other aquifers and will be discussed later.

Few water-level data exist for the Black Mingo. Aucott and Spieran (1985a and b) included the Black Mingo in the Tertiary sand aquifer system on the basis of similarities in water levels. Although this is probably true on a regional scale, the authors have observed several areas of higher head in the Black Mingo.

Water-level measurements for a well (34AA-q3) in the town of Allendale indicated a higher head than the surrounding wells completed in the Santee Limestone. This well is 434 ft deep with casing extending to a depth of 254 ft. The hole is open to both the Santee Limestone and Black Mingo Formation. An observation well (33Z-n1) in southern Barnwell County showed a substantial head difference. This well was drilled for the SCWRC in October 1984. Casing was set at 175 ft with an open hole extending to a depth of 200 ft. After completion, the well was equipped with an automatic water-level recorder. Upon examination of the drill samples, SCWRC geologists decided to deepen the well approximately 200 ft. In February 1985, the well was completed to a depth of 420 feet, with an open-hole interval between 175 and 420 ft in the Santee and Black Mingo. Before deepening the well, the water level in the Santee Limestone was at an elevation of about 141 ft m.s.l. After the Black Mingo was penetrated the water level rose to 156 ft m.s.l. Although this measurement represents a composite water level, it indicates that the potentiometric level for the Black Mingo is at least 15 ft higher than that of the Santee Limestone.

Congaree Formation and Santee Limestone

Sediments of the Congaree Formation constitute a good aquifer. Its sand beds of fluvial and near-shore marine environments are sufficiently porous and permeable to yield large quantities of water. The unit has been used extensively at SRP. The minable kaolinitic clay (Huber Fm) at the top of the unit in the vicinities of Augusta and Aiken is an excellent confining bed, but it pinches out in a seaward direction. In many other areas at SRP, the Congaree may be connected with upper sediments of the Black Mingo Formation. Downdip (wells 36W-j1 and 36X-x16, Plate), where the basal clay of the McBean is missing, the Congaree is hydraulically connected with overlying units, possibly extending to land surface (36X-x16) for a maximum combined aquifer thickness of 280 ft. Farther downdip, it is hydraulically connected with the Santee Limestone.

Occurrence and hydraulic character — In the northern part of the study area, the Congaree is composed of fine- to coarse-grained quartzitic sand and silty or clayey sand. The coarse-grained sand beds constitute a highly productive aquifer and are relied on for various uses. The unit thickens from about 50 feet in the northern part of SRP to a maximum thickness of 104 feet near the old town of Dunbarton, now in SRP. In a seaward direction, the sediments of the Congaree thin and become increasingly calcareous. Aucott and Speiran (1985a and b) lumped all of the Eocene sand formations together (Barnwell, McBean, and Congaree) because they act hydraulically as a single aquifer in most of the State. Locally, however, confining beds in these formations support a substantial head difference between overlying and underlying units.

The most notable confining bed is a clay layer at the top of the Congaree, known locally as the "green clay." This clay unit appears to be continuous over at least the southeastern two-thirds of SRP and attains a thickness of 60 feet in northern Allendale County. Where encountered, the green clay produces a groundwater head differential between the McBean and the Congaree that approaches 80 feet in some areas. At the base of the Barnwell, just above the McBean, a clay layer impedes vertical movement of water from the Barnwell to the McBean. Because this clay is not as continuous and has a greater hydraulic conductivity than the green clay, the head differential between the two is not as great. In some areas, water levels in the Barnwell are 12 feet higher than those in the McBean. Because of the head differences among some aquifers of the Tertiary sand formations and the similarities in head between the Santee and Congaree, only the last two are considered to act hydraulically as a single aquifer.

Sand beds of the Congaree form a highly productive aquifer in most of the northern part of the study area. Municipal wells at Barnwell yield as much as 400 gpm with 40 ft of drawdown. Maximum yields of 660 gpm (Siple, 1957) with 50 ft of drawdown have been obtained near the center of SRP. Updip, in the northwestern part of SRP, the Congaree becomes a clayey sand, and well yields are not nearly as high. Wells in this area generally produce 20-30 gpm with about 30 ft of drawdown. This is sufficient, however, for some light industrial and commercial uses. The Edisto Experimental Station at Blackville (Barnwell County) pumps an average of about 20,000 gallons per day from the Congaree. Most rural domestic water supplies are developed in the Congaree in Barnwell and northern Bamberg Counties.

The median value for hydraulic conductivity, from 10 slug tests (decay of an instantaneous head increase), is 5.9 ft/day near the center of SRP. With additional data from two water-level recovery tests, the median value is 4.9 ft/day.

A test by the U.S. Army Corps of Engineers indicated a median value of 43 percent for porosity. This value represents total porosity, however, and should not be used for ground-water flow calculations. Any ground-water velocity equations should use the effective porosity, and for this report the authors are estimating an average effective porosity of 20 percent for the Congaree Formation.

In its updip extent the Santee Limestone is very sandy, and wells must be constructed with screens to keep the hole from collapsing. Near Kline, in southern Barnwell County, the Santee Limestone consists of calcareous sand and abundant shell hash. Farther downdip, the limestone becomes well indurated and wells are generally of open-hole construction.

The Santee Limestone is used extensively in the southeastern part of the Coastal Plain as an aquifer. Porosity of this unit is primarily the result of solution of calcium carbonate. In much of the study area the unit is not confined by clay and is, therefore, hydraulically connected with the overlying sand; in many areas it is also connected with underlying units. It is this limestone that constitutes most of the Floridan aquifer system. Where it is hydraulically connected with units above and below, the composite is referred to as the Floridan/Tertiary sand aquifer (Aucott and Speiran, 1985a and b). This aquifer may be as much as 450 ft thick (36BB-j1), but insufficient geophysical, hydrologic, and lithologic data prevents accurate determination of its extent.

A municipal well for the town of Allendale (34AA-q2) is completed in the Santee Limestone. This is in an area of transition from sand to limestone. The limestone is moderately indurated but contains abundant sand; therefore, screens were set to prevent sand from entering the well. The well is 16 inches in diameter and has 12 5-ft sections of 6-inch screen set between the elevations of -59 and -149 ft m.s.l. In 1980 a pumping test was made at a discharge rate of 752 gpm. At the end of 24 hours the drawdown was 102 ft for a specific capacity of 7.5 gpm/ft. Data collected at the pumping well indicate a transmissivity of 3,300 ft^2/day. Eight miles northeast of Allendale, a well for the town of Ulmer (33Z-y1) is also completed in the Santee Limestone. This well is 24 inches in diameter and has 50 ft of 10-inch screen set between the elevations of 20 and -100 ft m.s.l. The well produced over 1,000 gpm during development, but discharge was maintained at 700 gpm for a short pumping test. A transmissivity of about 5,000 ft^2/day was indicated, and a projected specific capacity was 15 gpm/ft.

Approximately 2 miles north of Ulmer, in extreme southern Barnwell County, the SCWRC drilled an observation well (33Z-n1) into the Santee Limestone. At this location the limestone was well indurated and contained only small amounts of sand and shell fragments. The well was constructed with a 4-inch diameter casing and had approximately 25 ft of 4-inch diameter open hole below the casing at elevations of 20 to -5 ft m.s.l. After completion, the well was pumped at 80 gpm for 3 1/2 hours. Drawdown at the end of this time was 16 1/2 ft, for a specific capacity of 4.7 gpm/ft. Drawdown and recovery data indicate a transmissivity between 6,300 and 7,100 ft^2/day.

Farther northeast, the town of Govan has a 6-inch diameter municipal well (33Y-j1) completed in the Santee Limestone with an open-hole interval between 27 and -10 ft m.s.l. No pumping test was made, but the well yields 55 gpm with 113 ft of drawdown, for a specific capacity of 0.5 gpm/ft. A well drilled for the town of Bamberg (31X-m9) is 24 inches in diameter and has 50 ft of 8-inch screen set in the Santee Limestone between 53 and -52 ft m.s.l. This well produces 400 gpm with 47 ft of drawdown, for a specific capacity of 8.5 gpm/ft.

The town of Fairfax installed a well (33BB-p1) in 1983 with 40 ft of 10-inch screen set between -137 and -219 feet m.s.l. A pumping test made at the time of drilling indicated a transmissivity of about 500 ft^2/day. Discharge from the well was 298 gpm with 227 ft of drawdown, for a specific capacity of 1.3 gpm/ft.

The hydraulic characteristics of the Santee Limestone vary considerably with locale. This is probably the result of several different processes; however, the greatest effect seems to be caused by the dissolving of calcium carbonate by ground water. The removal of part of the aquifer material results in increased porosity and permeability. In many parts of the study area, the limestone has been dissolved to a point that large cavities have formed. A 6-inch open-hole well near Ulmer is completed in one of these cavities and reportedly produces 2,000 gpm with only a few feet of drawdown.

The variability in the amount of dissolution is strongly influenced by the chemical composition of the water and the local differences in geology and lithology that affect the rate of ground-water movement and, hence, of limestone dissolution. The unpredictability of the solution cavities causes problems in drilling operations. Sudden mud losses and drill-rod drops have been encountered throughout the study area. When conducting foundation test borings at SRP, the U.S. Army Corps of Engineers experienced many such problems in the McBean Formation in Barnwell County. Large quantities of cement grout had to be installed in these areas in order to stabilize the ground surface. Local well drillers tell of numerous experiences with these cavities in the Santee Limestone in Allendale and Bamberg Counties.

Unlike other areas of the State where land subsidence (with sinkholes) has resulted from the dissolution of limestone, only one (east of the old town of Ellenton) has been observed in the study area. This is probably because water levels have not shown a drastic decline but have remained fairly stable. Water in the aquifer exerts sufficient pressure on the surrounding material to support the weight of the overburden.

Water levels — Recharge occurs generally northwest of the study area where rainfall percolates into the outcrop and subcrop of the Congaree. The potentiometric map in Figure 32 indicates that major deviations in the flow direction occur where the aquifer has been deeply incised by streams, allowing water to be discharged from the aquifer. The Savannah River has the greatest areawide influence on water levels, followed by the South Fork Edisto and, to a much lesser degree, the Salkahatchie River. In the updip area, Upper Three Runs Creek controls the direction of ground-water movement. The green clay at the top of the Congaree has been breached by the stream, creating a ground-water sink that induces flow toward the stream. Using an average of transmissivity of 300 ft^2/day and an average hydraulic gradient of 25 ft per mile near Upper Three Runs Creek, there is an estimated 112,000 gallons per day being discharged through each 1-mile strip of the aquifer along the creek, for a total of 1.4 million gallons per day. Current studies by the USGS will refine these estimates, but this value gives an indication of the amount of ground water discharge.

From the shape of the contours in Figure 32, there appears to be an area of recharge north of Allendale, near the Barnwell county line. Drillers logs, soil samples, and geophysical logs indicate that near the Allendale-Barnwell County line, the green clay associated with the Congaree is missing. The McBean becomes very thin and is predominantly a sand, the lower calcareous zone having graded into the Santee Limestone.

Undoubtedly there are other areas of recharge to the Santee Limestone, both from downward percolation through the overlying sediments and by upward leakage from aquifers with higher heads. This area, however, constitutes a substantial zone of recharge, and further investigation is warranted to determine the areal extent and amount of recharge.

The SCWRC has been monitoring water levels in the Santee Limestone in Allendale and Bamberg Counties twice each year since 1981. These measurements are taken in March, when water use is low, and again in July, when demand is high because of summertime activities and irrigational practices. Only minor fluctuations have been noted, generally less than 5 ft. The rise and fall of water levels appear to be related more to rainfall than to pumping patterns. Water levels in March 1986 were 3 to 4 ft higher than when measured in July-August 1985; however, on several occasions in the past few years they have been higher in the summer than in early spring.

The monitoring program was expanded in 1985 to measure water levels in the Congaree Formation in conjunction with the Santee Limestone. Approximately 90 wells were measured in Aiken, Allendale, Bamberg, and Barnwell Counties. These wells will continue to be monitored twice each year for water-level changes, to determine seasonal fluctuations caused by rainfall or pumping.

McBean Formation

The McBean can be divided into two substantially different units in the updip area. An upper unit consisting of red sand and tan clayey sand and a lower unit consisting of tan to white calcareous clayey sand. Ground water occurs in both units, but neither is a very productive aquifer in the northwestern part of the study area. In some areas of SRP the McBean is confined (38Y-m1, Plate) and constitutes a single aquifer. In other areas of SRP its confinement is questionable. Southeastward from the southern part of SRP, where the McBean becomes a siltstone, permeability decreases, inhibiting the formation's water yielding abilities. In other areas downdip (36AA-f1 and 36BB-j1, Plate), the unit becomes a calcareous sand and eventually grades into the Santee Limestone. In these areas the formation is part of the Floridan/Tertiary sand aquifer of Aucott and Speiran (1985a and b).

Tests at SRP indicate an average hydraulic conductivity of 0.43 ft/day for the upper unit and 0.23 for the calcareous zone. During drilling operations, drillers noted many instances of drill-rod drops and loss of circulation when penetrating the calcareous zone. Usually, this is an indication of high permeability. However, subsequent pumping tests indicate that these zones of seemingly high permeability are not connected and that, regionally, the permeability of the calcareous zone is very low. In northern Barnwell County, the town of Williston has one well completed in the McBean, but no hydraulic data are available. It appears that the McBean is capable of supplying water in limited quan-

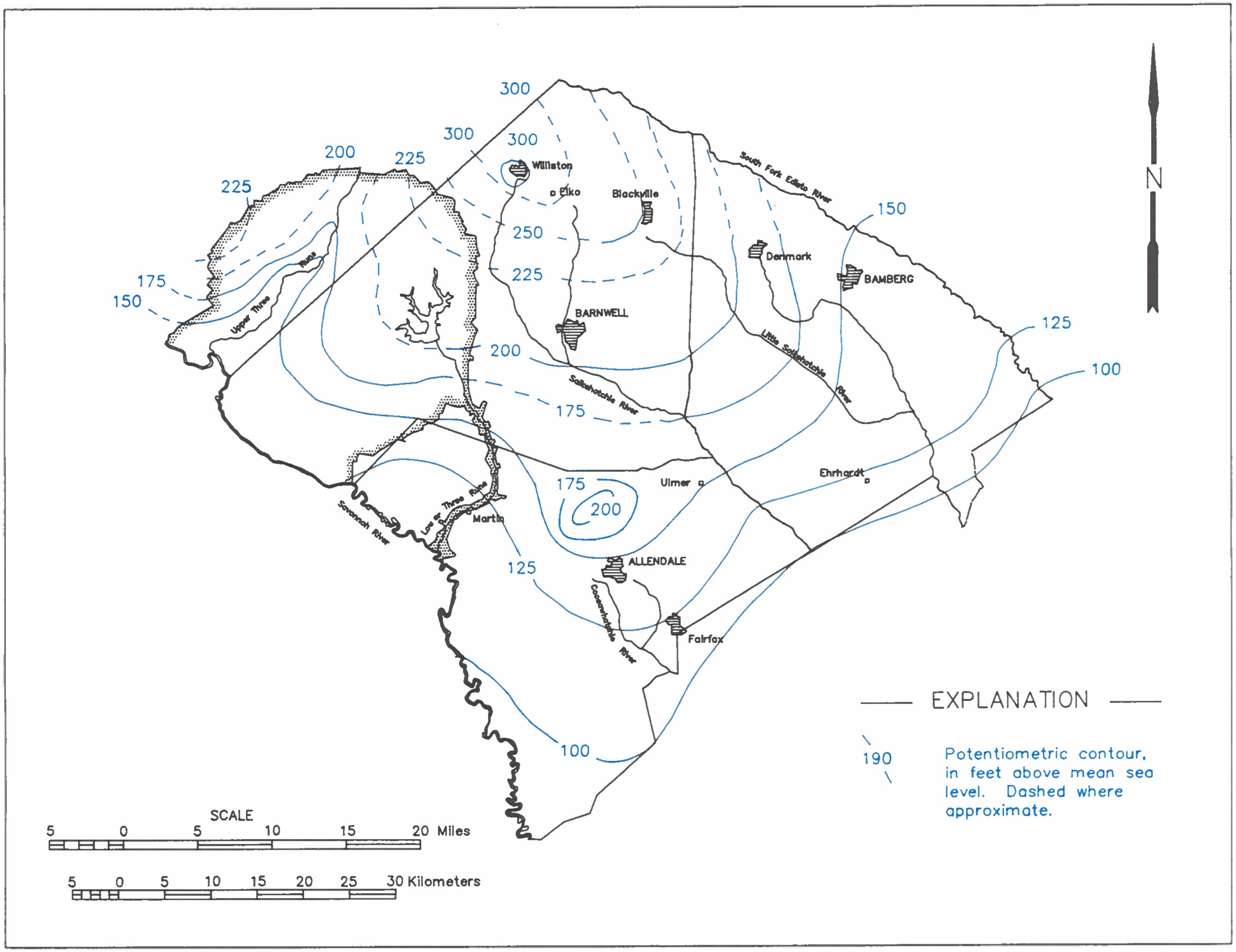


Figure 32. Potentiometric surface in the Congaree Formation and Santee Limestone, August 1985.

tities to wells. It is probably used for domestic purposes in the northeastern third of the study area, but the extent of its use is not documented.

No water-level data are available for the McBean except within SRP. In this area the ground-water flow paths are controlled by the local topography. Topographic highs are areas of recharge and low creek valleys and swamps serve as areas of discharge. The McBean is incised by many streams that dissect the area, dividing the unit into separate hydrologic regimes, each having its own area of recharge and discharge. Ground water that enters the McBean in one area cannot migrate to another area if it must cross a stream valley.

Generally, the water table is found within the Barnwell. Where this is true, the tan clay at the bottom of the Barnwell impedes the vertical movement of water and supports a head difference between the Barnwell and McBean of about 12 ft. The green clay at the top of the Congaree, just below the McBean, impedes the movement of water from the McBean to the Congaree. This clay serves as a very effective confining unit and in some areas supports a head differential of more than 80 ft.

Barnwell Formation

The Barnwell can be divided into three separate units in the northwestern part of the study area. The lowermost unit, the tan clay, impedes the movement of water through it; however, it does allow for some recharge to the McBean. Above the clay is a unit consisting of silty sand that is slightly more permeable than an overlying clayey sand unit. An average value of 0.13 ft/day for the hydraulic conductivity of the clayey sand has been calculated from point-dilution tracer tests at SRP (Christensen, 1983). A pumping test in a sand lens in the silty sand indicates a hydraulic conductivity of 0.99 ft/day.

The Barnwell does not generally yield water to wells because of the large amounts of silt and clay in the updip area. Local lenses of fairly clean sand, however, may yield sufficient quantities for domestic use. Farther downdip, the sediments become increasingly calcareous and the silt and clay content tends to decline, thereby increasing the permeability. The downdip limit of the Barnwell is an approximate line extending from Denmark through Allendale. Southeast of this line, equivalent sediments of the Cooper Group are encountered. These two units are probably in hydraulic connection and provide water for domestic supplies throughout most of Allendale and Bamberg Counties and in eastern Barnwell County.

The Barnwell and Cooper Groups have several inclusive formations and members, each representative of a different lithofacies as discussed earlier. As the lithology of these formations and members varies, so do the porosity and permeability. Therefore, depending upon which lithofacies is present, the water yielding capability of these groups varies. Where few or no clay beds are present, as in the eastern part of the study area, they are hydraulically connected with the underlying sediments.

MULTI-AQUIFER WELLS

Pumping tests provide their most useful information when they use wells that are open to at least 80 percent of the aquifer thickness and to only one aquifer. In South Carolina, however, most wells are constructed with several screened intervals in an effort to obtain all the water available. Many pumping tests have been made with wells screened in two or more aquifers. It is not known what percentage of the total discharge is being derived from each aquifer; therefore, any value for transmissivity calculated from multi-aquifer pumping tests will reflect only a minimum estimate of the total transmissivity of all the aquifers penetrated.

Large-capacity wells in SRP are usually screened in the Middendorf and Black Creek. Properly constructed wells in this area are capable of producing 2,000 gpm with an expected drawdown of about 50 ft. Farther south, Sandoz Color & Chemical Corporation uses a well screened throughout the Black Creek and Peedee. This well, 36AA-o1, was test pumped at 2,257 gpm and had a specific capacity of 20 gpm/ft. A similarly constructed well at Whitlock Combing Company, 36AA-b1, showed a specific capacity of 12 gpm/ft when pumped at 1,000 gpm. An Allendale Industrial Park well, 34BB-k1, is screened opposite the Black Creek and Peedee and had a specific capacity of 29 gpm/ft or less at 1,250 gpm. In central Allendale County an irrigation well, 34BB-h2, produced 1,753 gpm from the Black Creek and Peedee with a specific capacity of 13 gpm/ft.

Aquifers in the shallower formations increase toward the south in their importance as potential ground-water supplies. In the downdip areas, as these formations thicken, various combinations of aquifers are utilized. The town of Denmark uses three wells open to the Black Mingo and Santee Limestone. These wells pump 400-500 gpm, and specific capacities range from 3.1 to 3.4 gpm/ft.

WATER QUALITY

Major Naturally Occurring Chemical Constituents

The chemical quality of ground water is dependent on several factors. As precipitation enters the ground, minerals from the surrounding rock are dissolved. The amount of mineralization depends on the character and composition of the water as it enters the ground, the composition of the soil, and the amount of time the water has been in contact with the rock.

Rainfall that recharges aquifers in Aiken, Allendale, Bamberg, and Barnwell Counties is low in dissolved gases and slightly acidic. The types of minerals that are dissolved vary among aquifers, but the amount of mineralization is generally low in areas of recharge and increases with depth and distance from the recharge area.

An abundance of certain chemical species can cause adverse effects. The sources and effects of several of these constituents are listed in Table 5. The quality of ground water in all aquifers in the study area is generally good and acceptable for most uses.

Over 100 water samples were obtained in the study area and analyzed by the SCWRC laboratory. Complete chemical analyses for selected wells are listed in Appendix C. A convenient method of comparing the amount of chemical constituents in one water sample to those in another is by the means of Stiff diagrams. These diagrams are constructed by converting the concentration of major ions from milligrams per liter to milliequivalents per liter and plotting their respective percentages on four parallel horizontal axes extending on both sides of a vertical zero axis. The resultant diagram represents a comparative "type" of water and aids in visualizing the differences between water types.

The correlation of aquifers on the basis of water type becomes exceedingly difficult in the updip reaches of the aquifers where the water is low in total dissolved solids because of its short residence time in the aquifer. Another difficulty in correlation arises when facies changes within an aquifer are encountered. Over a distance of several miles, the lithology of an aquifer may change from a quartzitic sand to a calcareous sand to a limestone. As a result, water within a single aquifer may exhibit very different chemical-quality characteristics. Figure 33 shows Stiff diagrams depicting water quality in various aquifers and combinations of aquifers.

Middendorf Formation

Water from the Middendorf is low in dissolved solids, soft, and acidic, making it corrosive to most metals. This is particularly true near the outcrop where the water is almost saturated with dissolved oxygen. Appreciable amounts of dissolved carbon dioxide also cause the water to be aggressive. Characteristically, sodium and potassium cations exceed those of calcium and magnesium, and the sulfate, chloride, and nitrate anions exceed the bicarbonate.

Because of the low concentration of dissolved solids (generally less than 50 mg/L) and the low values of pH (4.2 to 6.9), water from the Middendorf can be very corrosive to metal; it dissolves iron pipes readily.

Black Creek Formation

The quality of the water in the Black Creek is similar to that in the Middendorf in the updip areas, with only a slight increase in dissolved solids. As the water moves downdip, the amount of mineralization increases and the dissolved-solids concentration approaches 200 mg/L in southern Allendale County. Sodium concentrations also increase, from about 3 to more than 60 mg/L and constitute over 90 percent of the dissolved cations present. Alkalinity increases from less than 20 to more than 150 mg/L because of the presence of bicarbonate anions. The pH values of over 8.7 indicate the presence of carbonate alkalinity also. Water from the Black Creek is very soft and suitable for most purposes throughout the study area.

Peedee Formation

Only one water sample was obtained from the Peedee. This water exhibited a pH of 5.5 and dissolved solids of less than 60 mg/L, making it slightly aggressive. Water from the Peedee is used to supply the town of Bamberg, which has other wells that draw water from the Black Mingo Formation and Santee Limestone.

Ellenton Formation

No water samples were obtained from the Ellenton exclusively; however, wells that are screened in the Ellenton and another aquifer exhibit certain qualities not characteristic of water from the other aquifer alone. The Ellenton appears to contain water that is low in total dissolved solids (generally less than 50 mg/L) but high in iron (an average of about 1 mg/L) and with a high ratio of sulfate anions to total anions. Calcium ions exceed bicarbonate ions, indicating the presence of noncarbonate hardness. This may be the result of dissolution of calcium sulfate from gypsum crystals that occur in the Ellenton.

Table 5. Source, effect, and treatment of selected constituents in ground water

Constituent or property	Source and/or solubility	Effects	Treatment
Silica	Most abundant compound in earth's crust, resistant to solution	Causes scale in boilers and deposits on turbine blades	Reverse osmosis or ion exchange.
Iron	Very abundant element, readily precipitates as hydroxide.	Stains laundry and porcelain, bad taste.	Zeolite type ion-exchange water softeners, manganese-green sand, birm, or oxidation by aeration.
Manganese	Less abundant than iron, present in lower concentrations.	Stains laundry and porcelain, bad taste.	same as for iron.
Calcium	Dissolved from most rock, especially limestone and dolomite.	Causes hardness, forms boiler scale, helps maintain good soil structure and permeability.	Zeolite or other ion-exchange water-softener devices.
Magnesium	Dissolved from rocks, industrial wastes.	Same as calcium	Same as calcium
Sodium	Dissolved from rocks, industrial wastes.	Injurious to soils and crops and certain physiological conditions in man.	Reverse osmosis or ion exchange
Potassium	Abundant, but not very soluble in rocks and soils.	Causes foaming in boilers.	Zeolite or other ion-exchange water-softener devices.
Bicarbonate	Abundant and soluble from limestone, dolomite, and soils.	Causes foaming in boilers and embrittlement of boiler steel.	Distillation
Sulfate	Sedimentary rocks, mine water, and industrial wastes.	Excess: cathartic, taste.	Activated charcoal filtration cartridges.
Chloride	Rocks, soils, industrial wastes, sewage, brines, sea water.	Unpleasant taste, increases corrosiveness.	Ion exchange, reverse osmosis, or distillation.
Fluoride	Not very abundant, sparingly soluble, seldom found in industrial wastes except as spillage, some in sewage.	Over 2 mg/L causes mottling of children's teeth, 0.9 to 1.5 mg/L aids in preventing tooth decay.	Reverse osmosis, distillation, activated alumina absorption, or activated charcoal in filtration cartridges.
Nitrate	Rocks, soil, sewage, industrial wastes, normal decomposition, bacteria.	High value indicates pollution, causes methemoglobinemia in infants.	Reverse osmosis.
Hardness as CaCO		Excessive soap consumption, scale in pipes interferes in industrial processes. Below 60 mg/L -- soft 60 to 120 mg/L -- moderately hard 121-200 mg/L -- hard over 200 mg/L -- very hard	Same as calcium and magnesium.

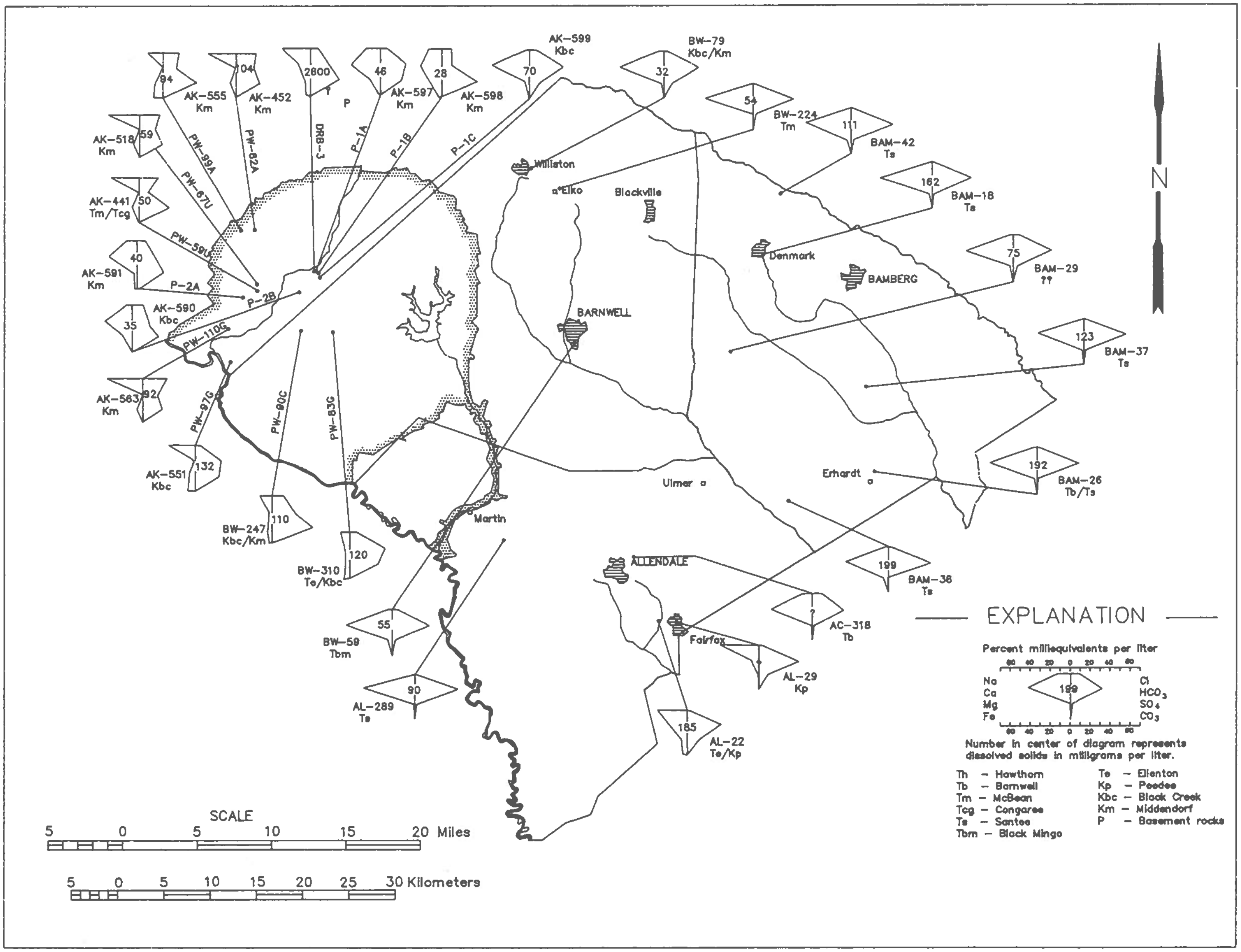


Figure 33. Stiff diagrams showing water quality variations both within and between various aquifers.

Black Mingo Formation

Water samples were not collected from the Black Mingo in the study area. Samples from neighboring Orangeburg County suggest that the quality of water from the Black Mingo is fair to poor. The pH is acidic and the iron content is generally high. The occurrence of hydrogen sulfide gas gives the water an unpleasant "rotten-egg" odor.

Congaree Formation and Santee Limestone

Water in the updip areas of the Congaree is similar to that in the Middendorf, both formations being predominantly sand. The water is extremely low in total dissolved solids (generally less than 20 mg/L) and has a pH of about 5.5, making it acidic. Locally there may be objectionable amounts of iron. Only a short distance downdip, the dissolved solids increase to about 100 mg/L and the pH is about 6.2. The increase in dissolved solids is mainly attributed to the increase in calcium and bicarbonate ions. Sand beds of the Congaree are not calcareous in this area but probably contained calcareous cement in the past. Farther downdip, the sand becomes calcareous and is in hydraulic connection with the Santee Limestone. Water from this unit is a calcium bicarbonate type with dissolved solids generally around 200 mg/L and a pH of about 8.

There is a gradual increase in dissolved solids in a downdip direction. In the vicinity of the town of Allendale, however, there is a marked decrease in dissolved solids. South and east of Allendale, the concentration resumes its downdip increase. Areas of lower dissolved solids indicate close proximity to recharge. This phenomenon, coupled with the anomaly in the potentiometric surface in this locale, suggests an area of local recharge. Drillers logs and geologic samples indicate the absence of a confining unit above the limestone.

Water from this unit is of good quality throughout the study area. It is relied upon for most domestic needs in the northern portion of the area and for municipal, industrial, agricultural, and some domestic needs in the southern portion.

McBean Formation

In the updip areas, the McBean can be divided into two units with differing water quality: an upper unit consisting of tan clayey sand and occasionally red sand, and a lower unit consisting of light-tan to white calcareous clayey sand. Water from both units is low in dissolved solids, but that in the upper sand is much the lower of the two, commonly less than 20 mg/L and with all constituents being very low. The calcareous sediments yield water with greater than 50 mg/L dissolved solids and a higher calcium and bicarbonate content. The pH of the water is about 7 for the calcareous deposits and generally less than 5 for the upper sand. Downdip, the McBean grades into the Santee Limestone and the water exhibits characteristics typical of a limestone environment. The dissolved solids approach 200 mg/L, the major constituents being calcium and bicarbonate, and the pH is near 8.

The quality of water from the McBean is generally good throughout its extent. In the updip areas the water is very soft and slightly acidic but of acceptable quality for most purposes. The town of Williston is the only municipality to use water from the McBean, but it is heavily relied on for rural domestic needs.

Barnwell Formation

The Barnwell Formation does not contain a characteristic "type" of water, but the calcium and bicarbonate ions are much lower than in other formations. The pH is low, usually between 5 and 6. Water from the Barnwell in the updip areas is low in dissolved solids, commonly less than 25 mg/L. Downdip in the formation the calcium and bicarbonate ion concentrations may increase, as the sediments appear to represent a residuum of a sandy limestone that is probably the shoreward facies of the Ocala Limestone.

Potential for Interaquifer Contamination

There are a number of hydrologic interrelationships between the various aquifers in the study area, the most important of which is the overall head difference between aquifers in the Cretaceous sediments and aquifers in the Tertiary sediments. In areas where the head in the Tertiary aquifers is higher than the head in the Cretaceous aquifers, the potential exists for downward migration of contaminated water into the Black Creek and Middendorf. Aquifers in these formations are used extensively, both individually and together, to meet municipal and irrigation needs.

Generally, the updip area is dominated by a downward head gradient. In this area the "green clay" at the top of the Congaree is discontinuous and much thinner than it is downdip, and the tan clay at the top of the McBean is missing. The Ellenton, which constitutes a very effective confining unit between Tertiary and Cretaceous aquifers downdip, does not appear to be as thick or as impermeable near its updip

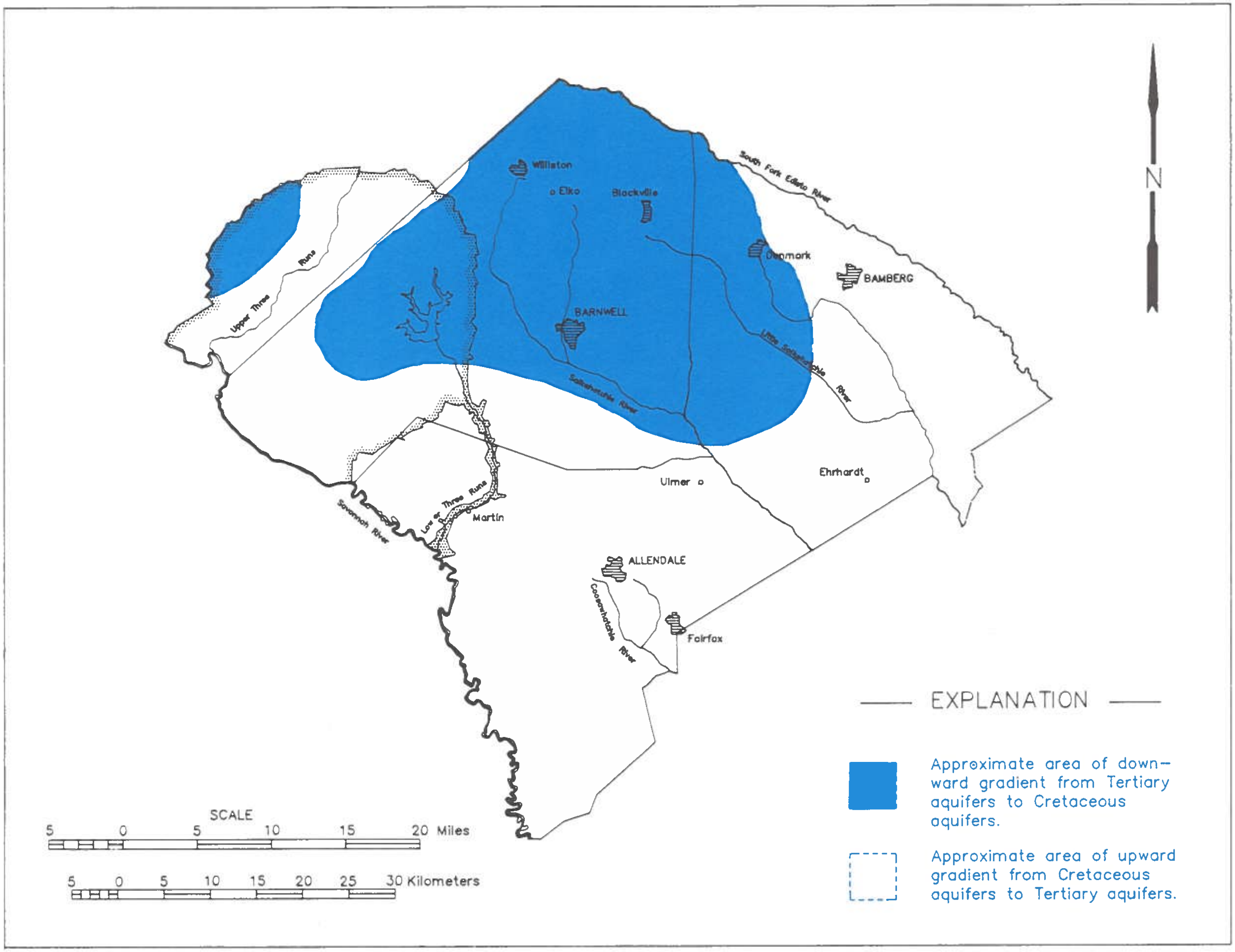


Figure 34. Relative ground-water head situations in the study area.

termination. Therefore, discontinuous areas of leakage are present from the Barnwell, through the underlying aquifers, into the Black Creek and Middendorf.

An indication of the areas where a head reversal exists between the Tertiary and Cretaceous aquifers is provided by a map constructed to show relative heads in the study area (Fig. 34). Data for this map were produced by subtracting the potentiometric levels of the Congaree (Fig. 32) from the potentiometric levels of the Black Creek (Fig. 30). Because of limited data, the map is generalized and should be used only to indicate the expected direction of vertical gradient in general areas.

The map indicates a general downward gradient in the updip areas. Downdip, the confining units between Cretaceous and Tertiary Formations are more effective and create an upward head differential between the two. The most pronounced feature of the map is the effect that the major streams in the area have on water levels. The Congaree is deeply incised by the Savannah River, South Fork Edisto River, and Upper Three Runs Creek. In these areas, discharge to the streams draws the water level in the Congaree down below that of the Black Creek. Heavy withdrawals from Cretaceous aquifers have reduced the amount of head difference near the center of SRP, but an upward gradient still exists in this area.

SUMMARY

Allendale, Bamberg, and Barnwell Counties and part of Aiken County are underlain by complex lithologic units. Environmental conditions during the period of deposition controlled the types of sediment that were deposited. Change in environmental conditions resulted in change of sedimentary deposits, and periods of nondeposition resulted in stratigraphic unconformities. Additionally, deposition in the study area was influenced by tectonic events such as subsiding or rising structural or deformational features.

The pre-Cretaceous basement complex, composed of igneous and metamorphic rocks of the Piedmont Province, is at the base of the stratigraphic column in the area. A graben in the basement complex in the vicinity of the Savannah River Plant, the Dunbarton Basin, is occupied by sandstone, siltstone, and mudstone of Triassic age. The surface of the basement strikes about N.65^0 E. and dips to the southeast at an average rate of 37 ft/mi.

Directly overlying the basement are sedimentary units of Late Cretaceous age. These units consist predominantly of interbedded sand, silt, and clay of fluvial, deltaic, and marginal marine environments. The surfaces of these units strike northeast and dip southeast at a rate of 12-37 ft/mi.

Above the Late Cretaceous units are Tertiary-age sediments. These sediments consist of sand, silt, clay, and limestone of deltaic and shallow marine environments. The surfaces of these generally strike northeast and dip southeast at a rate of 8-25 ft/mi.

Aquifers of principal use are the Middendorf and Black Creek Formations in the northwestern half of the study area. In the updip areas the two formations are considered to be a single aquifer. Locally, the two formations appear to be separated by beds of slit and clay.

Recharge to both the Middendorf and Black Creek occurs mainly as leakage through the overlying Tertiary sediments, with discharge occurring in the outcrop areas. Discharge also occurs as water moves downgradient and eventually leaks up through the confining units.

In most of the study area the Middendorf is capable of yielding more than 3,000 gpm to properly constructed wells. The results of pumping tests indicate an average transmissivity of 32,000 ft^2/day and storage coefficients ranging from 0.0002 to 0.0008. Wells completed in the Middendorf at SRP commonly have specific capacities between 40 and 60 gpm/ft.

Pumping tests at SRP indicate an average transmissivity of 12,000 ft^2/day for the Black Creek, and a storage coefficient of 0.0004. Few data are available on the hydraulic characteristics of the Black Creek outside of SRP; however, it appears to be a prolific aquifer throughout the study area.

Because of the high transmissivities, large withdrawals from both formations have had little effect on water levels, and cones of depression are not areally extensive.

The aquifer of principal use in the southeastern part of the study area is the Santee Limestone. Recharge to the Santee Limestone occurs generally northwest of the study area where rainfall percolates into the outcrop and subcrop of the McBean and Congaree Formations. As the water moves downgradient, some discharge occurs to major streams and natural springs. In the vicinity of Allendale an area of local recharge has been suggested.

Hydraulic characteristics vary considerably with locale, but in general the Santee Limestone is capable of yielding more than 1,000 gpm to properly constructed wells. In areas where solution cavities are encountered, yields are the greatest. Pumping tests indicate transmissivities ranging from 500 to more than 7,000 ft^2 day.

The Santee Limestone is relied on heavily for irrigation and domestic use. The stress applied to the aquifer by development has had little effect on water levels. Minor water-level declines have occurred areawide, but some wells had a higher water level in August 1985 than in the early 1950's.

The quality of water in the Middendorf and Black Creek is similar in the updip areas. Both contain water that is low in dissolved solids (generally less than 50 mg/L), soft, and acidic (pH of 4.2 to 6.9), making it corrosive. In southern Allendale County, water in the

Black Creek is a sodium bicarbonate type with dissolved solids of over 200 mg/L and a pH as high as 8.8.

Water in the Santee Limestone is of excellent quality except for its hardness. It is a calcium bicarbonate type, with dissolved solids around 200 mg/L and a pH of about 8.

Activities associated with the disposal of radioactive wastes at SRP have resulted in ground-water contamination. Ground-water cleanup operations have been implemented and alternative methods of disposal are being considered.

RECOMMENDATIONS

There is a sparsity of detailed geologic and hydrologic data (except for SRP) on which to base ground-water management and protection practices for Aiken, Allendale, Bamberg, and Barnwell Counties; therefore, the authors of this report recommend that an intensive geohydrologic investigation be conducted in the area. The investigation should be based on the installation of several strategically located well clusters. Each cluster should consist of one deep well cored to the basement rock and several surrounding wells completed in separate aquifers. Each well should be completed as an observation well and equipped with an automatic water level recorder.

Completion of such a well cluster system will provide detailed lithologic, stratigraphic, and hydrologic data. Continuous cores to the basement rock will provide accurate lithologic information about the formations (and aquifers) encountered. Samples from the cores should be taken to determine the age and permeability of the various formations; geophysical log traces would be correlated with lithologic changes; more accurate stratigraphic correlations for the area could be made; and detailed structure and isopachous maps could be constructed.

Pumping tests and continuous monitoring of water levels of wells completed in separate aquifers will provide invaluable hydraulic data. The information obtained could be used in ground-water flow models to aid in the determination of: 1) ground-water flow rates, volumes, and directions; 2) interaquifer relationships for various aquifers in the area; 3) water budgets. More detailed potentiometric maps could be constructed. Water quality analyses would provide data to characterize each aquifer and to identify local water quality problems.

________, 1982, The stratigraphic subdivision of the Hawthorn Group in Georgia (abstract); in Scott, T., et al., eds., Miocene of the southeastern United States; proceedings of a symposium: Special Publication, Florida Bureau of Geology, v. 25, p. 183-184.

Huddlestun, P.F., and Hetrick, J.H., 1978, Stratigraphy of the Tobacco Road Sand - a new formation; in Short contributions to the geology of Georgia: Georgia Geological Survey Bulletin, v. 93, p. 56-77.

____, 1979, The stratigraphy of the Barnwell Group of Georgia: Georgia Geological Survey Open-File Report 80-1.

Jordana, M.J., 1984, The accuracy and efficiency of using computer produced graphics to map regional unconformities of the South Carolina Coastal Plain: Columbia, South Carolina, University of South Carolina Department of Geology M.S. thesis, 122 p.

Kite, L.E., 1983, Geologic map of the Seivern 15-minute quadrangle: South Carolina Geological Survey Open-File Report 32.

________, 1984, Geology of the Woodford 15-minute quadrangle, Upper Coastal Plain, South Carolina: South Carolina Geological Survey Open-File Report 40, 9 p.

Langley, T.M., and Marter, W.L., 1973, The Savannah River Plant Site: DP-1323: E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Lonnon, G.E., Burnette, C.B., and Morris, H.J., 1983, Water use in South Carolina, 1980: South Carolina Water Resources Commission Report No. 138, 20 p.

Marine I.W., and Siple, G.E., 1964, Geohydrology section, in Storage of radioactive wastes in basement rock beneath the Savannah River Plant: E.I. DuPont de Nemours and Co., Savannah River Laboratory, DP-844, 39p., Appendix A through G, 10 figs.

Marine, I.W., 1966, Hydraulic correlation of fracture zones in buried crystalline rock at the Savannah River Plant, Aiken, South Carolina, U.S. Geological Survey Professional Paper 550-D, pp. 223-227.

______, 1967, The permeability of fractured crystalline rock at the Savannah River Plant near Aiken, South Carolina: U.S. Geological Survey Professional Paper 575-B, pp. B203-B211.

________, 1974, Geohydrology of the buried Triassic basin at the Savannah River Plant, South Carolina: American Association of Petroleum Geologists Bulletin, v. 58 no. 9, p. 1825.

______, 1975, Water level fluctuations due to earth tides in a well pumping from slightly fractured crystalline rock: Water Resources Research, v. 11, no. 1, page 165.

____, 1976a, Structural and sedimentational model of the buried Dunbarton Triassic Basin, South Carolina and Georgia: USERDA Report DP-MS-74-39, pp. 38, Available from Technical Information Center, Oak Ridge, Tennessee.

______, 1976b, Geochemistry of groundwater at the Savannah River Plant: USERDA Report DP-1536, p. 30, E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Marine, I.W., 1979, Hydrology of buried crystalline rocks at the Savannah River Plant near Aiken, South Carolina: U.S. Department of Energy, DOE/SR-WM 79-2, 220 p.

Marine, I.W., and Root, R.W., Jr., 1976, Summary of hydraulic conductivity tests in the SRP separations areas, Paper 21 in Crawford, T.V. (compiler) Savannah River Laboratory Environmental Transport and Effects Research Annual Report, 1975, USERDA Report DP-1412, E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

____, 1978, Geohydrology of deposits of Claiborne age at the Savannah River Plant: Paper 10 in Crawford, T.V. (compiler) Savannah River Laboratory Environmental Transport and Effects Research Annual Report 1977, USERDA Report DP-1489, E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Marine, I.W., and Routt, K.R., 1975, A ground water model of the Tuscaloosa aquifer at the Savannah River Plant: Paper 14 in Crawford, T.V. (compiler), Savannah River Laboratory Environmental Transport and Effects Research Annual Report, 1974, USERDA Report DP-1374, E.I. duPont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Marine, I.W., and Siple, G.E., 1974, Buried Triassic basin in the central Savannah River area, South Carolina and Georgia: Geological Society of America Bulletin, v. 85, no. 2, p. 311-320.

Nystrom, P.G., Jr., and Willoughby, R.H., eds., 1982, Geological investigations related to the stratigraphy in the kaolin mining district, Aiken County, South Carolina: South Carolina Geological Survey Field Trip Guidebook, South Carolina GeologicalSociety, October 9-10, 183 p.

Oldham, R.W., 1981, Surface to subsurface geology of eastern Aiken, western Orangeburg, northern Bamberg, and northern Barnwell Counties and structural attitude and occurrence of the Black Mingo Formation in the subsurface between the Santee and Savannah rivers, South Carolina: Columbia, South Carolina, University of South Carolina Department of Geology M.S. thesis, 111 p.

Park, A.D., 1985, The ground-water resources of Charleston, Berkeley, and Dorchester Counties, South Carolina: South Carolina Water Resources Commission Report No. 139, 145 p.

Petty, A.J., Petrafeso, F.A., and Moore, F.C., Jr., 1965, Aeromagnetic map of the Savannah River Plant area, South Carolina and Georgia: U.S. Geological Survey Geophysical Investigations Map GP-489.

Pooser, W.K., 1965, Biostratigraphy of Cenozoic Ostracoda from South Carolina: University of Kansas, Paleontological Contributions, Arthropoda, Article 8, 80 p.

Popenoe, Peter, and Zietz, Isidore, 1977, The nature of the geophysical basement beneath the Coastal Plain of South Carolina and northeastern Georgia: in Rankin, D.W., ed., Studies related to the Charleston, South Carolina, earthquake of 1886 - A preliminary report: U.S. Geological Survey Professional Paper 1028, p. 119-137.

Powell, R.J., 1981, Stratigraphic and petrologic analysis of the middle Eocene Santee Limestone, South Carolina: Chapel Hill, North Carolina, University of North Carolina M.S. thesis, 182 p.

Powell, R.J., Textoris, D.A., Wheeler, W.H., and Baum, G.R., 1981, Stratigraphy, structural framework, and depositional environment of the middle Eocene Santee Limestone, South Carolina: Geological Society of America Abstracts with Programs, v. 13, no. 1, p. 33.

Prowell, D.C., and O'Connor, B.J., 1978, Belair fault zone: Evidence of Tertiary fault displacement in eastern Georgia: Geology, v. 6, no.11, p. 681-684.

Prowell, D.C., O'Connor, B.J., and Rubin, Meyer, 1975, Preliminary evidence for Holocene movement along the Belair fault zone near Augusta, Georgia: U.S. Geological Survey Open-File Report 75-680, 8 p.

Prowell, D.C., Christopher, R.A., Edwards, L.E., Bybell, L.M., and Gill, H.E., 1985, Geologic section of the updip Coastal Plain from central Georgia to western South Carolina: U.S. Geological Survey, to accompany Miscellaneous Field Studies Map MF-1737, 10 p.

Root, R.W., Jr., 1977a, Results of pumping tests in shallow sediments in the separations areas: Paper 11 in Crawford, T.V. (compiler), Savannah River Laboratory Environmental Transport and Effects Research Annual Report, 1976, USERDA Report DP-1455, E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

_____, 1977b, A conceptual geohydrological model of the separations area: Paper 13 in Crawford, T.V., (Compiler), Savannah River Laboratory Environmental Transport and Effects Research Annual Report, 1976, USERDA Report, DP-1455, E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

_____, 1983, Numerical modeling of ground-water flow at the Savannah River Plant: DP-1638, E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Ruffin, Edmund, 1843, Report on the commencement and progress of the Agricultural Survey of South Carolina: Columbia, South Carolina, 120 p.

Siple, G.E., 1957, Geology and ground water in parts of Aiken, Barnwell, and Allendale Counties, South Carolina: Unpublished report prepared for the Savannah River operations office of the Atomic Energy Commission, 128 p.

_____, 1964a, Geohydrology of storage of radioactive waste in crystalline rocks at the AEC Savannah River Plant, South Carolina: U.S. Geological Survey Professional Paper 501-C, p 180-184.

_____, 1964b, Artesian aquifer systems of the central Savannah River area, South Carolina - Georgia (abstract): Proceedings of Geological Society of America, 1964. p. 18.

_____, 1960, Piezometric levels in the Cretaceous sand aquifer of the Savannah River basin: Georgia Mineral Newsletter, v. 13, no. 4, p. 163-166.

_____, 1967, Geology and ground water of the Savannah River Plant and vicinity, South Carolina: U.S. Geological Survey Water-Supply Paper 1841, 113 p.

_____, 1984, Ground water resources of the Central Savannah River Area, South Carolina - Reevaluated: in Proceedings, A Conference on the Water Resources of Georgia and Adjacent Areas, Georgia Department of Natural Resources, Environmental Protection Division, p. 142-158.

Siple, G.E., and Marine, I.W., 1966, A newly discovered Trassic basin in the central Savannah River area, South Carolina (abstract): Proceedings annual meeting Southeastern Section Geological Society of America, p. 40-41.

Siple, G.E., and Pooser, W.K., 1975, Proposal of the name Orangeburg Group for outcropping beds of Eocene age in Orangeburg County and vicinity, South Carolina; in Cohee, G.P, and Wright, W.R., Changes in stratigraphic nomenclature by the United States Geological Survey, 1973: U.S. Geological Survey Bulletin, v. 1395, p. A-55.

Sloan, Earl, 1907, Geology and mineral resources (South Carolina); in Handbook of South Carolina: South Carolina State Department of Agriculture, Commerce, and Immigration, v. 2, p. 77-145.

_______, 1908, Catalog of the mineral resources of South Carolina: South Carolina Geological Survey, Series 4, Bulletin 2 (Reprinted 1958, South Carolina State Development Board, Division of Geology, 505 p.).

Smith, G.E., III, and White, T.C., 1979, Geologic map of Aiken County, South Carolina: South Carolina Geological Survey Open-File Report 19.

Sohl, N.F., and Christopher, R.A., 1983, The Black Creek-Peedee formational contact (Upper Cretaceous) in the Cape Fear River region of North Carolina: U.S. Geological Survey Professional Paper 1285, 37 p.

South Carolina Water Resources Commission, 1971, Water use in South Carolina—1970: South Carolina Water Resources Commission, Columbia, South Carolina.

Steele, J.L., 1983, M-Area groundwater remedial action, Project S-2583: E.I. du Pont de Nemours and Company, Savannah River Plant, Aiken, South Carolina.

Steele, K.B., 1985, Lithostratigraphic correlation of Cretaceous and younger strata of the Atlantic Coastal Plain Province within Aiken, Allendale, and Barnwell Counties, South Carolina: Columbia, South Carolina, University of South Carolina Department of Geology M.S. thesis, 174 p.

Swift, D.J.P., and Heron, S.D., Jr., 1969, Stratigraphy of the Carolina Cretaceous: Southeastern Geology, v. 10, p. 201-245.

U.S. Army Corps of Engineers, 1952, Geologic-engineering investigations, Savannah River Plant: U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Van Nieuwenhuise, D.S., 1978, Ostracode biostratigraphy and litho stratigraphy of the Black Mingo Formation, South Carolina Coastal Plain: Columbia, South Carolina, University of South Carolina Department of Geology Dissertation, 92 p.

Van Nieuwenhuise, D.S., and Colquhoun, D.J., 1982, The Paleocene - Lower Eocene Black Mingo Group of the east central coastal plain of South Carolina: South Carolina Geology, v. 26, p. 47-67.

Ward, L.W., Blackwelder, B.W., Gohn, G.S., and Poore, R.Z., 1979, Stratigraphic revision of Eocene, Oligocene, and Lower Miocene formations of South Carolina: Geologic Notes, v.23, no.1, South Carolina Geological Survey, State Development Board, p. 2-32.

Webster, D.S., Proctor, J.F., and Marine, I.W., 1970, Two-well tracer test in fractured crystalline rock: U.S. Geological Survey Water-Supply Paper 1544-I.

Willoughby, R.H., 1983, Geologic map of the Graniteville quadrangle: South Carolina Geological Survey Open-File Report 31.

_______, 1984, Geologic map of the Aiken NW 7.5-minute quadrangle: South Carolina Geological Survey Open-File Report 39.

____, 1985, Geologic map of the Trenton 7.5-minute quadrangle: South Carolina Geological Survey Open-File Report 43.

Zullo, V.A., and Kite, L.E., 1984, Barnacles of the Jackson (upper Eocene) Griffins Landing Member, Dry Branch Formation in South Carolina and Georgia: South Carolina Geology, v. 28, no. 1, p. 1-21.

APPENDIX A
SELECTED WELL DATA

Well Number:	Location of well in Figures 4 and 9.
County Number:	Sequential number assigned each well inventoried in a county.
Other Number:	Number assigned to a well by owner or assigned to indicate use in a special project.
Latitude/Longitude:	Location in degrees, minutes, and seconds of latitude and longitude.
Elevation (feet):	Relative to mean sea level; S, surveyed; T, estimated from topographic map.
Well use:	ABN - Abandoned DOM - Domestic IND - Industrial IRR - Irrigation OBS - Observation PS - Public supply REC - Recreation STK - Livestock UNU - Unused
Total depth:	Depth of well, in feet. Geophysical logs: Available geophysical logs C - Caliper G - Natural gamma GG - Gamma-gamma density FR - Fluid-resistivity LN - Long-normal resistivity LT - 6-foot lateral resistivity R - Resistance SN - Short-normal resistivity SP - Spontaneous-potential T - Temperature
Aquifer:	Aquifer (formation) tapped by well MC - McBean C - Congaree F - Floridan BM - Black Mingo E - Ellenton BC - Black Creek M - Middendorf
Remarks:	D-log: Drillers log available. Litho-log: Lithologic log available. WQ tab: Chemical analysis reported in the water quality tabulation (Appendix B).

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
18AA-e2	BRK-430		330441 795958	10 T	IND	1900	G,SP,R		D-log
25Z-b1	DOR-211		330925 803180	80 T	OBS	2060	G,GG,SP,R,N		ADR,P/T
28Y-e2	ORG-26		331459 804905	121 T	PS	278		C/F	
29Y-q1	BAM-40		331119 805332	147 T	DOM	127		C/F	
29Y-t1	BAM-46		331156 805015	110 T	UNU	114		C/F	
31X-m6	BAM-27		331714 810228	152 T	PS	550	G,SP,R	BC	D-log QW
31X-m8	BAM-15		331742 810214	162 T	PS	200		C/F	
31X-m9	BAM-31		331746 810213	120 T	PS	176		C/F	
31Y-q1	BAM-62		331140 810332	151 T	OBS	260	G,SP,R,SN, LN,LT		ADR
31Y-s1	BAM-37		331115 810115	144 T	PS	200		C/F	QW
31Z-t1	BAM-26		330605 810041	140 T	PS	225	SP,R	C/F	D-log, QW

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
31AA-r1	COL-219		330150 810248	117 T	PS	280		C/F	
32W-m1	BAM-42		332226 810704	194 T	DOM	140		C/F	QW tab
32X-d1	BAM-23		331927 810825	244 T	PS	306	G,SP,R		D-log P/T
32X-g1	BAM-14		331859 810845	244 T	PS	473		C/F	D-log
32X-g2	BAM-22		331055 810820	220 T	PS	397	G,SP,R	C/F	D-log, P/T
32Y-h1	BAM-34		331315 810759	200 T	DOM	175		C/F	
32Z-e1	BAM-63		330909 810943	183 T	ABN	144		C/F	
32AA-b2	BAM-36		330435 810653	131 T	DOM	220		C/F	QW
32AA-g1	ALL-295		330304 810856	140 T	DOM	220		C/F	
32AA-j1	BAM-65		330340 810528	108 T	PS	0		C/F	
32AA-s1	ALL-333		330150 810646	140 T		800		BC	

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
33V-p2	BRN-240		332620 811421	205 T	OBS	403	G,SP,R,C,T, N,D,P		CORE
33V-r2	ORG-95		332651 810729	242.3 S	OBS	304	G,SP,R,C,N	C/F	
33W-11	BAM-49		332235 811115	253 T	IRR	920		M	
33W-m1	BAM-53		332257 811235	275 T	IRR	590		BC	
33X-b1	BAM-28		331956 811117	260 T	IRR	340	G,SP,R	C/F	
33Y-b1	BAM-54		331450 811105	210 T	IRR	446	G,SP,R,SN, LN,LT		D-log
33Y-j1	BAM-25		331319 811021	240 T	PS	250	G	C/F	
33Z-n1	BRN-295		330737 811345	195	OBS	420	G,SP,R,SN	C/F	ADR, P/T
33Z-v1	ALL-336		330611 811118	142.71 T	STK	280		C/F	
33Z-w1	ALL-50		330555 811210	160 T	PS	200	G,C	C/F	QW

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
33AA-c2	ALL-204		330437 811232	160 T	IRR	580	G,R,C,T,FR		
33AA-c3	ALL-337		330333 811232	172.24 T	STK	220		C/F	
33AA-f1	ALL-337		330333 811441	172.24 T	STK	220		C/F	
33AA-n2	ALL-292		330112 811321	140 T	IND	200		C/F	
33BB-n1	ALL-7		325700 811340	137.13 S	OBS	700		BC	
33BB-o4	ALL-29		325731 811418	140 T	PS	668			QW
33BB-o7	ALL-311		325756 811492	135 T	REC	390		C/F	
33BB-p1	ALL-326		325631 811420	120 T	PS	344	G,SP,R		
33BB-y2	ALL-306		325525 811420	110 T	IRR	750	G,T,PR		
33BB-y4	ALL-325		325513 811421	115 T	IRR	291	G,R,LT,C	C/F	

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
33CC-f1	HAM-80		325357 811414	105 T	OBS	60	G	C/F	L-log, P/T
34W-p4	BRN-311		332148 811947	320 T	PS	320	G,SP,R,LN		
34W-s1	BRN-5		332118 811620	285 T	UNU	200		C/F	
34W-s4	BRN-75		332142 811631	290 T	PS	465	G,SP,R		D-log P/T
34AA-11	ALL-312		330101 811652	170 T	REC	450		C/F	
34AA-h1	ALL-316		330343 811721	190 T	DOM	300		C/F	
34AA-m1	ALL-33		330218 811722	180 T	IRR	777	G,SP,R	BC	D-log
34AA-q3	All-320		330106 811832	200 T	OBS	431	G,SP,R,SN,C		ADR
34AA-r1	ALL-318		330106 811712	172 T	ABN	119			QW
34AA-r2	ALL-330		330136 811712	172 T	IRR	280		C/F	

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
34AA-t1	ALL-300		330123 811502	140 T	DOM	250		C/F	
34AA-x3	ALL-4		330015 811826	176 T	PS	180		C/F	
34AA-y2	ALL-274		330018 811950	190 T	DOM	200		C/F	
34AA-y4	ALL-35			190 T	PS	570	G,C,T,FR		
34BB-c1	ALL-46		325935 811750	180 T	IRR	908	SP,R		
34BB-h1	ALL-36		325045 811714	156 T		837	G,SP,R,C,		
34BB-h2	ALL-44		325850 811745	162 T	IRR	860	G,SP,R		
34BB-k1	ALL-22		325758	140 T	IND	830	SP,R	BC	D-log, QW
35BB-i1	ALL-49		325840 812145	250 T	IRR	849	SP,R		D-log
35CC-k	ALL-298		325209 812034	140 T	IRR	1033		BC	QW
35DD-f1	ALL-47		324816 812403	60 T	IRR	1020	G,SP,R		QW

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
35W-e1	BRN-44		332404 812453	353.1 T	PS	823	R	M	
35W-f1	BRN-79		332348 812407	360 T	PS	780	G,SP,R	BC/M	QW
35W-m1	BRN-223		332246 812249	345 T	PS	140		C/F	
35W-m2	BRN-224		332246 812249	350 T	PS	140		MC	QW
35X-v1	BRN-63		321508 812129	230 T	PS	312		C	D-log
35Y-b5	BRN-39		331417 812154	215.71 S	UNU	230		C/F	D-log, QW
35Y-b6	BRN-55		331410 812151	150 T	IND	280		C	D-log
35Y-b8	BRN-60		311407 812159	150 T	IND	330		C/BM	D-log, P/T
35Y-b10	BRN-67		331438 812117	220 T	PS	318		C/F	
35Y-c5	BRN-73		331425 812255	225 T	PS	281	SP,R		

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
35Y-i1	BRN-59		331358 812148	150 T	PS	252		BM	qw
35Z-k1	BRN-29		330728 812034	240 T	PS	900			QW
36W-a3	BRN-10		332410 812519	350 T	PS	150			
36W-j1	BRN-78		332359 812520	340 T	PS	775	G,SP,R		P/T
36X-x16	BRN-71		331530 812845	260 T	IND	931	G,SP,R		
36X-x19	BRN-70		331515 812825	270 T	IND	886	G,SP,R		
36X-x20	BRN-301		331519 812802	258.15 S		162		C/F	BC
36X-x21	BRN-306	WM-14	331519 812802	258.15 S	OBS	404		BC	
36Y-e1	BRN-72		331458 812932	258 T	IND	985	G,SP,R,SN, LN		
36Z-y1	ALL-272		330541 812932	158 T	DOM	240		C/F	

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
36AA-12	ALL-289		330243 812648	250 T	DOM	290			QW
36AA-b1	ALL-19		330430 812648	161.47 S	IND	760	SP,R		D-log
36AA-b4	ALL-332		330433 812642	155 T		764		BC	
36AA-d4	ALL-16		330430 812	130 T	DOM	215		C/F	
36AA- o1	ALL-27		330232 812900	186.5 S	IND	790	G,SP,R		D-log, P/T
36BB-12	ALL-319		325734 812611	140 T	PS	121		C/F	QW
36BB-14	ALL-331		325745 812613	140 T	PS	321		C/F	C/F
36BB-e1	ALL-322		325952 812926	100 T	REC			C/F	
36BB-j1	All-116		330804 812559	150 T	REC	583	G,SP,R,C		
36BB-s1	ALL-38		325653 812639	100 T	REC	298	G	C/F	QW

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
36BB-u1	ALL-290		325513 812523	120 T	DOM			C/F	
37Y-f5	BRN-250	905-93P	331342 813440	320 T	IND	614	SP,R	D-log, P/T	
37Y-o1	BRN-243	P-13TA	331209 013440	252.59 S	OBS	1066	G,SP,R,SN, LN,LT,C	M	L-log, SRP
37Y-o2	BRN-321	P-13B	331209 813440	253.03 S	OBS	266		C/F	
37Y-o3	BRN-323	P-13A	331209 813440	252.87 S	OBS	325		C/F	
37Y-o4	BRN-327	P-13TB	331209 813440	252.96	OBS	767		M	SRP
37Y-o5	BRN-328	P-13TC	331209 813440	253.01 S	OBS	657		BC	SRP
37Y-o6	BRN-329	P-13TD	331209 913440	253.07 S	OBS	449		BC	SRP
37Z-m1	BRN-324		330734 813244	203 T		1356	G,GG,SP,R,C	M	
37Z-n1	ALL-40		330718 813319	240 T	IRR	750	SP,R	BC	

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
37Z-n10	ALL-329		330718 813306	230 T	DOM	320		C/F	
37Z-o1	ALL-344	VSC-1	330706 813450	219.0 S		620	G,SP,SN,LN, N		L-log, (1983)
37Z-q3	ALL-66		330655 813356	202 T	IRR	800			P/T
37Z-p4	ALL-345	VSC-4	330624 813406	156.7 S		1024	G,N		L-log, (1983)
37AA-c1	ALL-41		330449 813212	140 T	DOM	500	G,SP,R,C		
37AA-c6	ALL-339		330453 813206	140 T	IRR	280		C/F	
38X-a3	AIK-646		331943 813515	300 T	IND	315		C/F	
38X-g1	AIK-647		331800 813834	290 T	PS	900	G,R,SP, SN,LN,LT		
38X-i1	BRN-308	P-14TA	331834 813625	294 T	OBS	850	G,SP,R,SN, LN,C,T	M	L-log, SRP
38X-i2	BRN-320	IDB-1B	331833 813625	293.83 S	OBS	201		C/F	

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
38X-i3	BRN-324	P-14TB	331833 813625	293.56 S	OBS	572		M	SRP
38X-i5	BRN-326	IDB-1A	331833 813625	293.87 S	OBS	349		BC	SRP
38X-n1	AIK-447	PW-80H	331750 814030	290 T		908	G,SP,R		D-log
38K-n10	AIK-582	P-3A	331705 813859	277.10 S	OBS	935			
38X-n14	AIK-586	HC-1A	331708 813835	299.50 S	OBS	222		C/F	
38X-n16	AIK-600	P-3B	331706 813859	277.60 S	OBS	547		M	
38X-n17	AIK-601	P-3C	331706 813859	278.J S	OBS	410		BC	
38X-n23	AIK-607	HC-3B	331710 813831	300.60 S	OBS	196		C/F	
38X-o4	AIK-597	P-1A	331707 813949	287.90 S	OBS	920		M	QW
38X-o5	AIK-598	P-1B	331707	289.10 S	OBS	555		M	QW

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
38X-o6	AIK-599	P-1C	331707 813950	289.4 S	OBS	368		BC	QW
38X-o8	AIK-651	HC-8B	331742 813933	262.30 S	OBS	130		C/F	
38X-o10	AIK-653	HC-10A	331738 813907	228.00 S	OBS	114		C/F	
38X-o14	AIK-465	DRB-3	331708 813949	285.50 S	OBS	1942	G,N		D-log, QW
38X-p2	AIK-683	DRB-2WW	331645 813928	281.73 S	OBS	222		C/F	
38X-u1	AIK-613	P-7A	332000 813553	273.50 S	OBS	713		M	
38Y-b1	BRN-303	P-19TA	331445 813657	294 T	OBS	990	G,SP,R,SN,		SRP
38Y-b2	BRN-334	P-10A	331446 813657	296.70 S	OBS	851		M	
38Y-d1	BRN-310	905-83G	331452 813852		IND	585		E/BC	QW
38Y-h1	BRN-287	CMP-12A	331338 813735	300 T	OBS	296	G,SP,SN,LN, LT,C		

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
38Y-h2	BRN-288	CMP-15A	331330 813733	270 T	OBS	304	G, SP, SN, LN, LT, C		
38Y-m1	BRN-246	P-15TA	331253 813730	253.07 S	OBS	1066	G, SP, R, SN, LN, LT, C	M	SRP
38Z-i1	BRN-245	P-5R	330845 813628	200 T	OBS	1313	G		
38Z-i7	BRN-299	P-5A	330848 813627	206.40 S	OBS	983		M	
38Z-j1	BRN-302	VSC-2	330810 813555	201.7 S	OBS	600	G, SP, SN, LN, N	C/F	L-log (1983)
38Z-k2	BRN-305	VSC-3	330740 813525	170.3 S	OBS	570	G, SP, SN, LN, N	BC	L-log (1983)
38Z-11	BRN-319		330717 813308	160 T	IRR	240		C/F	
38Y-m2	BRN-322	P-15B	331253 813730	253.09 S	OBS	220		C/F	
38Y-m3	BRN-330	P-15TB	331253 813244	253.02 S	OBS	727		M	SRP
38Y-m4	BRN-331	P-15TC	331253 813730	253.01 S	OBS	628		BC	SRP

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
39X-e2	AIK-689	MSB-9A	331950 814418	356.70 S	OBS	242		C/F	
39X-e4	AIK-657	MSB-10B	331950 814422	352.70 S	OBS	215		C/F	
39X-e5	AIK-658	MSB-11A	331955 814417	363.00 S	OBS	240		C/F	
39X-e6	AIK-659	MSB-11B	331955 814417	362.80 S	OBS	203		C/F	
39X-e7	AIK-660	MSB-12A	331944 814428	345.90 S	OBS	230		C/F	
39X-e8	AIK-661	MSB-12B	331944 814428	346.50 S	OBS	191		C/F	
39X-e9	AIK-662	MSB-13A	331942 814421	343.30 S	OBS	246		C/F	
39X-e10	AIK-663	MSB-12B	331942 814421	343.70 S	OBS	172		C/F	
39X-e11	AIK-664	MSB-14A	331947 814411	346.50 S	OBS	202		C/F	
39X-e12	AIK-665	MSB-17A	331936 814435	356.30 s	OBS	202		C/F	

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
39X-e14	AIK-667	MSB-20A	331948 814448	351.90 S	OBS	202		C/F	
39X-i1	AIK-638	FC-5A	331835 814137	204.40 S	OBS	220	G		
39X-i4	AIK-641	FC-5D	331835 814137	205.40 S	OBS	70		C/F	
39X-k11	AIK-622	FC-2A	331729 814029	147.52 S	OBS	235		C/F	
39X-k12	AIK-623	FC-1A	331719 814054	316.77 S	OBS	221		C/F	
39X-k23	AIK-682	DRB-1WW	331748 814015	263.00 S	OBS	202		C/F	
39X-k6	AIK-516	PW-101F	331714 814028	310 T	IND	900	G,SP,R		D-log, P/T
39X-k8	AIK-619	FC-3B	331738 814004	269.20 S	OBS	208		C/F	
39X-13	AIK-617	FC-4B	331744 814104	239.10 S	OBS	163		C/F	
39X-n4	AIK-518	9056-7U	331713 814323	271.80 S	IND	730		M	D-log, QW

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
39X-t3	AIK-592	P-2C	331634 814012	249.00 S	OBS	350		BC	
39X-t4	AIK-595	DRB-4	331635 814011	250.80 S	OBS	1938	G,N		D-log
39X-t5	AIK-685	DRB-4WW	331634 814010	246.00 S	OBS	198		C/F	
39X-u2	BRN-276	905-52C	331511 814019	296.05 S	IND	575			QW
39Y-a1	BRN-247	905-90C				0		BC/M	QW
39Y-f1	AIK-468	S-411	331320 814405	157.53 S	UNU	270			
40X-a2	AIK-681	AC-3A	331904 814507	300.40 S	OBS	153		C/F	
40X-c2	AIK-351		331925 814731	198 T	DOM	60		C/F	
40X-x1	AIK-642	P-4A	331502 814811	105.30 S	OBS	596		M	
40Y-a1	AIK-563	905-110G				0		M	QW

Well Number	County Number	Other Number	Latitude/ Longitude	Elevation (m.s.l.)	Well Use	Total Depth	Geophysical Logs	Aquifer	Remarks
40Y-i3	AIK-348		331329 814609	108 T	DOM	85		C/F	
40Y-k1	AIK-519		331238 814537	140 T	OBS	275	G,SP,R,T,C, SN,LN,FR		
40Y-k5	AIK-551	905-97G	331247 814536		IND	359		BC	QW
41V-x3	AIK-183		332550 815314	254.85 T	OBS	320		M	D-log

APPENDIX B
SELECTED WATER QUALITY ANALYSES

All analyses were made by the South Carolina Water Resources Commission laboratory, Lawrence H. Lagman, Chief Chemist.

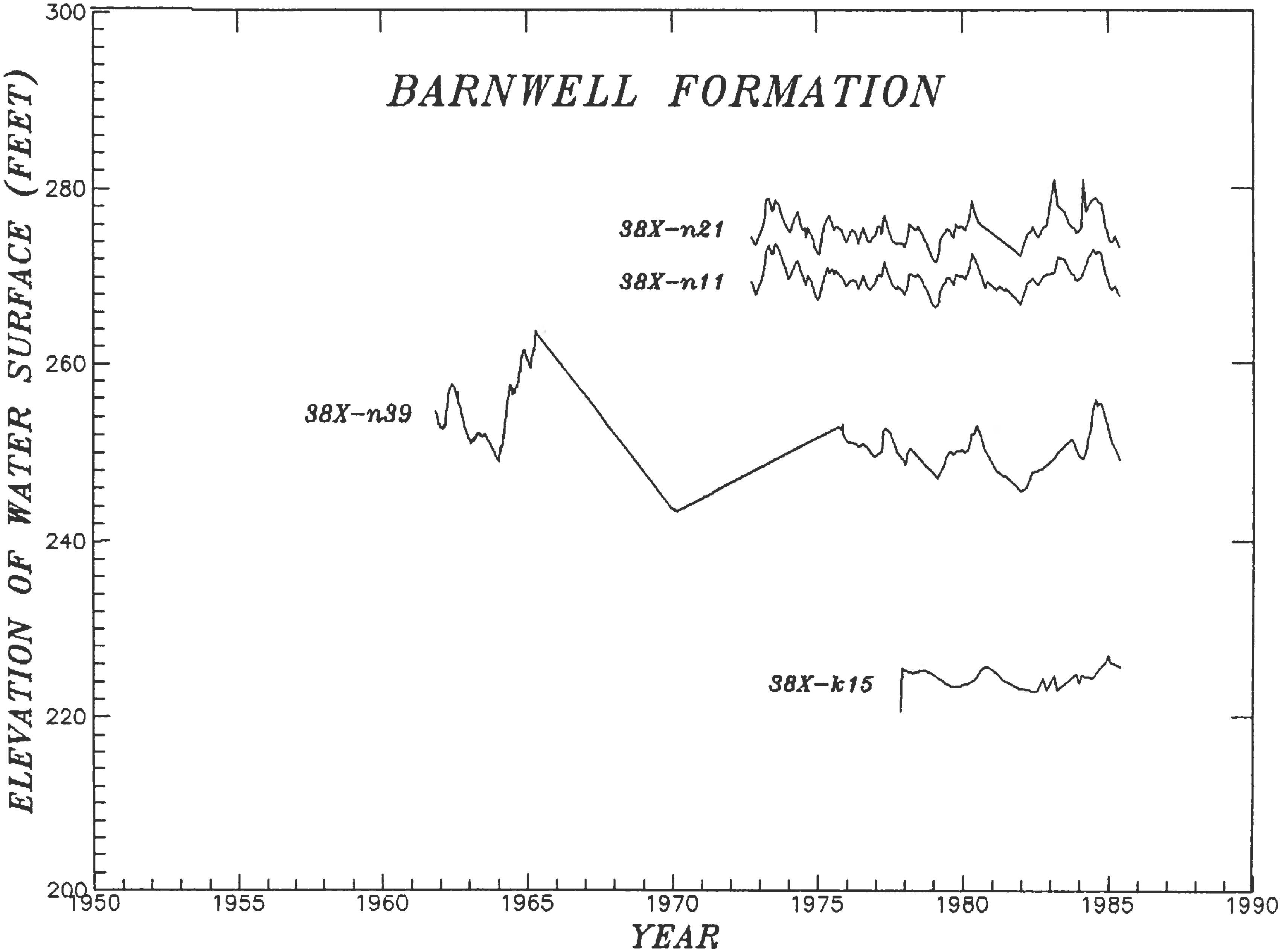
Explanation:

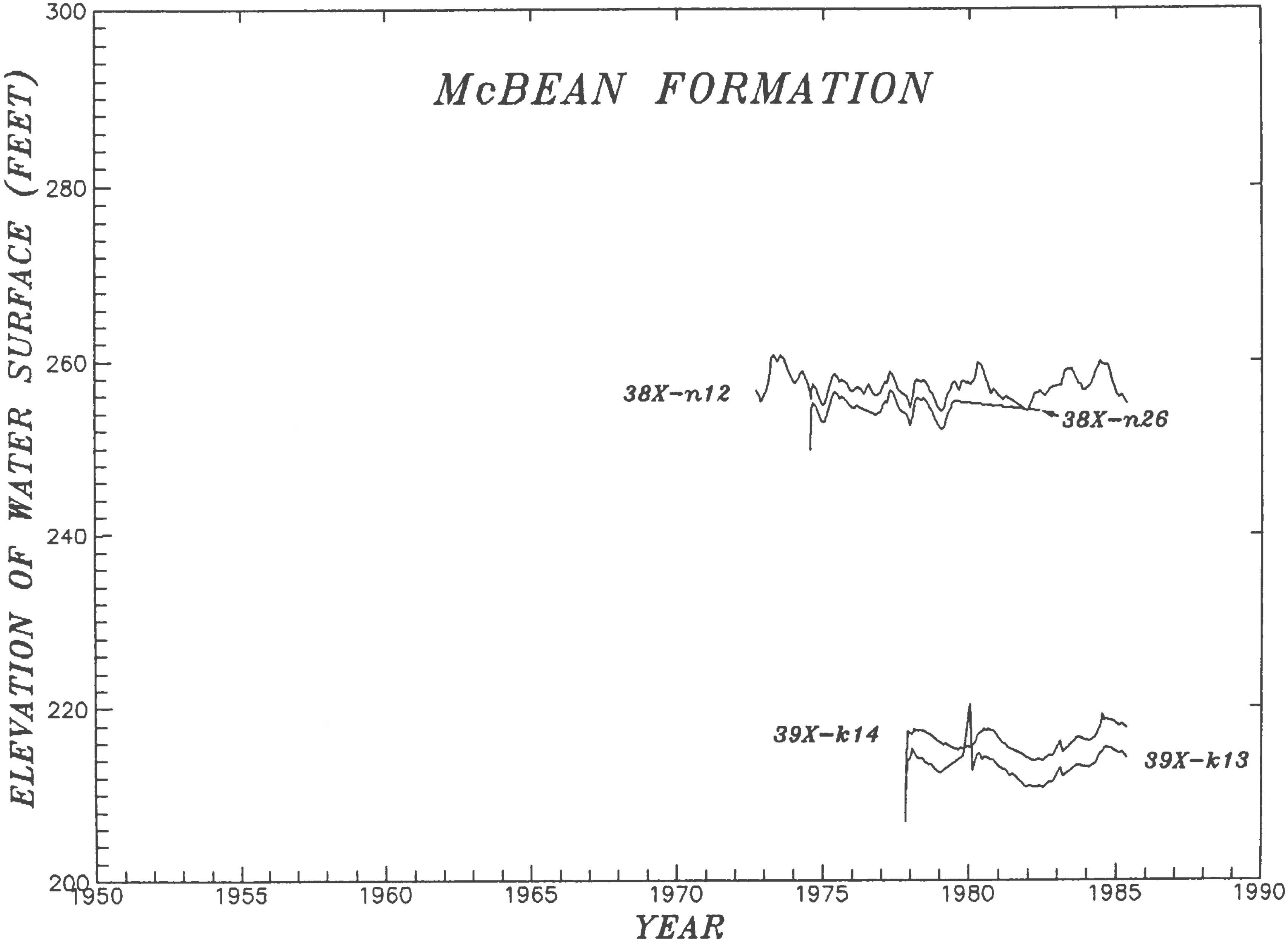
Sampled interval, in feet below land surface; O, sample taken at wellhead while pumping.
Specific conductance, in micromhos per centimeter at 25°C.
Temperature, in degrees Celsius.
pH, in standard units.
Iron and manganese, in micrograms per liter.
All other constituents and properties are in milligrams per liter.

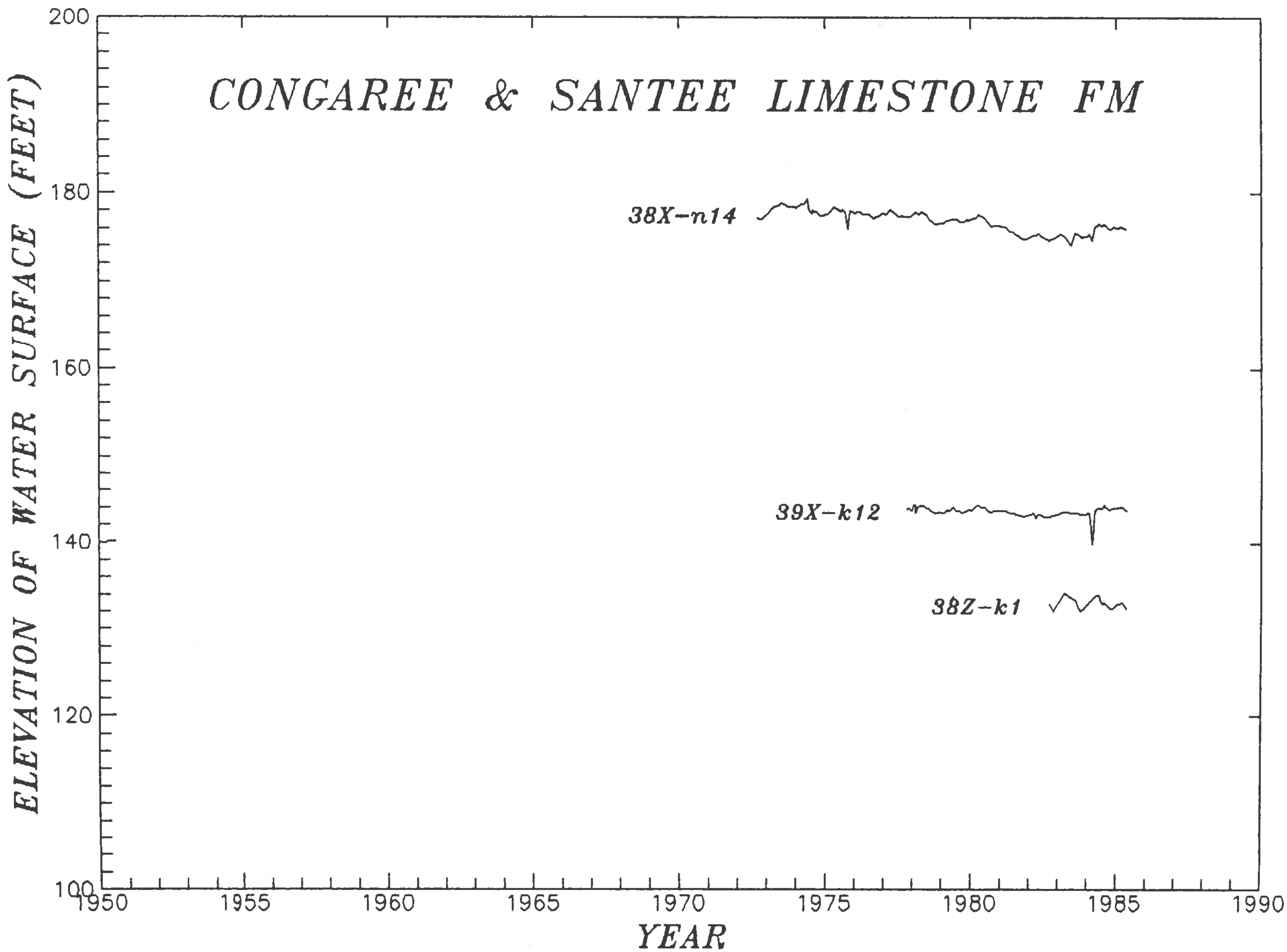
SCWRC number	Field number	Sampled interval	Acidity	Alkalinity	Chloride	Specific conductance	Fluoride	Hardness (calculated)	pH (field)	Total dissolved solids	Sulfate	Temperature (field)	Calcium (total) (dissolved)	Iron (total) (dissolved)	Magnesium (total) (dissolved)	Manganese (total) (dissolved)	Potassium (total) (dissolved)	Silica (dissolved)	Silicon (dissolved)	Sodium (total)
29Y-q1	BAM-40	35	1.0	62.0	11.2	200	0.15	93.0	0.00	84.0	18.3	25.0	36.5 34.5	207.00 0.00	0.50 0.41	42 10	0.67 0.66	7.98	3.73	6.80
29Y-t1	BAM-46	70	0.0	129.0	3.7	0	0.13	129.0	0.00	105.0	4.0	0.0	48.4 45.5	80.00 0.00	2.09 2.08	0 0	0.78 0.77	14.00	6.54	3.30
30Y-t1	BAM-38	180	1.0	69.0	1.8	150	0.22	142.0	0.00	110.0	90.0	0.0	23.2 21.4	175.00 24.00	3.10 3.07	12 3	14.73 7.49	29.11	13.61	3.80
31X-m3	BAM-7/20	0	0.0	142.0	12.4	300	0.06	158.0	7.50	232.0	16.1	21.5	63.2 59.1	606.00 520.00	1.25 1.05	36 18	1.25 1.13	14.50	6.78	6.60
31X-m4	BAM-21	169	0.0	116.0	10.4	240	0.06	134.0	7.35	191.0	8.4	22.0	51.9 49.6	496.00 313.00	1.15 1.08	50 31	1.77 1.64	25.43	11.89	5.50
31X-m6	BAM-27	490	3.0	11.0	3.0	35	0.29	7.0	6.70	27.0	5.2	25.0	2.3 1.5	2300.00 2020.00	0.37 0.36	112 89	7.50 7.40	3.14	1.47	1.80
31X-m7	BAM-6	0	2.5	24.0	3.5	75	0.14	28.0	7.20	84.0	10.2	21.0	9.9 9.5	1750.00 936.00	0.92 0.91	6 0	8.30 7.50	23.50	1.31	1.20
31X-m9	BAM-31	115	0.0	137.0	9.4	270	0.07	151.0	7.80	192.0	9.3	22.0	58.8 56.1	138.00 45.00	0.97 0.96	0 0	1.37 1.27	16.00	7.48	5.40
31X-m11	BAM-16	160	0.0	143.0	0.0	342	0.06	167.0	7.10	236.0	17.9	21.5	65.1 59.7	400.00 318.00	1.12 1.09	23 4	1.51 1.40	15.25	7.13	7.70
31X-m12	BAM-17	0	0.0	143.0	11.9	300	0.05	164.0	7.00	204.0	13.3	20.5	64.1 59.2	206.00 165.00	1.02 0.92	10 9	1.29 1.28	7.19	15.38	7.00
31Y-s1	BAM-37	140	0.0	143.0	5.5	240	0.08	140.0	0.00	123.0	4.6	21.0	53.4 52.5	545.00 194.00	1.51 1.47	43 17	1.07 1.04	11.23	5.25	3.10
31Z-t1	BAM-26	0	1.0	142.0	4.3	265	0.12	147.0	0.00	192.0	4.8	20.5	55.9 53.4	2220.00 1179.00	1.74 1.70	137 116	3.60 3.26	30.84	14.42	3.60
32W-m1	BAM-42	75	1.0	121.0	1.6	220	0.07	133.0	7.30	111.0	8.0	21.0	49.4 44.6	318.00 15.00	2.27 2.17	44 0	1.54 1.30	31.63	14.79	2.40
32X-d1	BAM-23	275	0.0	108.0	4.4	210	0.43	109.0	6.50	136.0	2.9	23.0	40.8 37.3	70.00 28.00	1.75 0.86	9 5	1.27 1.15	22.37	10.46	3.00
32X-g1	BAM-14	0	2.5	26.0	4.4	100	0.04	26.0	7.10	61.0	5.6	22.0	9.7 9.6	24310.00 87.00	0.62 0.61	385 125	0.82 0.79	13.64	6.38	3.00
32X-g2	BAM-22	0	0.0	107.0	3.5	210	0.05	125.0	7.00	149.0	3.6	21.0	46.9 45.5	184.00 107.00	1.93 1.88	18 6	1.21 1.17	23.25	10.92	3.40
32X-g3	BAM-18	235	0.0	113.0	3.5	220	0.04	144.0	7.00	162.0	4.3	22.0	54.9 50.5	362.00 48.00	1.70 1.66	. 43 17	1.18 1.05	26.14	12.22	3.00

SCWRC number	Field number	Sampled interval	Acidity	Alkalinity	Chloride	Specific conductance	Fluoride	Hardness (calculated)	pH (field)	Total dissolved solids	Sulfate	Temperature (field)	Calcium (total) (dissolved)	Iron (total) (dissolved)	Magnesium (total) (dissolved)	Manganese (total) (dissolved)	Potassium (total) (dissolved)	Silica (dissolved)	Silicon (dissolved)	Sodium (total)
32Y-h1	BAM-34	0	2.0	60.5	2.4	118	0.05	69.0	0.00	51.0	3.8	20.5	26.6	675.00	0.80	24	0.74	11.29	5.28	1.90
													24.7	2.00	0.76	16	0.57			
32Z-f1	BAM-45	0	0.0	116.0	3.2	0	0.07	124.0	0.00	111.0	4.8	0.0	46.9	2270.00	1.79	15	1.15	17.05	7.97	2.20
													44.0	883.00	1.66	6	1.03			
32AA-b2	BAM-36	0	0.0	155.0	2.4	0	0.10	159.0	0.00	199.0	4.6	0.0	57.6	154.00	3.58	0	5.54	33.54	15.68	3.60
													53.0	70.00	3.36	0	4.97			
33X-b1	BAM-28	340	2.5	104.0	3.1	0	0.06	116.0	0.00	138.0	5.2	0.0	44.1	2750.00	1.38	108	0.89	20.60	9.63	2.10
													40.5	49.00	1.30	103	0.87			
33Y-j1	BAM-25	400	4.5	65.0	4.4	115	0.11	80.0	7.70	93.0	0.0	22.0	30.7	120.00	0.89	0	0.77	12.77	5.97	1.70
													28.5	30.00	0.84	0	0.77			
33Y-j2	BAM-29	200	1.0	63.0	3.9	120	0.04	75.0	7.70	75.0	4.7	21.0	28.3	8660.00	1.01	161	0.97	2.80	1.31	1.70
													26.5	142.00	1.00	93	0.87			
33Y-v2	BAM-33	0	2.0	32.0	3.9	80	0.09	43.0	6.20	94.0	2.9	22.0	16.2	39.00	0.61	0	0.62	11.48	5.37	1.50
													14.9	31.00	0.54	0	0.58			
33Z-w1	ALL-50	150-200	0.0	97.0	3.7	180	0.14	92.2	7.75	251.0	10.9	20.0	32.5	2900.00	1.38	113	1.69	18.20	0.00	2.03
													30.2	510.00	1.38	103	1.52			
34V-t1	BRN-242	320	7.5	0.0	1.3	35	0.06	1.0	0.00	6.0	7.7	21.0	0.0	423.00	0.24	12	0.58	11.46	5.36	1.10
													0.0	417.00	1.14	0	0.46			
34W-i1	BRN-309	0	0.0	92.0	3.5	155	0.03	101.0	7.90	258.0	0.0	19.0	39.0	49.00	0.81	0	0.81	13.92	6.51	2.20
													36.3	45.00	0.77	0	0.73			
34W-p2	BRN-41	0	0.0	76.5	2.5	175	0.08	86.0	0.00	107.0	9.0	24.0	33.1	243.00	0.82	6	1.36	35.66	16.67	1.90
													31.8	15.00	0.79	0	1.27			
34W-s1	BRN-5	0	0.0	116.0	2.5	210	0.08	136.0	7.90	186.0	4.7	21.0	52.3	2526.00	1.32	58	1.26	38.48	17.99	2.00
													49.2	2306.00	1.29	49	1.22			
34W-s3	BRN-140	0	0.0	125.0	3.9	220	0.08	149.0	7.40	208.0	2.9	21.0	58.1	460.00	1.10	42	1.27	37.37	17.47	2.10
													57.6	431.00	1.00	10	1.20			
34W-s4	BRN-75	0	0.0	115.0	3.0	250	0.05	149.0	7.60	208.0	5.4	21.0	57.5	391.00	1.38	13	1.72	32.40	15.15	2.40
													42.0	42.00	1.18	9	1.51			
34W-s6	BRN-226	350	9.0	59.0	3.9	280	0.05	175.0	7.20	207.0	6.5	21.0	67.3	18800.00	1.75	122	1.68	32.55	15.22	3.30
													24.5	3800.00	1.12	58	1.44			
34AA-q3	ALL-320	0	0.0	29.5	2.3	70	0.06	24.0	0.00	36.0	6.2	22.0	9.4	4790.00	0.16	11	8.81	2.86	1.34	2.50
													7.8	41.00	0.10	0	8.41			
34AA-r1	ALL-318	102	11.5	83.0	14.3	200	0.07	95.0	0.00	98.0	4.5	20.0	36.4	2900.00	1.02	16	5.02	8.90	4.16	9.50
													36.3	20.00	0.95	12	4.95			

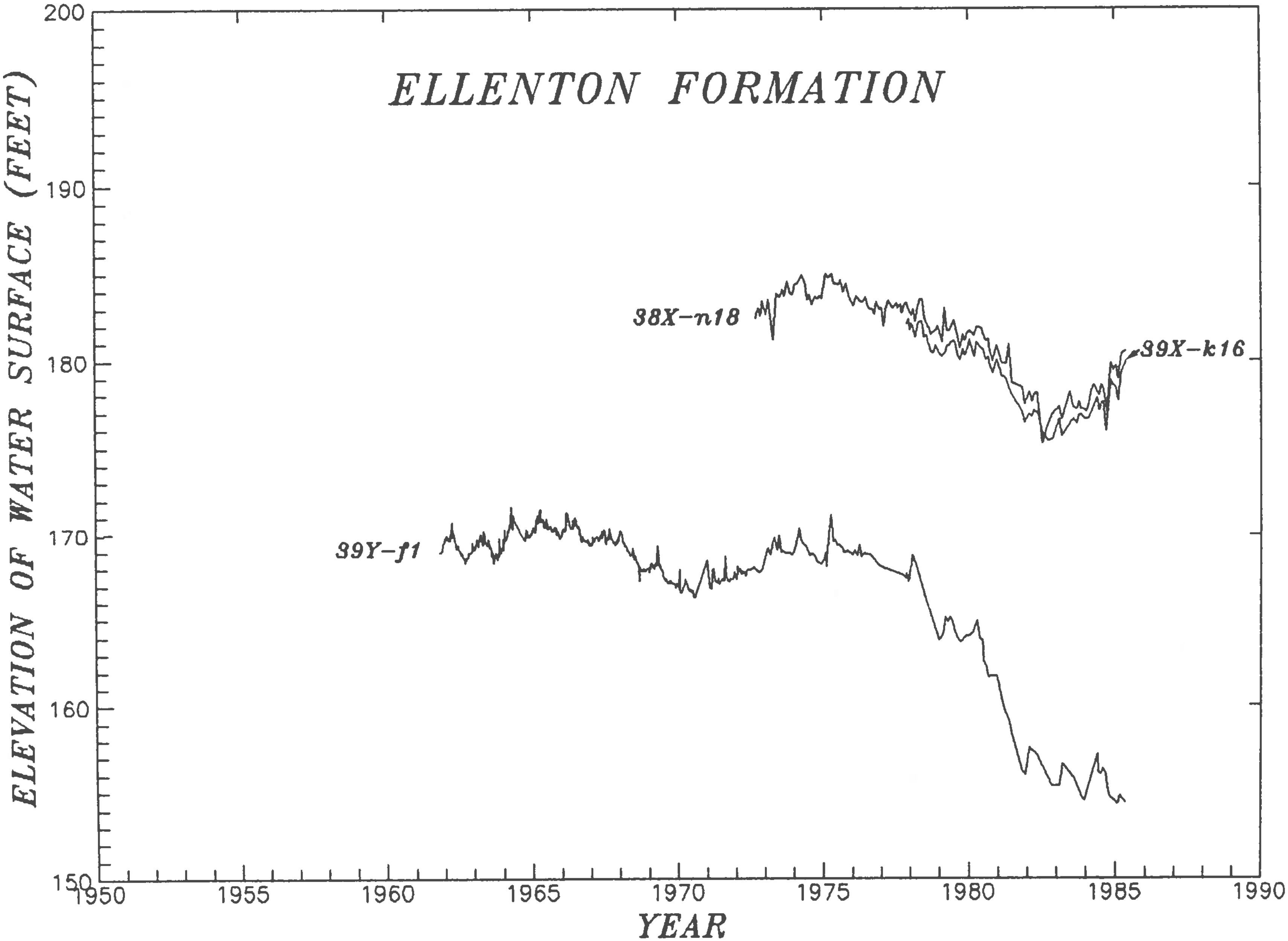
SCWRC number	Field number	Sampled interval	Acidity	Alkalinity	Chloride	Specific conductance	Fluoride	Hardness (calculated)	pH (field)	Total dissolved solids	Sulfate	Temperature (field)	Calcium (total) (dissolved)	Iron (total) (dissolved)	Magnesium (total) (dissolved)	Manganese (total) (dissolved)	Potassium (total) (dissolved)	Silica (dissolved)	Silicon (dissolved)	Sodium (total)
35W-f1	BRN-79	660	2.0	42.0	1.9	115	0.16	48.0	0.00	32.0	8.5	20.5	18.2	250.00	0.60	126	1.07	11.36	5.31	1.90
													16.9	35.00	0.54	121	0.92			
35W-m2	BRN-224	0	0.0	75.0	3.4	140	0.10	82.0	0.00	54.0	3.4	20.0	32.4	241.00	0.43	6	0.72	9.39	4.39	2.20
													30.8	48.00	0.34	3	0.65			
35X-v1	BRN-63	0	6.0	47.0	3.0	100	0.09	50.0	7.20	223.0	2.9	23.5	19.1	57.00	0.68	11	0.63	21.43	10.02	1.60
													16.1	11.00	0.65	8	0.60			
35Y-b5	BRN-39	230	0.0	0.0	2.8	116	0.14	49.0	0.00	79.0	2.1	0.0	18.0	0.74	0.70	0	0.60	21.00	0.00	4.20
													0.0	0.19	0.00	0	0.00			
35Y-b6	BRN-55	0	5.5	32.0	3.2	80	0.06	40.0	6.80	196.0	0.0	22.0	15.1	101.30	0.61	25	0.73	23.89	11.17	2.60
													13.0	30.00	0.57	5	0.60			
35Y-b7	BRN-53	315	6.0	35.0	3.9	85	0.12	40.0	8.00	30.0	0.0	22.0	14.9	498.00	0.64	9	0.50	15.72	7.35	1.60
													14.3	0.00	0.62	4	0.50			
35Y-b8	BRN-60	265	8.5	38.0	3.5	90	0.06	43.0	7.20	49.0	2.9	21.0	16.0	0.00	0.67	5	0.69	28.81	13.47	1.50
													15.5	0.00	0.64	0	0.68			
35Y-b10	BRN-67	0	8.0	32.0	3.0	75	0.16	40.0	7.00	203.0	0.0	22.5	15.1	115.00	0.63	0	0.60	15.14	7.08	2.10
													13.0	36.00	0.61	0	0.59			
35Y-c1	BRN-56	215	5.5	14.0	2.5	50	0.08	16.0	6.80	24.0	2.9	21.0	5.8	17.00	0.42	2	0.85	21.64	10.12	2.30
													5.5	0.00	0.37	0	0.81			
35Y-c4	BRN-57	240	13.0	6.0	4.2	30	0.06	7.0	6.80	7.0	2.9	21.0	2.0	112.00	0.57	0	1.07	17.54	8.20	2.50
													1.5	48.00	0.54	0	1.02			
35Y-c5	BRN-73	0	9.0	6.0	3.0	30	0.07	11.0	7.00	137.0	0.0	22.0	3.4	10.00	0.64	6	1.00	16.51	7.72	2.40
													1.5	3.00	0.56	0	1.00			
35Y-i1	BRN-59	230	12.0	39.0	3.2	90	0.09	44.0	6.80	55.0	2.9	21.0	16.8	124.00	0.66	26	0.69	19.98	9.34	2.30
													15.7	0.00	0.64	12	0.67			
35Y-i2	BRN-62	0	9.5	50.0	3.5	100	0.10	54.0	7.00	72.0	0.0	21.0	20.5	110.00	0.72	0	0.70	18.69	8.74	2.40
													17.1	36.00	0.69	0	0.67			
35Y-i3	BRN-66	305	2.5	54.0	3.5	120	0.09	63.0	7.00	94.0	2.9	21.0	24.3	195.00	0.71	18	0.73	21.96	10.27	1.60
													22.1	0.00	0.69	0	0.69			
35Z-k1	BRN-29	0	0.0	111.0	2.5	215	0.09	116.0	0.00	91.0	8.2	25.0	45.3	9660.00	0.58	14	0.82	18.59	8.69	2.00
													42.8	8810.00	0.56	7	0.79			
35Z-u2	ALL-304	0	6.5	16.0	3.4	50	0.32	18.0	0.00	0.0	3.5	24.0	6.3	23.06	0.51	18	1.65	16.81	7.86	2.30
													5.0	0.00	0.43	16	1.60			
35AA-l1	ALL-301	0	4.0	134.0	4.7	178	0.04	119.0	7.20	209.0	6.5	14.0	45.5	51.00	1.36	0	2.18	35.00	16.40	2.80
													44.6	4.00	1.34	0	2.15			

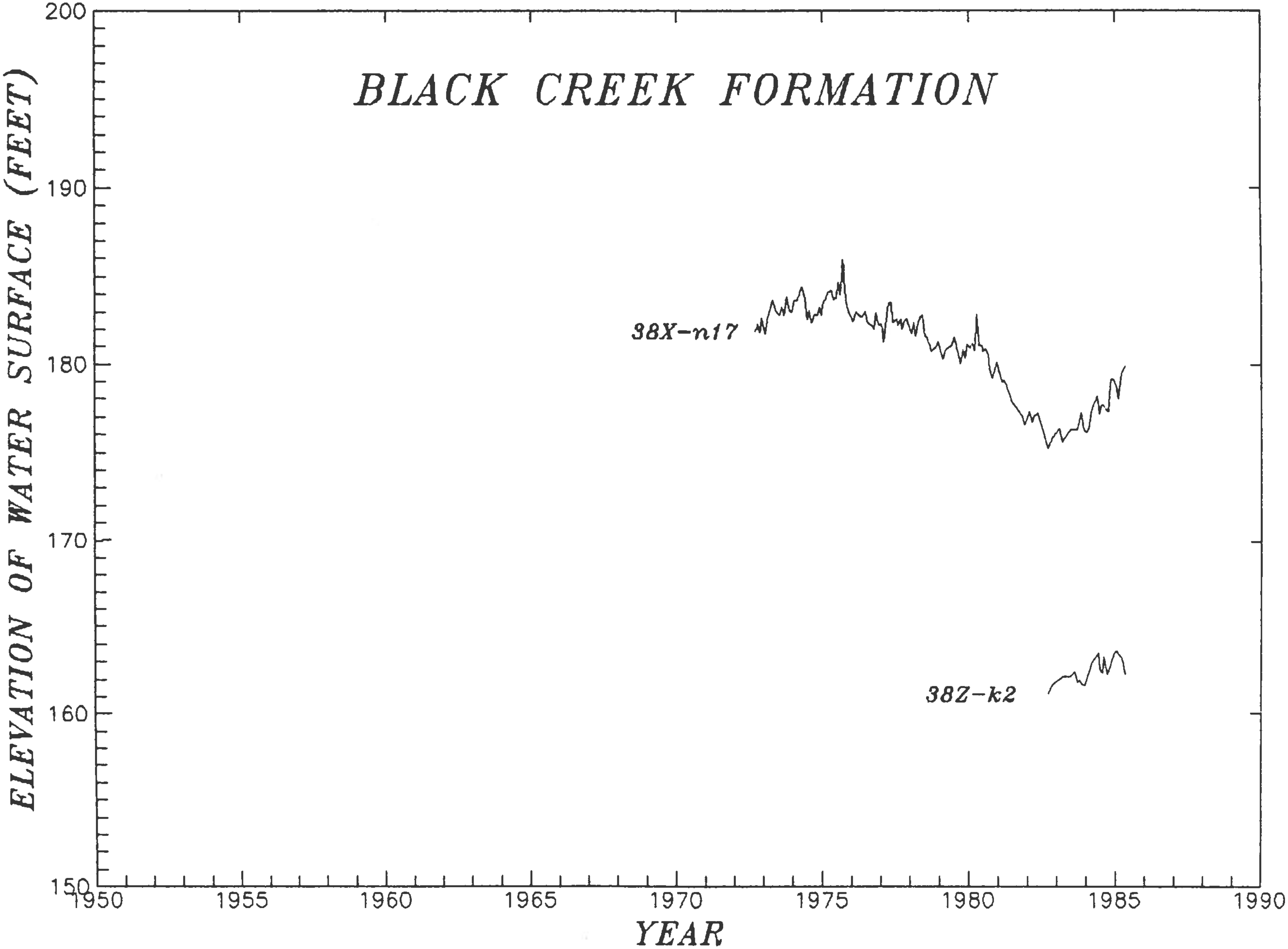

BARNWELL FORMATION
ELEVATION OF WATER SURFACE (FEET)
YEAR
300
280
260
240
220
200
1950
1955
1960
1965
1970
1975
1980
1985
1990
38X-n21
38X-n11
38X-n39
38X-k15

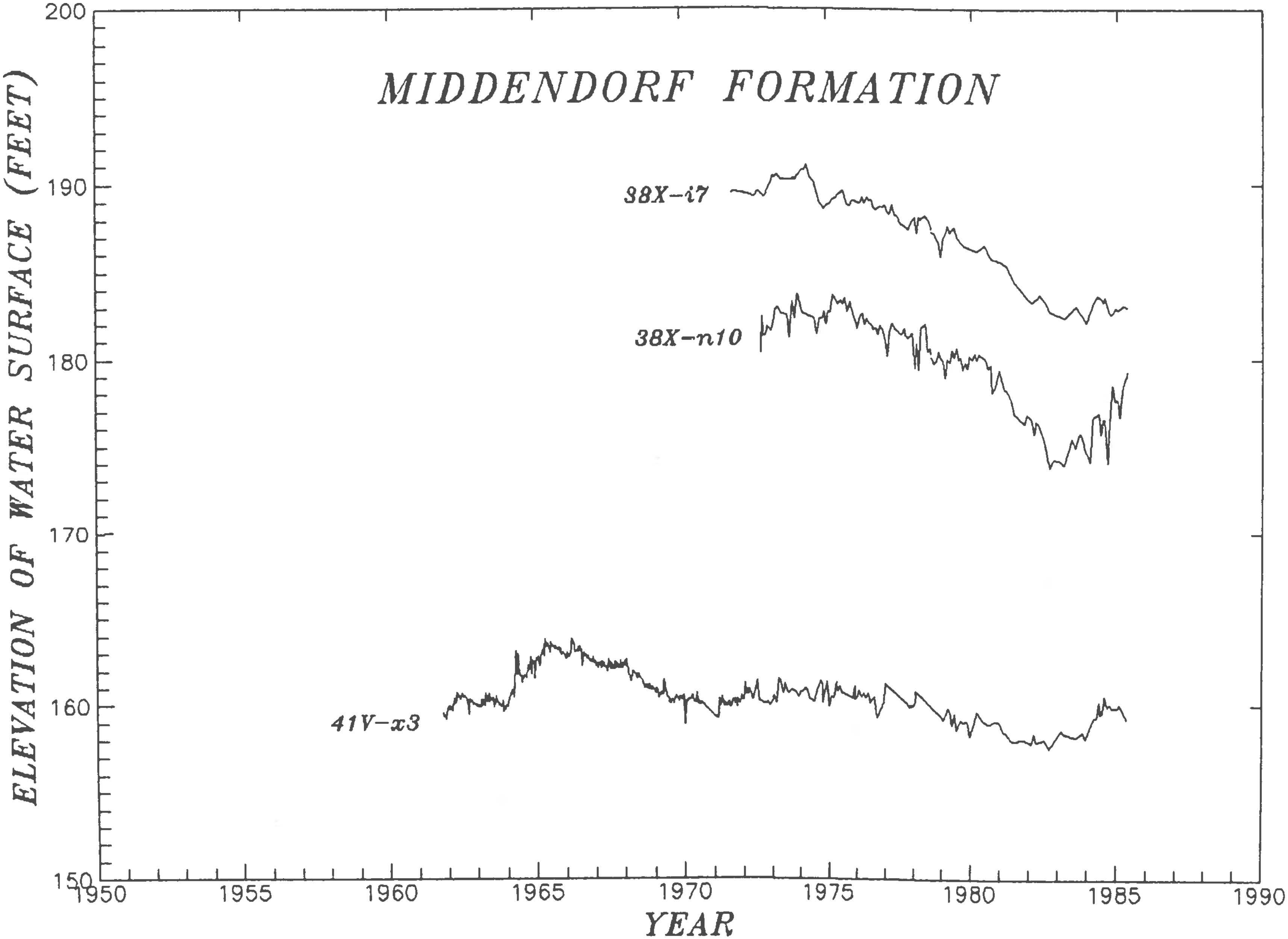

McBEAN FORMATION
ELEVATION OF WATER SURFACE (FEET)
300
280
260
240
220
200
38X-n12
38X-n26
39X-k14
39X-k13
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR

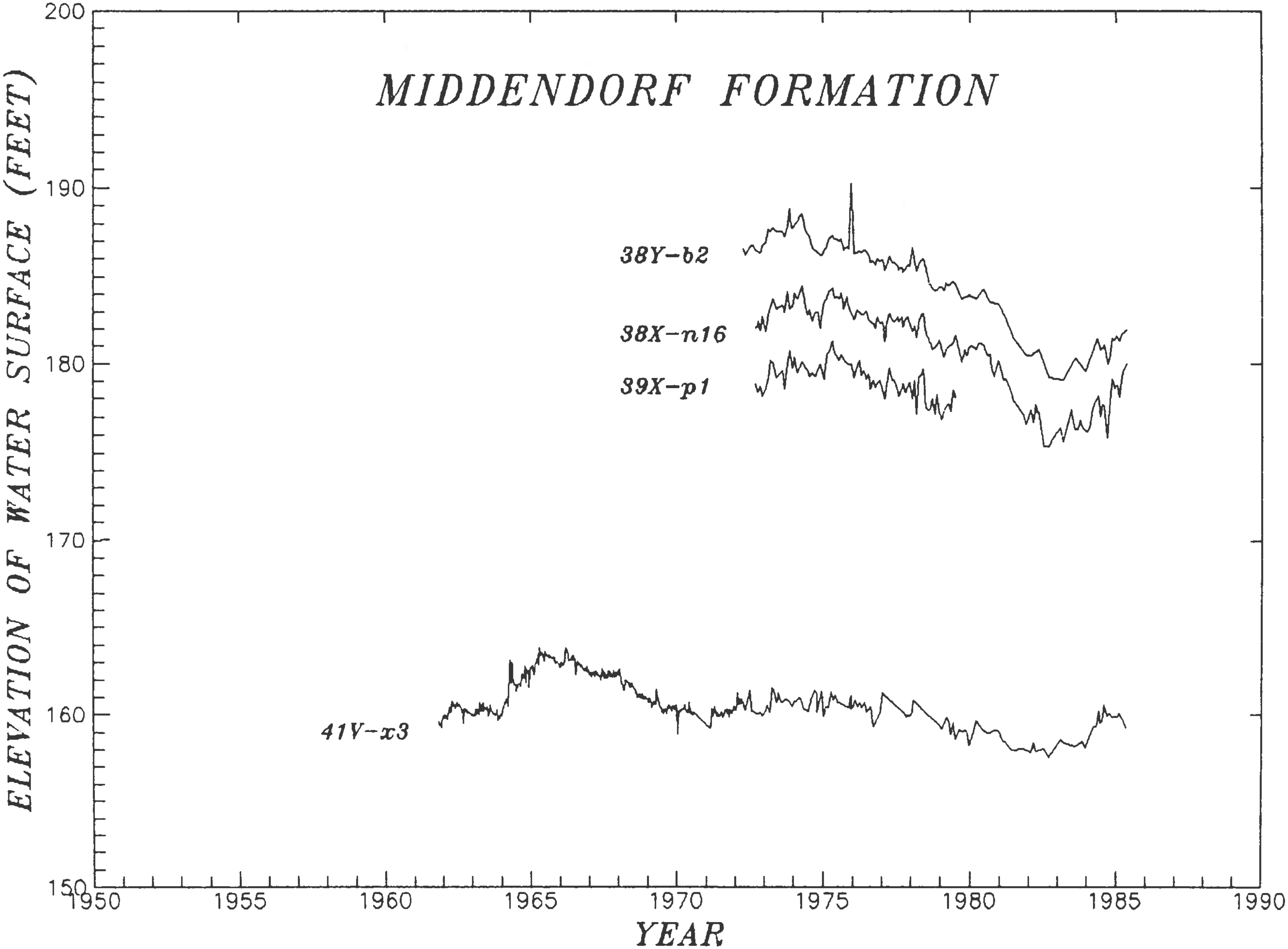


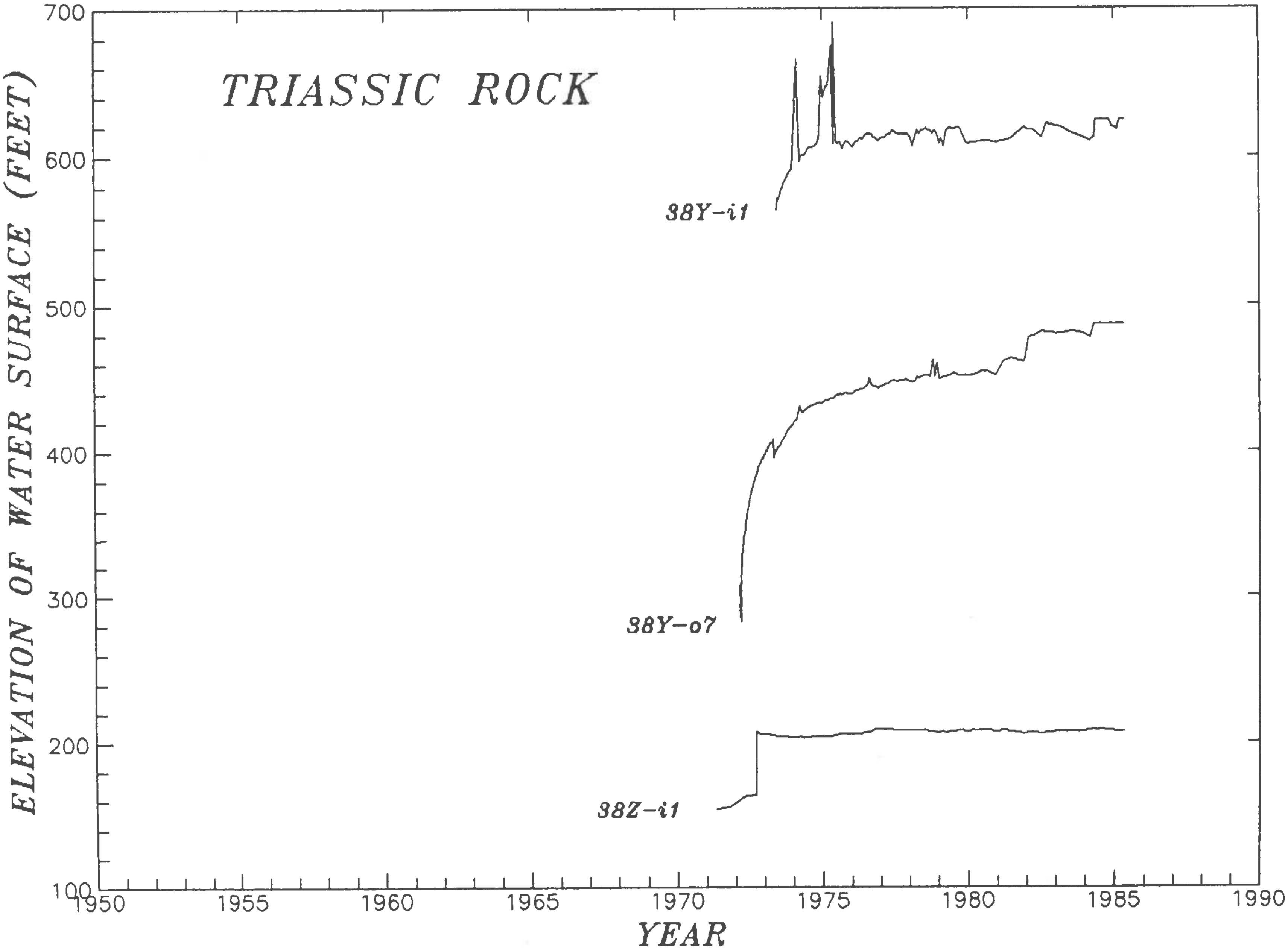
CONGAREE & SANTEE LIMESTONE FM
ELEVATION OF WATER SURFACE (FEET)
YEAR
38X-n14
39X-k12
38Z-k1
200
180
160
140
120
100
1950
1955
1960
1965
1970
1975
1980
1985
1990

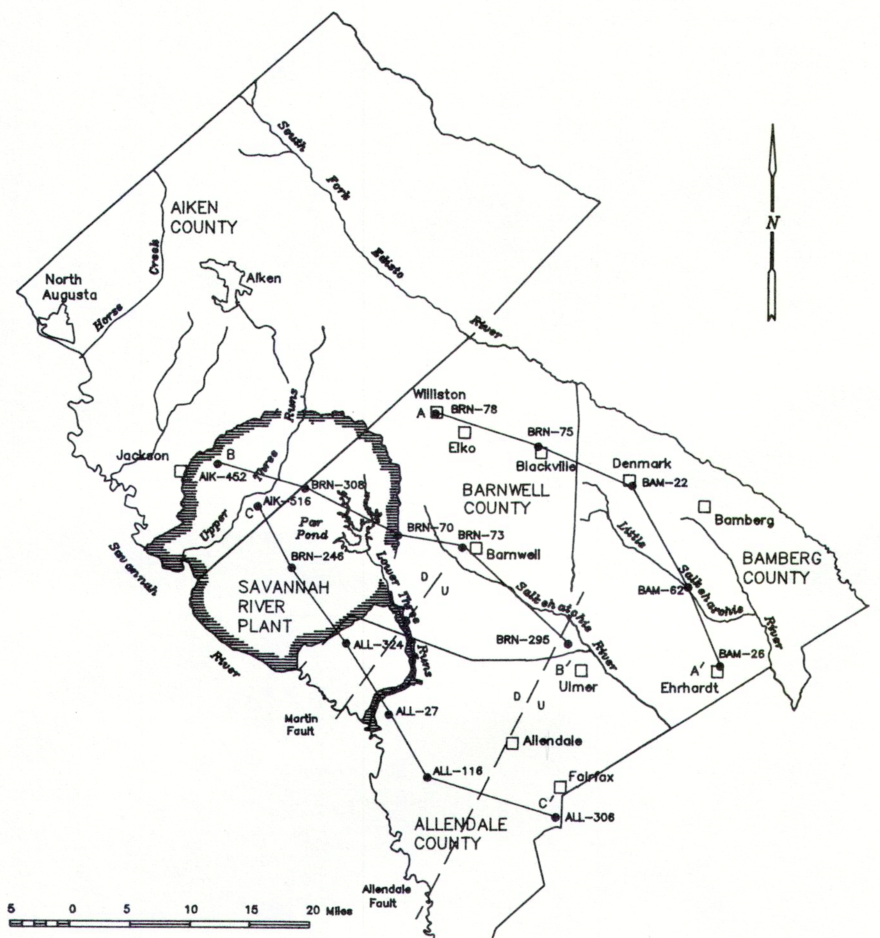

ELLENTON FORMATION
ELEVATION OF WATER SURFACE (FEET)
YEAR
38X-n18
39X-k16
39Y-f1
200
190
180
170
160
150
1950
1955
1960
1965
1970
1975
1980
1985
1990


BLACK CREEK FORMATION
ELEVATION OF WATER SURFACE (FEET)
YEAR
200
190
180
170
160
150
1950
1955
1960
1965
1970
1975
1980
1985
1990
38X-n17
38Z-k2


MIDDENDORF FORMATION
38X-i7
38X-n10
41V-x3
ELEVATION OF WATER SURFACE (FEET)
YEAR
200
190
180
170
160
150
1950
1955
1960
1965
1970
1975
1980
1985
1990

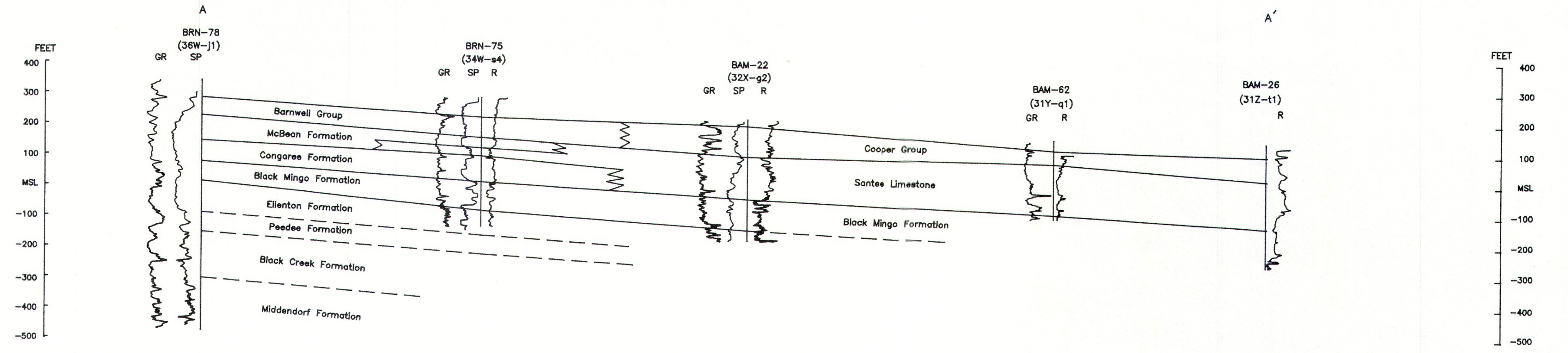

MIDDENDORF FORMATION
ELEVATION OF WATER SURFACE (FEET)
YEAR
38Y-b2
38X-n16
39X-p1
41V-x3
200
190
180
170
160
150
1950
1955
1960
1965
1970
1975
1980
1985
1990

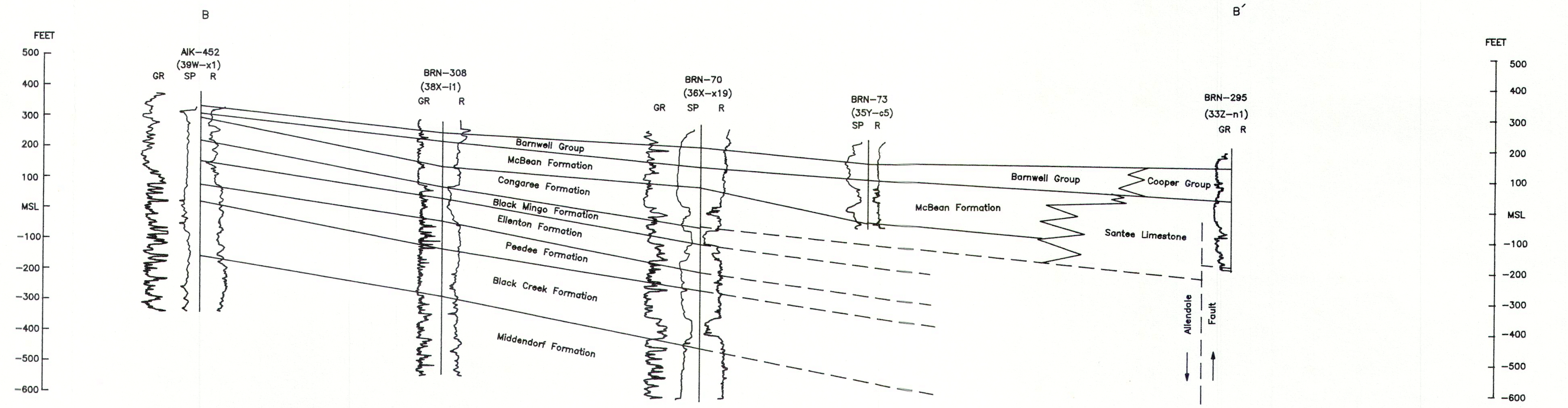

TRIASSIC ROCK
ELEVATION OF WATER SURFACE (FEET)
YEAR
38Y-i1
38Y-o7
38Z-i1
100
200
300
400
500
600
700
1950
1955
1960
1965
1970
1975
1980
1985
1990

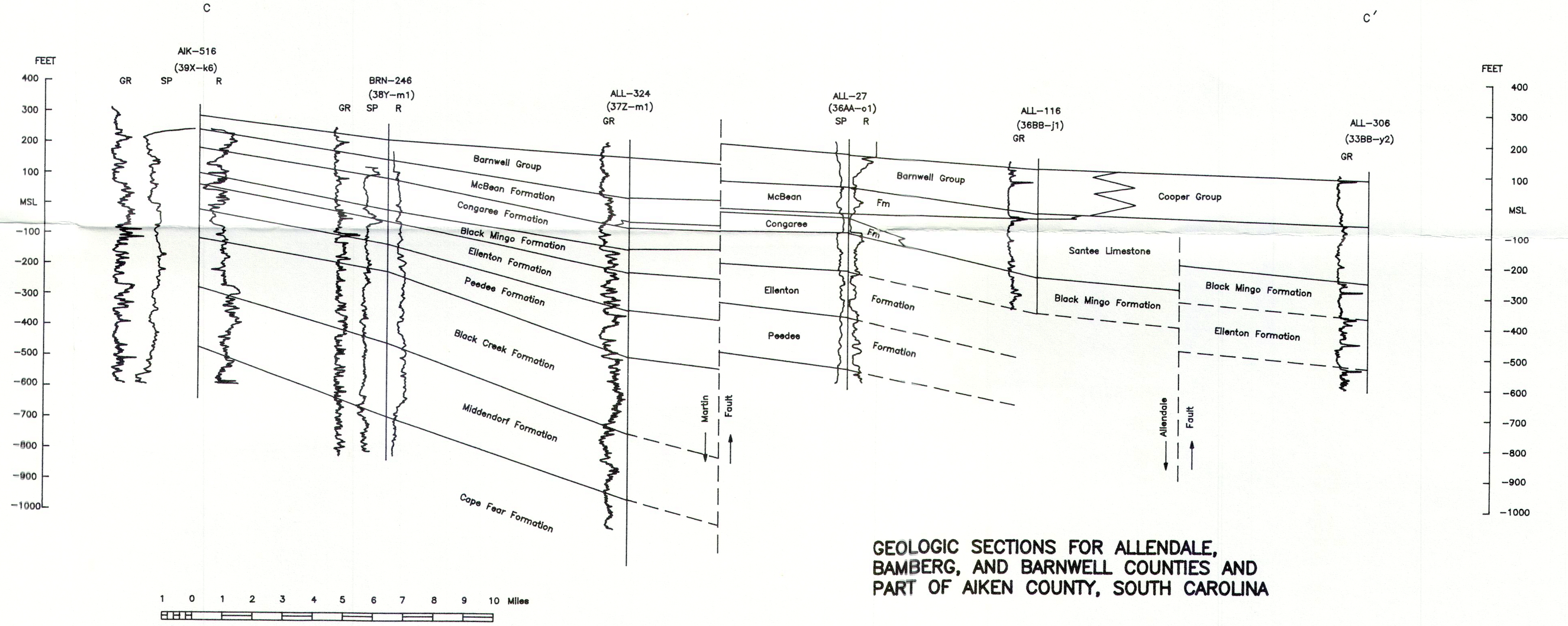


EXPLANATION

A —A′ – Geologic section
• BRN–78 – Well and number
(36W–j1) – SCWRC grid number
GR – Gamma-ray log
SP – Spontaneous-potential log
R – Resistivity log







GEOLOGIC SECTIONS FOR ALLENDALE, BAMBERG, AND BARNWELL COUNTIES AND PART OF AIKEN COUNTY, SOUTH CAROLINA