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Hydrogeology of the Southeastern Coastal Plain Aquifer System in Mississippi, Alabama, Georgia, and South Carolina

By ROBERT A. RENKEN

REGIONAL AQUIFER-SYSTEM ANALYSIS—
SOUTHEASTERN COASTAL PLAIN

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1410-B

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FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The Regional Aquifer-System Analysis (RASA) Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which, in aggregate, underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and, accordingly, transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information; to analyze and develop an understanding of the system; and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number beginning with Professional Paper 1400.

Gordon P. Eaton

Gordon P. Eaton
Director

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For readers who prefer to use metric (International System) units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
mile (mi)	1.609	kilometer (km)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
square mile (mi^2)	2.590	square kilometer (km^2)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

HYDROGEOLOGY OF THE SOUTHEASTERN COASTAL PLAIN AQUIFER SYSTEM IN MISSISSIPPI, ALABAMA, GEORGIA, AND SOUTH CAROLINA

By Robert A. Renken

ABSTRACT

Cretaceous and Tertiary clastic sedimentary rocks in the Coastal Plain of Mississippi, Alabama, Georgia, and South Carolina and adjacent areas of northern Florida and southeastern North Carolina collectively make up a major aquifer system called the Southeastern Coastal Plain aquifer system. Seven hydrogeologic units—four regional aquifers consisting of fine- to coarse-grained, feldspathic, glauconitic, quartz sand and minor sandstone, gravel, and occasional limestone beds separated by three confining units of chalk, clay, mudstone, and shale—crop out in adjacent bands except where they are covered by younger strata. Southeastern Coastal Plain rocks are commonly, but not exclusively, nonmarine to marginal marine at their landwardmost extent and grade to deeper marine deposits, forming a thick sedimentary wedge as they extend coastward, or westward in Mississippi, into the subsurface.

Vertical and horizontal boundaries of the regional aquifers and confining units do not everywhere correspond to boundaries of rock- and time-stratigraphic units. Hydrogeologic units were defined on the basis of a qualitative appraisal of lithology, porosity, and permeability as determined from borehole geophysical and sample logs. The complex stratigraphic and hydrologic Coastal Plain system sediments were greatly idealized to simplify the hydrogeologic framework. A new nomenclature was introduced to describe the delineated regional aquifer and confining units that encompass several formations and chronostratigraphic units as well as locally named aquifer and confining beds. Cross sections and structure contour, thickness, and facies maps illustrate the extent, lithologic and hydraulic character, and geometry of the major hydrogeologic and rock- and time-stratigraphic units and demonstrate their regional equivalency.

Pre-Cretaceous rocks that include metamorphic, sedimentary, and igneous rocks and saprolite form the nearly impermeable base of the regional aquifer system. A large part of the aquifer system consists of Cretaceous strata. However, the oldest (Coahuilan and Comanchean) Cretaceous rocks generally occur below the base of freshwater. Basal Upper Cretaceous (Gulfian) strata consist of a thick, dominantly nonmarine sequence (Woodbinian to early Austinian in age) of sparsely fossiliferous sand and gravel with interbedded clay and shale. As a result of a widespread inundative phase during middle Austinian to Navarroan time, upper Gulfian rocks contain a thick sequence of marine strata. Fluvial deposition during this time was restricted to the northern Mississippi embayment, eastern Georgia, and South Carolina.

Tertiary rocks that are part of the Southeastern Coastal Plain aquifer system are largely of Paleocene to Eocene age. Except in Mississippi, most of the younger Tertiary and Quaternary beds are part of the overlying Floridan aquifer system or its upper confining unit or the surficial aquifer. A widespread carbonate platform sequence covered much of southern Alabama, Georgia, and South Carolina during Paleocene, Eocene, and Oligocene time. Clastic deposition was restricted to updip and middip areas of these States. In Mississippi, however, clastic nonmarine and marginal-marine deposits were more extensive.

The Chickasawhay River aquifer, the uppermost regional aquifer of the Southeastern Coastal Plain aquifer system, extends only across southern Mississippi and southwestern Alabama. It consists of a thick sequence of Oligocene and Miocene sand, clay, and minor limestone deposits of marine to fluvial origin. It is underlain in this area by the clay and marl deposits of the Pearl River confining unit. Both of these regional hydrogeologic units extend westward into Louisiana and grade by facies change eastward to the Floridan aquifer system and its upper confining unit.

The sand, gravel, and minor limestone beds of the Pearl River aquifer are of Paleocene to late Eocene age and extend in outcrop or in the subsurface across Mississippi to South Carolina. The Pearl River aquifer grades seaward to less permeable clay and marl in the western half of the study area, but in the eastern half it grades into, or is overlain by, the hydraulically interconnected Floridan aquifer system. The boundary between these two aquifers represents a time-transgressive facies boundary. Two different confining units underlie the Pearl River aquifer; the shallowest Chattahoochee River confining unit is found to the east, whereas the deeper Black Warrior River confining unit underlies the aquifer in Mississippi and in western Alabama.

The Chattahoochee River aquifer, a feldspathic to glauconitic quartz sand sequence of Cretaceous to late Paleocene age, occurs in Georgia and South Carolina and in a fairly small area in eastern Alabama. Correlative water-bearing strata of Late Cretaceous age, overlain and underlain by the Black Warrior River confining unit in northernmost Mississippi, are part of a more extensive aquifer.

The Black Warrior River aquifer, the most widespread regional clastic aquifer of the Southeastern Coastal Plain aquifer system, crops out in a wide area of Mississippi, Alabama, and western Georgia, but it is entirely covered by shallower aquifers farther to the east. The aquifer consists mostly of Cretaceous nonmarine sand, sandstone, and gravel, interbedded with nonmarine to marginal-marine clay, mudstone, and shale. The transmissivity of the aquifer is much greater in Mississippi and western Alabama than to the east.

The comparison of regional facies, aquifer thickness, and simulated transmissivity values indicates that the most water-transmissive parts of these clastic aquifers are associated with nonmarine water-bearing strata. Those strata deposited in marine-shelf areas are least water transmissive. Marginal- and transitional-marine water-bearing beds occur as discrete, hydraulically independent units. Change in lithofacies appears to be the most important factor controlling the distribution of transmissivity within the aquifers of the Southeastern Coastal Plain aquifer system. With a few exceptions, tectonic features are far less influential, and their effects are considered to be indirect, in that they may have controlled the pattern of deposition.

INTRODUCTION

Clastic sedimentary rocks of Cretaceous and Tertiary age in the Coastal Plain of Mississippi, Alabama, Georgia, and South Carolina and adjacent areas of northern Florida and southeastern North Carolina make up a major aquifer system called the Southeastern Coastal Plain aquifer system. This system is 1 of 28 regional aquifer systems identified in the United States (Sun, 1986) that collectively provide most of the Nation's ground-water supplies. The Southeastern Coastal Plain aquifer system is being studied as part of the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) Program. The RASA Program is described in U.S. Geological Survey Professional Papers 1400–1428, which include regional descriptions of the geology, hydrology, and geochemistry of each aquifer system (Sun, 1986).

The clastic sediments that make up the Southeastern Coastal Plain aquifer system have been grouped into seven major hydrogeologic units. The composition, texture, bedding character, and, accordingly, the hydraulic character of these units differ considerably from place to place. Sand aquifers of this system are massive to thinly bedded, fine to coarse grained, quartzose, glauconitic to feldspathic, and commonly contain minor sandstone, gravel, and limestone beds. Chalk, clay, shale, and mudstone form confining units that separate the major aquifers. Hydraulic conditions range from unconfined in areas where the major aquifers crop out to confined in areas where they are covered by thick confining units of clay, chalk, and shale.

The major objectives of the Southeastern Coastal Plain aquifer-system study are as follows:

1. to identify, delineate, and map the permeability distribution of clastic Coastal Plain aquifers;
2. to describe the chemical evolution and quality of ground water as it moves down the hydraulic gradient from areas of recharge to areas of discharge;
3. to examine the pattern of ground-water flow within a network of regional aquifers whose hydrologic boundaries cross State boundaries and major river basins; and
4. to simulate regional ground-water flow by the use of a digital computer model.

PURPOSE AND SCOPE

This report is one of a series of chapters of Professional Paper 1410 that provides a comprehensive discussion of the hydrogeology, hydrochemistry, and hydrology of the Southeastern Coastal Plain aquifer system. The purposes of this report (chapter B) are as follows:

1. to describe the permeability distribution of clastic Coastal Plain strata—specifically, to describe the configuration and overall character of the rocks that form regionally extensive aquifers and confining beds in the aquifer system;
2. to summarize the regional geology and develop a hydrogeologic framework that relates the regional stratigraphy to regionwide distribution of permeable clastic Coastal Plain strata;
3. to explain how depositional and tectonic events directly or indirectly controlled the hydraulic properties of the hydrogeologic units and ground-water flow in the Southeastern Coastal Plain;
4. to provide a unified regional hydrogeologic framework that explains the relations between aquifers and confining beds and demonstrates their equivalency on a regional scale; and
5. to provide the geometry of a multilayered regional aquifer system for a digital computer model that simulates the regional ground-water flow system.

Two reports published prior to this one (Renken, 1984; Renken and others, 1989) defined the major hydrogeologic units of the Southeastern Coastal Plain aquifer system and used cross sections and structure contour maps to depict their geometry and extent. Additional data have been incorporated since those reports were published, necessitating minor revisions. For example, the line showing the extent of the overlying Floridan aquifer system as mapped by Miller (1982a, b, c, 1986) was shifted northward to include limestone beds in Orangeburg, Clarendon, and Calhoun Counties, S.C. (compare Renken, 1984; Renken and others, 1989). In addition, the specific position of a certain chronostratigraphic interval in some wells, as originally determined from correlation of geophysical logs, was revised to agree with more detailed lithologic and paleontologic data collected in South Carolina (Reid and others, 1986a, b) and elsewhere.

The results of the Southeastern Coastal Plain aquifer-system study are presented within the eight chapters of Professional Paper 1410 (chapters A–H). A summary of these various reports is presented in chapter A. Chapter C describes the hydrology and regional flow system; the hydrochemistry of the system is presented in chapter D. The hydrology of the Southeastern Coastal Plain aquifer system is described in more detail in subsequent chapters: chapter E describes the hydrology of South Carolina; chapter F, Georgia; chapter G, Mississippi; and chapter H, the Alabama Coastal Plain.

LOCATION AND PHYSIOGRAPHIC SETTING

The Southeastern Coastal Plain is the central connecting link among four adjacent and overlapping regional Coastal Plain aquifer systems: the Northern Atlantic Coastal Plain regional aquifer system to the northeast, the Floridan aquifer system to the southeast, and the Mississippi embayment and coastal lowland aquifer systems to the west (fig. 1). Three of the major clastic aquifers in Cretaceous and Tertiary rock that together make up the Southeastern Coastal Plain aquifer system, the focus of this investigation, extend beyond Mississippi or South Carolina and become part of the adjoining Mississippi embayment, coastal lowland, and northern Atlantic Coastal Plain aquifer systems. In addition, clastic strata grade southward into carbonate rocks of equivalent age present in Florida, southern and southwestern Georgia, southern Alabama, and southwestern South Carolina that make up the highly productive Floridan aquifer system (Johnston and Bush, 1988). In these States, the Southeastern Coastal Plain aquifer system is mostly overlain by, and hydraulically interconnected with, the Floridan aquifer system. The limestone units that compose the Floridan aquifer system generally grade to, or interfinger with, the clastic rocks of the Southeastern Coastal Plain aquifer system and are therefore considered an integral part of the total ground-water flow system there.

The Southeastern Coastal Plain of the United States encompasses more than 120,000 mi^2 in Mississippi, Alabama, Georgia, South Carolina, and adjacent parts of southeastern North Carolina and northern Florida (fig. 1) and is drained by streams flowing to the Gulf of Mexico and the Atlantic Ocean. The Cape Fear River in North Carolina and the Mississippi River in the central Gulf Coastal Plain, respectively, are the easternmost and westernmost streams that drain the study area. The Southeastern Coastal Plain includes the Sea Island and East Gulf Coastal Plain sections and a small part of the Mississippi Alluvial Plain section of the Coastal Plain physiographic province (Fenneman and Johnson, 1946). The Southeastern Coastal Plain extends southward to the Atlantic Ocean and the Gulf of Mexico from the Fall Line, a physiographic boundary that marks the inner margin; it is bounded to the north by the Piedmont, Valley and Ridge, Appalachian Plateaus, and Interior Low Plateaus physiographic provinces. The Florida peninsula is part of the Coastal Plain but is not included in the study area (fig. 2).

The outcrop of the Southeastern Coastal Plain sediments in large part extends as a narrow band along the Fall Line. The plain itself consists of poorly consolidated Cretaceous, Tertiary, and Quaternary rocks that underlie the study area (fig. 3). The topography of the Coastal Plain varies from low-lying flat plains to rounded hills with long, gentle slopes and broad valleys to ridges with steep slopes separated by narrow valleys. The elevation of the plain varies from sea level along the coastline to as great as 1,000 ft along the inner edge of the plain in Mississippi. Some of the most permeable clastic rocks rim the northern edge of the plain as smoothly rounded hills of low relief to hills and ridges of 200 ft in relief between the adjacent valley and adjoining crest of the hill. These rocks form the foothills to the adjacent Piedmont, Valley and Ridge, Appalachian Plateaus, and Interior Low Plateaus provinces. Some of the least permeable rocks form level to slightly rolling plains; elsewhere, they form broadly rounded hills of low relief. Differences in the lithology and length of time that the plain strata were exposed and subject to erosion are important factors controlling the topographic relief of the study area. For example, the low-lying, flat Dougherty Plain is the result of rapid dissolution of the underlying limestone. Sinkhole and karstlike topography is generally prevalent where limestone strata lie near the surface of the Coastal Plain. The low-lying coastal terraces, which occupy much of the Coastal Plain of South Carolina and southeastern Georgia, reflect erosional intervals during different Pleistocene sea level stands and have not been subject to intensive dissection by surface drainage.

PREVIOUS INVESTIGATIONS

Numerous reports have been published in the last 150 years that describe geologic conditions within the area encompassed by the Southeastern Coastal Plain aquifer system. The majority of these reports are primarily concerned with evaluating the lithostratigraphic and biostratigraphic character of outcropping Cretaceous and Tertiary strata and their separation into a systematic stratigraphic framework. The search for oil and gas supplies as well as an increasing demand for larger, dependable supplies of ground water to fulfill municipal,

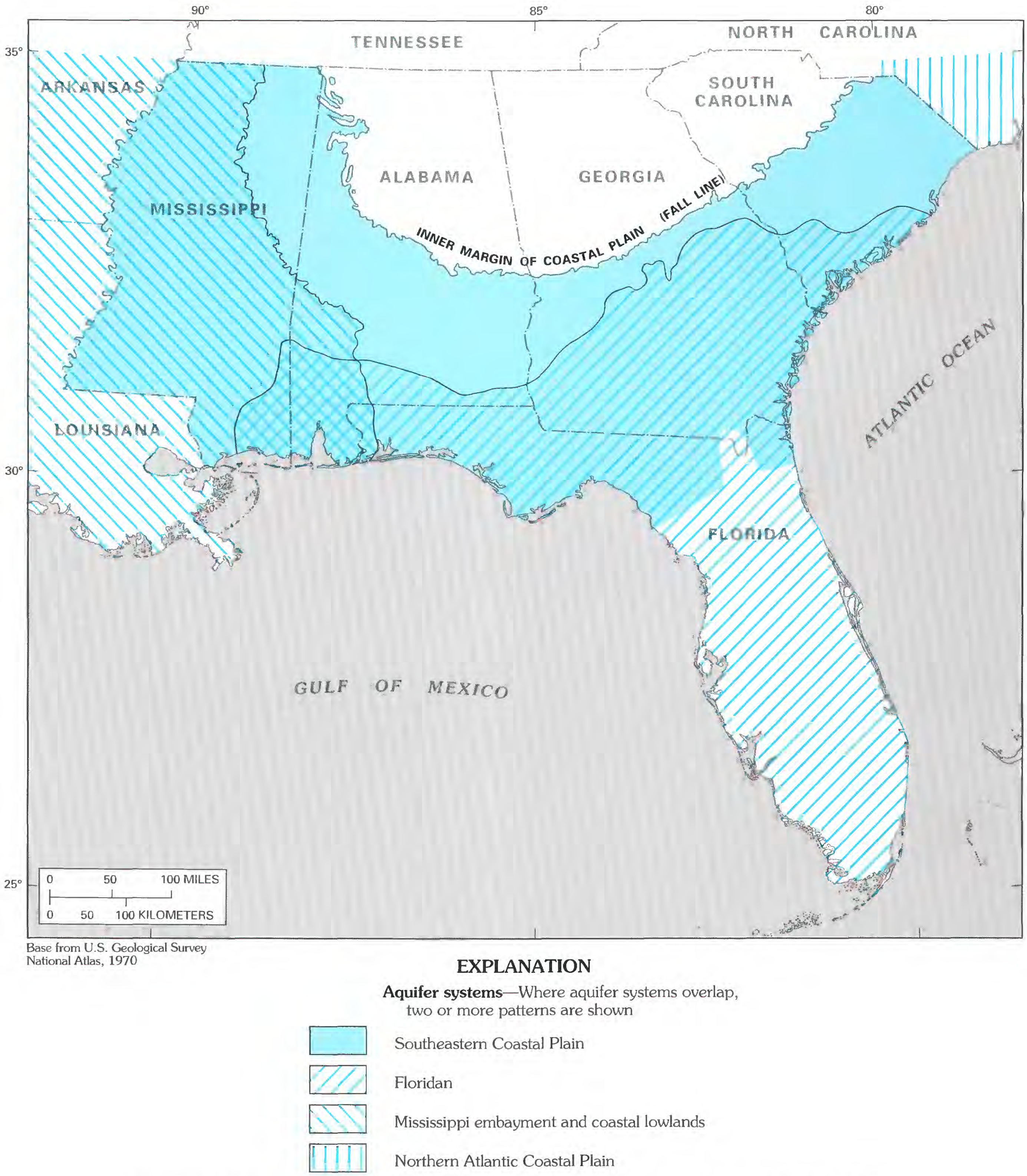


FIGURE 1.—Areal extent of regional aquifer systems of the Southeastern Coastal Plain of the United States.

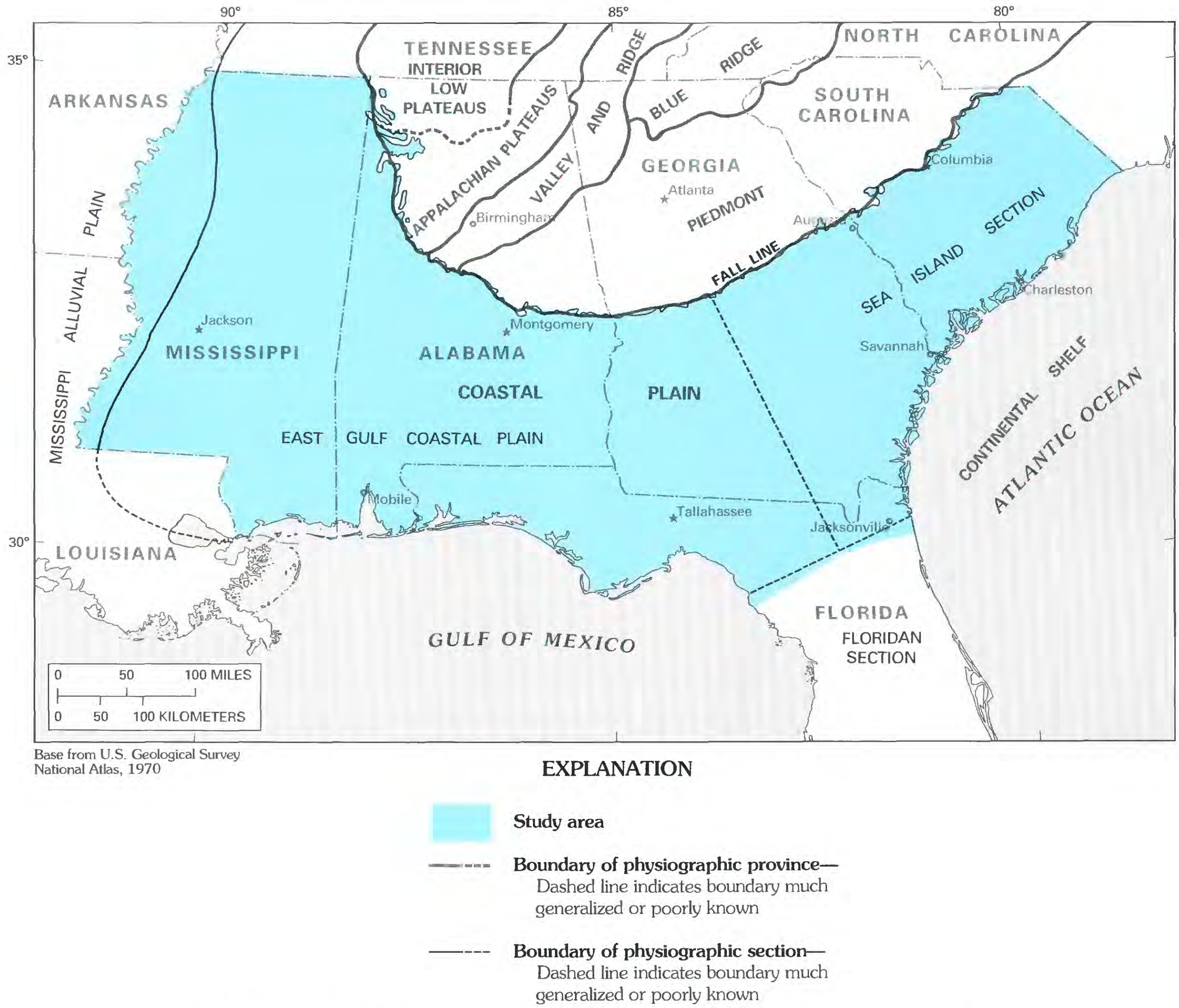


FIGURE 2.—Location of study area and major physiographic provinces in the Southeastern United States.

industrial, and irrigation requirements has provided the impetus for many of the local to multicounty studies. These studies have examined the shallow and deep subsurface geologic units of the Southeastern Coastal Plain, but, unfortunately, a large number of these investigations are constrained by local or State boundaries. Consequently, there are no published reports that describe both the regional geologic and hydrogeologic conditions within the study area. However, some reports, even though they are not at a regional level, deserve mention and are described below.

The outcrop geology of South Carolina is discussed in several different publications, including those by Cooke (1936), Cooke and MacNeil (1952), and Swift and Heron (1969). A comprehensive analysis of the subsurface geology of Cretaceous and Tertiary Coastal Plain rock units in South Carolina is given in reports by Colquhoun and others (1982, 1983). Reports by Gohn and others (1978a, b) also provide additional information useful in the correlation of Coastal Plain strata along the South Carolina coast. Cooke (1943) and Eargle (1955) provide synopses of the outcrop stratigraphy of Georgia; subsurface geologic descriptions in Georgia can be found in several reports, especially those by Applin and Applin (1944, 1947, 1965, 1967), Herrick (1961), and Herrick and Vorhis (1963). Publications by Smith and Johnson (1887), Smith and others (1894), Stephenson and Monroe (1938), Monroe (1941), MacNeil (1946a, b, 1947), Copeland

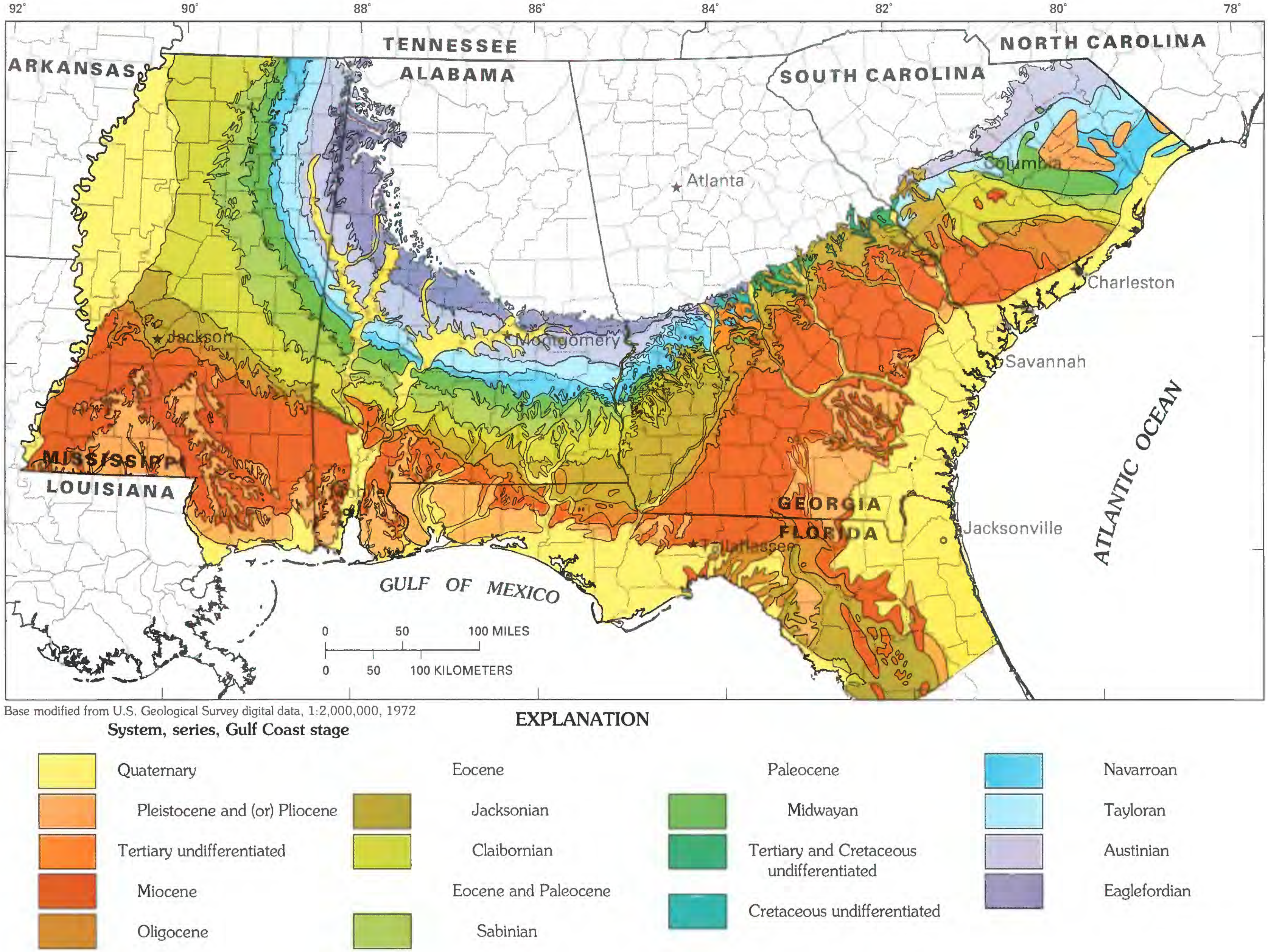


FIGURE 3.—Generalized geology of the Southeastern Coastal Plain of the United States (modified from Cooke, 1936; Belt and others, 1945; MacNeil, 1946a; Georgia Geologic Survey, 1976; King and Beikman, 1974; Colquhoun and others, 1983; Miller, 1986).

(1966, 1968), and Toulmin (1977) describe the major outcropping lithostratigraphic units of Alabama; the subsurface geologic conditions in most of southwestern and southeastern Alabama are presented in reports by Moore and Joiner (1969) and Moore (1971). Publications that provide statewide coverage of outcropping strata of Mississippi include reports by Lowe (1933), Stephenson and Monroe (1938, 1940), Thomas (1941), MacNeil (1946a, 1947), and Russell and others (1982); the subsurface stratigraphy is described in publications by McGlothlin (1944), Nunnally and Fowler (1954), Mellen (1958), Boswell (1963), Rainwater (1964, 1967), Boswell and others (1965), Hosman and others (1968), Cleaves (1980), and Devery (1982). Descriptions of the surface geology of panhandle Florida can be found in the works by Vernon and Puri (1956), whereas Applin and Applin (1965, 1967), Chen (1965), Babcock (1969), and Miller (1986) describe subsurface conditions in Florida.

Most of the reports cited examine the character of outcropping and subsurface beds within the confines of State or local boundaries. There are several additional reports that examine conditions on a regional scale which also deserve notation. Two of the earliest regional investigations include work by Stephenson (1914) and by Berry (1919), who both examined the lithostratigraphy of Cretaceous rocks that extend from Mississippi into Georgia. Many of their findings have been subsequently revised. However, their work does provide insight into the evolution of scientific thought as well as the development of a regional lithostratigraphic nomenclatural scheme. Gohn and others (1978a, b, 1979), Brown and others (1979), Valentine (1982, 1984), and Christopher (1982) describe the subsurface stratigraphy of coastal and some inland areas of Georgia and South Carolina and have correlated stratigraphic units across State boundaries. Reports by Applin and Applin (1944, 1947, 1965, 1967), Maher (1965, 1971), and Maher and Applin (1968) provide cross sections and maps that transect multistate areas of Mississippi, Alabama, Georgia, South Carolina, and Florida. Reports by Cushing and others (1964), Boswell and others (1965), Rainwater (1967), and Hosman and others (1968) describe the general subsurface geologic conditions in Mississippi and Alabama and correlate strata there with rock units found in adjacent States to the west.

Regional hydrogeologic studies are far less numerous; a report by Cederstrom and others (1979) encompasses an area of similar extent to this report, but it is not as comprehensive, particularly in terms of identifying the regionally extensive aquifers and confining units that are described here. Useful regional hydrogeologic studies on extensive areas of Georgia and South Carolina include reports by Stephenson and Veatch (1915), Callahan (1964), Brown and others (1979), and Pollard and Vorhis (1980). Reports by Boswell and others (1965), Hosman and others (1968), and Cushing and others (1964, 1970) provide the most comprehensive description, to date, of the hydrogeology of Alabama, Mississippi, and adjacent States to the west. A hydrogeologic description of the Floridan aquifer system, which overlies the Southeastern Coastal Plain aquifer system in part of the study area, is provided in reports by Stringfield (1966) and Miller (1986).

ACKNOWLEDGMENTS

Appreciation is expressed to those organizations and individuals who contributed data and provided helpful suggestions during the course of the study. Lithologic well cuttings and some cores were made available from the Georgia Geologic Survey, Geological Survey of Alabama, South Carolina Geological Survey, South Carolina Water Resources Commission, and North Carolina Geological Survey. P.M. Brown, retired from the North Carolina Geological Survey and formerly of the U.S. Geological Survey, provided the author with well location maps, geophysical and lithologic logs, and paleontologic data files.

METHOD OF INVESTIGATION

DEFINITION OF THE HYDROGEOLOGIC FRAMEWORK

A regional hydrogeologic system, or aquifer system, can be described as a body of strata having wide areal distribution and containing an extensive set of aquifers and confining units. The aquifers are hydraulically connected in varying degrees and in areal extent, and can be regionally treated as a single flow system. Poland and others (1972) define an aquifer system as "a heterogeneous body of intercalated permeable and poorly permeable material that functions regionally as a water-yielding hydraulic unit; it comprises two or more permeable beds separated at least locally by aquitards that impede ground-water movement but do not greatly affect the regional hydraulic continuity of the system." The hydrogeologic framework of an aquifer system is usually described by cross sections, structure contour maps, and isopach maps that are used to illustrate graphically the spatial arrangement, distribution, and physical attributes of the individual aquifers and confining units that contain the regional ground-water flow system.

This report is concerned with the hydraulic character of Coastal Plain strata and is, therefore, unlike sedimentary basin studies that generally emphasize primary rock characteristics within a specific rock-stratigraphic or time-stratigraphic interval. The limits of an aquifer may locally parallel those of a rock unit defined by lithology or by time or mode of deposition. However, a body of hydraulically interconnected, permeable strata in areal extent does not always coincide with such constraining time-stratigraphic boundaries. The physical character of rocks that are stratigraphically equivalent generally changes from place to place; such rocks may be an aquifer in one place and a confining unit in another place. Similarly, the correlation of outcropping rock-stratigraphic units with their subsurface counterparts is often difficult, as the recognition of formations is commonly based on local outcrop descriptions that may not be representative elsewhere, especially in the subsurface. Rocks that compose a regional aquifer or confining unit, as mapped herein, consist of a series of sand and clay beds that may form discrete aquifers and confining units in small areas. However, when viewed on a regional scale, these rocks, which may vary in permeability, are hydraulically interconnected and tend to behave as a single hydrologic unit. Strata that make up regional aquifers were combined according to (1) degree of hydraulic interconnection, (2) the continuity of potentiometric surfaces, and (3) areal distribution and extent.

To subdivide the hydrogeologic framework of the Southeastern Coastal Plain into a sequence of regional aquifers and confining units that are suitable for simulation with a digital ground-water flow model, the complex stratigraphic and hydrologic nature of these rocks must be generalized. Definitive geologic and hydrologic data are lacking for much of the Southeastern Coastal Plain, particularly where the different hydrogeologic units lie at great depths. The hydrogeologic framework described in this report was delineated on the basis of limited available data. Much additional information would have been required to provide a more detailed definition of the subregional aquifer units or to test the validity of a more detailed digital flow model. Identification of the lithologic and hydraulic character of regional units expedites their extrapolation into areas having limited data.

Establishing the time equivalency of different rock units is essential to subsurface correlation techniques. Early investigations into the stratigraphy of outcropping beds of the Southeastern Coastal Plain were oriented toward classifying sedimentary strata on the basis of lithologic and, to a lesser degree, biostratigraphic criteria. Many of the succeeding revisions to early nomenclatural schemes were the result of the recognition of supposed unconformities determined partly from refinement of the stratigraphic ranges of key index fossils and partly from delineation of erosional surfaces that occurred between and, in some cases, within lithostratigraphic units. Many of these unconformities were later disregarded in favor of a different interpretation.

The stratigraphic nomenclatural scheme currently applied to outcropping beds of the Southeastern Coastal Plain is further complicated because this scheme tends to separate and name formations within a highly varied sequence of nonmarine, marginal-marine, and shallow-marine sediments that were deposited in the area during Cretaceous and Tertiary time. Because depositional strike and structural strike do not necessarily correspond where equivalent Coastal Plain strata crop out, numerous facies changes may be encountered along outcrops in addition to the facies changes that are encountered as these same beds extend coastward into the subsurface. Many of the Cretaceous strata that crop out adjacent to the inner Coastal Plain margin consist dominantly of highly oxidized, coarse- to fine-grained, gravelly, feldspathic, quartzose sand that lacks diagnostic megafauna or microfauna. Rock-stratigraphic units were accordingly often extended beyond actual boundaries, and the resulting miscorrelation and misapplication of rock unit names has been perpetuated in the geologic literature. The grouping of strata of differing age, provenance, and depositional history merely because they have a similar lithology has complicated and further obscured stratigraphic relations that are often relatively simple. The attempted projection of these rock-stratigraphic units into the subsurface compounds this stratigraphic dilemma. Thickening and thinning of rock units are commonplace in the Southeastern Coastal Plain; episodic offlap, overlap, nondeposition, and erosion have resulted in numerous local unconformities, and the situation is further complicated by faulting and uplift in local areas, making the projection of lithologic units problematic.

The different stratigraphic names that have been applied to rocks penetrated by a well in Allendale County, S.C. (fig. 4), serve to illustrate the different interpretations that are possible when subtle lithologic differences are used to separate geologic units. The F. Whitaker well (local number AL-19, SC-ALL-01 of this report) was used for correlation on cross sections in three of the four reports cited in figure 4. For comparative purposes, the author has extended into the stratigraphy for this well the lithostratigraphic divisions identified by Bechtel Corporation (1982) in nearby wells.

Many of the rock-stratigraphic names applied to the Cretaceous and Tertiary units identified at this well do not apply to strata that crop out in eastern Georgia or western South Carolina. For example, the lithostratigraphic column presented by Colquhoun and others (1983) uses terminology extrapolated from outcropping units in eastern South Carolina, whereas most of the terminology used by Bechtel Corporation (1982) is taken from that used in western and central Georgia. The

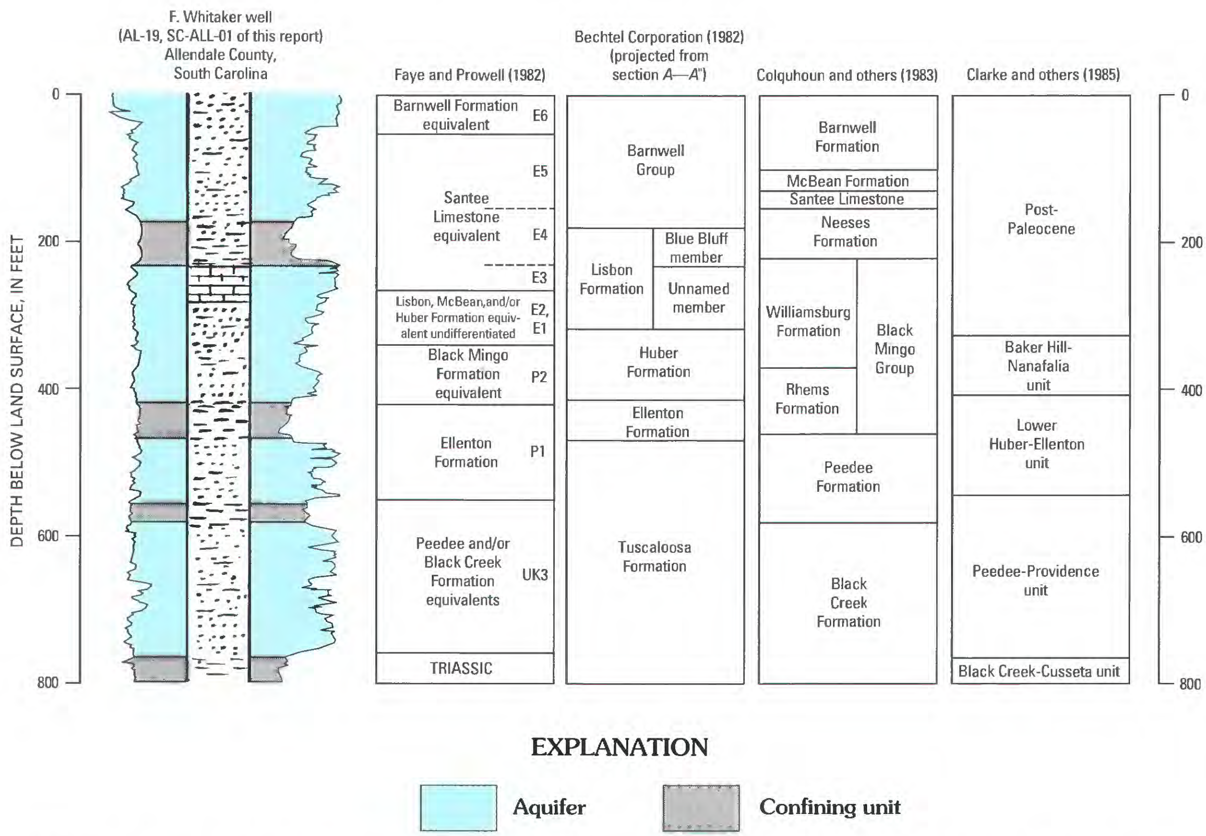


FIGURE 4.—Different stratigraphic nomenclatures applied to rocks penetrated by one well in Allendale County, S.C.

Ellenton Formation of Midwayan age is the only unit named for rocks found in the area near the Georgia–South Carolina State boundary.

The term Tuscaloosa Formation, as it is often applied to describe nonmarine beds in eastern Georgia and in South Carolina, is an excellent example of the misuse of terminology. The misapplication of this term still occurs in the literature. The Tuscaloosa terminology was extended from its type section in western Alabama by Stephenson (1914), who used the name to describe the dominantly nonmarine Cretaceous beds that crop out or lie in the shallow subsurface adjacent to the inner margin of the Coastal Plain from Mississippi to North Carolina. Later workers limited the extent of the Tuscaloosa Formation on the basis of paleontologic criteria and have shown that the bulk of these strata in eastern Georgia and South Carolina are post-Tuscaloosa in age. Continued usage of the term Tuscaloosa to describe these younger Cretaceous rocks is no longer recognized by the U.S. Geological Survey.

Faye and Prowell (1982) and Clarke and others (1985) apparently recognized the problem with extrapolating into Georgia the terminology established for lithologically different outcropping units found elsewhere. They used these names on an informal basis only. The "UK3" unit (Peedee and (or) Black Creek Formation equivalent) of Faye and Prowell (1982) and the correlative Peedee-Providence unit of Clarke and others (1985) consist largely of quartz sand, silt, and kaolinitic clay of Navarroan age that were deposited in a marginal-marine to nonmarine environment. The lithology of these beds contrasts greatly with that of the marine-shelf marl of the Peedee Formation where it crops out in eastern South Carolina. Given the lithologic disparities between this subsurface nonmarine unit and its outcropping equivalent on the marine shelf, it is appropriate that the name Peedee equivalent or Black Creek equivalent be used in Georgia.

The "Triassic" lithostratigraphic break shown by Faye and Prowell (1982) for the Allendale well (fig. 4) illustrates the problems associated with defining stratigraphic breaks on the basis of subtle lithologic criteria. Studying well cuttings in a nearby well (Creek Plantation well AL–66, SC–ALL–05 of this report), they noted that the basal clay beds were highly oxidized, having a distinctive dark red color and containing rock fragments of green schist, and were quite similar to the Triassic beds of the Dunbarton Basin. A more detailed petrographic and mineralogic analysis by Bechtel Corporation (1982) suggested that the color of these beds was probably not a good comparative index and that substantial textural and lithologic differences existed between the basal clay beds and the Dunbarton Triassic beds. Bechtel Corporation noted that Triassic rocks contain a substantial amount of plagioclase and minor amounts of potassium feldspar, the predominant clay minerals being illite, chlorite, and mixed-layer clays. In the basal red beds of well SC–ALL–05, kaolinite is the dominant clay type, and only minor amounts of potassium feldspar and no plagioclase occur there. Accordingly, these beds have greater affinity to overlying nonmarine Cretaceous strata than to the Triassic rocks of the Dunbarton Basin.

The lack of diagnostic fauna and (or) flora helps explain some of the differences between the authors' assignment of the position of the Cretaceous-Tertiary boundary, as well as boundaries of other stratigraphic units. The juxtaposition of sparsely fossiliferous, nonmarine strata of differing ages has made separation of these beds extremely difficult. In the deeper Georgia–South Carolina subsurface, however, these strata grade by facies change to fossiliferous marine beds and are more easily separated.

SOURCES OF DATA

The hydrogeologic framework presented in this report is based on detailed study of geophysical, lithologic, and paleontologic data from more than 1,000 oil, gas, and water wells. Selected deep-well data were examined from the entire Southeastern Coastal Plain between the Mississippi River and the Cape Fear River in North Carolina. Borehole geophysical log data were collected primarily from commercial geophysical log service companies. State and local governments and U.S. Geological Survey files were the primary sources of water well data. Well data presented in numerous reports also provided additional information; lithologic and paleontologic descriptions were far less common than the other types of data. Drill-cutting samples and cores were examined from selected water wells and oil test holes to obtain additional lithologic and paleontologic information.

Electric and natural gamma ray geophysical logs were the most common types of borehole geophysical data utilized in this study, due primarily to availability and ease of correlation. Well-cutting data were used in conjunction with sand percentage estimates made from geophysical logs to gain a qualitative estimate of lithologic continuity, hydraulic character, and depositional history. Electric logs were used in conjunction with a limited amount of lithologic descriptions to identify the coastward limit of permeability of two of the major clastic regional aquifers, the Pearl River and Chattahoochee River aquifers, that are described in this report.

Electric log data were also used to provide quantitative estimates of water quality and to determine the vertical and horizontal extent of water containing dissolved-solids concentrations of greater than 10,000 milligrams per liter (mg/L). Spontaneous-potential and resistivity curves were used to provide a quantitative measure of the chemical quality of water (Alger, 1966). Turcan (1966) and Brown (1971) summarized methods to calculate the concentration of dissolved solids using electric log data. Chemical analyses of water from several wells were used where available to supplement these calculations. The position of the line of water containing 10,000 mg/L of dissolved solids is shown on the different regional aquifer maps in this report, but is largely based on interpretative work summarized by Boswell (1963), Cushing (1966), Brown and others (1979), Epsman and others (1981), Gandl (1982), Sprinkle (1982), Lee and others (1986), and Strickland and Mahon (1986). Where the position of the 10,000-mg/L line was indefinite, additional calculations were made to estimate the location.

APPROACH AND DATA SYNTHESIS

During the course of the investigation, 12 hydrogeologic sections parallel to regional dip and 1 hydrogeologic section parallel to strike were constructed to illustrate the relation between time-stratigraphic units and regional aquifer and confining units (pls. 19–31, 33, 40). Plate 1 shows the lines of the sections, the wells used to construct them, and additional wells used in constructing maps of geologic and hydrogeologic units. On each section, wells are identified by State, county, and a sequential project number. Due to space limitations, abbreviations of State and county names were used (a list of these is given in table 1). Well headings for each section cite the operator or driller, the lease or well name, and the datum elevation. For example, a well presented on cross section *C–C′* (pl. 26), which was the third well from which data were obtained in Dorchester County, S.C., has been assigned the project identification number SC–DOR–03. The operator is cited as the U.S. Geological Survey and the well name is the St. George test hole. The datum altitude is given as 80 ft above sea level. Structure contour and isopach maps were constructed for eight chronostratigraphic Cretaceous and Tertiary units (pls. 1, 3–7, 9–18). The distributions of clastic and carbonate facies during each of the chronostratigraphic intervals chosen for mapping are shown in figures 8–16. Detailed cross sections (pls. 19–22, 24–31, 33, 40) were generalized (figs. 21–24, 26–34, 36) to further illustrate the relation between the regional aquifers and confining units and selected rock-stratigraphic terms that are currently in use. Structure contour and isopach maps were also constructed showing the distribution, configuration, thickness, and major rock unit constituting the upper surface of these regional aquifers and confining

TABLE 1.—*County and State abbreviations used in this report*

Abbreviation	County	Abbreviation	County
Alabama (ALA), 34 Counties			
AUT	Autauga	HEN	Henry
BAL	Baldwin	HOU	Houston
BAR	Barbour	LAM	Lamar
BIB	Bibb	LOW	Lowndes
BUL	Bullock	MAC	Macon
BUT	Butler	MAR	Marengo
CHO	Choctaw	MOB	Mobile
CLA	Clarke	MON	Monroe
COF	Coffee	MOT	Montgomery
CON	Conecuh	PER	Perry
COV	Covington	PIC	Pickens
CRE	Crenshaw	PIK	Pike
DAL	Dale	RUS	Russell
DLL	Dallas	SUM	Sumter
ESC	Escambia	TUS	Tuscaloosa
GEN	Geneva	WAS	Washington
GRE	Greene	WIL	Wilcox
Florida (FLA), 22 Counties			
CAL	Calhoun	LIB	Liberty
COL	Columbia	MAD	Madison
DUV	Duval	NA	Nassau
ESC	Escambia	OKA	Okaloosa
GAD	Gadsden	SR	Santa Rosa
GF	Gulf	STJ	St. Johns
HOL	Holmes	SUW	Suwannee
JX	Jackson	TAY	Taylor
JEF	Jefferson	WAK	Wakulla
LAF	Lafayette	WAL	Walton
LEO	Leon	WAS	Washington
Georgia (GA), 55 Counties			
APP	Appling	JOH	Johnson
ATK	Atkinson	LAU	Laurens
BIB	Bibb	LIB	Liberty
BRA	Brantley	LOW	Lowndes
BRO	Brooks	MAC	Macon
BUL	Bulloch	MIT	Mitchell
BUR	Burke	MON	Montgomery
CAL	Calhoun	PIE	Pierce
CAM	Camden	PUL	Pulaski
CHN	Charlton	QUI	Quitman
CHT	Chatham	RAN	Randolph
CHA	Chattahoochee	RIC	Richmond
CLA	Clay	SCR	Screven
CLI	Clinch	SEM	Seminole
COF	Coffee	STE	Stewart
COQ	Colquitt	SUM	Sumter
CRP	Crisp	TEL	Telfair
DEC	Decatur	THO	Thomas
DOD	Dodge	TOO	Toombs
DOO	Dooly	TRU	Treutlen
DOU	Dougherty	TWI	Twiggs
EAR	Early	WAS	Washington
ECH	Echols	WAY	Wayne
EMA	Emanuel	WHE	Wheeler
GLY	Glynn	WIX	Wilcox
HOU	Houston	WIL	Wilkinson
JDA	Jeff Davis	WOR	Worth
JEF	Jefferson		
Mississippi (MIS), 73 Counties			
ALC	Alcorn	LOW	Lowndes
ATA	Attala	MAD	Madison
BEN	Benton	MAR	Marion
BOL	Bolivar	MRS	Marshall
CAL	Calhoun	MNR	Monroe
CAR	Carroll	MON	Montgomery
CHI	Chickasaw	NES	Neshoba
CHO	Choctaw	NEW	Newton
CLA	Claiborne	NOX	Noxubee
CLR	Clarke	OKT	Oktibbeha
CLY	Clay	PAN	Panola
COA	Coahoma	PEA	Pearl River
COP	Copiah	PER	Perry
COV	Covington	PON	Pontotoc
DES	De Soto	PRE	Prentiss
FOR	Forrest	QUT	Quitman
FRA	Franklin	RAN	Rankin
GEO	George	SCO	Scott
GRE	Greene	SHA	Sharkey
GRN	Grenada	SIM	Simpson
HAN	Hancock	SMI	Smith
HND	Hinds	STO	Stone
HOL	Holmes	SUN	Sunflower
HUM	Humphreys	TAL	Tallahatchie
ITA	Itawamba	TAT	Tate
JAC	Jackson	TIP	Tippah
JAS	Jasper	TUN	Tunica
JON	Jones	UNI	Union
KEM	Kemper	WAL	Walthall
LAF	Lafayette	WAR	Warren
LAM	Lamar	WAS	Washington
LAU	Lauderdale	WAY	Wayne
LAW	Lawrence	WEB	Webster
LEA	Leake	WIN	Winston
LEE	Lee	YAL	Yalobusha
LEF	Leflore	YAZ	Yazoo
LIN	Lincoln		
North Carolina (NC), 8 Counties			
BLA	Bladen	HAN	New Hanover
BRU	Brunswick	PEN	Pender
COL	Columbus	ROB	Robeson
HOK	Hoke	SCO	Scotland
South Carolina (SC), 27 Counties			
AIK	Aiken	FLO	Florence
ALL	Allendale	GEO	Georgetown
BAM	Bamberg	HAM	Hampton
BAR	Barnwell	HOR	Horry
BEA	Beaufort	KER	Kershaw
BRK	Berkeley	LEE	Lee
CAL	Calhoun	LEX	Lexington
CHN	Charleston	MRN	Marion
CHE	Chesterfield	MLB	Marlboro
CLA	Clarendon	ORG	Orangeburg
COL	Colleton	RIC	Richland
DAR	Darlington	SUM	Sumter
DIL	Dillon	WIL	Williamsburg
DOR	Dorchester		

units and are presented on plates 23, 32, 34–39, and 41–42 and in figures 25, 35, and 37.

Clastic strata of Cretaceous and Tertiary age were evaluated in terms of their depositional origin, thereby providing additional insight as to the textural character of these rocks on a regional basis. Three basic facies types were considered: (1) offshore stable shelf (neritic); (2) marginal, transitional, and nearshore marine; and (3) fluviodeltaic. Shelf deposits were found largely to consist of glauconitic, quartzose marine sand, clay, shale, and marl that become increasingly calcareous as they extend and interfinger with a carbonate-evaporate facies associated with the Florida platform. The marginal-, transitional-, and nearshore-marine facies include beds deposited in such shallow marine and tidal-influenced environments as strand plains, barrier islands, tidal flats, estuaries, bays, and lagoons. Rocks deposited in such conditions commonly consist of medium-bedded to thinly laminated, lignitic, fossiliferous, glauconitic, and quartzose sand, silt, clay, and shale. The fluviodeltaic facies includes strata that consist of massively bedded, coarse-grained, nonmarine sand, gravel, and clay meander-belt deposits and sandy and carbonaceous, silty, clayey delta-plain deposits.

Provincial Gulf Coast Stages (Murray, 1961) were used, insofar as possible, as the benchmark for mapping time-synchronous geologic units and to aid in ascertaining the equivalency of regional hydrogeologic units (pl. 2). Paleontologic data served as an important means to document and justify correlation of the chronostratigraphic (stage) units. Reports by Applin and Applin (1944, 1965, 1967), Mellen (1958), Herrick (1961), Monroe (1964), Swain and Brown (1964), Pooser (1965), Hazel (1969), Maher (1971), Brown and others (1972), Hazel and others (1977), and Valentine (1982, 1984) were sources for some of these data. Additional unpublished paleontologic descriptions for test well data were obtained from the files of the U.S. Geological Survey. Unpublished reports made available to the author from the files of P.M. Brown, formerly of the North Carolina Geological Survey and U.S. Geological Survey, and from J.A. Miller of the U.S. Geological Survey.

The chronostratigraphic units mapped in this report largely coincide with Provincial Gulf Coast Stages that Murray (1961) defined. It was not possible to make a chronostratigraphic breakdown of the entire rock column in the study area. For example, basal Upper Cretaceous sediments in the Southeastern Coastal Plain consist of a thick sequence of nonfossiliferous to poorly fossiliferous sand, gravel, and clay deposited over a time span of approximately 20 million years. Given the complex nature and pattern of facies that this sparsely fossiliferous section represents, it is impractical to separate it into individual time-stratigraphic units. Lithostratigraphic criteria were accordingly used to differentiate major stratigraphic units in the lower part of the Upper Cretaceous beds.

Paleontologic data were available for only a few hundred of the more than one thousand boreholes studied. Therefore, correlation of stratigraphic units by means of electric logs served as the major tool to extend these units throughout the study area. Given the limited amount of paleontologic data, marker-type parastratigraphic units were considered extremely important in extending correlations regionally. For example, such marker units as the ash bed "kick" of Tayloran age, the Marine shale unit of the Tuscaloosa Group, the Arcola Limestone Member of the Mooreville Chalk, and the Bashi Formation have distinctive electric log patterns, are well documented in the literature, and serve as useful horizons in establishing stratigraphic equivalency.

The line marking aquifers containing 10,000 mg/L of dissolved solids lies within the transition zone between freshwater and seawater. All water containing less than 10,000 mg/L is considered part of the freshwater flow system. In the simulation of ground-water flow described in chapter C (Barker and Pernik, 1994), freshwater is assumed to occur landward of the line showing 10,000-mg/L concentrations, and this line of concentration is assumed to be a no-flow boundary.

Following the classification of saline waters, Kreiger and others (1957) proposed that a dissolved-solids concentration of 10,000 mg/L represents the separation between moderately saline and very saline water. Waters with dissolved-solids concentrations between 3,000 and 10,000 mg/L are suitable for some industrial purposes, whereas waters containing less than 3,000 mg/L of dissolved solids generally are useful for agricultural purposes; the upper limit for fresh drinking water is 1,000 mg/L of dissolved solids. Therefore, a salinity interface showing the location of ground water containing concentrations of 10,000 mg/L of dissolved solids can be used to identify the limit of normally usable ground water. For purposes of this report, ground water with dissolved-solids concentrations of less than 10,000 mg/L is considered part of the freshwater flow system.

GEOLOGY

REGIONAL SETTING

Coastal Plain deposits in the Southeastern United States form a thick wedge of unconsolidated to poorly consolidated, largely clastic strata that dip gently seaward from the Fall Line, except in Mississippi, where they dip southwest and west toward the Mississippi River. These deposits are the product of the cyclical advance and retreat of ancient seas over preexisting Paleozoic and Mesozoic rocks. The Coastal Plain strata were deposited under marine, marginal-marine, and nonmarine conditions during Jurassic to Holocene time. The fluctuating depositional conditions resulting from regional uplift, subsidence, and sea-level changes caused the lithology, texture, bedding character, and therefore the hydraulic properties of these deposits to vary considerably, thus affecting the occurrence and flow of ground water within the Coastal Plain strata. Coastal Plain deposits are underlain in places by metamorphic, crystalline, and sedimentary rocks of Paleozoic and early Mesozoic age that are, in part, an extension of the Piedmont province and in places by indurated sedimentary rocks of Paleozoic age that are a southwestern extension of the Appalachian Mountains. These rocks, taken together, are herein referred to as the base of the Coastal Plain.

Coastal Plain sedimentary rocks that compose the Southeastern Coastal Plain aquifer system exceed depths of 7,000 ft below sea level in downdip areas of Mississippi, Alabama, and northwestern Florida. In Georgia and northeastern Florida, the base of the Southeastern Coastal Plain is generally less than 4,000 ft below sea level, whereas in South Carolina, maximum depths are generally less than 3,000 ft (fig. 5).

GEOLOGIC STRUCTURE

Differential movement within the rocks that make up the Coastal Plain and its base has resulted in a number of major to minor structural features. The principal structural features of the Southeastern Coastal Plain are shown in figure 6.

Three major sedimentary deposition areas, or embayments, are present in the area: the Southeast Georgia embayment, Southwest Georgia embayment, and Mississippi embayment. The Mississippi embayment is part of an aulacogen, representing the northern failed arm of a Paleozoic triple junction spreading center (Burke and Dewey, 1973). Tensional subsidence associated with this former rift zone (Reelfoot rift) during the Mesozoic resulted in downwarping of the embayment (Ervin and McGinnis, 1975). This embayment forms a broad reentrant, its axis approximately parallel to the present course of the Mississippi River, filled with strata that range from Jurassic to Holocene age. In response to continued subsidence, the axis has shifted slightly westward to its present position. Subsidence also appears to have initiated in the south and shifted northward. For example, Lower Cretaceous rocks extend farther north than the underlying Jurassic strata. Recent seismicity in the northern parts of the embayment indicates that tectonic adjustments are continuing at the present time. Rock units that fill this embayment are typically nonmarine to marginal marine at their northernmost extent, grading to deeper marine deposits as they extend south into the deep subsurface. The Southwest Georgia embayment, alternately called the Appalachicola embayment, encompasses parts of southwestern Georgia and Florida and forms a shallow downwarp that was filled with sediments of Early Cretaceous age prior to deposition of Upper Cretaceous sediments. Its origin is probably related to the underlying graben of Triassic age. The Southeast Georgia embayment, also referred to as the Okefenokee embayment, forms a reentrant between northeastern Florida and southeastern South Carolina. This basement depression subsided mostly in Triassic to Jurassic time but continued to subside to a lesser degree into Tertiary time.

The Southeast and Southwest Georgia embayments are connected by a structurally low area that has been variously referred to as the Suwannee strait, Suwannee channel, and Suwannee saddle. The Suwannee strait has been attributed to different origins including structural, differential deposition, and a combination of structural and erosional origins.

Prominent, structurally high features include the Cape Fear arch, Peninsular arch, Ocala uplift, South Mississippi uplift, Wiggins anticline, Jackson dome, and the Monroe-Sharkey uplift. The Jackson dome and the Monroe-Sharkey uplift are both the direct result of Late Cretaceous igneous activity (fig. 6). The closure about the Jackson dome is several hundred feet at land surface and exceeds 4,000 ft in the deep subsurface, as is shown on the Comanchean structure contour map (pl. 3). The Wiggins anticline, in combination with the South Mississippi uplift, forms a poorly defined positive structure that may have originated as an updomed, ruptured continental margin. This structure forms a restrictive barrier and separates the Interior Mesozoic Basin from the coast. The thickening of sediments of Late Cretaceous age in a coastward direction is interrupted by this feature in southern Mississippi and southwestern Alabama. The Peninsular arch forms a positive structural element that extends from peninsular Florida in a north-northwesterly direction into southern Georgia. Cretaceous sediments show a marked thinning over this arch in southern Georgia, suggesting that it was a structurally high feature through much of Cretaceous time. The Cape Fear arch marks the eastern extent of the study area and forms a positive element whose axis extends in a southeasterly direction parallel to the Cape Fear River in North Carolina. Cretaceous and Tertiary sediments are either thin or absent across this arch, suggesting that it has been structurally high during much of Cretaceous and younger time.

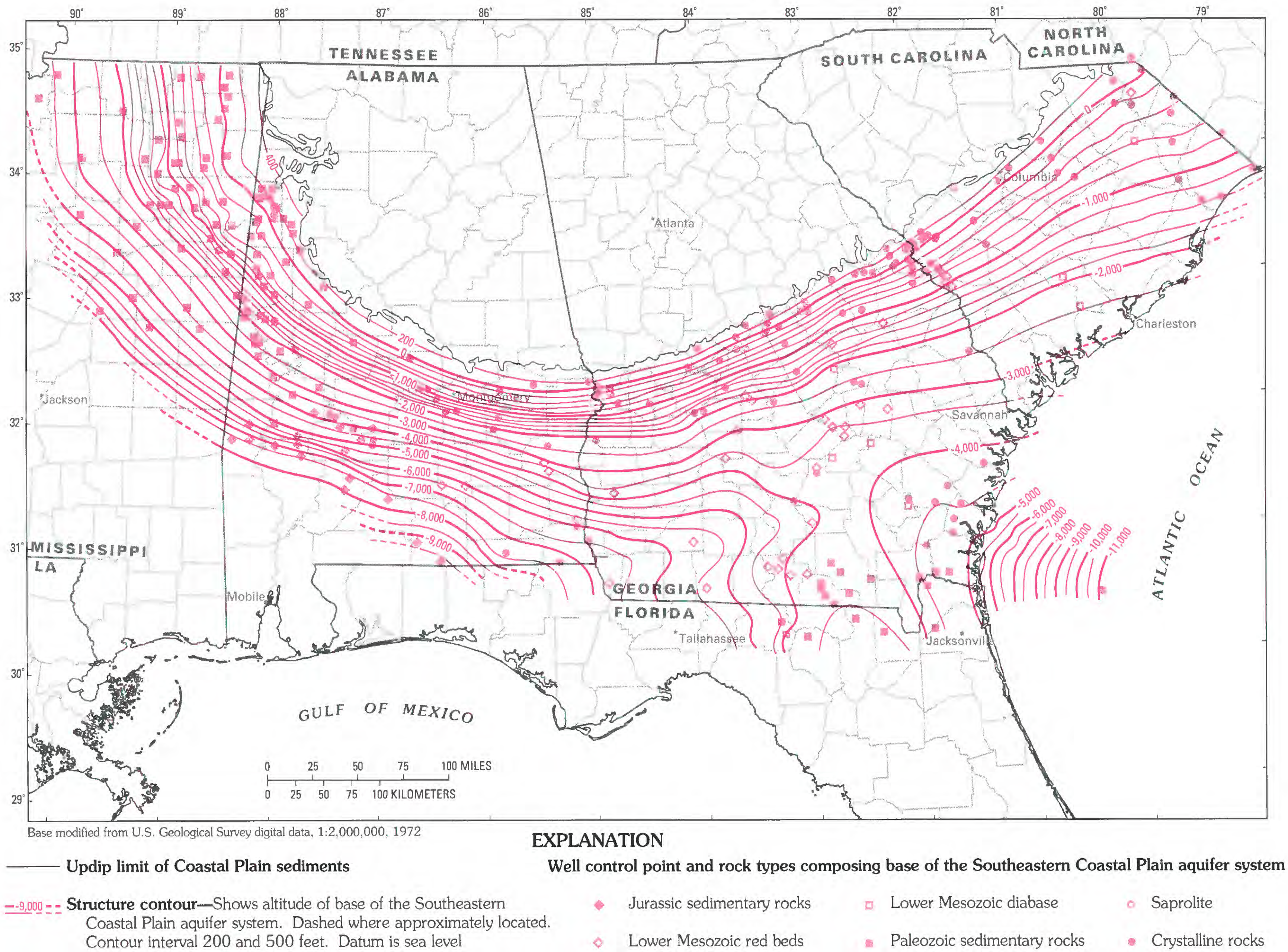
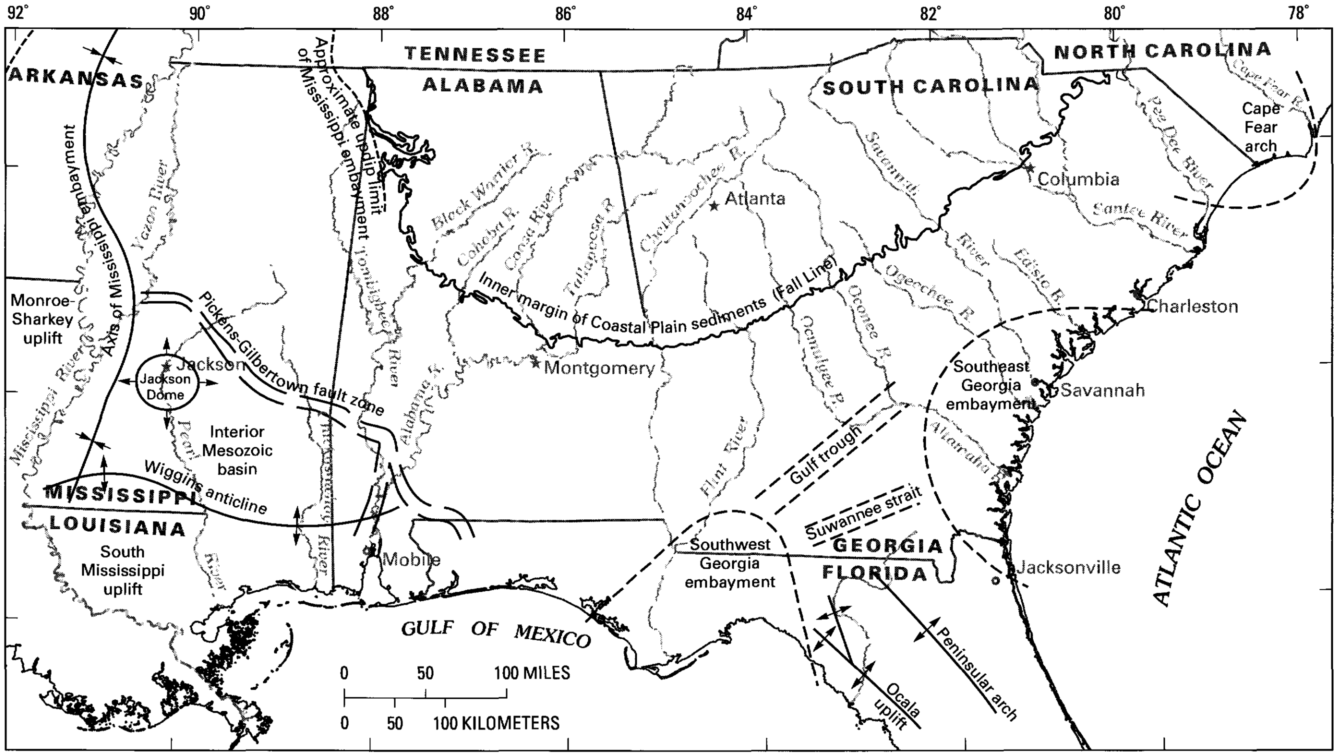


FIGURE 5.—Configuration and character of pre-Cretaceous rocks underlying the Southeastern Coastal Plain of the United States (from Wait and Davis, 1986).



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

FIGURE 6.—Principal structural features of the Southeastern Coastal Plain of the United States (modified from Vernon and Puri, 1956; Copeland, 1966; Applin and Applin, 1967; Williams, 1969; Cederstrom and others, 1979; Smith and others, 1981; Gelbaum and Howell, 1982).

Roper (1979) has summarized the evidence for post-Jurassic tectonic activity in the Gulf and Atlantic Coastal Plain; numerous workers have documented widespread evidence for faulting and uplift resulting from compressional and tensional tectonic stresses. However, the effect of faulting is not easily recognized beneath the thick cover of Coastal Plain sediments. Two fault systems found in the study area, the Gulf trough and the Pickens-Gilbertown fault zone, deserve mention. The Gulf trough is an elongate feature that has a marked effect on Tertiary and younger sediments and was apparently caused by faulting (Gelbaum, 1978). This feature extends northeastward across the south Georgia Coastal Plain and has been interpreted as being a reactivated crystalline basement graben (Klitgord and Popenoe, 1984). Until more borehole data are collected and a more detailed analysis can be made, it appears that faulting in this area is limited to rocks of Claibornian age or younger and is possibly due to structural flexing. The Pickens-Gilbertown fault zone forms a significant series of grabens that have displaced Alabama and Mississippi Coastal Plain sediments downward in varying degrees; it is part of the larger Balcones, Mexica-Talco, and Arkansas fault zones that rim the Gulf Basin; it is the likely result of Mesozoic tensional stress that had a pronounced effect on sediments of Jurassic and Early Cretaceous age, with lesser, but continued, movement more subtly affecting younger sediments.

Additional authors discussing structure in the study area include Dall and Harris (1892), Cooke (1943), Pressler (1947), Hull (1962), DeVries and others (1963), Cushing and others (1964), Chen (1965), Applin and Applin (1967), Smith and others (1981), Gelbaum and Howell (1982), Dillon and others (1983), Miller (1986), and Johnston and Bush (1988).

PRE-CRETACEOUS ROCKS

Wait and Davis (1986) mapped the configuration of pre-Cretaceous rocks in the study area using data compiled from a variety of published and unpublished sources (fig. 5). They identified five categories of rocks that were defined as collectively marking the base of the Southeastern Coastal Plain aquifer system: undifferentiated crystalline rocks; saprolite; red beds, diabase, and basalt of early Mesozoic age; sedimentary rocks of Paleozoic age; and sedimentary rocks of Jurassic age.

Crystalline rocks underlying the Southeastern Coastal Plain include low- to high-grade Paleozoic metasedimentary rocks (slate, quartzite, quartz-pebble conglomerate, schist, phyllite, and gneiss) and Paleozoic to early Mesozoic felsic and mafic metavolcanic and igneous rocks (quartz diorite, diorite, granite, rhyolite, diabase, basalt, tuff, and tuffaceous arkose) of intrusive and extrusive origin. These rocks represent an extension of the Piedmont physiographic province. The crystalline rocks underlie a large part of the Coastal Plain in Alabama, Georgia, and South Carolina and have very low permeability except where they are fractured or faulted.

Saprolitic rocks that underlie the Southeastern Coastal Plain include chemically weathered crystalline and sedimentary rocks that consist mostly of clay but maintain the original rock texture. Saprolite is recognized on electric logs by its distinctive low resistivity and positive spontaneous potential that contrast greatly with the high resistivity and negative spontaneous potential of underlying unweathered crystalline rocks (Wait and Davis, 1986). A saprolitic layer of weathered, decomposed, untransported crystalline rock was recovered from a test well (MRN–78) at Britton's Neck, Marion County, S.C. The samples were varicolored reddish-brown and brown, highly micaceous clay and silt containing minor amounts of quartz sand (Reid and others, 1986b). Some samples exhibited relict vertical foliation of the parent rock.

Paleozoic strata underlying the Southeast Coastal Plain consist of folded to flat-lying consolidated sedimentary rocks that extend southwestward from the Alabama Valley and Ridge, Appalachian Plateaus, and Interior Low Plateaus physiographic provinces as well as relatively flat lying strata that underlie the "Suwannee Basin" (Braunstein, 1955) of southwestern Georgia and northern Florida. Well-cemented quartz arenite and red, gray, and black shale of Early Ordovician to Middle Devonian age form much of the floor of the Suwannee Basin. Paleozoic rocks that underlie Cretaceous strata in northeastern Mississippi and west-central Alabama consist of highly weathered and fractured limestone, chert, and sandstone.

Jurassic strata, found in the deep subsurface, form the base of the Southeastern Coastal Plain aquifer system; the northernmost extent of these strata approximates a line that extends from the intersection of the Arkansas, Louisiana, and Mississippi State borders, southeast across the southwestern corner of Alabama, and into the northwestern Florida panhandle. Locally, Jurassic strata have been mapped as extending into the Southwest Georgia embayment (Brown and others, 1979; Chowns and Williams, 1983). The basal part of the Jurassic section in Alabama and Mississippi consists of evaporite, carbonate, and shale beds. The upper part of the section occurs in Mississippi, Alabama, Georgia, and Florida and consists of alluvial and eolian sands with nonmarine to shallow-marine, fine- to coarse-grained sandstone and shale.

ROCKS OF EARLY AND LATE CRETACEOUS AGE: COAHUILAN AND COMANCHEAN SERIES

Cretaceous rocks of the Southeastern Coastal Plain can be divided into three series: the Coahuilan Series of Early Cretaceous age, the Comanchean Series of Early and earliest Late Cretaceous age, and the Gulfian Series of Late Cretaceous age (Murray, 1961). Rocks of the Coahuilan Series do not crop out anywhere in the study area and are found only in the deep subsurface of southern Mississippi, southwestern Alabama, panhandle Florida, and, questionably, southwestern Georgia (Nunnally and Fowler, 1954; Maher and Applin, 1968; Brown and others, 1979). These rocks are mostly of fluvial origin and typically consist of very fine to coarse-grained, well- to poorly consolidated sandstone that is red, white, pink, or green and thickly interbedded with gray, brown, and red clay and siltstone (Murray, 1961).

Like the underlying Coahuilan strata, rocks of the Comanchean Series do not crop out in the Southeastern Coastal Plain; their northernmost extent lies a minimum of 25 mi south of the inner margin of the Coastal Plain (pl. 3). Comanchean beds extend landward past the limit of Coahuilan strata in an overlap relationship and overlie Paleozoic and crystalline rocks in a band north of the maximum extent of Coahuilan rocks. Plate 3 illustrates the influence of several tectonic features on Comanchean rocks. For example, the anticlinal "high" of the South Mississippi uplift–Wiggins anticline extends across panhandle Mississippi. Other uplifted areas include the Jackson dome near Jackson, Miss., the Hatchetigbee anticline of western Alabama, and the Peninsular arch of northern Florida and southeastern Georgia. Structurally low areas include the Southeast and Southwest Georgia embayments. The Pickens-Gilbertown fault zone extends across central Mississippi and into southwestern Alabama as a series of disconnected graben features that have been downdropped as much as 1,500 ft. Rocks of the Comanchean Series consist mostly of a nonmarine sequence of red and varicolored clay and shale, interbedded with poorly sorted, fine to coarse sand and gravel and minor amounts of noncalcareous to slightly calcareous clay. Rocks of Trinitian, Fredericksburgian, and Washitan age that constitute the Comanchean Series remain largely undifferentiated over most of the study area, due in large part to the lack of diagnostic microfauna or extensive marker beds. In southern Mississippi and peninsular Florida, however, equivalent rocks contain some strata that were deposited in a marine to brackish-water environment, allowing local separation of these groups.

It is not a simple task to differentiate Comanchean strata from rocks of the overlying Gulfian Series in much of the study area. Lithologic differences between rocks of the two series are often subtle, and no single, distinctive lithologic criterion can be used to identify either series throughout the Southeastern Coastal Plain. Upper Comanchean strata are nonmarine throughout practically the entire study area. Rocks of the basal part of the Gulfian Series are likewise commonly nonmarine. Accordingly, there is no paleontologic evidence, except very locally, that allows separation of the Comanchean and Gulfian Series. Local to subregional lithologic criteria that have been used to identify the top of Comanchean rocks include the highest appearance of red shale or multicolored sand (Applin and Applin, 1965, 1967), the highest occurrence of pink nodular limestone (McGlothlin, 1944; Nunnally and Fowler, 1954; Braunstein, 1959), and the change from marine to nonmarine sands (Applin and Applin, 1947). For the most part, however, the top of the Comanchean rocks has been extended upbasin by means of geophysical log correlation from downbasin areas, where sufficient lithologic and paleontologic evidence exists to allow the Comanchean and Gulfian Series to be differentiated.

There is little agreement about the extent of Comanchean rocks in the Southeastern Coastal Plain. Stephenson (1914) and Conant (1964) thought the lithology of nonmarine Cretaceous rocks that crop out in central and western Alabama resembled that of Lower Cretaceous beds elsewhere, but Stephenson (1926) later revised his interpretation. Drennen (1953) and Christopher (1972) thought these rocks were of Late Cretaceous age. Brown and others (1979) show Lower Cretaceous beds extending further into South Carolina than mapped in this report (pl. 3). They considered beds containing the ostracode *Fossocytheridea lenoirensis* Swain and Brown, and the updip, unfossiliferous equivalents of these beds to be of Early Cretaceous age. Later workers (Hazel and others, 1977; Valentine, 1982; Owens and Gohn, 1985) considered *F. lenoirensis* to range into beds of Late Cretaceous age. In this report, the thin sequence of strata mapped as Early Cretaceous by Brown and others (1979) is included in the rocks of Austinian to Woodbinian age (Late Cretaceous).

ROCKS OF LATE CRETACEOUS AGE: GULFIAN SERIES

The entire outcropping sequence of Cretaceous strata in Mississippi, Alabama, Georgia, and South Carolina consists of rocks of the Gulfian Series. Where rocks of the Gulfian Series crop out in Texas, they have been divided into five chronostratigraphic units. In ascending order, these are the Woodbinian, Eaglefordian, Austinian, Tayloran, and Navarroan Stages. The entire five-unit breakdown cannot be extended into the study area, however. It is possible to delineate the tops of only the Navarroan, Tayloran, and Austinian Stages with some degree of confidence within the Mississippi, Alabama, Georgia, and South Carolina area described in this report. Rocks of late Austinian and younger ages in the study area are predominantly marine (and accordingly contain sufficient fauna and flora to allow them to be dated), whereas rocks of Woodbinian, Eaglefordian, and early Austinian age are largely nonmarine and are therefore difficult to accurately date. Because the top of rocks of Austinian age is the oldest Gulfian chronostratigraphic horizon that can be mapped throughout the study area, the Gulfian Series is divided in this report into three chronostratigraphic units. From oldest to youngest, these strata are rocks of Woodbinian through Austinian age, rocks of Tayloran age, and rocks of Navarroan age. The lithostratigraphic units that make up each of these chronostratigraphic units are discussed below.

It is also possible to apply a subregional rock-stratigraphic breakdown to Gulfian strata in the Mississippi and Alabama Coastal Plain. Two rock-stratigraphic units of group rank, namely, the Tuscaloosa and Selma Groups, constitute the bulk of Gulfian rocks in these two States. These groups are separated by the McShan and Eutaw Formations (pl. 2). The Tuscaloosa Group and the McShan and Eutaw Formations are predominantly sand, interbedded with minor amounts of nonmarine to marine clay. The Selma Group in Mississippi consists mostly of chalk but includes minor sand and limestone. In eastern Alabama, these calcareous rocks grade into a thick sequence of marine sands containing a few clay beds. The rock-stratigraphic units that make up the Gulfian Series are discussed herein in two sequences: (1) pre-Selma beds and their equivalents (largely nonmarine rocks) and (2) Selma Group and equivalents (largely marine sediments). Because this rock-stratigraphic separation does not correspond exactly to a time-stratigraphic break, rocks that make up the Austinian part of the Selma Group (pl. 2) are referred to as "basal beds of the Selma Group and equivalent rocks."

Rocks of the Gulfian Series crop out as a continuous arcuate band that diminishes gradually in width as it extends southward and southeastward from Tennessee into Mississippi, Alabama, and western Georgia; equivalent beds also extend southwestward from North Carolina into central South Carolina (pl. 4). In eastern Georgia and westernmost South Carolina, Gulfian strata are largely covered by overlapping Tertiary rocks, except in localities where erosion has exposed the Cretaceous beds and they discontinuously crop out. In such places, Gulfian rocks are extremely weathered, poorly fossiliferous to nonfossiliferous, lithologically homogeneous, and quite similar in overall appearance to the overlying Tertiary clastic beds, making them difficult to differentiate. The thickness of Gulfian rocks (pl. 4) increases in a coastward direction from a featheredge along the inner Coastal Plain margin to more than 3,000 ft in southern Mississippi, southwestern Alabama, and western panhandle Florida and more than 2,000 ft in coastal Georgia and South Carolina. Gulfian beds are thickest in the Mississippi embayment area and in the vicinity of the Southeast Georgia embayment. Other structural features such as the Wiggins anticline, Cape Fear arch, and Suwannee strait result in the thinning of these beds. Along the Suwannee strait, Gulfian sediments thin to 1,500 ft or less in a narrow strip that extends from the Southwest Georgia embayment to the Southeast Georgia embayment. Gulfian rocks show no major increase in thickness in the Southwest Georgia embayment, indicating that this tectonic element remained relatively stable throughout Late Cretaceous time.

ROCKS OF WOODBINIAN THROUGH AUSTINIAN AGE

The upper surface of rocks of Austinian age (pl. 5) is the oldest chronostratigraphic horizon within the Gulfian Series that can be mapped throughout the study area. A number of structural features can be readily identified. The Jackson dome near Jackson, Miss., for example, has more than 2,000 ft of closure at this horizon, whereas the Hatchetigbee anticline of western Alabama has more than 500 ft of closure. The Wiggins anticline–South Mississippi uplift extends across southern Mississippi in a direction that nearly parallels the Pickens-Gilbertown fault zone that lies to the north. The series of downdropped grabens that forms this fault zone extends in a more southerly direction in southwestern Alabama and appears to form the eastern boundary of the Wiggins anticline. The uppermost Austinian beds have been downdropped as much as 1,500 ft within this fault zone. An east-trending fault known as the Andersonville fault extends across Schley, Sumter, and Dooly Counties, Ga., but is considered to be of minor consequence. The Livingston fault zone of western Alabama (Monroe and Hunt, 1958) is also shown, but data were not available to determine the amount of possible displacement. The Peninsular arch forms a structural high separating the structurally low Southeast and Southwest Georgia embayments. The westernmost and easternmost margins of the mapped area are bounded by the Mississippi embayment and the Cape Fear arch, respectively.

Rocks of Woodbinian age are not known to crop out anywhere in the Southeastern Coastal Plain but lie in deep subsurface areas of Mississippi, Alabama, Georgia, and panhandle Florida; they are not found anywhere in South Carolina. Rocks of Eaglefordian through Austinian age crop out or subcrop as a wide band that extends south from northern Mississippi and then eastward into central Georgia. Rocks of Eaglefordian age are not known to crop out east of western Georgia, whereas rocks of Austinian age crop out in North and South Carolina. In central Georgia, equivalent beds are overlapped but crop out discontinuously where erosion has removed the younger beds. Given their dominantly nonmarine, sparsely fossiliferous, and homogeneous nature, Woodbinian through Austinian strata remain largely undifferentiated from younger, but lithologically similar, Cretaceous and Tertiary beds.

The thickness of Woodbinian through Austinian beds is greatest (1,500 to 2,000 ft) in Mississippi, Alabama, and western Georgia (pl. 6). In eastern Georgia and South Carolina, some of the older Eaglefordian and Woodbinian strata are missing, and the section thins to 1,000 ft or less. The entire sequence also thins in southern Georgia and northern Florida where it crosses the Peninsular arch and in southwestern Alabama, southern Mississippi, and western Florida where it crosses over the Wiggins anticline–South Mississippi uplift. Excluding outcrop areas, the thinnest sections of Woodbinian through Austinian rocks are found where these beds extend over the Cape Fear arch and in the northern part of the Mississippi embayment, where Woodbinian beds are probably absent.

Chronostratigraphic breaks marking the top of Woodbinian or Eaglefordian strata coincide, in places, with lithostratigraphic breaks, but elsewhere lie within major lithostratigraphic units. These strata commonly consist of nonmarine clastic sedimentary rocks that are sparsely fossiliferous to nonfossiliferous, thereby prohibiting an accurate time-stratigraphic breakdown. Chronostratigraphic separation of the Woodbinian to Austinian sequence is far from being resolved at the time of this writing (1989). For example, the Marine shale of Mississippi, Alabama, Georgia, and Florida has been variously assigned to the Woodbinian (Cushman and Applin, 1946; Swain and Brown, 1964; Applin and Applin, 1967), Eaglefordian (Hazel, 1969), and part Eaglefordian–part Woodbinian age (Mancini and others, 1980). Early workers did recognize, however, that subsurface rocks of early Woodbinian through Austinian age found in the study area could be divided subregionally into a basal, marine to nonmarine sand sequence; a middle Marine shale largely of marine origin; and an upper, mostly nonmarine sequence.

Despite the associated chronostratigraphic difficulties, the Marine shale is one of the more persistent rock-stratigraphic units within the entire Woodbinian to Austinian sequence. Therefore, the Marine shale represents an important marker horizon that can be regionally traced (pl. 7).

Many of the structural features shown on plates 3 and 5 are also shown on plate 7, including the structurally high Jackson dome, Hatchetigbee anticline, Peninsular arch, and Cape Fear arch as well as the structural lows of the Mississippi embayment and Southeast and Southwest Georgia embayments. The Wiggins anticline–South Mississippi uplift and the Pickens-Gilbertown fault zone also substantially control the configuration of this horizon.

LITHOSTRATIGRAPHIC UNITS

Pre-Selma Beds and Equivalents

The Gulfian section can be separated into two broad lithologic categories: an upper unit consisting of the marine chalk, calcareous shale, and clay of mid-Austinian to Navarroan age that are assigned to the Selma Group; and a lower unit herein referred to as the pre-Selma and consisting of dominantly nonmarine to shallow marine beds of sand, gravel, and clay that range from middle Woodbinian to Austinian in age. The Tuscaloosa Group, McShan Formation, Eutaw Formation, and Atkinson Formation are included as part of these pre-Selma beds. In South Carolina and adjacent areas of North Carolina, the Middendorf and Cape Fear Formations crop out or lie in the shallow subsurface and are included herein as part of the pre-Selma strata. In the deeper subsurface of coastal South Carolina, unnamed beds of Eaglefordian age are also included with the pre-Selma beds.

Tuscaloosa Group or Formation

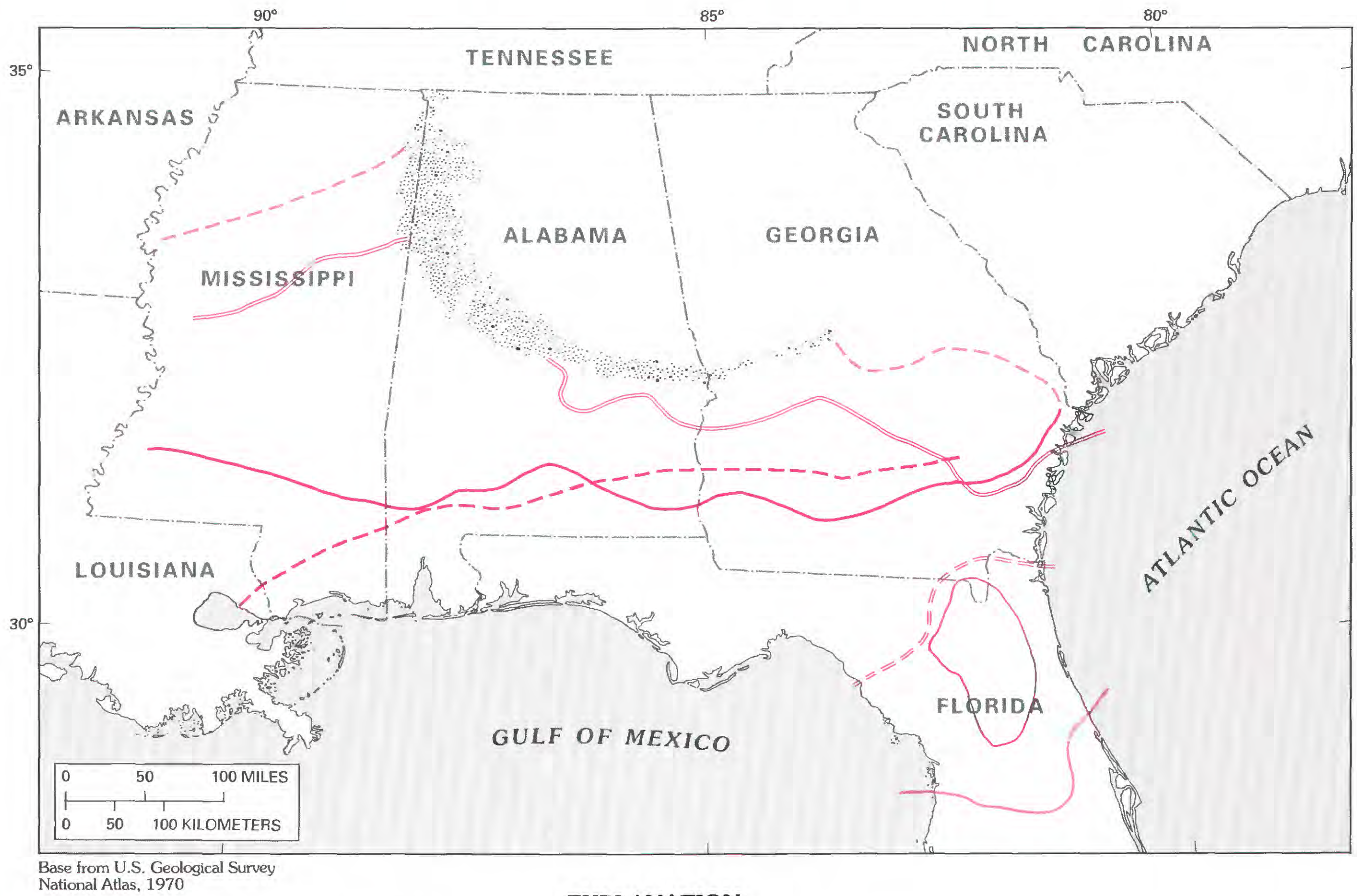
The rock-stratigraphic term Tuscaloosa has been correctly and incorrectly applied to rocks of similar lithologic character that crop out near the inner margin of the Coastal Plain in an area that extends from Tennessee to North Carolina (see discussion of Middendorf Formation). The name Tuscaloosa has also been used to describe beds that lie in the subsurface in an area that extends from Louisiana to North Carolina. As applied in this report, the term Tuscaloosa is used to describe the dominantly nonmarine outcropping sequence of variegated clay, sand, and gravelly sand of Cretaceous age that occurs between the underlying sedimentary and crystalline Paleozoic rocks and the overlying Eutaw Formation. In Mississippi and Alabama the Tuscaloosa is divided into formations and is of group rank; in Georgia it is considered a formation. The Tuscaloosa Group or Formation crops out (fig. 7) in an arcuate belt that extends from northeasternmost Mississippi to western Georgia, its widest band of outcrop occurring in Alabama. In the Mississippi subsurface, Tuscaloosa rocks dip to the west and southwest; in Alabama and Georgia, they dip south and southwest and extend to the coast. Tuscaloosa rocks are absent from northwestern Mississippi. The Tuscaloosa Formation merges with, or in part grades to, the predominantly marine Atkinson Formation in the subsurface of eastern Alabama and Georgia.

Berry's (1919) studies of the fossil flora of the Tuscaloosa were the first to illustrate the lithologic variability associated with this rock unit. This variability, both in the subsurface and in outcrop, helps explain why there have been so many different nomenclatural schemes devised to subdivide the Tuscaloosa sequence (pl. 8).

A number of textural and compositional differences are identifiable between strata of the Tuscaloosa Group of Mississippi and western Alabama and the equivalent rocks in eastern Alabama and western Georgia, the latter consisting of coarse, commonly gravelly, arkosic sand and lesser amounts of clay and silt. They contrast greatly with the gravel and cherty, in places glauconitic sand of the Tuscaloosa Group in Mississippi and western Alabama. Eargle (1955) noted several other differences: gravel in the Tuscaloosa of Georgia consists of metaquartzite and quartz derived from the Piedmont, whereas the cherty gravel beds of western Alabama and Mississippi were derived from chert nodules in Mississippian limestones. In the east, the Tuscaloosa Formation is more indurated and clays are more deeply mottled. Cementing materials are largely silica and argillaceous material in the east, compared with calcite and iron materials in the Tuscaloosa Group to the west.

The lithologic character of the subsurface Tuscaloosa beds in Mississippi and western Alabama is similar to that of their outcropping counterparts. Boswell (1963, 1978) successfully applied Drennen's (1953) nomenclature for outcropping units to shallow subsurface areas of Mississippi. Facies changes are much more apparent, however, as the units extend deeper into the subsurface. Here, the Tuscaloosa Group is characterized by marker horizons informally known as the Upper Tuscaloosa, Marine shale, and Lower Tuscaloosa (Braunstein, 1959).

The Lower Tuscaloosa of the subsurface, equivalent in part to the outcropping Coker Formation, is characterized by a basal Massive sand member (Vick Formation of Conant (1946, 1964)), a term that Moore (1962) did not consider applicable in southwestern Mississippi because the Massive sand member was not deposited there. In the shallow subsurface, the Lower Tuscaloosa consists of a basal 20-ft chert and quartz gravel bed, overlain by a medium to coarse sand and gravel unit of white to brown quartz and chert, lesser amounts of interbedded shale,



EXPLANATION

Area of outcrop, Tuscaloosa Group or Formation

Southern limit of coarse clastics within the Gordo Formation and the upper part of the Atkinson Formation

Southern limit of coarse clastics within the Coker Formation and the lower part of the Atkinson Formation

Northern limit of Marine shale

Southern limit of Marine shale

Northern extent of carbonate deposition

Northernmost extent of Tuscaloosa Group and Atkinson Formation

Exposed landmass

FIGURE 7.—Distribution of major lithofacies within the Tuscaloosa Group or Formation and the Atkinson Formation, Southeastern Coastal Plain.

and trace amounts of siderite and pyrite. The Lower Tuscaloosa grades to conglomeratic sand with scattered pebbles as the unit extends into the deeper subsurface. Koons and others (1974) found that shale beds form only a small part of this Massive sand member of the Lower Tuscaloosa, except in southernmost Mississippi and southwestern Alabama. Shaly beds of the overlying stringer section range from gray to red and are interbedded with medium to fine, glauconitic to quartzose sand that has been interpreted to represent marine to fluvial conditions (Karges, 1962; Berg and Cook, 1968; Mancini and Payton, 1981). Gray shale predominates in the deeper subsurface of Mississippi and southwestern Alabama, whereas red shale occurs mostly in the northern middip and updip areas. In extreme southwestern Mississippi, the entire Lower Tuscaloosa grades to a marine facies of fine to very fine, silty, glauconitic, micaceous, calcareous to noncalcareous, occasionally sideritic sand interbedded with thin, dark-gray or black, micaceous, carbonaceous shale. In Harrison County, Miss., these beds typically contain highly bioturbated shale, dark burrowed siltstone, and lenticular and flaser-bedded sand and shale units (Hearne and Lock, 1985).

The subsurface Marine shale, alternately referred to as the Marine Tuscaloosa or Middle Tuscaloosa and considered equivalent to the upper part of the outcropping Coker Formation, consists of dark-gray to greenish-gray to brownish-gray micaceous, flaky, splintery shale with streaks of calcareous, glauconitic sand. On electric logs, the distinctively low spontaneous potential and resistivity pattern of the Marine shale make it an important subsurface marker bed in Mississippi, Alabama, Georgia, and Florida.

The Upper Tuscaloosa unit of the subsurface, equivalent to the outcropping Gordo Formation, is characterized by beds of red shale, poorly sorted sand, and gravel that are all nonmarine and nonfossiliferous. Eargle (1948) found that the proportion of gravel to sand and clay in the Upper Tuscaloosa increases to the north, from the subsurface to outcrop, the lower part of the unit in updip areas consisting entirely of sandy chert gravel and overlain by varicolored, mottled clay with interbedded, fine to coarse, poorly sorted, micaceous, sideritic sand. The basal part of the Upper Tuscaloosa unit contains the Chicken-Feed Chert Zone (McGlothlin, 1944), a zone of gravel beds that grade to a conglomeratic sand, then to a sand with scattered pebbles in the deeper subsurface. This zone is of fairly limited extent; Applin and Applin (1947) could identify it no farther south and east than Sumter County in western Alabama. Taken as a whole, the Upper Tuscaloosa grades southwest, south, and southeast to progressively more marine beds consisting of fine- to medium-grained, white to gray, cherty to glauconitic sand; gray to green carbonaceous mudstone; and gray shale.

The Tuscaloosa Group or Formation can be best described on a regional basis as a complex fluviodeltaic-marine deposit. Channel-fill sandstones, meandering stream deposits, and flood-plain deposits have all been recognized as part of the fluvial environments that dominated the depositional conditions of the Tuscaloosa Group from outcrop into middip subsurface areas of Mississippi, Alabama, and Georgia. Lagoonal, interdeltaic, deltaic fringe, and shallow-marine deposits, although present locally in updip areas, are more common in the deeper subsurface. The subsurface Marine shale represents an inundative phase approximately in the middle of this sequence.

Atkinson Formation

The name Atkinson Formation was applied by Applin and Applin (1967) to describe the dominantly marine, pre-Selma sand, siltstone, and shale sequence that extends in the subsurface across southern Alabama, southern Georgia, and northern Florida (fig. 7). Stratigraphic equivalents of the Atkinson Formation can be mapped as far south as the Florida Keys.

The lower part of the Atkinson Formation includes the persistent, fossiliferous Marine shale that is part of the Tuscaloosa Group, which is underlain by siltstone, sandstone, and unconsolidated sand that are largely of marine origin; these beds, in turn, lie unconformably over Comanchean and, in updip localities, Paleozoic rocks. The lower part of the Atkinson can be further divided into four mappable, intergradational lithofacies representing depositional environments ranging from fluvial to shallow marine. This lower part commonly contains a distinctive arenaceous benthonic microfauna, the Barlow fauna (Applin, 1955), that is indicative of shallow brackish-water, lagoonal, or estuarine depositional environments.

The upper part of the Atkinson Formation is characterized by a shallow-water sandstone, siltstone, and shale sequence, interbedded with a few limestone beds. Similar to the lower part, four mappable, intergradational lithofacies can be identified. These facies are indicative of depositional environments that range from nonmarine to shallow-marine carbonate shelf. In the study area, only three of these facies are found. In landwardmost areas, a nonmarine, coarse-grained sandstone, shale, and mudstone facies occurs that is quite similar to the outcropping Tuscaloosa Formation. These strata merge coastward to a fine- to medium-grained marine sandstone containing scattered gray to greenish-gray shale lenses. A calcareous marine shale and very fine grained white sandstone and siltstone sequence occurs farther to the south.

McShan and Eutaw Formations

The McShan Formation consists largely of glauconitic sand and laminated clay that is quite similar in appearance to the Eutaw Formation. The McShan Formation has never been recognized as a distinct outcropping formation in eastern Alabama; however, Applin and Applin (1947) believed subsurface beds equivalent to the McShan Formation formed the uppermost part of the Atkinson Formation in eastern Alabama and western Georgia. The restricted Eutaw Formation, they concluded, did not extend east of central Alabama. The

Tombigbee Sand Member of the overlying Eutaw Formation is characterized in places by indurated calcareous sandstone ledges that are seen at its type section at Plymouth Bluff, Lowndes County, Miss., but more commonly consists of massively bedded, gray, very fine grained, glauconitic, micaceous, locally fossiliferous quartz sand. The Tombigbee Sand Member is underlain by the unnamed lower member of the Eutaw Formation. Boswell (1963) described two types of lithologies associated with this lower Eutaw unit in Mississippi: an upper, thin-bedded, gray carbonaceous clay containing fine glauconitic sand and a lower, highly crossbedded, fine to medium glauconitic sand that contains local thin beds of fine gravel. Clay and shale content gradually increase southward as the unit extends into the subsurface.

Separation of the Eutaw Formation from the McShan Formation in the subsurface of Mississippi and western Alabama is extremely difficult. Lithologic differences between the McShan and the Eutaw Formations are more subtle than apparent; their separation at outcrop is partly dependent on recognition of an unconformity that separates them. Monroe and others (1946) arbitrarily separated the two formations in Mississippi and western Alabama by identifying the location of a series of lenses of coarse sand containing a few pebbles, which occur approximately 150 ft below the base of the Mooreville Chalk. McGlothlin (1944) separated the Eutaw Formation into upper and lower units; he considered the lower unit (McShan Formation equivalent) to be transitional, having a lithologic character in updip counties of Mississippi that was quite similar to the "Upper Tuscaloosa." Braunstein (1959) decided that the Eutaw Formation and what he called the "Eagle Ford" unit (McShan equivalent) formed a single depositional sequence in the updip and middip areas of Mississippi. Basinward, he thought rocks equivalent to the Eutaw Formation graded from interbedded glauconitic, fine to medium calcareous sand and micaceous shale to chalky shale and argillaceous shale. It was only in these downdip areas that Braunstein could readily separate beds equivalent to the Eutaw Formation from his "Eagle Ford" unit (McShan Formation) that underlies them. Boswell (1963) mapped the McShan in the shallow Mississippi subsurface only as a provisional formational unit, and concluded that he could not satisfactorily differentiate it.

The Eutaw and McShan Formations were both deposited in a shallow marine environment with progressively deeper water deposits being represented by the Tombigbee Sand Member in the Eutaw Formation. As these same beds extend deeper into the subsurface, deeper marine environments are represented, particularly in subsurface areas of western and southern Mississippi. The widespread accumulation of oyster banks consisting of *Ostrea cretacea* Morton in the Tombigbee Sand Member of Alabama suggests that these uppermost beds were deposited in a brackish, shallow-water, nearshore environment (Sohl, 1964). Parts of the Eutaw and McShan Formations were possibly deposited in marine waters below the turbulent wave zone (Leopold and Pakiser, 1964). A varied marine environment of deposition for the Eutaw and McShan Formations has been substantiated by Bergenback (1964), Reinhardt and Gibson (1981), Frazier (1982), and Russell and others (1982), who have suggested a range of depositional conditions from quiet to well-agitated and including such subenvironments as shoreface, tidal channel, barrier-bar, and back-barrier (open bay) facies. Nonmarine (fluvial) environments are locally represented where the Eutaw and McShan Formations crop out in northwestern Mississippi and western Georgia (Eargle, 1955; Reinhardt and Gibson, 1981; Russell and others, 1982).

Unnamed Rocks

An unnamed clastic, shallow-marine sequence of interlayered sandstone, mudstone, and shale of probable Eaglefordian age (Valentine, 1982, 1984) has been identified in cores and cuttings collected from deepwater wells and oil test holes drilled in coastal areas of South Carolina and North Carolina. These beds are, in part, equivalent to strata previously assigned to "Unit F" of Brown and others (1972, 1979) and the "K2" unit of Gohn and others (1978b). These strata are characterized by interbedded noncalcareous silty clay; feldspathic to muddy conglomeratic sand; glauconitic, fossiliferous, limy quartzose sand; and calcareous, sandy, silty clay. Lithologic and paleontologic data suggest that they were probably deposited in a nearshore environment, possibly a brackish-water lagoonal area.

Cape Fear Formation

The Cape Fear Formation (Stephenson, 1907), as it is currently defined (Heron and others, 1968), is characterized by gray sandstone and interbedded mudstone weathered to a mottled red color. The most notable characteristic of the Cape Fear Formation is its thick to very thick cyclic stratification; a typical sequence consists of a basal, gravelly sand containing quartz megaclasts, clay clasts, and crossbedded sand, overlain by a mud bed having an erosional upper surface that is, in turn, overlain by another graded, muddy sand to sandy mud couplet.

The outcrop extent of the Cape Fear Formation is largely confined to river and creek valleys in North Carolina; its subsurface extent has been the subject of considerable debate, largely due to the lack of paleontologic data. Heron and others (1968) considered the Cape Fear Formation to be of Early Cretaceous age and correlated it with the Lower Cretaceous strata that Swain and Brown (1964, 1972) and Brown and others (1972, 1979) identified in the subsurface of North and South Carolina. Valentine (1982, 1984) and Christopher and others (1979) thought that such correlations were untenable; they maintained that subsurface beds of Early Cretaceous age were actually Cenomanian (Eaglefordian) in age, whereas their outcropping equivalent, the Cape Fear Formation, was even younger (Austinian).

Strata lithologically similar to the outcropping Cape Fear Formation have been identified in a number of test holes in the South Carolina Coastal Plain. Gohn and others (1977) identified the Cape Fear Formation in a test hole at Clubhouse Crossroads, S.C., and later revised the top of the formation upward (G.S. Gohn, oral commun., 1983) to include a rhythmic succession of thick-bedded, fining-upward sand and clay sequences. This author has also found this cyclic sequence of sand fining upward to clay in cores from wells drilled at Britton's Neck in Marion County and St. George in Dorchester County, S.C. (Reid and others, 1986a, b). Prowell and others (1985) reported that a similar sequence is also found in shallow subsurface areas of Georgia.

Heron and others (1968) considered the cyclical bedding of the Cape Fear Formation to be indicative of sheet-flood deposition on coastal alluvial plains and of density underflows in coastal environments such as estuaries and lagoons during periodic river flooding. The presence of a shallow-water foraminiferal fauna (Hazel and others, 1977) in the Cape Fear Formation indicates that the unit was deposited partly in a highly restricted fluvial to marginal-marine environment. After deposition, the sediments were exposed to the atmosphere and underwent oxidation and erosion.

Middendorf Formation

As the Middendorf Formation is currently defined, its outcrop extent is generally limited to the Sand Hills area of North and South Carolina (Colquhoun and others, 1983; Brown, 1985). The Middendorf Formation is often incorrectly called the Tuscaloosa Formation in South Carolina. The term Middendorf Formation is not extended geographically into Georgia. A number of workers have extended the term "Middendorf Formation" into the subsurface of South Carolina despite facies changes that distinguish it from its outcrop lithology (Gohn and others, 1977; Woollen and Colquhoun, 1977b; Colquhoun and others, 1983).

The Middendorf Formation is characterized by loose to poorly indurated, muddy to clean to pebbly, fine- to coarse-grained, ferruginous, feldspathic quartz sand and lenticular kaolinitic clay. Sand beds range from massive to thin and crossbedded, consist of point-bar and channel-fill deposits, and contain minor disconformities or diastems. Sandy beds commonly contain discontinuous mud lenses embedded in a relatively clean sand or masses of thinly laminated sand and mud. The Middendorf Formation is representative of a fluvial depositional environment as shown by current and festoon crossbeds and beds of clean and clayey to silty sand that are indicative of river channel and floodwater deposition; lenticular clays were probably deposited in oxbow lakes.

Additional authors who describe the Middendorf Formation include Sloan (1904, 1908), Cooke (1926, 1936), Smith (1929), Dorf (1952), Heron (1958), Snipes (1965), Scrudato and Bond (1972), Abbott and Zupan (1975), Tschudy and Patterson (1975), and Hutchenson (1978).

BASAL BEDS OF THE SELMA GROUP AND EQUIVALENT ROCKS

Plate 2 shows the poor correspondence between rock- and time-stratigraphic units of the Gulfian Series in the Southeastern Coastal Plain. In Mississippi and Alabama, for example, rocks that mark the upper surface of the Austinian Stage in Mississippi and Alabama include beds within the lower part of the Selma Group, specifically the lower part of the Mooreville Chalk, whereas in northern Mississippi they include the lowermost part of the Coffee Sand. In eastern Alabama and western Georgia, strata equivalent to the lower part of the Blufftown Formation form the upper surface of rocks of Austinian age. Farther to the east, in central and western Georgia and in western South Carolina, beds of latest Austinian age are not known to crop out or occur in the shallow subsurface, but are found in the middip and deep subsurface areas (Prowell and others, 1985) of these States.

The top of rocks of Austinian age generally does not coincide with a rock-stratigraphic change in the study area; rather, the top commonly falls within one of several formations (pl. 2). Accordingly, the lithologic units discussed in this section are all partly Austinian and partly Tayloran in age. Marker beds of varying extent within these formations, however, do coincide with the chronostratigraphic break between the Austinian and Tayloran stages. The structural surface of rocks of Austinian age shown on plate 5 represents a composite of a number of these marker beds.

The name Selma Group is used to describe the extensive chalk beds of the Alabama Coastal Plain. Stephenson (1917) first recognized the major facies changes that occurred within the Selma Group from its northernmost extent in Mississippi, south and east to its easternmost extent in eastern Alabama. He introduced the concept of intertonguing beds to help explain the observed variation in lithology along strike as the Selma Group graded to, or merged with, clastic beds. First described as a group by

McGlothlin (1944), the Selma was formally raised to group status by the Mississippi Geological Society (1945), which defined it as including all post-Eutaw strata of Cretaceous age regardless of the nonchalk lithology of some of the subordinate member units.

Additional authors who discuss the Selma Group include Winchell (1857), Smith and others (1894), Smith (1903), and Stephenson (1917).

Mooreville Chalk

The Mooreville Chalk is the basal formation of the Selma Group (pl. 2). The Mooreville Chalk crops out in a band that extends from northern Mississippi to western Alabama and consists of impure chalk, marl, or calcareous, fossiliferous clay and shale; it also locally contains fine glauconitic sand and relatively pure chalk beds. The limy, chalky clay or shale of the Mooreville grades to the Coffee Sand of the Selma Group in northern Mississippi and to sand and clay of the Blufftown Formation of the Selma Group in eastern Alabama and western Georgia.

In the Mississippi and Alabama subsurface, the Mooreville Chalk consists of dark- and light-gray calcareous shale, argillaceous chalk, and chalky shale. Equivalent beds found in the deep subsurface of southern Georgia consist of moderately hard, white to light-gray, chalky limestone and marl (Applin and Applin, 1967). In the lower part of the unit, lenses of speckled shaly chalk or marly shale occur, the speckles reflecting the presence of numerous fragments of globigerinid Foraminifera. In northern peninsular Florida, equivalent beds grade locally to a chalky shelf deposit of hard, white to light-gray, fine- to very fine grained calcitic sandstone.

The contact of the Mooreville Chalk with the underlying Eutaw Formation has been variously described as conformable or gradational (Berry, 1919; Eargle, 1948; Stearns, 1957; Boswell, 1963; Russell, 1967; Russell and others, 1982), unconformable (Stephenson and Monroe, 1938, 1940; Applin and Applin, 1944; McGlothlin, 1944; Monroe, 1946; Pryor, 1960; Scott, 1960; Sohl, 1960; Conant, 1967; Jones, 1967), disconformable (Monroe, 1941; Scott, 1957), or a combination of gradational in places and unconformable in other locations (Copeland, 1968). The distinctive lithologic change between upper chalk beds and underlying sandy strata is well reflected on electric log curves and can be readily used to map the base of the chalk section in the subsurface of Mississippi and Alabama.

The Mooreville Chalk can be divided into a thin, upper Arcola Limestone Member and an underlying "lower marly member" of chalk, clay, and shale. The Arcola Limestone Member is composed of one or more nearly pure limestone beds (90 percent calcium carbonate) consisting of calcispheres in a matrix of microcrystalline calcite and clay (Russell and others, 1982). Characterized as "bored rock" (Toumey, 1858) or "twin rocks" by local well drillers (Boswell, 1963), the Arcola Limestone Member contains numerous crustacean borings filled with calcareous clay.

The prominent limestone "kick" on electric logs exhibited by the Arcola Limestone Member is an important subsurface marker horizon often used as the Austinian-Tayloran chronostratigraphic break (Monroe, 1941; Braunstein, 1959; Boswell, 1963; Jones, 1967; Russell, 1967). Russell and others (1982) place the Arcola Limestone Member in the upper part of the *Calculites ovalis* Zone (late early Campanian age) or the *Globotruncana elevata* Zone (late early to middle Campanian age), which would more properly place the Austinian-Tayloran break below it, in the lower part of the Mooreville Chalk. Given the sparse paleontologic data for wells drilled in much of Mississippi and western Alabama, the nondescript nature of the underlying impure chalk, marl, calcareous clay, and shale, and the relatively thin section of rock that separates known Austinian beds (Tombigbee Sand Member of the Eutaw Formation) from the known Tayloran beds (Arcola Limestone Member), one may consider the Arcola "kick" to closely approximate the upper surface of Austinian rocks. The actual time-stratigraphic break is below it, however (pl. 2). Additional authors discussing the Mooreville Chalk include Stephenson (1914, 1917), Stephenson and Monroe (1938), and Monroe (1941, 1946).

Coffee Sand

The Coffee Sand of the Selma Group (Safford, 1869) crops out in northern Mississippi and extends northward into Tennessee. The Coffee Sand consists of well-sorted, fine- to medium-grained, glauconitic and micaceous quartz sand that is commonly interlaminated to thinly bedded with carbonaceous clay. In places, beds are finely crossbedded to massively bedded. Southward in outcrop areas, the transitional Tupelo Tongue Member, a massively bedded glauconitic sand, is recognized in the Coffee Sand; farther south, it grades into the impure clay and shaly chalk of the Mooreville Chalk. In the Mississippi subsurface, the Coffee Sand grades from a sandy, nearshore-marine facies to an argillaceous, deeper water chalk and marl facies. The Coffee Sand maintains a distinctive electric log pattern in most of the northern Mississippi subsurface, allowing it to be readily mapped (Boswell, 1963), and includes poorly sorted volcanic debris where it extends across the northern flank of the Monroe-Sharkey uplift (fig. 6) (Mellen, 1958). The uppermost part of the Coffee Sand has been shown to grade laterally in outcrop and in the subsurface to the Demopolis Chalk of Tayloran age (Stephenson and Monroe, 1938; Boswell, 1963).

The Coffee Sand is a complex depositional unit that includes terrestrial to marine environments. The presence of plant remains (Berry, 1919), clay galls and pebbles, local unconformities, kaolinitic clays, and thin lignitic beds (Pryor, 1960) in Tennessee are all suggestive of fluviodeltaic conditions. In Mississippi, the lower part of the outcropping Coffee Sand contains fossiliferous strata that are largely dominated by a molluscan fauna suggestive of a shallow-shelf, mixed sand-silt environment, the upper part containing fauna that more closely resembles that associated with the chalk facies. Nearshore sand, barrier-bar sand, and lagoonal clay are some of the strata deposited in subenvironments associated with the marine part of the Coffee Sand where it crops out in northern Mississippi (Russell and others, 1982).

Blufftown Formation

The Blufftown Formation of the Selma Group (Veatch, 1909) is most distinctly exposed in the Chattahoochee River Valley of eastern Alabama and western Georgia. It consists of a basal, crossbedded sand overlain by sandy carbonaceous, micaceous, and fossiliferous clay. The Blufftown Formation grades to the east into a nonfossiliferous coarse sand. East of the Flint River in Georgia it cannot be separated from the overlying Cusseta Sand and underlying Eutaw Formation on the basis of lithologic criteria. The origin of the Blufftown Formation has been described as either nearshore marine (Monroe, 1941), lagoonal (Eargle, 1955), delta front (Hester and Risatti, 1972), or transitional from a barrier-bar to an open, inner shelf environment (Reinhardt and Gibson, 1981).

DEPOSITIONAL SETTING DURING LATE AUSTINIAN TIME

Depositional conditions during late Austinian time are shown in figure 8. Shallow-shelf chalk and shale, equivalent to the Mooreville Chalk, were deposited over much of Mississippi, Alabama, southern Georgia, and panhandle Florida. At the northern end of the Mississippi embayment in Tennessee lie permeable fluvial deposits that grade to a less permeable, glauconitic, quartz sand sequence of deltaic and prodeltaic origin that lies immediately to the south. Volcanic debris found within beds of the Coffee Sand is the result of volcanic activity and uplift of the Monroe-Sharkey uplift in northwestern Mississippi (fig. 6). Farther southward in Mississippi, in most of Alabama, and in extreme southern Georgia and northern Florida, upper Austinian rocks consist of argillaceous chalk, chalky shale, and minor limestone beds, all of which were deposited in a marine, shallow- to mid-shelf environment. In eastern Alabama and southern Georgia, calcareous sand and sandy, carbonaceous clay of marginal- and nearshore-marine origin occur as a band eastward into South Carolina. In Georgia and South Carolina, sediments grade landward to a coarser grained, massive- to thinly bedded, ferruginous sand, gravelly sand, and sandy to kaolinitic clay sequence of fluvial origin.

ROCKS OF TAYLORAN AGE

Rocks of Tayloran age crop out or lie in the shallow to deep subsurface throughout most of the study area (pl. 9). Cropping out as a crescent-shaped band, Tayloran strata extend south from Tennessee into Mississippi and eastward into Alabama and western Georgia, where they are overlapped by younger beds of Cretaceous and Tertiary age. A second band of Tayloran rocks crops out, extending southwestward from North Carolina into South Carolina, where the Tayloran strata are covered by younger Tertiary beds. Tayloran rocks also crop out very locally in central Georgia but are not shown on plate 9, as they cannot be readily differentiated from older and younger beds. Structural features reflected on the upper surface of Tayloran rocks include the Southeast Georgia embayment, Southwest Georgia embayment, Mississippi embayment, Jackson dome, Wiggins anticline–South Mississippi uplift, Peninsular arch, Cape Fear arch, and Pickens-Gilbertown fault zone. The Andersonville fault in western Georgia (Zapp and Clark, 1965; Owen, 1963), an east-trending fault with the upthrown side occurring to the south, can also be seen on plate 9. Displacement on this fault is less than 100 ft, and it is considered to be only of local consequence.

Rocks of Tayloran age thicken as they extend southwestward from an outcropping featheredge into the deep subsurface of Mississippi and western Alabama. In southern Mississippi and southwesternmost Alabama, they thin across the Wiggins anticline–South Mississippi uplift (pl. 10) in a trend similar to that of the underlying Woodbinian and Austinian sequence. Tayloran rocks thicken greatly just downdip from their outcrop or shallow subcrop in Georgia and South Carolina, then subsequently thin coastward. Thick accumulations of Tayloran strata in the Southeast and Southwest Georgia embayments are separated by a thin area that probably forms the Suwannee strait.

DEMOPOLIS CHALK

The name Demopolis Chalk is used to describe relatively pure chalk beds that crop out and extend continuously from northern Mississippi into western Alabama. The Demopolis Chalk grades to, or merges with, the upper part of the Coffee Sand and lower part of the Ripley Formation in northern Mississippi, whereas the chalk grades to the Cusseta Sand in eastern Alabama. As currently defined, the Demopolis Chalk includes all chalk

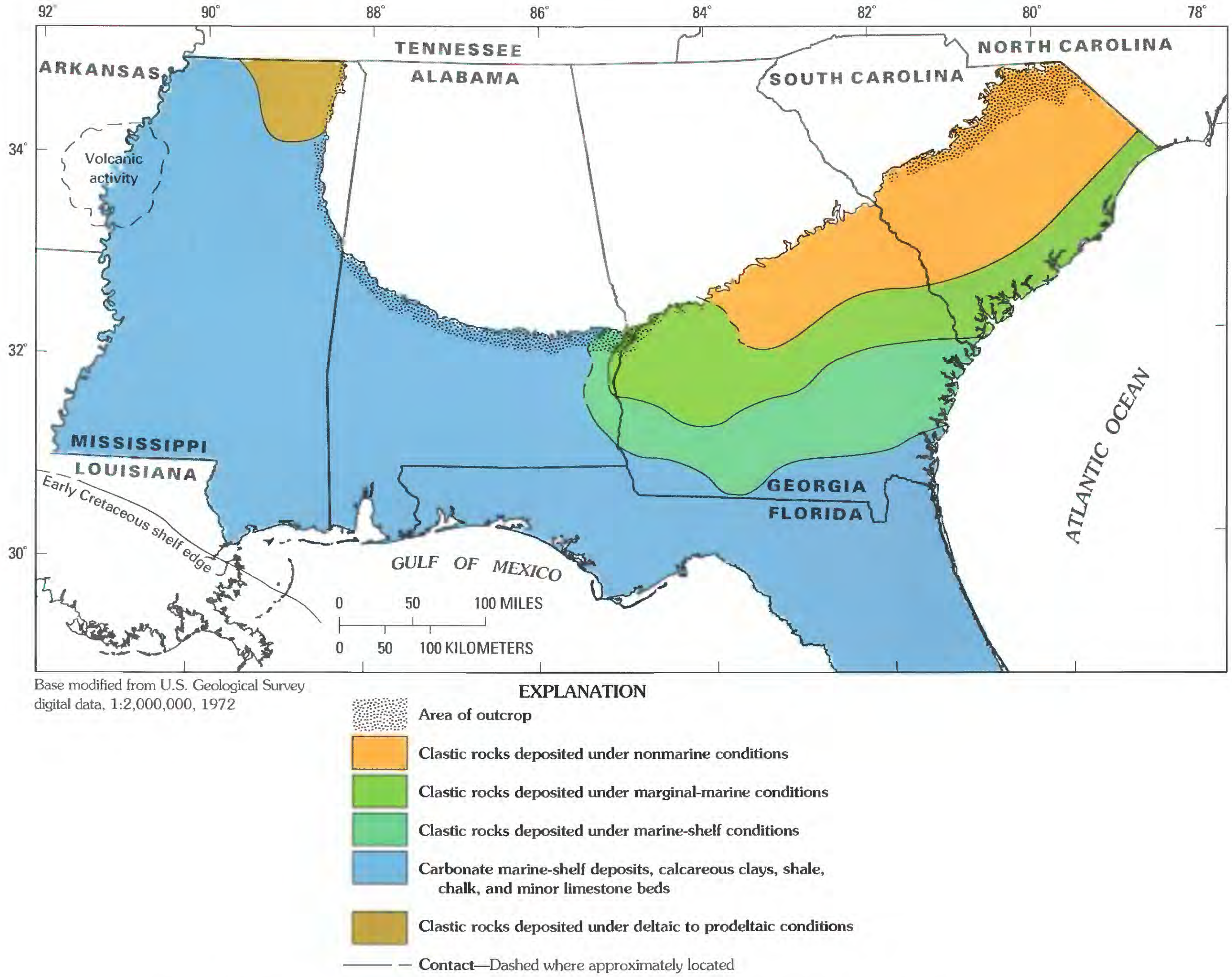


FIGURE 8.—Distribution of major lithofacies in the Southeastern Coastal Plain during late Austinian time.

and marl beds between the underlying Arcola Limestone Member of the Mooreville Chalk and the overlying Ripley Formation. The main body of the chalk grades upward to and includes the massive chalky marl, clayey chalk, and calcareous clay of the Bluffport Marl Member of early Navarroan age. In Alabama, the lower part of the Demopolis Chalk in the subsurface consists of thin beds of marly chalk, whereas the upper part of the unit consists of a relatively pure chalk facies. The Bluffport Marl Member in the upper part of the Demopolis forms a transitional facies between the pure Demopolis Chalk and the sandy chalk and sand of the underlying Ripley Formation. Pyroclastic and volcanic debris occur in subsurface Demopolis Chalk beds near the Sharkey platform (McGlothlin, 1944).

In Mississippi, several distinctive marker beds in the subsurface equivalents of the Demopolis Chalk and older Tayloran rocks serve as useful aids in correlation. For example, Stearns (1957) used a slight, but characteristic, electric log "kick" that he called the "x" point, located between the Ripley Formation and Eutaw Formation, to divide the Late Cretaceous Epoch into two units in northeastern Mississippi. The name "Coonewah bed" refers to two chalk beds that also produce distinctive log patterns and that lie parallel to, and approximately 20 ft above, the "x" point of Stearns. Mellen (1958) considered the Coonewah bed to be as important a reference marker as the Marine shale marker bed of the Tuscaloosa Group. A more subtle marker horizon is the Bluffport Marl Member, which Monroe (1956) considered to be a readily traceable horizon in outcrop areas, and Boswell (1963) mapped with some consistency in the east-central Mississippi subsurface. A fourth major marker bed in the Demopolis Chalk equivalent is a thin bentonitic clay bed that occurs in the southern Georgia and northern Florida subsurface. This bed exhibits a sharp deflection on electric logs and was used by Applin and Applin (1967) to mark the upper surface of rocks of Tayloran age. Additional authors discussing the Demopolis Chalk include Smith (1903), Stephenson and Monroe (1938), and Copeland (1968).

CUSSETA SAND

The name Cusseta Sand refers to the unconsolidated, fine to coarse, irregularly bedded, noncalcareous sand that underlies the Ripley Formation. The Cusseta is a formation in Georgia (Eargle, 1955), and its upper contact with the Ripley Formation is distinctive. This contact is not as easily identified in Alabama, where the Cusseta is considered a member of the Ripley Formation (Stephenson and Monroe, 1938).

The lithologic character of the Cusseta Sand changes along strike, where it crops out across eastern Alabama and western Georgia. In Alabama, the Cusseta consists of calcareous sand, sandstone, and sandy chalk that interfinger to the west with chalk of the Selma Group. In the Chattahoochee River Valley area, the Cusseta Sand consists of crossbedded, coarse to fine, highly glauconitic sand containing scattered pebbles, montmorillonitic clay, shell material, and lignite fragments. Eastward in central Georgia, the Cusseta is lithologically indistinguishable from underlying and overlying beds. The Cusseta was probably deposited in a nearshore- to marginal-marine environment. Stephenson (1914) noted the presence of fossil leaf fragments in the Cusseta and suggested that it had formed in a shallow-marine or estuarine environment and was, in part, of freshwater origin. Hester and Risatti (1972) suggested that the Cusseta in eastern Alabama formed in a barrier island–shoal sand complex constructed by currents that moved the sand westward from a major fluvial area in Georgia. Reinhardt and Gibson (1981) studied the thick Cusseta clays that were interlaminated with sand and carbonaceous material and showed evidence of bioturbation; they concluded that back-barrier, restricted lagoon environments were represented by these beds.

BLACK CREEK FORMATION

The Black Creek Formation (Sloan, 1908), as it is currently defined, is characterized as a dark-gray, laminated clay that is interbedded to interlaminated with micaceous quartz sand that ranges from fine to coarse. Minor constituents include lignite, glauconite, phosphate, pyrite, and shell fragments ranging from common to numerous. More thickly bedded sands are typical of the upper part of the formation in the subsurface of the South Carolina Coastal Plain.

The Black Creek Formation is usually interpreted to be representative of lower delta-plain deposits (Brett and Wheeler, 1961), nearshore, shallow-marine bay (Stephenson, 1923), estuarine and lagoonal (Swift and Heron, 1969), or tidally influenced environments that include barrier-bar, lagoon, bay or delta marine fringe (Woollen and Colquhoun, 1977a, b), or tidal-flat environments (Sohl and Christopher, 1983).

The Black Creek Formation crops out and extends southwest from North Carolina into South Carolina, where it is progressively overlain by younger beds. Many of the Black Creek exposures in South Carolina appear to contain considerably less sand than those in North Carolina.

DEPOSITIONAL SETTING DURING TAYLORAN TIME

The Tayloran sea inundated a large part of the study area; low-permeability shelf chalk, calcareous clay, shale, mudstone, and minor limestone beds were deposited over a large part of Mississippi, Alabama, southern Georgia, and northern Florida (fig. 9). A major site of fluviodeltaic deposition is centered in the eastern Georgia–western South Carolina area. Highly permeable, coarse-grained, nonmarine, feldspathic, and quartzose sand and kaolinitic clay beds, called the Middendorf Formation by Snipes (1965), form the bulk of these fluviodeltaic deposits in Burke, Jefferson, Richmond, and Washington Counties, Ga., and in Aiken, Allendale, Barnwell, Lexington, and Orangeburg Counties, S.C. These rocks grade coastward to a moderately permeable, marginal-marine sequence. Strata that are typical of this marginal-marine facies include interlaminated and interbedded sand, silt, calcareous clay, mud, and marl that are locally lignitic and shelly. This facies extends southwestward from North Carolina into South Carolina, Georgia, and eastern Alabama.

ROCKS OF NAVARROAN AGE

Rocks of Navarroan age represent the youngest Cretaceous strata that crop out or occur in subsurface areas of the Southeastern Coastal Plain. Navarroan strata crop out as a narrow band (pl. 11) that extends southward from Tennessee into Mississippi and eastward into Alabama and eastern Georgia. A wider band that extends from North Carolina into South Carolina either crops out or subcrops beneath a thin veneer of Pleistocene deposits. In central and eastern Georgia and in western South Carolina, Navarroan rocks are progressively overlapped by Tertiary strata and crop out only where they have been exposed by erosion of younger beds. Beds of Navarroan age dip coastward from a featheredge at outcrop into the deep subsurface; in Mississippi, however, they dip toward the axis of the Mississippi embay-

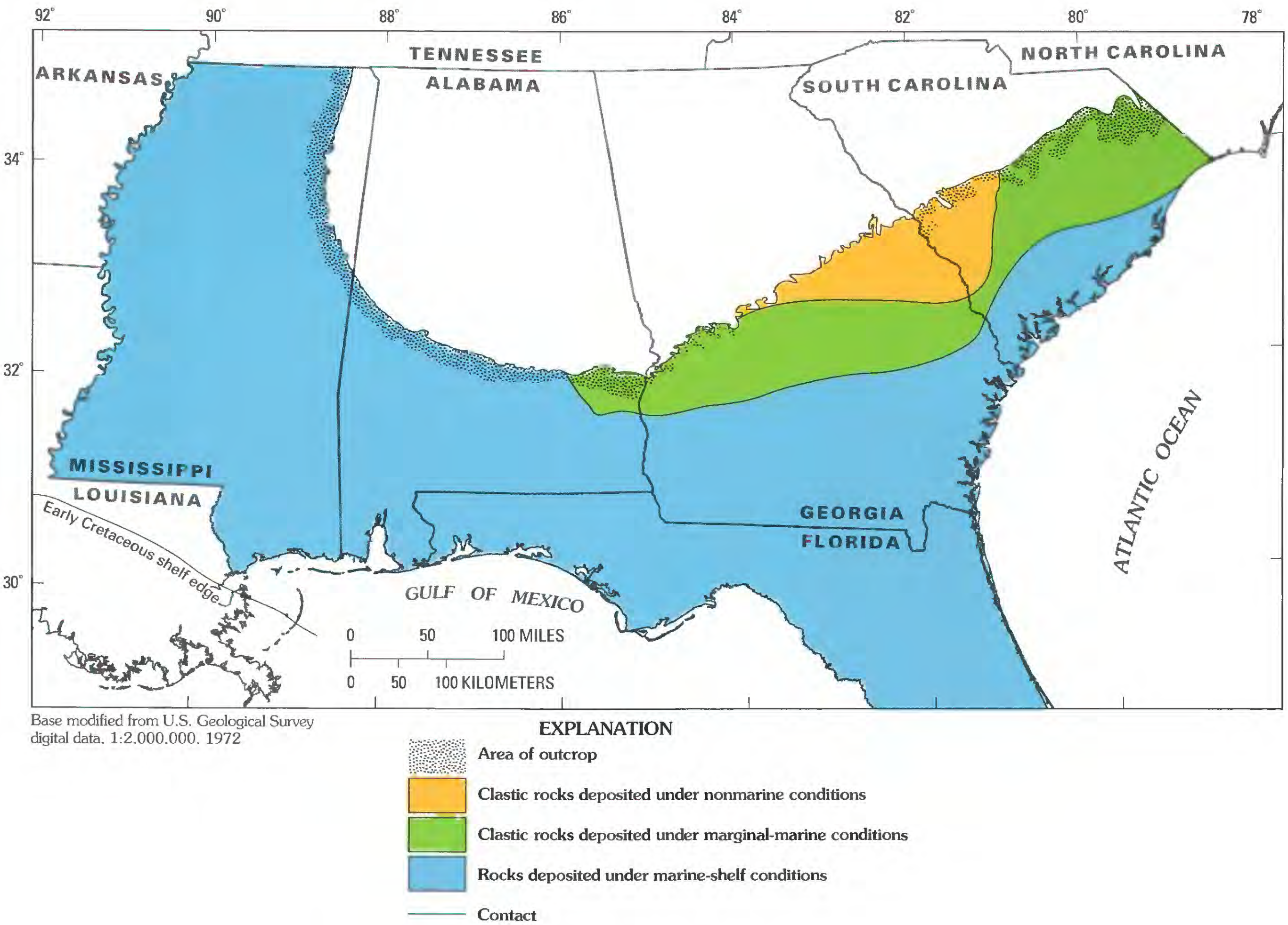


FIGURE 9.—Distribution of major lithofacies in the Southeastern Coastal Plain during Tayloran time.

ment. Equivalent strata are not present in southwestern Georgia and panhandle Florida, due to post-Cretaceous erosion.

Many of the structural features seen on deeper horizons are also well exhibited on the upper surface of the Navarroan rocks. These features include the Southeast Georgia embayment, Cape Fear arch, Mississippi embayment, Peninsular arch, Jackson dome, Hatchetigbee anticline, Wiggins anticline–South Mississippi uplift, Pickens-Gilbertown fault zone, and Andersonville fault. The Southwest Georgia embayment is not shown, as erosional processes have removed Navarroan or equivalent strata in much of southwestern Georgia and panhandle Florida.

Rocks of Navarroan age are thin throughout most of the study area (pl. 12), particularly in Mississippi and Alabama, where they consist of predominantly chalky shelf deposits and range from about 100 to 200 ft in thickness. In northernmost Mississippi, however, these strata thicken due to an influx of terrigenous clastic material from the northern part of the embayment. The thickness of the Navarroan section is greatest in the Southeast Georgia embayment and along the northeast margin of the Southwest Georgia embayment, where the deposition of the Lawson Limestone occurred. The influence of the Suwannee strait is evident in southern Georgia, where a relatively thin sequence of Navarroan beds occurs. In parts of southern Georgia and Alabama, and in most of panhandle Florida, Navarroan rocks are missing, possibly due to erosion during the worldwide lowering of the sea that occurred at the end of the Cretaceous. It is likely that the sea dropped below the shelf edge, allowing subsequent erosion of Navarroan strata.

RIPLEY FORMATION

The number of members (Coon Creek Tongue, McNairy Sand, Chiwapa Sandstone Members) assigned to the Ripley Formation in Mississippi is symbolic of the lithologic variability associated with this dominantly marine sequence. The Ripley Formation ranges from a glauconitic quartz sand and chalky sand to clay, marl, and minor limestone. Where it crops out in northernmost Mississippi, the Ripley consists of irregularly bedded, nonmarine, nonglauconitic, sparingly feldspathic quartz sand and carbonaceous clay that are part of the McNairy Sand Member. As the Ripley Formation extends southward from outcrop into the subsurface, it grades to glauconitic quartz sand. Farther southward, in western Alabama, the Ripley grades to progressively less sandy beds of fossiliferous, calcareous, micaceous, very fine to fine-grained sandy clay and chalk. Boswell (1963) mapped the Ripley Formation into the Mississippi subsurface, but he could not identify the various members of this formation beyond a limited shallow subsurface area in extreme northeastern Mississippi.

The Ripley Formation grades in eastern Alabama from a marine shelf chalk facies to a shallower marine sand and clay facies. The character of the Ripley Formation changes further at outcrop and in the shallow subsurface of eastern Georgia; there it consists of coarse sand containing carbonaceous clay lenses and is often difficult to distinguish from underlying beds of the Cusseta Sand.

In northern Mississippi, the Ripley Formation was deposited largely in a transitional-marine environment between fluvial and deltaic sediments of the McNairy Sand Member found to the north and a shallow-shelf chalk facies found in central Mississippi and western and central Alabama. In eastern Alabama and western Georgia, the Ripley Formation also represents a similar inner shelf environment grading landward to a tidal-flat environment (Reinhardt, 1982). Additional authors describing the Ripley Formation include Hilgard (1860), Smith and Johnson (1887), Harris (1896), Veatch and Stephenson (1911), Stephenson (1914), Stephenson and Monroe (1937, 1938), Eargle (1955), and Sohl (1960).

PRAIRIE BLUFF CHALK AND OWL CREEK FORMATION

The Prairie Bluff Chalk (Winchell, 1857) is the uppermost formational unit of chalk within the Selma Group. It crops out as a narrow band of strata and extends south and then east from northern Mississippi into eastern Alabama. In Mississippi outcrop areas, the Prairie Bluff Chalk consists of a dense, poorly fossiliferous upper chalk and a highly fossiliferous, glauconitic lower chalk (Russell and others, 1982). The lithology of the Prairie Bluff Chalk changes in northern Mississippi, where it merges with the nonchalky, silty, and clayey glauconitic sand and sandy clay of the Owl Creek Formation. For the most part, however, Boswell (1963) was unable to separate the Owl Creek Formation from the Prairie Bluff Chalk in the northern Mississippi subsurface. In Alabama, the Prairie Bluff Chalk consists of an indurated, micaceous and glauconitic, fossiliferous, fine- to medium-grained, quartzose sandy chalk and marl (Smith, 1907) that grades to and merges with the Providence Sand of eastern Alabama.

The Prairie Bluff Chalk probably originated as an open-shelf mud, while the Owl Creek Formation represents deposition in an environment that was closer inland, but decidedly marine. Pryor (1960) suggested an inner neritic environment for the Owl Creek Formation based on the larger planktonic Foraminifera population he found in the unit compared with the Ostracoda and benthonic Foraminifera population. However, as Russell and others (1982) observed, the Owl Creek Formation grades to a nearshore sand environment as it extends into Tennessee. Additional authors describing the Prairie Bluff Chalk and Owl Creek Formation include Hilgard (1860), Veatch (1909), and Stephenson (1917).

PROVIDENCE SAND

The Providence Sand (Veatch, 1909) is noted for its lithologic variability where it crops out or lies in the shallow subsurface of Alabama and Georgia. The upper unnamed member consists of a coarse arkosic sand with minor varicolored, kaolinitic clay lenses. It grades downdip into a more marine sequence of fossiliferous fine to coarse sand containing clay lenses. The Providence Sand grades westward to sandy chalk and marl of the Prairie Bluff Chalk. The Providence is indistinguishable from underlying nonmarine Cretaceous rocks east of the Ocmulgee River in western Georgia. Coastward, the Providence Sand becomes a fine sand, silty clay, and sandy mud sequence as it extends into the shallow subsurface of western Georgia and eastern Alabama. Chalk and marl dominate its lithology in the deeper subsurface.

The Providence Sand was deposited under a variety of environmental conditions that include shallow as well as deeper water (Cooke, 1943). The presence of steep and long foreset beds associated with the unit in outcrop led Eargle (1955) to believe that the Providence formed in a deltaic environment. Reinhardt and Gibson (1981) believed that the unit was deposited, in part, in marine-shelf as well as barrier-bar depositional conditions. Donovan (1985) also supported a shallow-marine origin but considered the bulk of the Providence Sand equivalents found in the shallow subsurface to represent marine deposition; most of the sediments seen at outcrop were thought to represent tidal delta and tidal inlet deposition. Additional authors describing the Providence Sand include Veatch and Stephenson (1911), Stephenson and Monroe (1938), and Eargle (1950).

PEEDEE FORMATION

The name Peedee was introduced by Ruffin (1843) to describe the youngest Cretaceous strata that crop out in South Carolina along the Pee Dee River. The Peedee Formation is a dark-green or dark-gray, finely micaceous, glauconitic, argillaceous, fossiliferous, massive, interstratified marine clay, muddy sand, and sandy marl. It is typically interbedded with ledges of hard marlstone or impure limestone where the unit crops out in North Carolina and South Carolina. The Peedee maintains a similar lithologic character as it extends coastward into the subsurface; in Dorchester County, S.C., for example, it consists of light-olive-gray, light-gray, and dark-gray sandy clay, clay, and fine sand interbeds that locally are shelly, glauconitic, and phosphatic. Clay is the dominant component of the Peedee Formation and ranges from massive (occasionally bioturbated) to thick beds containing occasional thin sand and silt laminae.

The open-marine, shelf depositional environment of the Peedee Formation (Stephenson, 1923; Brett and Wheeler, 1961; Swift and Heron, 1969; Sohl and Christopher, 1983) changes as the formation extends westward and is overlapped by Tertiary rocks. In the western South Carolina Coastal Plain, equivalent beds consist of marginal-marine to nonmarine, poorly consolidated, clayey sand, fine to very coarse, subangular to subrounded quartz sand, minor gravel, and kaolinitic clay. Additional authors discussing the Peedee Formation include Sloan (1908) and Stephenson (1912).

LAWSON LIMESTONE

The Lawson Limestone consists of an algal-rudistid dolomitic limestone that is locally gypsiferous (Applin and Applin, 1944, 1967). It is divided into upper and lower members: the lower member consists mostly of white chalk interbedded with chalky dolomite; the upper member is characterized by the algal-rudistid biostrome. The Lawson Limestone is thickest within the Southeast and Southwest Georgia embayments, where it is reported to be 700 to 900 ft thick. Only within the Southeast Georgia embayment is the Lawson Limestone permeable enough to be water bearing and thus part of the Floridan aquifer system (Miller, 1986).

DEPOSITIONAL SETTING DURING NAVARROAN TIME

Low-permeability shelf deposits of chalk, calcareous clay, marl, and shale were deposited over much of Mississippi, Alabama, Georgia, and South Carolina in Navarroan time (fig. 10). A carbonate sequence with minor evaporites was deposited in peninsular Florida during that time and includes algal-rudistid dolomitic limestone and dolomite laid down in a semirestricted, shallow-water environment.

Two sites of fluvial deposition were present in the study area during Navarroan time. A moderately permeable, glauconitic quartz sand and clay sequence found in northern Mississippi possibly represents the prodelta facies of a prograding river system that emanated from the north in Tennessee. These strata were covered during the latter part of Navarroan time as the sea transgressed and deposited chalk and clay. A second site of fluvial deposition is found in central to eastern Georgia and the western South Carolina Coastal Plain. Nearshore and marginal-marine deposits of glauconitic quartz sand, calcareous and lignitic clay, silt, and marl are found coastward and rim the feldspathic, quartzose sand and gravel sequence of fluvial origin. Still farther southward, chalk, clay, and minor limestone beds were deposited in a shallow-marine shelf.

ROCKS OF TERTIARY AGE

Tertiary Coastal Plain rocks of the Southeastern United States can be divided into five series: Paleocene, Eocene, Oligocene, Miocene, and Pliocene. Some of the clastic Oligocene and Miocene beds in southern Mississippi, southwestern Alabama, and westernmost Florida together form locally important clastic aquifers and associated confining units. However, the Tertiary rocks that are part of the Southeastern Coastal Plain aquifer system consist dominantly of Paleocene and Eocene rocks.

Paleocene and Eocene rocks of the Southeastern Coastal Plain can be divided into two major facies types: (1) a carbonate-evaporate platform facies that is primarily found in peninsular Florida but also extends into parts of South Carolina, southern Georgia, Alabama, and southwesternmost Mississippi and (2) a siliciclastic marine to nonmarine facies that extends from South Carolina into Mississippi. These Tertiary clastic beds extend well beyond the study area; they can be mapped as far west as Texas and as far north as southern Illinois. However, they are conspicuously absent in the northeastern part of the South Carolina Coastal Plain as they pinch out against the Cape Fear arch. Tertiary strata crop out as a series of adjacent bands and generally lie to the south of Cretaceous strata in an offlapping relation; in Georgia they overlap Cretaceous beds.

LOWER PALEOCENE SERIES: ROCKS OF MIDWAYAN AGE

The term Midway was originally used by Smith and Johnson (1887) to describe limestone and calcareous marl beds of the modern-day Clayton Formation. In later studies, Smith and Johnson also included the overlying "Sucarnochee Clay" (now called the Porters Creek Formation) and Naheola Formation as part of this unit. Until

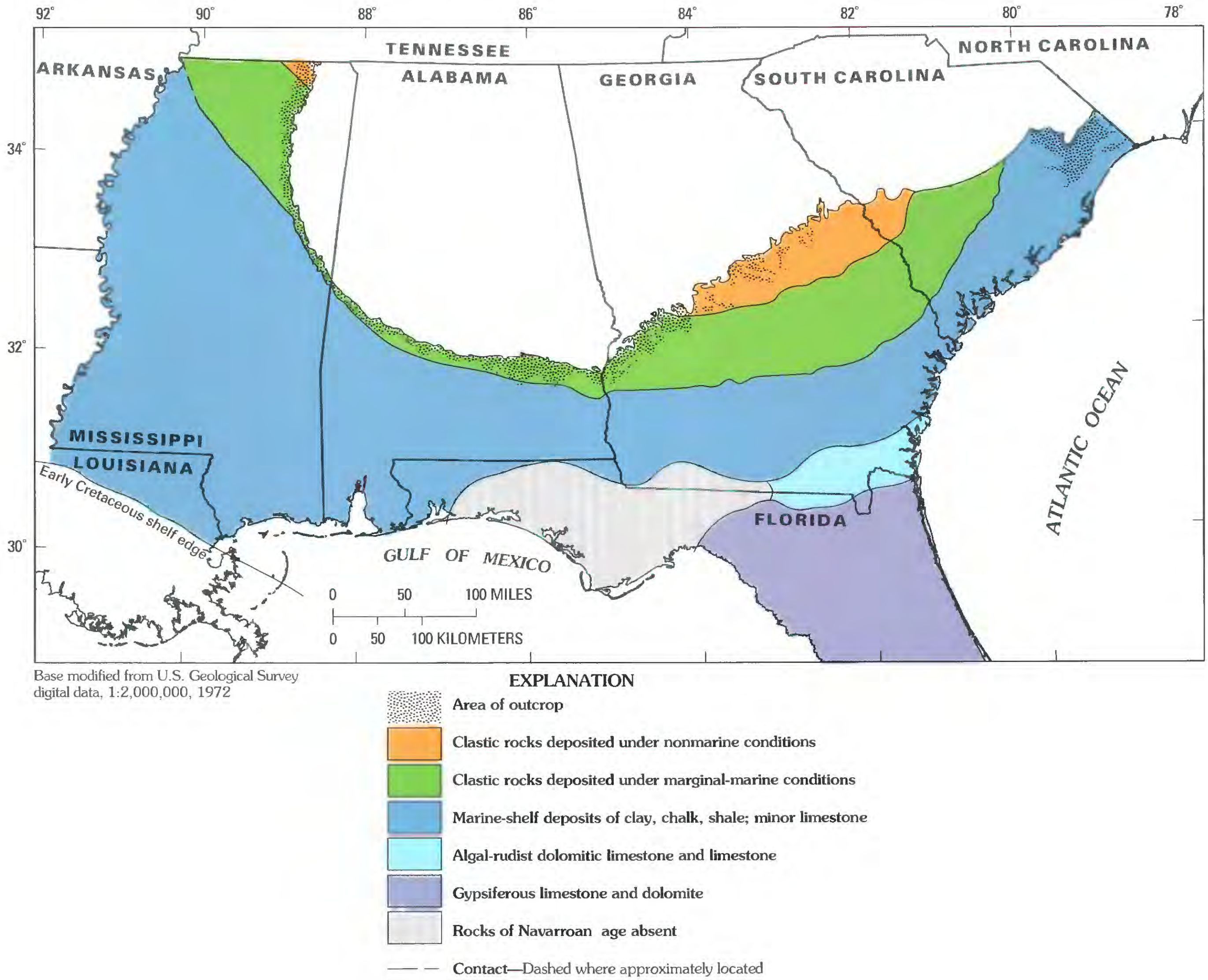


FIGURE 10.—Distribution of major lithofacies in the Southeastern Coastal Plain during Navarroan time.

recently, many workers equated the Midway Group with the Paleocene Series. Berggren's (1965) analysis of Tertiary planktonic Foraminifera indicated that exact correlation of the Gulf Coast Midwayan Stage with the Paleocene of the European section was incorrect. The lower part of the Gulf Coast Sabinian Stage is now known to be of Paleocene age, a stratigraphic boundary change that has been substantiated in the Southeastern Coastal Plain by the works of Reinhardt and Gibson (1981), Frederiksen and others (1982), Gibson and others (1982), and Gibson (1982a). As used in this report, Midwayan rocks are considered to be of early Paleocene age and include the Clayton, Porters Creek, and Naheola Formations in Mississippi and Alabama; the Clayton, Porters Creek, and Cedar Keys Formations in Georgia; the Beaufort and Ellenton Formations and lower part of the Black Mingo Formation in South Carolina; and the Cedar Keys Formation in Florida.

Rocks of Midwayan age crop out or subcrop as a crescent-shaped band that extends from Tennessee southward into Mississippi and eastward into Alabama and western Georgia (pl. 13). Many of the structural elements that dominate the configuration of underlying Cretaceous horizons similarly appear on the Midwayan surface. They include the Southeast and Southwest Georgia embayments, Peninsular arch, Wiggins anticline–South Mississippi uplift, Hatchetigbee anticline, Jackson dome, and Pickens-Gilbertown fault zone. Midwayan beds are entirely covered and overlapped by younger Tertiary rocks in eastern Georgia and western South Carolina; they are only locally exposed in central South Carolina and do not extend farther east because they pinch out on the flank of the Cape Fear arch. Midwayan rocks thicken in downbasin directions toward the axis of the Mississippi embayment and in a coastward direction elsewhere (pl. 14). Thin Midwayan sections occur locally where these rocks cross the Wiggins anticline–South Mississippi uplift and the Jackson dome. A thick Midwayan section is present across southern Georgia where these strata appear to fill in the Suwannee strait as well as the Southeast Georgia embayment. The thick section of Midwayan beds in the Suwannee strait represents a change in the character of this feature; rather than being a site of thin to minimal deposition as it was during much of the Cretaceous, the Suwannee strait became a site of thick sedimentary accumulation during Midwayan time.

CLAYTON FORMATION

The name Clayton is used to describe the oldest Paleocene formation that crops out in Mississippi, Alabama, and western Georgia. At its type section in Clayton, Ala., the Clayton Formation is divided into a lower sand and sandy limestone that includes reworked Cretaceous sediments; a middle, somewhat chalky, earthy, porous, fossiliferous limestone that changes at depth to a more massive, crystalline, sandy limestone; and an upper, gray to black, fossiliferous clay that Reinhardt and Gibson (1981) considered to be equivalent to the Porters Creek Formation. This uppermost clay grades to a massive, crystalline sandy limestone or indurated sand as it extends into the subsurface. The Clayton Formation contains more clastic material, in general, in its outcrop and shallow subsurface localities; there it consists largely of massive, crossbedded, medium to coarse sand with local layers of calcareous sand, clay, and shelly debris.

The lithologic character of the Clayton Formation changes further as it extends into central and western Alabama; there, workers tend to divide it at outcrop and in the shallow subsurface into two members: the lower Pine Barren Member and the upper McBryde Limestone Member. The Pine Barren Member consists of sandy, calcareous silt that alternates between being indurated and being unconsolidated, but is overlain by an uppermost sand and sandy limestone bed ("Turritella rock"). The McBryde Limestone Member consists of foraminiferal marl or clayey chalk.

The Clayton Formation in outcrop and in the shallow subsurface areas of eastern Alabama and western Georgia represents a complex pattern of depositional environments; marginal-marine to nearshore subtidal, bay, or estuarine conditions that alternate between open-marine and restricted environments are all represented (Cofer and Frederiksen, 1982; Gibson, 1982b). Clayton beds in the eastern Alabama and western Georgia subsurface contain a molluscan cast-and-mold limestone suggestive of a biostrome deposited in relatively shallow marine waters with little clastic influx. To the west, deeper, more open marine conditions existed. Additional authors describing the Clayton Formation include Smith and others (1894), MacNeil (1946a), Copeland (1968), and Toulmin (1977).

PORTERS CREEK FORMATION OR CLAY

The term Porters Creek (Safford, 1869) was first applied to clay beds found along Porters Creek near Middleton, Tenn. Termed the Porters Creek Formation in Alabama, or Porters Creek Clay in Mississippi, this stratigraphic unit consists of gray, black, brown, and olive-green, massive, calcareous to noncalcareous clay that is characterized by subconchoidal fractures and a nearly impervious nature. The upper 10 to 20 ft of the formation has been called the Matthews Landing Marl Member, which differs from underlying beds by its fossiliferous, marly nature. In some areas, such as western Alabama and Mississippi, the Porters Creek Formation or Clay is highly lignitic and becomes increasingly calcareous as it merges eastward with the Clayton Formation. The Porters Creek Clay also contains a local marine or estuarine sand or sandstone, known as the Tippah Sand Lentil, that is best developed in Tippah and Benton Counties of northern Mississippi.

Depositional conditions associated with the Porters Creek Formation or Clay vary as the unit extends across Mississippi and Alabama. Rainwater (1964) considered the few microfossils found in the unit in the subsurface to be indicative of lagoonal to restricted marine conditions. Lignitic Porters Creek beds that crop out or lie in the shallow subsurface of east-central Mississippi and northwestern Alabama are indicative of nearshore to marginal-marine environments. The increasingly calcareous nature of the rocks of Porters Creek in the southeastern Alabama subsurface reflects deeper marine conditions. Additional authors discussing the Porters Creek Formation or Clay include Smith and Johnson (1887), Lowe (1915, 1933), and MacNeil (1946a, b).

NAHEOLA FORMATION

The Naheola Formation (Smith and Johnson, 1887) includes glauconitic sand, clay, and marl that crop out between Calhoun County, Miss., and Butler County, Ala. East of Butler County, the unit is either missing or unidentifiable. The Naheola Formation can be divided at outcrop and in the shallow subsurface into a lower, gray, carbonaceous, laminated and interbedded silt, clay, and fine sand unit and an upper fossiliferous, glauconitic, fine to medium sand that is, in places, highly lignitic. Beds of the Naheola Formation crop out in northern Mississippi and are generally considered to be part of a progradational delta-front wedge; they are commonly included as part of Mississippi's Wilcox Group of Sabinian age whether they are mapped in outcrop or in the subsurface (Boswell, 1976a; Cleaves, 1980) because they are lithologically similar and genetically related to the Wilcox Group.

ELLENTON FORMATION

The name Ellenton Formation (Siple, 1967) describes clayey sand and lignitic sandy and silty clay beds that are penetrated by wells drilled near Ellenton, S.C., an abandoned town located within the Savannah River Plant nuclear facility in Barnwell and Allendale Counties, S.C. Prowell and others (1985) extended the use of this name to rocks of similar character and age in adjacent areas of South Carolina and Georgia. The Ellenton Formation can be divided into an upper oxidized, carbonaceous, dense, sandy clay and a basal, medium to coarse clayey sand; a fluviodeltaic or possible nearshore, brackish-water origin is suggested for this unit.

BLACK MINGO FORMATION (LOWER PART)

Sloan (1908) first used the term Black Mingo to describe a lower Eocene sequence of rocks in South Carolina, although Cooke and MacNeil (1952) later suggested that the lowermost Black Mingo beds might also be of Paleocene age. Pooser (1965) supported this Paleocene age assignment based on ostracode assemblages of Paleocene (Midwayan) as well as early Eocene (Sabinian) age. In this report, the entire Black Mingo Formation is considered to be of Paleocene age. The lower part of the formation is placed in the Midwayan Stage, whereas the upper part is thought to be part of the Sabinian Stage (pl. 2).

The lower part of the Black Mingo Formation is characterized by an upper, pelecypod-rich, clayey quartz sand and a lower, laminated to bioturbated, arenaceous clay, shale, and clayey sand (Van Nieuwenhuise and Colquhoun, 1982). This sandy, marly texture is readily visible in well cuttings collected from the Albany Felt Company test well at St. Stephens, Berkeley County, S.C. (100 to 250 ft below land surface) but contrasts sharply with textures of cores collected from the St. George test well (400 to 550 ft below land surface), Dorchester County, S.C. In the St. George test well, the lower part of the Black Mingo Formation consists of light- to dark-gray to grayish-black, calcareous clay that is occasionally interlaminated with fine sand. Minor constituents include lignite, glauconite, mica, and shell fragments (Reid and others, 1986a). Gohn and others (1977) used the term Beaufort(?) Formation to describe equivalent beds in a nearby Dorchester County well (Clubhouse Crossroads corehole 1), preferring to restrict the use of the name Black Mingo Formation to younger strata. In the Clubhouse Crossroads well, the laminated to bioturbated, moderately calcareous, sandy and silty clay of the Black Mingo is quite similar to beds seen in the St. George test hole. Where it lies in the shallow subsurface or crops out, the Black Mingo Formation was probably deposited under nearshore to littoral conditions. Inner neritic conditions prevailed where these beds were laid down in what is now the deeper subsurface.

DEPOSITIONAL SETTING DURING MIDWAYAN TIME

Following a major lowering of the ocean during the latter part of Cretaceous time, the sea returned to cover much of the Southeastern Coastal Plain during Midwayan time. A carbonate-evaporate platform facies of Midwayan age extends across much of southeastern Georgia and the Florida peninsula (fig. 11). Low-permeability crystalline limestone interbedded with anhydrite forms the lower two-thirds of the Cedar Keys Formation, which represents the bulk of Midwayan carbonate rocks in that area. The major part of the lower confining unit of the Floridan aquifer system is composed of these beds in peninsular Florida and extreme southeastern Georgia (Miller, 1986).

A mix of Midwayan clastic and carbonate beds is found in an area that includes much of the Georgia and eastern Alabama Coastal Plain. These strata consist of shallow, open-marine biostromal limestone interbedded with shelly sand lenses that grade northward to, and interfinger with, nearshore-marine deposits. In combination with limy platform deposits in southeastern Georgia, these beds represent the northernmost advance of carbonate rocks during early Paleocene (Midwayan) to middle Eocene (Claibornian) time. These strata quickly grade landward to a nearshore and marginal, restricted-marine, locally deltaic sequence of clay, silt, and sand found in a narrow band extending from easternmost Alabama into central South Carolina (fig. 11). In eastern Georgia and South Carolina, these transitional-marine deposits consist of carbonaceous, laminated, and thinly bedded sand and clay. In western Alabama, Midwayan lignitic sand and silty clay beds are probably associated with coastal marsh areas that were part of a lower delta plain complex (Mancini, 1981, 1983).

Midwayan marine-shelf deposits include fossiliferous, glauconitic, calcareous mud, clay, shale, muddy sand, and marl; such conditions existed over much of easternmost Georgia and southern South Carolina. Clayey marine strata found in Mississippi, southwestern Alabama, and panhandle Florida are increasingly calcareous

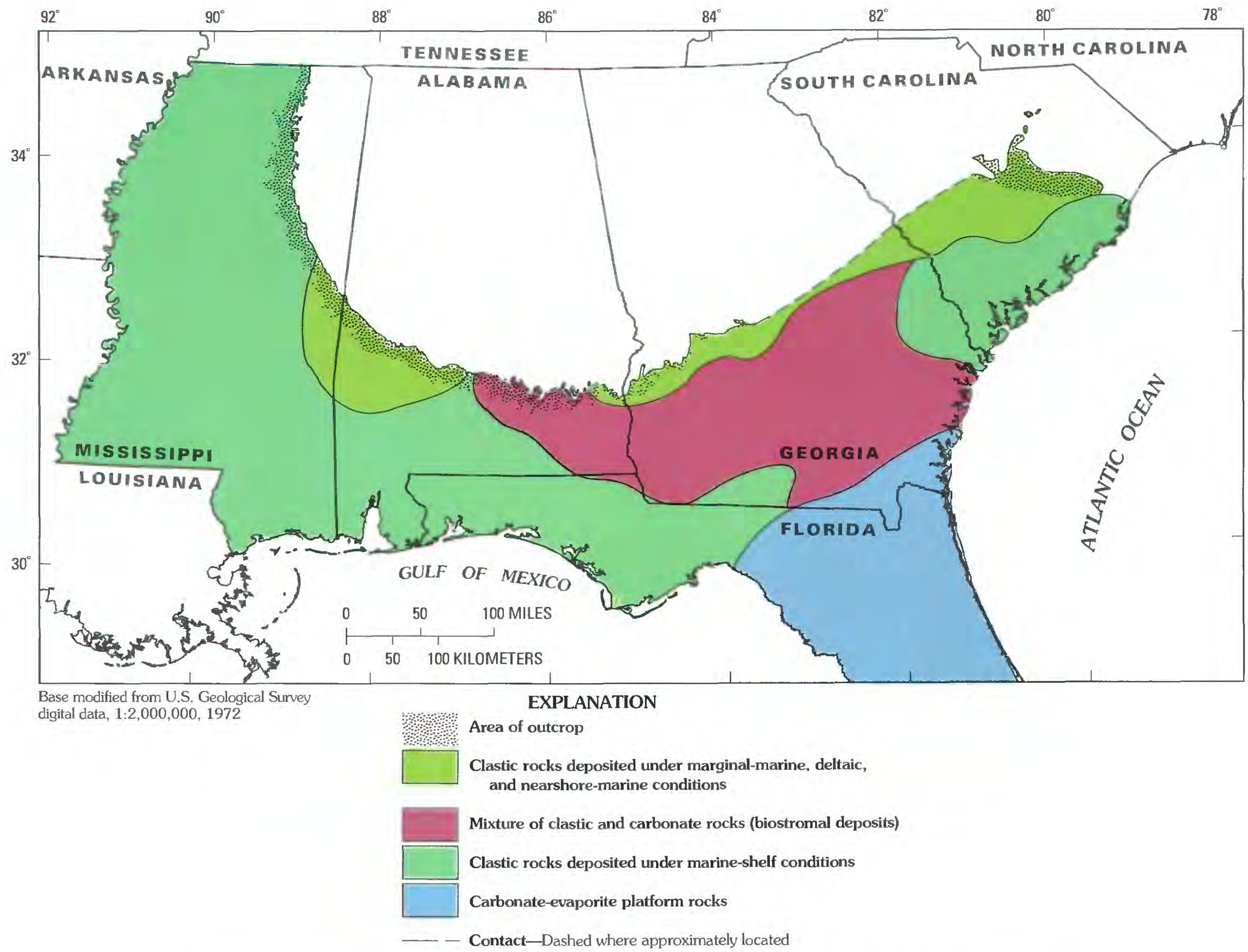


FIGURE 11.—Distribution of major lithofacies in the Southeastern Coastal Plain during Midwayan time.

as they grade to, and interfinger with, carbonate strata that lie to the east and southeast.

Clayey Midwayan beds in Mississippi are largely noncalcareous, massive, and nearly impervious. The South Mississippi uplift–Wiggins anticline created a restrictive barrier across southern Mississippi and southwesternmost Alabama during Midwayan time, inhibiting a more open marine environment. The thick marine clay deposits found here are inferred to represent these more restrictive conditions.

UPPER PALEOCENE AND LOWER EOCENE SERIES: ROCKS OF SABINIAN AGE

Sabinian rocks crop out as an arcuate band across much of Mississippi, Alabama, and western Georgia and in a small area in southeasternmost South Carolina (pl. 15). They crop out discontinuously or lie in the shallow subsurface across central Georgia and southwestern South Carolina, where they are overlapped by younger Tertiary beds. In central and eastern Georgia, Sabinian rocks cannot be easily separated from overlying and underlying beds, because many of the Tertiary rocks in this area were deposited under similar shallow nonmarine to marginal-marine conditions.

Rocks of Sabinian age dip coastward; however, in Mississippi they dip westward toward the axis of the Mississippi embayment. Many of the structural elements that can be recognized on underlying horizons are similarly well displayed on the structural surface of the Sabinian rocks. These include the Southeast and Southwest Georgia embayments, Peninsular arch, Jackson dome, Monroe-Sharkey uplift, and Pickens-Gilbertown fault zone. Deposition continued in the Southeast Georgia embayment and in the Suwannee strait during Sabinian time. The sequence of Sabinian rocks thickens seaward elsewhere, except where these rocks extend across the Wiggins anticline–South Mississippi uplift, Jackson dome, Hatchetigbee anticline, and Peninsular arch (pl. 16).

BLACK MINGO (UPPER PART) AND FISHBURNE FORMATIONS

The upper part of the Black Mingo Formation of South Carolina is mapped with Sabinian rocks in this report. The upper part is lithologically similar to the lower (Midwayan) part of the Black Mingo, except that it is sandier, and the two parts are separated largely on the basis of paleontologic criteria. Van Nieuwenhuise and Colquhoun (1982) describe outcropping and shallow subsurface beds of the upper Black Mingo as consisting of an upper, littoral, fossiliferous, argillaceous sand and mollusk-rich bioclastic limestone that overlies and interfingers with a lower, inner neritic, siliceous shale and fossiliferous clayey sand. Uppermost Sabinian beds (early Eocene) found only in deep subsurface areas are part of the Fishburne Formation (Gohn and others, 1983), a fossiliferous, glauconitic biomicrite. Fishburne beds are readily distinguished by their low permeability and distinctive electric log pattern and locally separate permeable sandy beds within the Black Mingo Formation from overlying carbonate beds of the Santee Limestone. These uppermost Sabinian rocks were deposited in sublittoral conditions in a warm-temperate or subtropical environment. The extent of the Fishburne Formation is limited to subsurface coastal areas of Charleston and Beaufort Counties and southern Dorchester County, S.C.

WILCOX GROUP

Smith and others (1894) first used the term Wilcox Group to describe beds of Eocene age that crop out in Wilcox County, Ala., but proposed that a different set of formational names be used in Mississippi than in Alabama. The Mississippi terminology was subsequently revised (MacNeil, 1946a) to correspond to that used in Alabama. The name Wilcox has been used synonymously as a provincial rock unit based on lithologic criteria and as a time-rock unit based on faunal criteria and equated with beds of early Eocene age. Murray (1955) proposed that the name Wilcox be restricted to group status (a rock-stratigraphic rather than a time-stratigraphic unit) and be used to describe the deltaic mass of rock of early Eocene age found in Mississippi. Toulmin (1977) similarly avoided use of the term Wilcox except as a rock unit and preferred to use the time-stratigraphic designations Paleocene or Eocene and the time-rock designations Sabinian or Midwayan Stage.

The Wilcox Group, as it is currently defined, is largely equated with the Sabinian Stage and includes the Nanafalia, Baker Hill, Tuscahoma, Bashi, and Hatchetigbee Formations, all of which are more easily separated as distinctive rock units in Alabama than elsewhere. Subdividing the Wilcox Group either at outcrop or in the subsurface is virtually impossible north of Lauderdale County, Miss., largely due to the fluviodeltaic nature of the strata and lack of widespread intervening marine clays. Other workers have attempted to separate the Wilcox Group in Mississippi into hydrogeologic or depositional entities (Hosman and others, 1968; Boswell, 1976a, b; Cleaves, 1980). Because the Wilcox Group and the beds that lie immediately above or below it both formed in a similar environment, many workers tend to include the Wilcox with beds not actually part of the Wilcox Group, particularly in the subsurface of Mississippi. Taken together, the Wilcox Group consists of a complex sequence of fine to coarse sand, occurring as lenticular to massive channel deposits, grading laterally to finer grained overbank or deltaic sand and lignitic clay deposits. Where equivalent beds extend eastward and southward into Alabama and southern Mississippi, they include deeper marine deposits and are more easily differentiated.

NANAFALIA AND BAKER HILL FORMATIONS

The Nanafalia Formation (Smith and Johnson, 1887) is named for exposures at Nanafalia Landing on the Tombigbee River, Marengo County, Ala. The Nanafalia Formation consists of beds of (1) a basal, fluvial, lenticular, crossbedded, coarse sand and fine gravel; (2) a middle, marine, glauconitic quartz sand, sandy clay, clay, and marl containing the guide fossil *Ostrea thirsae*; and (3) an upper, marginal-marine clay, sandy clay, and sand.

Toulmin and others (1951) reported that a sharp resistivity "kick" seen on electric logs from wells in Choctaw County, Ala., is commonly used as a marker horizon to define the top of the Nanafalia Formation in the subsurface. The Nanafalia as mapped by some workers includes a basal glauconitic sand that is more correctly assigned to the Tuscahoma Formation. The lower contact of the Nanafalia is difficult to identify, owing to a lithology that is similar to the underlying Naheola Formation.

The Baker Hill Formation (Gibson, 1982a) is named for kaolinitic, bauxitic, and carbonaceous clay and crossbedded sand exposed near Baker Hill, Ala., and in adjacent areas in eastern Alabama and western Georgia. The formation includes massive kaolinitic clay and thick, crossbedded quartz sand that contain sparse pollen, spores, and dinoflagellates.

Coastward, marine beds of the Nanafalia Formation predominate and largely represent inner neritic marine conditions. The uppermost beds of the Nanafalia possibly represent marginal-marine to lower delta plain deposition. The Baker Hill Formation is considered to have formed in a fluvial to brackish-water environment.

Tuscahoma Formation

Named for exposures at Plymouth Bluff on the Tombigbee River, Lowndes County, Miss. (Smith and Johnson, 1887), the Tuscahoma Formation is characterized by nonfossiliferous, abundantly carbonaceous, interlaminated silt, fine sand, and silty clay in Alabama and western Georgia. As many as four glauconitic, sandy marl layers have been identified where the Tuscahoma Formation crops out in western Alabama. The character of the Tuscahoma Formation changes as it extends into Mississippi, where it consists of lenticular sand and interlaminated clay and silt deposits of deltaic origin, whereas a protected, quiet-water lagoon, bay, and tidal-flat environment is suggested for the Tuscahoma Formation in Alabama and western Georgia. The easternmost extent of the Tuscahoma is not well defined and is usually not mapped east of the Ocmulgee River in central Georgia. In general, the glauconitic, lower part of the formation has a higher sand content than the laminated, silty, clayey, commonly carbonaceous upper part. The Tuscahoma Formation can be identified in the shallow subsurface of Alabama and Georgia by its electric log curves of characteristically low spontaneous potential and resistivity.

Hatchetigbee and Bashi Formations

Strata that are part of the Hatchetigbee and Bashi Formations combine to form the uppermost beds of the Wilcox Group of Mississippi, Alabama, and western Georgia. The Hatchetigbee Formation was divided by MacNeil (1946a) into an unnamed upper member and a lower Bashi Member. Gibson and Bybell (1981) demonstrated a coeval, interfingering relationship between the two units and raised the Bashi to formational rank. The interlaminated, carbonaceous, very fine to fine sand, silt, and clay of the Hatchetigbee Formation are lithologically similar to the older Tuscahoma Formation. Massively bedded to crossbedded quartz sand is found where the Hatchetigbee Formation crops out in eastern Alabama. The Bashi Formation consists of a neritic, shelly, glauconitic sand and clayey silt that is conformably overlain by the Hatchetigbee Formation; in deeper subsurface areas of Alabama, the marine-shelf “Bashi” lithology is readily identified on electric logs by its distinctive resistivity pattern. Equivalent beds found in shallow subsurface areas of central Georgia consist of thick, well-laminated to massive clay with thinner beds of quartz sand (Prowell and others, 1985), all of marginal-marine origin.

DEPOSITIONAL SETTING DURING SABINIAN TIME

The extent of major clastic and carbonate facies during Sabinian time is illustrated in figure 12. Platform carbonate and evaporite rocks are shown to extend farther into the panhandle of Florida and coastal South Carolina than rocks deposited during Cretaceous or early Paleocene time. However, Midwayan biostromal limestones are far more extensive in Georgia than Sabinian carbonate beds (compare figs. 11 and 12). Partially dolomitized, micritic to finely crystalline limestone beds of Sabinian age (Oldsmar Formation) and local, interbedded to lenticular gypsum, anhydrite, and chert beds form a minor confining unit within the Floridan aquifer system in southern Georgia. Low-permeability, thick-bedded limestone, dolomitic limestone, and anhydrite of the upper part of the Cedar Keys Formation combine with the overlying Oldsmar Formation in southern Georgia and northernmost Florida to form the lowermost confining unit of the Floridan aquifer system (Miller, 1986). Minor limestone beds of Sabinian age are also found in southernmost coastal South Carolina that include low-permeability, glauconitic, clayey, fossiliferous, crystalline limestone of the Fishburne Formation and the underlying, moderately permeable, pelecypod-mold biomicrudite of the upper Black Mingo Formation (Powell and Baum, 1981).

Much of the Southeastern Coastal Plain was inundated by the Sabinian sea, resulting in the deposition of a sequence of inner to middle-neritic beds that extend as a wide band across south-central South Carolina, southwestern Georgia, and western panhandle Florida. Slightly to moderately glauconitic and micaceous in places, these beds consist dominantly of macrofossiliferous and microfossiliferous, calcareous clay, shale, and silt with occasional thinly bedded to lenticular sand and sandstone layers. Applin and Applin (1944) reported, however, that equivalent clastic beds in northern Florida contain a poorly preserved and sparse foraminiferal assemblage.

The Mississippi embayment served as the principal site of an extensive complex of fluviodeltaic deposition during Sabinian time. A second site, much less extensive, was in eastern Georgia. Sabinian strata in both localities consist of a complex sequence of massive to lenticular, fine to coarse sand, highly lignitic clay, silt, and muddy sand. Kaolinitic clay is common in beds of Sabinian age in the Georgia area, whereas highly lignitic sand, silt, and clay beds are more typical in Mississippi. Similar nonmarine Sabinian deposits are also found in some local areas of eastern Alabama.

A marginal-marine Sabinian facies extends from western Alabama across Georgia and into central South Carolina and includes nearshore- to restricted-marine deposits including tidal-flat, brackish-water lagoon, marsh, and beach areas. Deltaic deposition occurred

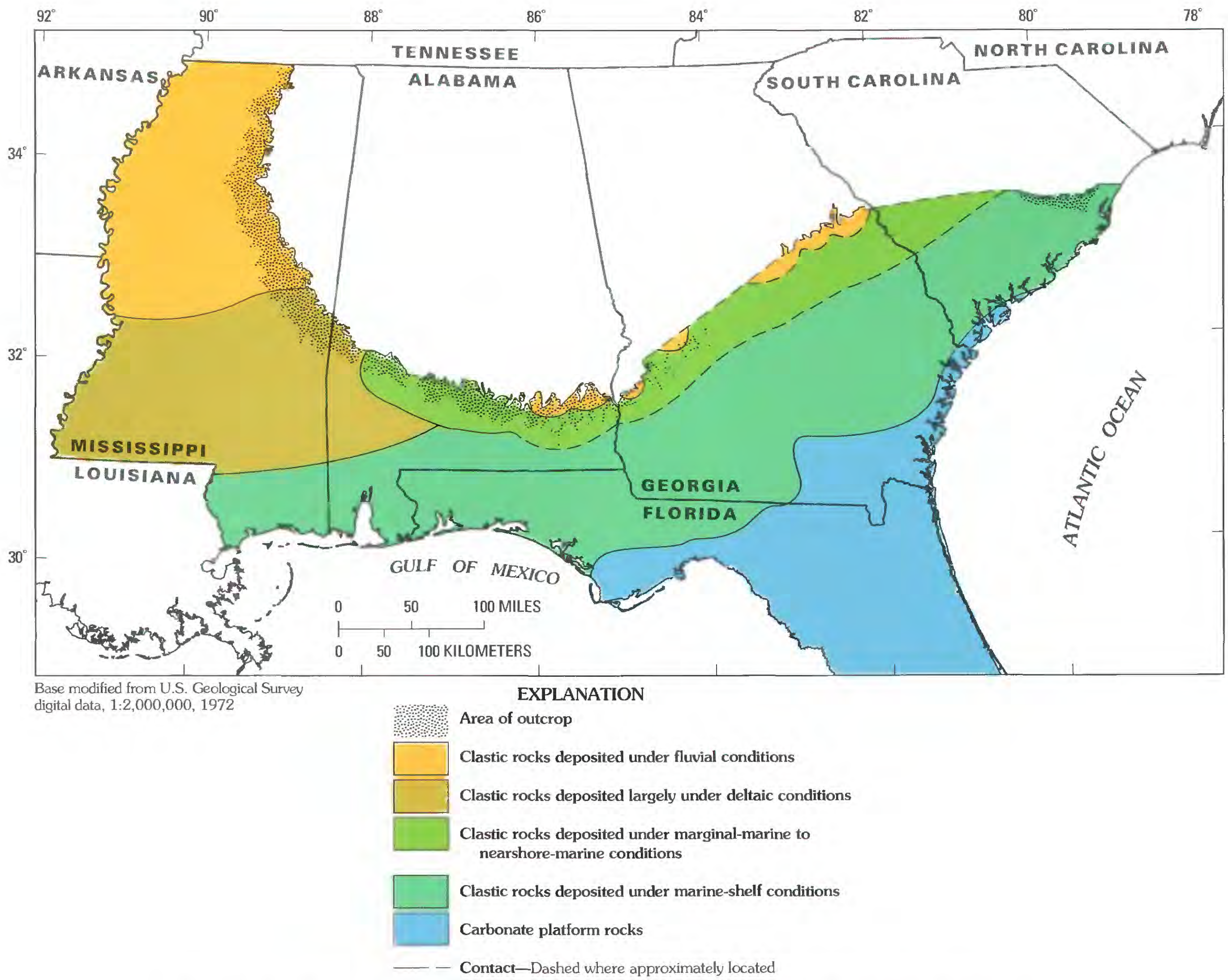


FIGURE 12.—Distribution of major lithofacies in the Southeastern Coastal Plain during Sabinian time.

during Sabinian time adjacent to, and interfingering with, nonmarine deposits found in Georgia and eastern Alabama. Rocks that form these beds consist of thick, highly to sparsely lignitic, massive to well-laminated units of micaceous, glauconitic, shelly, pyritic clay and crossbedded to massive, very fine to fine quartz sand.

EOCENE SERIES

ROCKS OF CLAIBORNIAN AGE

Rocks of Claibornian (middle Eocene) age crop out as a moderately wide band that extends southward from Tennessee and progressively narrows as it turns eastward across southern Mississippi and Alabama. Equivalent strata discontinuously crop out or are entirely covered by younger beds in much of Georgia and South Carolina. Rocks of latest Claibornian age (Cockfield Formation) subcrop in northwestern Mississippi, where they are covered by a mantle of Pleistocene loess and Quaternary alluvium.

The structural top of Claibornian rocks (pl. 17) illustrates the influence of several structural elements and erosional features. The subcrop pattern seen in northwestern Mississippi is a function of the structurally high Monroe uplift. The influence of the Jackson dome is seen immediately southwest of this feature. Claibornian beds in northwestern Mississippi form a relatively flat surface, attributed to erosion by the ancestral Mississippi River with subsequent deposition of alluvium of Holocene age. The Pickens-Gilbertown fault zone is shown extending across Mississippi and into Alabama. Its influence on the upper surface of Claibornian beds is uncertain due to the sparse distribution of wells used to construct this map. Newcome (1976) similarly failed to recognize any of these graben structures extending to this horizon. Rocks of Claibornian age are the oldest strata that can be shown to be directly affected by the northeasterly trending, grabenlike Gulf trough in Georgia. A possible northeastern extension of this feature is shown in Montgomery, Treutlen, Emanuel, and Wheeler Counties, Ga. Owing to a lack of deep test holes in the vicinity of this structural feature, it is not possible to definitively determine whether these faults extend deeper into the subsurface.

Rocks of Claibornian age generally thicken coastward, except in Mississippi, where equivalent strata thicken westward toward the axis of the Mississippi embayment (pl. 18). Thick sections of Claibornian rocks in the Southeast Georgia embayment, the Suwannee strait, the Southwest Georgia embayment, western panhandle Florida, and southwesternmost Alabama are all suggestive of basinal infilling and (or) continued subsidence. Conversely, rocks of Claibornian age thin as they extend across the structurally high Wiggins anticline, Jackson dome, and Peninsular arch.

Tallahatta Formation

The name Tallahatta Formation (Dall, 1898) refers to a dominantly open-marine shelf sequence of siliceous or opaline claystone (buhrstone) and interbeds of siliceous siltstone and sandstone that crops out in Mississippi, Alabama, and western Georgia and has been described as part of a "classic" transgressive-regressive sequence (Wise and Weaver, 1973). Basal nonmarine to marginal-marine Tallahatta sands occur in channels cut into the upper surface of the underlying Hatchetigbee Formation in eastern Alabama and western Georgia and are, in turn, overlain by cristobalitic clay of deeper marine origin (Wise and Weaver, 1973; Gibson and Bybell, 1981). Farther east, where these strata crop out in Georgia and occur in the shallow subsurface of eastern Alabama and Georgia, the slightly clayey sand of the Tallahatta Formation is not easily separated from the overlying, lithologically similar Lisbon Formation. Tallahatta microflora and the presence of mica, lignite, carbonaceous clay, and clay-lined burrows are all suggestive of marginal-marine conditions. Although most early workers considered the Tallahatta Formation to be strictly of middle Eocene age, Gibson and Bybell (1981) have shown its basal beds in Alabama to be early Eocene in age. In western Alabama and in Mississippi, strata included as part of the Tallahatta Formation grade to a thicker, sandier sequence. Three members are recognized: a lowermost, highly crossbedded, lignitic to nonlignitic, fluvial Meridian Sand Member; a middle, open-marine, siliceous claystone having a basal glauconitic sand of nearshore origin at its base (Basic City Shale Member); and an upper, nonglauconitic to slightly glauconitic, irregularly bedded, massive to crossbedded sand of nearshore origin (Neshoba Sand Member).

Huber Formation

Buie (1978) first proposed the name Huber to describe all post-Cretaceous to pre-upper Eocene strata found in the kaolin mining district of central and eastern Georgia. The lithologic character of the Huber Formation is diverse and ranges from nearly pure kaolinitic clay to massive, crossbedded, coarse, pebbly sand. The age of these beds is as varied as the lithology; the Huber Formation ranges from Sabinian to Claibornian age. The occurrence of abundant freshwater agal cysts, marine acritarchs and dinoflagellates, lignitic and carbonaceous clay layers, all embedded in a thick sequence of coarse- to medium-grained sand and gravel, and occasional pisolitic kaolin boulders, suggests a nearshore to freshwater environment of deposition probably associated with fluvial or deltaic conditions (Scrudato and Bond, 1972; Tschudy and Patterson, 1975). Similar sandy, crossbedded, fluvial and deltaic beds are also found in Schley and Sumter Counties in west-central Georgia.

Congaree, Warley Hill, and McBean Formations

The Congaree Formation consists of poorly sorted quartz sand interbedded with sandy and silty clay and indurated siltstone and sandstone. The textural character of these beds, in combination with the occurrence of fragile, thin-shelled pelecypods within them, is considered suggestive of estuarine to nearshore, but decidedly quiet-water, conditions. The Warley Hill Formation is composed of noncalcareous to calcareous glauconitic sand and arenaceous, glauconitic limestone that represent deposition in an environment transitional between that of the deeper water carbonate rocks of the Santee Limestone and the paralic Congaree Formation. The McBean Formation consists of fine, loosely consolidated sand, sandy marl, clay and fullers earth. Carbonaceous beds, pelecypods, burrows, and crossbedded and interbedded sand and clay are all considered representative of nearshore, marginal-marine conditions. Additional authors describing the Congaree, Warley Hill, and McBean Formations include Sloan (1908), Cooke (1936), Cooke and MacNeil (1952), and Pooser (1965).

Lisbon Formation

The Lisbon Formation (Aldrich, 1886) can be described as a calcareous, fossiliferous, sandy marl, clay, and glauconitic sand. As it extends into westernmost Alabama, the marine character of the Lisbon Formation changes as it interfingers with a more nonmarine facies in Mississippi. In Georgia, the Lisbon Formation is characterized by interbedded fine to coarse sand and sandy, macrofossiliferous and microfossiliferous clay and marl of marginal-marine origin. In the subsurface of southeastern Alabama and Georgia, the Lisbon grades to interbedded sand, fossiliferous limestone, and marl that are not easily differentiated from the underlying Tallahatta Formation. In the deeper subsurface, these rocks grade to the carbonate Avon Park Formation of southernmost Georgia and panhandle Florida.

Winona Sand, Zilpha Clay, and Sparta Sand

The Winona Sand (Lowe, 1919) refers to the abundantly fossiliferous, highly glauconitic sand and clayey sand of marine origin that crop out and weather to a brilliant red color in Mississippi. The fauna of the Winona includes oysters, echinoids, and crustaceans indicative of deposition in a shallow-water, nearshore environment. The Winona Sand is immediately overlain by the Zilpha Clay (Hughes and Harbison, 1940), a carbonaceous shale and clay deposit of coastal marsh, bay, and lagoonal origin.

The Sparta Sand (Belt and others, 1945) overlies the Zilpha Clay and consists of a complex of fluviodeltaic sand interbedded with silt and clay and minor carbonaceous material. Described by the Mississippi Geological Survey (Cooke, 1926) as the Kosciusko Formation, the Sparta Sand is distinguished by its heterogeneous, highly lenticular bedding that includes clay stringers, pellets, balls, and inclusions. The Sparta Sand is recognized as a distinct lithologic entity in Arkansas and Louisiana, but loses its nonmarine character as it extends into Texas.

Cook Mountain and Cockfield Formations

The fluvial Sparta Sand is immediately overlain by the marine Cook Mountain Formation. The Cook Mountain (Belt and others, 1945) consists largely of highly calcareous, fossiliferous marl, carbonaceous clay, and glauconitic sand, but grades to a much sandier nonmarine facies in northern Mississippi.

The Cockfield Formation (Thomas, 1941) represents the uppermost formation of Claibornian age in Mississippi. The unit consists of massive to highly crossbedded, fine to medium ferruginous sand, laminated with beds of carbonaceous clay and thin beds of lignite. The lower part of the formation is sandier, and clays predominate in the upper part. The Cockfield is late Eocene in age and lagoonal or deltaic in origin.

Gosport Sand

The name Gosport Sand was applied by Smith (1907) to marine, fossiliferous coarse to fine glauconitic sand and carbonaceous shale beds that crop out in western Alabama and form the uppermost beds of Claibornian age in that State. The Gosport Sand is herein considered to be a unit of only local importance. The Gosport cannot be readily differentiated in the subsurface of southwestern Alabama (Davis and others, 1983) and is not found anywhere in outcrop or in the subsurface of eastern Alabama. References to the Gosport Sand that crops out (Herrick, 1961; LeGrand and Furcron, 1956) or occurs in the subsurface of Georgia (Counts and Donsky, 1963) have been largely discounted on the basis of stratigraphic and lithologic criteria (Carver, 1966; Miller, 1986).

Depositional Setting During Claibornian Time

Carbonate-evaporate strata of Claibornian age extend farther northward than underlying carbonate strata of Sabinian age, except in the central panhandle of Florida. These rocks combine with younger carbonate strata of Jacksonian and Oligocene age to form the major aquifers of the Floridan aquifer system. In southern Georgia and northern Florida, Claibornian strata are characterized by soft to well-indurated pelletal limestone, thickly to thinly interbedded with crystalline, slightly vuggy dolomite (Avon Park Formation). Bryozoan and pelecypod-rich biosparrudite and biomicrudite of the Santee Limestone form the major carbonate rock types of Claibornian age in South Carolina.

The Mississippi embayment was a major site of fluviodeltaic deposition during Claibornian time (fig. 13), punctuated by several marine transgressions and regressions caused by a combination of eustatic sea level changes and continued embayment subsidence. Evidence of this fluctuating shoreline is shown by stratification of fluvial beds with coastal marsh, brackish-water, nearshore-marine, and open-marine clay deposits. Local nonmarine deposits are also found in eastern Alabama and western Georgia (Gibson, 1982b).

Marginal-marine deposits that formed in such conditions as nearshore-marine, brackish-water lagoons and bays, and marsh-type environments are found in the eastern Alabama–western Georgia and east-central Georgia area. These strata are characterized by thinly laminated to interbedded glauconitic sand, carbonaceous clay, and sandy clay beds that are sparsely to abundantly fossiliferous and commonly contain clay-lined burrows and thin- to thick-shelled mollusks.

Marine-shelf conditions prevailed over much of southeasternmost Mississippi, southern Alabama, central and southern Georgia, western South Carolina, and western Florida during Claibornian time. Calcareous, glauconitic sandstone, siliceous (opaline) claystone or buhrstone, and shale with occasional interbeds of arenaceous, glauconitic limestone constitute the major rock types of these

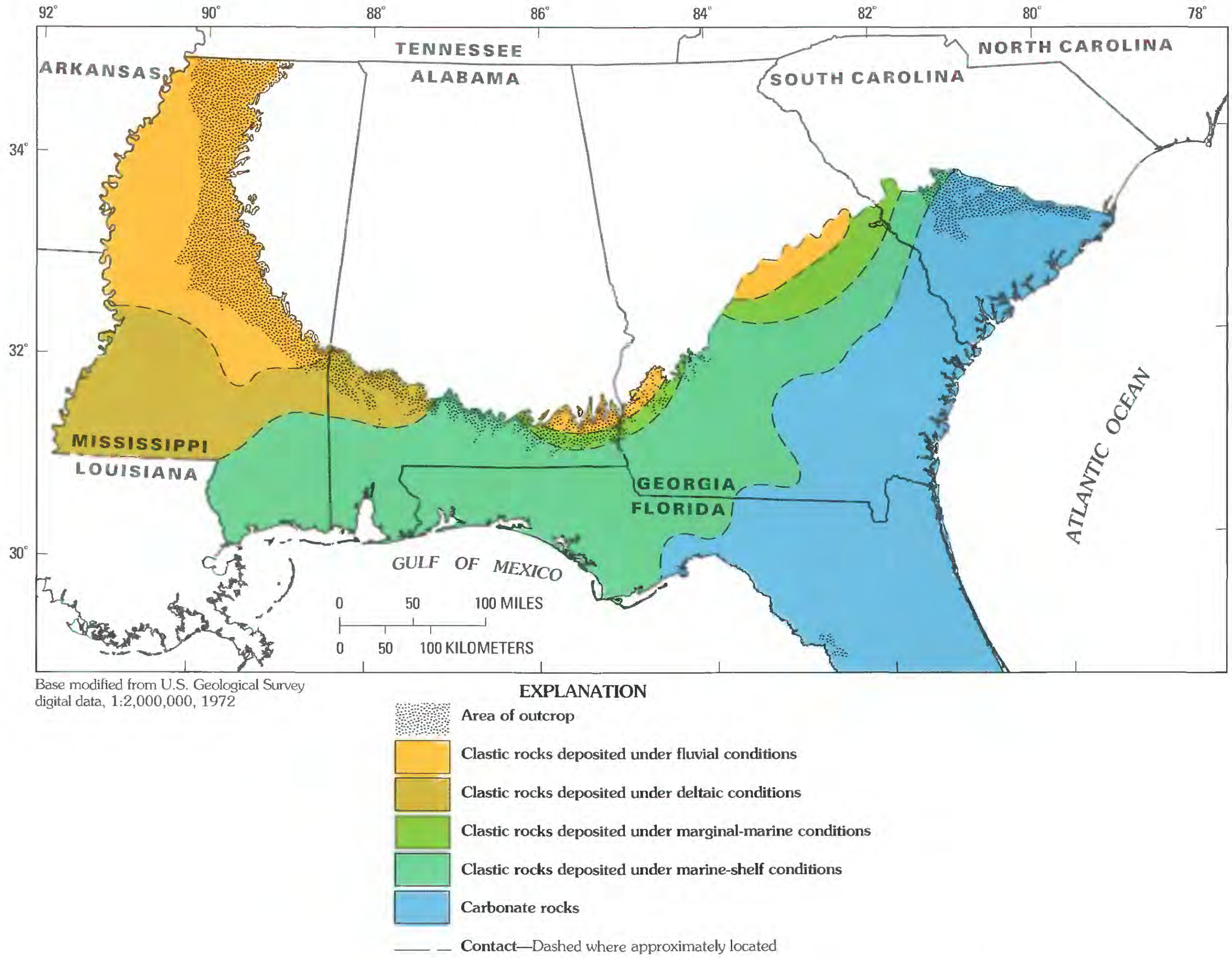


FIGURE 13.—Distribution of major lithofacies in the Southeastern Coastal Plain during Claibornian time.

deposits. Although many workers do not differentiate Claibornian strata into distinct formational units in the deep subsurface, Chen (1965) divided the clastic Claibornian rocks into two sequences in southernmost Alabama and Georgia and northern Florida: a lower sequence of glauconitic, calcareous sandstone, sandy shale, arenaceous limestone, minor siliceous shale, and limestone beds; and an upper sequence of fossiliferous, glauconitic, sandy limestone and minor shale beds.

ROCKS OF JACKSONIAN AGE

Rocks of Jacksonian age (late Eocene) crop out as a thin triangular wedge that extends across southern Mississippi and as a thin, discontinuously outcropping band across Alabama (fig. 14). Equivalent rocks subcrop in westernmost Mississippi, where they underlie the alluvium of the Mississippi River. The area of greatest surface exposure of Jacksonian rocks occurs in Georgia and western South Carolina. Equivalent beds extend into the subsurface with a general southerly dip and offlap the older Eocene strata that crop out in Mississippi and Alabama; rocks of Jacksonian age overlap the older Tertiary and Cretaceous strata in Georgia and western South Carolina.

Most of the rocks that were deposited in the Southeastern Coastal Plain during the late Eocene are part of an extensive carbonate platform sequence; the wide extent of this carbonate platform is demonstrative of a continued northward and westward shift of the limestone-dolomite-evaporite rocks that were deposited in shallow-shelf, tropical to subtropical waters during Paleocene and Eocene time.

Most carbonate beds of Jacksonian age found in the Southeastern Coastal Plain can be assigned to either the

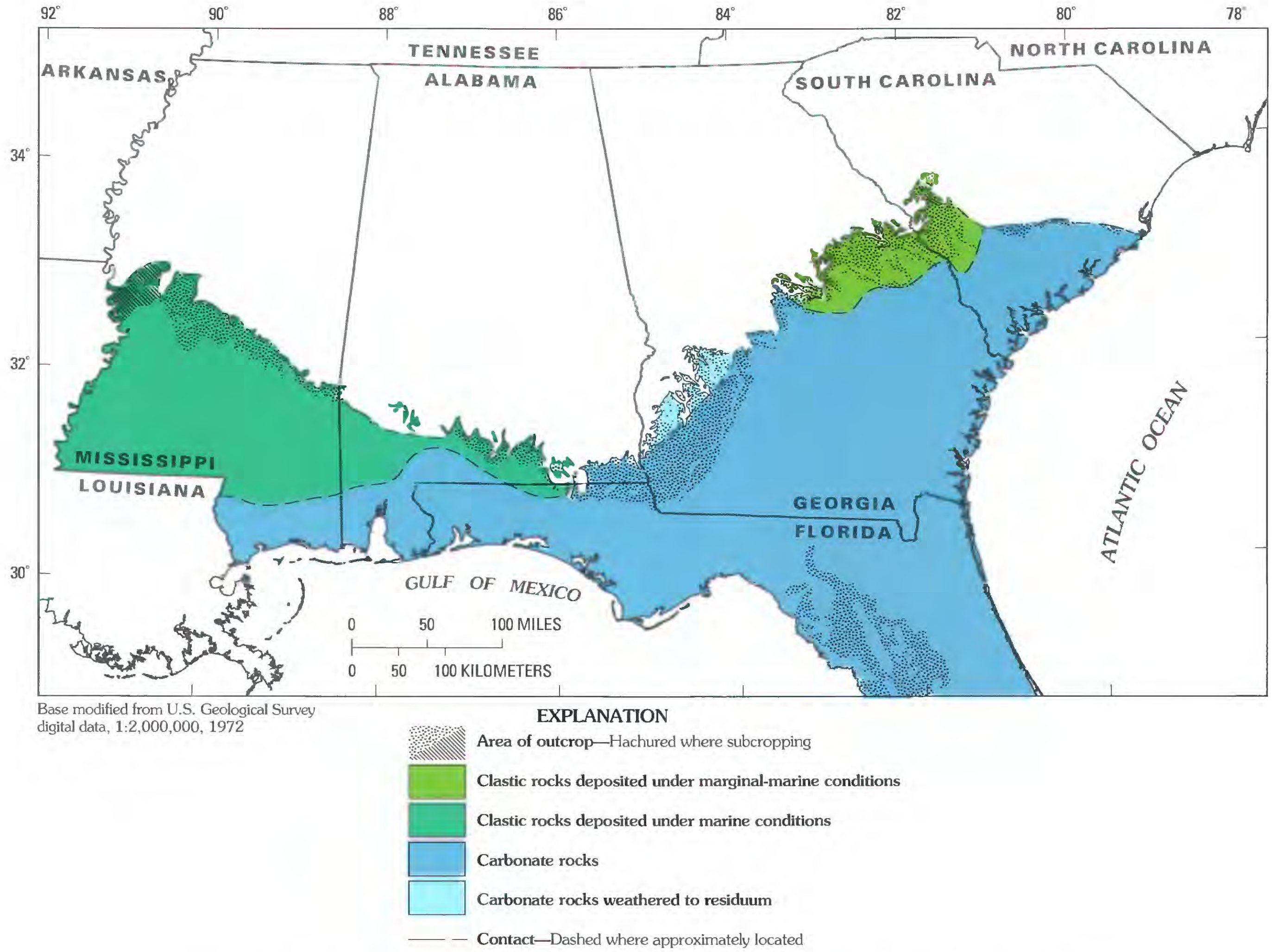


FIGURE 14.—Distribution of major lithofacies in the Southeastern Coastal Plain during Jacksonian time.

highly porous and permeable, abundantly fossiliferous, coquinoid limestone of the Ocala Limestone or the low-permeability, sandy, glauconitic, soft fossiliferous marl of the Cooper Formation (Harleyville and Parkers Ferry Members). The almost impervious nature of the Cooper Formation is easily demonstrated; unlined water conduit tunnels are constructed in it near Charleston, S.C. In Georgia, the Cooper Formation consists of sandy, loosely consolidated, glauconitic, abundantly fossiliferous marl. The water-bearing nature of the Ocala Limestone contrasts greatly with the impervious nature of the Cooper Formation; the Ocala is one of the more productive units in the upper part of the Floridan aquifer system. Where the Ocala Limestone crops out or lies in the shallow subsurface, it weathers to a residual sand, gravel, clay, and sandy clay with chert boulders. Dissolution of the limestone and subsequent collapse of overlying residuum often result in the residual material forming a jumbled mass of rock that combines with overlying rocks of Miocene and Pliocene age in southern Alabama (Scott and others, 1984) or beds of Oligocene age in southern Georgia (Hicks and others, 1981).

Marine clastic beds of late Eocene age crop out and, in the shallow subsurface, interfinger with, and grade to, these carbonate units in two principal localities: a band that extends from southern Mississippi to western Alabama and a smaller area in eastern Georgia and western South Carolina.

MOODYS BRANCH FORMATION

The Moodys Branch Formation (Lowe, 1915) is named for exposures along the Moodys Branch of the Pearl River near Jackson, Miss. Consisting of greenish-gray fossiliferous, calcareous, glauconitic sand and sandy marl and minor limestone beds, the Moodys Branch Formation extends across southern Mississippi and westernmost Alabama. Beds equivalent to the outcropping

Moodys Branch extend into the subsurface of western panhandle Florida and southern Alabama and interfinger with, and grade to, carbonate rock that forms the lower part of the Ocala Limestone.

Yazoo Formation

The Yazoo Formation (Lowe, 1915) consists of fossiliferous, calcareous clay, sandy clay, and sand and interfingers with, and grades to, the upper part of the Ocala Limestone where it extends into central Alabama. Four members are recognized where these beds crop out in Mississippi and extend into the shallow subsurface. From oldest to youngest, these are clay of the North Twistwood Creek Clay Member, calcareous sand of the Cocoa Sand Member, limestone and chalky marl of the Pachuta Marl Member, and calcareous clay of the Shubuta Member. The Yazoo Formation is easily identified on geophysical logs by its characteristically low spontaneous potential and resistivity. Separation of the Yazoo into discrete members in the deeper subsurface is virtually impossible. The older Moodys Branch Formation and the Yazoo Formation were both deposited under shelf-marine conditions in close proximity to the carbonate deposits that lie to the south and southeast. Marginal-marine conditions may have prevailed locally.

Barnwell Formation

The Barnwell Formation (Sloan, 1908; Cooke and Shearer, 1919) consists of fine to coarse arkosic sand interbedded with blocky glauconitic clay, marl, and fullers earth, and minor limestone beds. These rocks crop out or lie in the shallow subsurface of eastern Georgia and western South Carolina. The Barnwell Formation interfingers with, and grades to, the Ocala Limestone to the south in the shallow subsurface. Although it is classified by Huddlestun (1982) as a group, the Barnwell is considered here as a formation that includes the Twiggs Clay and the Irwinton Sand Members. The Twiggs Clay Member consists of silty to sandy clay that is locally fossiliferous and lignitic and was probably deposited under marginal-marine conditions. The Irwinton Sand Member consists of fine- to medium-grained, unconsolidated, thinly bedded to rarely crossbedded sand of tidal origin. The Barnwell Formation underlies much of the hilly uplands described as the Sand Hills and Fall Line Hills (Cooke, 1943) of eastern Georgia and western South Carolina.

Clinchfield Sand

The Clinchfield Sand, equivalent to the lower part of the Barnwell Formation (Carver, 1966), consists of medium-grained, well-sorted, loosely consolidated sand containing Bryozoa, mollusk shells, and a few Foraminifera and was deposited in nearshore to shoreline environments. Its outcropping extent is limited to a few counties (Bleckley, Houston, and Crawford) in central Georgia, but equivalent beds have been identified in wells over a wider area.

Tobacco Road Sand

The name Tobacco Road Sand (Huddlestun and Hetrick, 1978) is applied to medium to coarse quartz sand of late Eocene age that overlies the Barnwell Formation and crops out and extends into the shallow subsurface in northeastern Georgia and western South Carolina. Previous workers (LaMoreaux, 1946a; LeGrand and Furcron, 1956) have considered this sand to constitute the uppermost sand of the Barnwell Formation. The Tobacco Road Sand grades to bioclastic, microfossiliferous sandy marl of the Cooper Formation in the shallow subsurface of Georgia. Huddlestun and Hetrick (1978) recognized two facies associated with this unit: a nearshore, poorly sorted, pebbly, fine to coarse sand containing lesser amounts of clay, and a lagoonal, nonfossiliferous, bioturbated, clayey, glauconitic sand that locally contains limestone beds that they assigned to the Sandersville Limestone Member.

OLIGOCENE SERIES: ROCKS OF VICKSBURGIAN AND CHICKASAWHAYAN AGE

Rocks of Vicksburgian and Chickasawhayan (Oligocene) age crop out or occur in the subsurface in an area that extends from Louisiana across Mississippi, southern Alabama, southern Georgia, and northern Florida and continues eastward into southern South Carolina (fig. 15). These rocks crop out in an offlapping relation to the older Eocene strata that lie to the north. Erosional processes have removed much of the Oligocene in parts of extreme southeastern Georgia and peninsular Florida. Two major Oligocene facies are found in the Southeastern Coastal Plain sediments: a carbonate facies that covers much of southeastern Mississippi, Alabama, Georgia, and Florida (Bumpnose, Marianna, and Chickasawhay Formations and the Suwannee Limestone) and a siliciclastic facies that is more limited in extent, confined largely to central and western Mississippi. An intermediate or mixed clastic-carbonate lithosome is also found in southeastern Mississippi and forms a transitional area that separates the clastic rocks of deltaic and terrigenous shelf origin to the north from carbonate platform deposits that lie to the east. This mixed sandstone-limestone facies consists of a lower and upper clastic regressive depositional pulse separated by a transgressive carbonate bank deposit. A separate transitional clastic-carbonate facies is found in southern

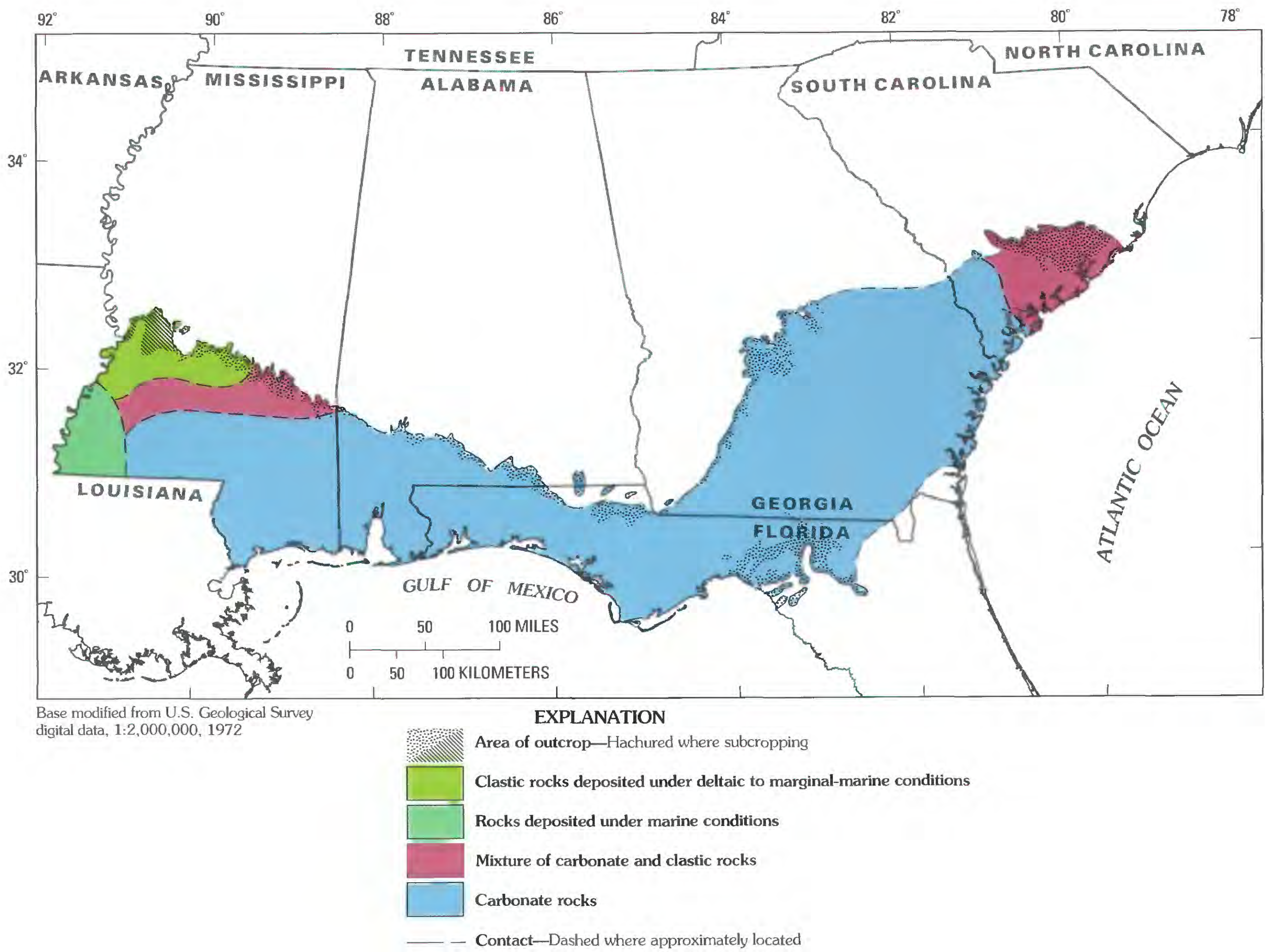


FIGURE 15.—Distribution of major lithofacies in the Southeastern Coastal Plain during Oligocene time.

South Carolina and contains beds with both terrigenous quartz sand and a large calcium carbonate content.

The carbonate platform and bank deposits of southeastern Mississippi, southwestern Alabama, and panhandle Florida consist of soft, glauconitic, highly fossiliferous (pelecypod-gastropod cast-and-mold and bryozoan remains) limestone of the Bumpnose Formation and soft, highly fossiliferous limestone, lime mudstone, and wackestone that grade southwest to deeper water limestone and dolomite of the Marianna Formation. Carbonate platform deposits in Georgia and northern Florida consist of a pelecypod cast-and-mold limestone of the Suwannee Limestone, an integral part of the Floridan aquifer system, interbedded locally with medium- to coarsely crystalline, saccharoidal, vuggy dolomite.

FOREST HILL AND RED BLUFF FORMATIONS

The Forest Hill (Cooke, 1918) and Red Bluff (Hilgard, 1860) Formations represent the oldest clastic beds of Oligocene age that crop out in the Southeastern Coastal Plain; they are found in an area that extends westward from southwestern Alabama into southwestern Mississippi and continues into Louisiana. The Red Bluff Formation consists of fossiliferous, dark-gray silty clay that commonly contains a concentration of ironstone in its lowermost outcropping parts. The Red Bluff grades upward as well as laterally to deltaic silty clay and sand of the Forest Hill Formation that lies to the west. As the Red Bluff Formation extends east into Clarke County, Ala., it becomes progressively more calcareous and eventually merges with limestone of the Bumpnose Formation. The origin of the Red Bluff Formation is probably associated with open-marine, middle sublittoral deposition (Hazel and others, 1980) or marine-shelf and delta-margin environments (Dockery, 1982).

The Forest Hill Formation is characterized by sand, laminated sand and clay, and minor lignite, glauconite, and fossil material. The Forest Hill is part of a delta that prograded southward and southwestward across western and central Mississippi; Dockery (1982) reports evidence of sporadic channel-sand deposits in several shallow test holes. The upper part of the formation consists of estuarine and lagoonal clay and sand.

MINT SPRING AND MARIANNA FORMATIONS

The Mint Spring Formation (Cooke, 1918) consists of fossiliferous sand and moderate amounts of clay deposited under nearshore-shelf conditions. Locally, crossbedded sand deposits occur where the unit crops out in southern Mississippi. The formation grades upward and laterally to the lime mudstone or wackestone of the Marianna Formation (Johnson, 1892) in eastern Mississippi and western Alabama, which was probably deposited as part of a widespread carbonate bank removed from the influence of terrigenous sedimentation (Coleman, 1983).

GLENDON, BYRAM, AND BUCATUNNA FORMATIONS

The Glendon Formation (Hopkins, 1917) consists of a ledge-forming limestone that crops out in Mississippi and western Alabama and is interbedded with some intervening sand and clay beds. This unit is probably associated with the Oligocene carbonate bank deposits described above. Although the characteristically high resistivity of the Glendon Formation is readily recognized on electric logs from shallow wells, Cagle (1963) found it was not possible to differentiate the Glendon from the Marianna Formation in Escambia County, Ala. The Glendon is overlain by fossiliferous, calcareous sand and limestone of the Byram Formation (Casey, 1902) that was deposited in relatively quiet marine waters such as an open bay or shelf lagoon. The Bucatunna Formation (Blanpied, 1934) consists of thinly bedded, dark-brown clay that is commonly lignitic and contains some fine glauconitic sand and sandy clay beds. The Bucatunna Formation represents deposition in a marginal-marine lagoonal environment.

CHICKASAWHAY LIMESTONE AND PAYNES HAMMOCK FORMATION

The Chickasawhay Limestone (Blanpied, 1934), a soft, fossiliferous, clayey to sandy limestone and interbedded marl and clay that crops out in southeastern Mississippi, southwestern Alabama, and panhandle Florida, was deposited in shallow-marine to estuarine conditions. The Chickasawhay Limestone is not considered to be a productive water-bearing unit in Mississippi, but its lithologic character varies as it extends into panhandle Florida, where it consists of gray to light-gray, hard, highly porous or vesicular limestone and dolomitic limestone and comprises the Upper Floridan aquifer (Miller, 1986).

The Paynes Hammock Formation (MacNeil, 1944) was originally defined as the upper member of the Chickasawhay Limestone because it consists of a lithology similar to that of the Chickasawhay. The Paynes Hammock is composed of fossiliferous, sandy, glauconitic marl interbedded with clay, sandstone, and limestone. It can be distinguished in the Mississippi subsurface by its somewhat lower electric log resistivity as compared with that of the Chickasawhay Limestone (May and others, 1974), but the two are not easily separated in the Florida subsurface.

COOPER FORMATION (ASHLEY MEMBER)

The Ashley Member (Ward and others, 1979), the uppermost member of the Cooper Formation, is recognized as being of Oligocene age and consists of phosphatic, muddy, calcareous, very fine sand where it occurs in the shallow subsurface and crops out in South Carolina. It represents deposition in a marine shallow-shelf to marginal-marine environment. As is true of the Cooper Formation's older members of late Eocene age, the Ashley Member is not a water-bearing unit; it acts, in large part, as a confining layer to underlying, more permeable limestone units.

CHANDLER BRIDGE FORMATION

The Chandler Bridge Formation (Sanders and others, 1982) is the name applied to thin, noncalcareous to slightly calcareous beds of fine- to medium-grained quartz-phosphate clayey sand of Oligocene age that are found in coastal counties of southern South Carolina. The permeability of these beds has resulted in the leaching of calcium carbonate. These beds contain phosphatized fossil material, including foraminiferal molds, solitary corals, pelecypods, and vertebrate bone material. These strata are localized in extent and probably represent marine to marginal-marine deposits laid down in nearshore-marine or lagoonal environments.

MIOCENE SERIES

Rocks of Miocene age crop out as a wide band that extends eastward from Louisiana across Mississippi. This band thins progressively across southern Alabama and panhandle Florida (fig. 16) but becomes much wider across southeastern Georgia and southern South Carolina. Beds of Miocene age in Georgia represent the most widespread time-stratigraphic Coastal Plain sequence that crops out in that State. The thickest sediments of Miocene age are found in coastal areas of Mississippi, where they are known to exceed 3,000 ft (Newcome, 1975).

The several Miocene facies types that are present in the study area include rock types associated with carbon-

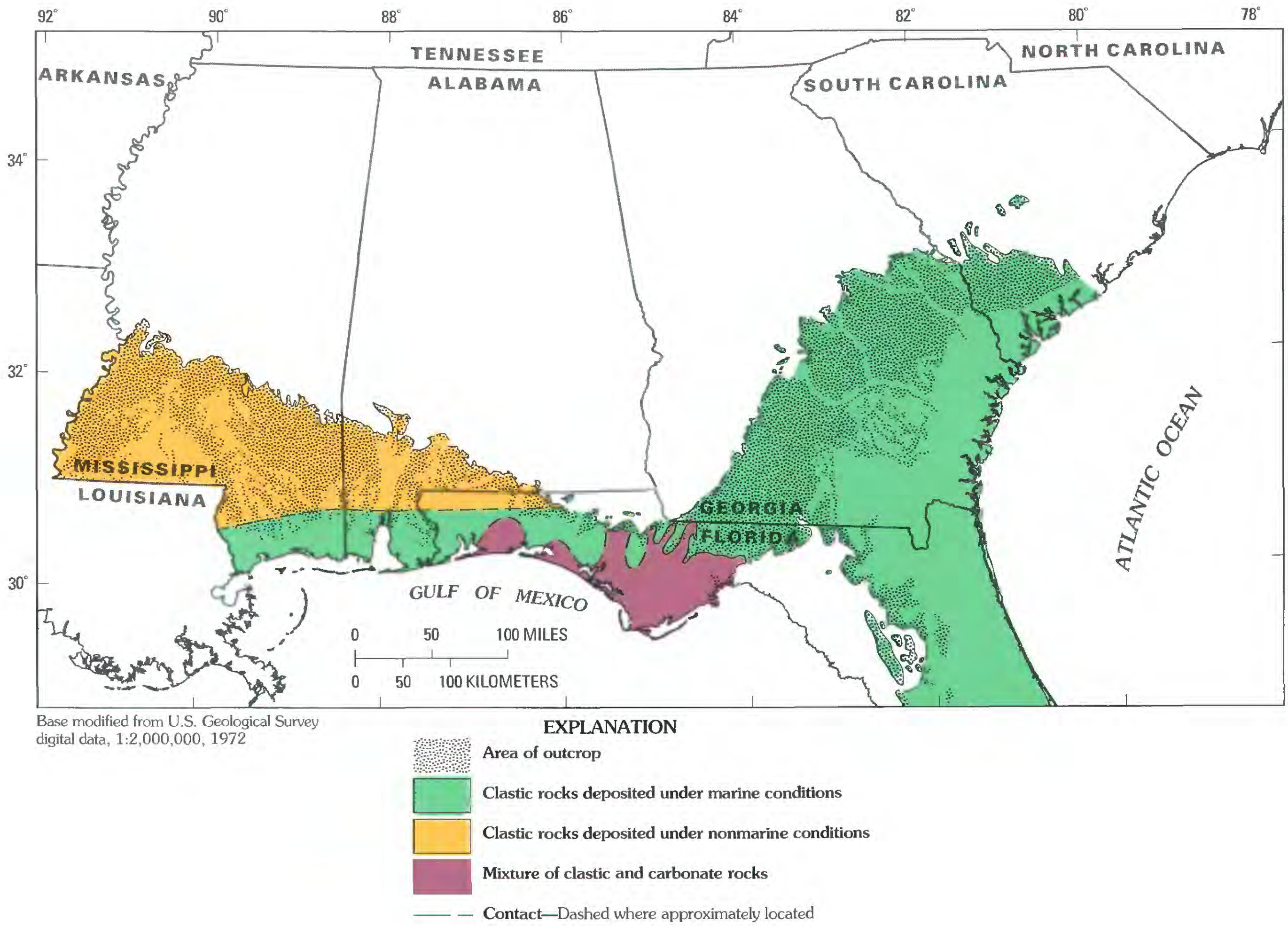


FIGURE 16.—Distribution of major lithofacies in the Southeastern Coastal Plain during Miocene time.

ate platform as well as siliciclastic marine and nonmarine environments. Siliciclastic marine Miocene deposits were laid down under a wide range of conditions, including transitional or nearshore-marine, marginal-marine, and marine shallow-shelf conditions. Carbonate-platform deposits formed during the Miocene are far less extensive than the widespread limestone-dolomite-evaporite sequence formed during Paleocene and Eocene time. Carbonate Miocene strata are, for the most part, restricted to the southernmost counties of central panhandle Florida. Here, the Tampa Limestone unconformably overlies lithologically similar rocks of Oligocene age. Dolomitic limestone and dolomite form the basal part of the Hawthorn Formation over a wider area but are not uniform in extent (Sever and others, 1967). In panhandle Florida the Tampa Limestone consists of a light-gray, sandy, pelecypod- and gastropod-rich limestone. To the north it pinches out and is overlapped by younger clastic deposits (Miller, 1986). Marsh (1966) reported that carbonaceous material is locally associated with this fossiliferous limestone where it is found in the subsurface of Escambia and Santa Rosa Counties, Fla.

Miocene beds that crop out in Mississippi and southwestern Alabama consist largely of nonmarine, fine to coarse sand with subordinate amounts of gravel, varicolored silt, siltstone, silty clay, and clay. Deltaic, lagoonal, and other brackish-water marine deposits consisting of silty to arenaceous clay of Miocene age are found to the south, where they are overlain in upland areas by Pleistocene beds. Newcome (1975) concluded that it was not possible to extend these outcropping units into the subsurface. The inability to differentiate these beds into distinctive lithologic units is attributed to a high degree of lithologic variability within them. The lack of paleontologic data or widespread marine marker horizons has further hindered their subdivision. However, in coastal areas of Louisiana and Mississippi to the west and southwest, an alternating Miocene sequence of regressive, nonmarine sand, silt, and clay and transgressive, shallow-marine clay beds containing benthonic Foraminifera allows a greater degree of subsurface differentiation. Nonmarine and transitional-marine Miocene deposits are also found in southwestern Alabama but are undifferentiated (Cagle and Newton, 1963; Reed, 1971a, b). In southern Georgia, outcropping sediments of Miocene age primarily consist of marginal-marine, phosphatic arenite and palygorskite-sepiolite clay (fullers earth) that grade to, and are overlain by, fluvial and lacustrine sand. In coastal areas of northwestern peninsular Florida, Miocene deposits are absent.

CATAHOULA SANDSTONE, HATTIESBURG FORMATION, PASCAGOULA FORMATION, AND UNDIFFERENTIATED ROCKS

Miocene rocks that crop out in Mississippi can be divided into the Catahoula Sandstone and the Hattiesburg and Pascagoula Formations. As discussed before, extension of these lithostratigraphic units into the Mississippi subsurface or even along strike into Alabama is difficult; accordingly, many of these Miocene strata are usually characterized as undifferentiated. The Catahoula Sandstone (Veatch, 1905; Blanpied, 1934) consists of fine to medium sand of nonmarine (fluvial) origin in updip outcrop areas. The occurrence of carbonaceous and calcareous material in the more southern areas of outcrop suggests that these beds grade to a transitional- or marginal-marine sequence. The overlying Hattiesburg Formation (Johnson, 1893; MacNeil, 1947) consists of clay and lesser amounts of silt, sand, and carbonaceous material. The Pascagoula Formation overlies the Hattiesburg Formation (McGee, 1892) and consists of sparsely fossiliferous, marine clay of deltaic to brackish-water origin. In Alabama, the Pascagoula and Hattiesburg Formations consist of similar clayey material and remain largely undifferentiated.

PLIOCENE SERIES

In terms of overall thickness, Pliocene strata are poorly represented in the eastern Gulf and South Atlantic Coastal Plain. The thickest Pliocene deposits are found in Mississippi, where the Graham Ferry Formation and the Citronelle Formation combine to attain a thickness of 400 ft near Pascagoula in Jackson County and exceed 1,000 ft near Gulfport in Harrison County. In most of the study area, Pliocene deposits are less than 200 ft thick, particularly where they crop out in the hilly uplands. For example, Pliocene sediments of southeastern Georgia average less than 100 ft in thickness, whereas equivalent beds in South Carolina are less than 50 to 100 ft thick. These strata occur largely as isolated outliers or as thin beds in the subsurface of easternmost coastal South Carolina.

EDISTO AND HAWTHORN FORMATIONS

The Edisto Formation (Ward and others, 1979) is the name applied to sandy limestone of early Miocene age that unconformably overlies the Cooper Formation in southern South Carolina. The Edisto occurs as thin erosional remnants and is unconformably overlain by the Pliocene Raysor Formation.

The Hawthorn Formation (Dall and Harris, 1892) is distinguished by its complex, varied lithology that ranges from dolomitic limestone and dolomite to sand, silt, and clay, all of shallow-marine, marginal-marine, and nonmarine origin. The Hawthorn Formation crops out and extends into the shallow subsurface in northern Florida, southern Georgia, and southernmost South Carolina. In an effort to further analyze its highly variable lithologic nature, some workers have attempted to divide the Hawthorn Formation further (Espenshade and Spencer, 1963; Reynolds, 1966; Sever and others, 1967; Miller, 1980), but such discretization is applicable only on a subregional to local basis. In general, however, the Hawthorn Formation consists of a basal dolomite or dolomitic limestone and a middle and an upper clastic member (Scott, 1988). The formation is typified by its predominance of sand, an abundant supply of phosphorite, and a palygorskite-sepiolite clay mineral suite that occurs in the middle and upper unnamed members. The high phosphate content of the formation results in a distinctive gamma ray log pattern; for example, Wait (1970) recognized four inflection points that occur on gamma ray logs for southeastern Georgia as a result of the presence of phosphate.

GRAHAM FERRY AND CITRONELLE FORMATIONS

The Graham Ferry Formation (Brown and others, 1944), named for brackish-water and nonmarine deposits that crop out along the Pascagoula River in Mississippi, primarily consists of clay and sand. The Citronelle Formation is composed of highly permeable quartz sand, chert, and gravel with lenticular clay beds. This formation (Matson, 1916) has been highly dissected by streams and is found as outliers in hilly upland areas of southern Mississippi and southwestern Alabama.

CHARLTON, RAYSOR, YORKTOWN, AND BEAR BLUFF FORMATIONS

The Charlton Formation (Veatch and Stephenson, 1911) is named for exposures that occur along the St. Mary's River near the county line of Charlton County, Ga., and Nassau County, Fla. It is composed of light-colored calcareous clay and impure limestone. The subsurface extent of the Charlton Formation is not well defined; for example, Herrick (1961) grouped it with Pleistocene and Holocene deposits he identified in wells of southeastern Georgia.

The Yorktown Formation (Blackwelder and Ward, 1979) is the name used to describe fossiliferous, sandy and silty limestone and calcareous silty sand of Pliocene age that occur in South Carolina as erosional outliers. The Yorktown is biostratigraphically correlative with shelly calcareous outliers of the Raysor Formation (Blackwelder and Ward, 1979), which can be distinguished from the Yorktown by its greater clastic component. The Goose Creek Limestone (Weems and others, 1982) of early to middle Pliocene age is a fine- to coarse-grained, quartzose, phosphatic, sparsely shelly calcarenite and occurs in outcrop and in the shallow subsurface of Charleston and Berkeley Counties, S.C. It is identified by its calcareous matrix as compared with the quartzose matrix of the Raysor Formation.

The upper Pliocene Bear Bluff Formation (DuBar, 1969) consists of clayey, fine-grained sand, clay, and calcarenite of possible lagoonal or marsh origin. These beds crop out and lie in the shallow subsurface of coastal Horry County, S.C.

PLEISTOCENE AND HOLOCENE SERIES

Rocks of Pleistocene and Holocene age include interbedded sand, gravel, and clay deposits of fluvial and littoral origin that rim the coastline of Mississippi, Alabama, Florida, Georgia, and most of South Carolina. With the exception of the alluvial deposits that in some localities extend to the inner margin of the Coastal Plain, most Pleistocene and Holocene sand, gravel, and clay beds do not extend more than 100 mi landward from the present coastline. In South Carolina, however, a veneer of Pleistocene sediments provides a surface cover over much of the Coastal Plain. They can be broadly categorized as either alluvial terrace deposits or shoreline terrace deposits and were deposited largely in response to climatic changes and (or) eustatic sea level changes that occurred during Pleistocene and Holocene time. Herrick's (1965) thickness map shows Pleistocene deposits to average less than 50 ft in thickness in Georgia; a similar thickness of Pleistocene strata is found in South Carolina (Colquhoun and others, 1983).

Alluvial and terrace deposits adjoin the Mississippi River in Mississippi and are the product of large-scale erosion and deposition during Pleistocene and Holocene time. A number of sedimentary features indicative of fluvial deposition are associated with these rocks, such as abandoned meander scars, oxbow lakes, natural levees, and erosional bluffs that are cut into older beds (Boswell and others, 1968). These alluvial beds typically consist of yellow, orange, and red, subangular to rounded quartz sand, chert, and gravel with lenticular, backswamp clay and silt beds. The terrace deposits consist of multicolored, fine to coarse quartz sand and gravel. Together, alluvial and terrace deposits range from 50 to 200 ft in thickness in the Mississippi River Valley. Separation of these beds into distinctive lithostratigraphic units is difficult; however, Gandl (1982) divided them into a lower gravel and sand, a middle sand, and an upper silty clay.

HYDROGEOLOGY

AQUIFERS AND CONFINING UNITS OF THE SOUTHEASTERN COASTAL PLAIN AQUIFER SYSTEM

Most of the rocks that underlie the Southeastern Coastal Plain in the United States can be assigned either to the clastic Southeastern Coastal Plain aquifer system or to the carbonate Floridan aquifer system. The overwhelming majority of Tertiary and minor Cretaceous carbonate rocks in Alabama, Georgia, South Carolina, and Florida make up the Floridan aquifer system (Miller, 1986; Johnston and Bush, 1988). Low-permeability clastic beds that are interbedded with carbonate rock of Oligocene to Pliocene age form the upper confining unit of the Floridan aquifer system. This upper confining unit is, in turn, overlain by unconsolidated sand and gravel deposits of Pliocene to Holocene age. These uppermost deposits form a surficial aquifer that contains water under water table conditions (fig. 17). Additional detailed information concerning the regional hydrology, geology, and geochemistry of the Floridan aquifer system and its associated confining units is provided in U.S. Geological Survey Professional Paper 1403, chapters A–I.

The Southeastern Coastal Plain aquifer system has been divided into seven regional hydrogeologic units during the study: four regional aquifers and three regional confining units (fig. 18). These hydrogeologic units cannot be adequately described by existing geological nomenclature, partly because of the regional extent of the units and partly because of their poor correspondence with the physical boundaries of rock- and time-stratigraphic units. A major reason for this poor correspondence is that many of the siliciclastic deposits that constitute some of the major aquifer units were deposited in alluvial or transitional- to marginal-marine environments that were restricted in areal extent, particularly when compared with less permeable but regionally more extensive open-water marine deposits. Deeper marine sediments are much easier to correlate, locally and regionally, since they have a more uniform lithologic character that is consistent over a wider area. They also contain faunal elements that are more easily recognized and better understood in terms of interbasin and world-

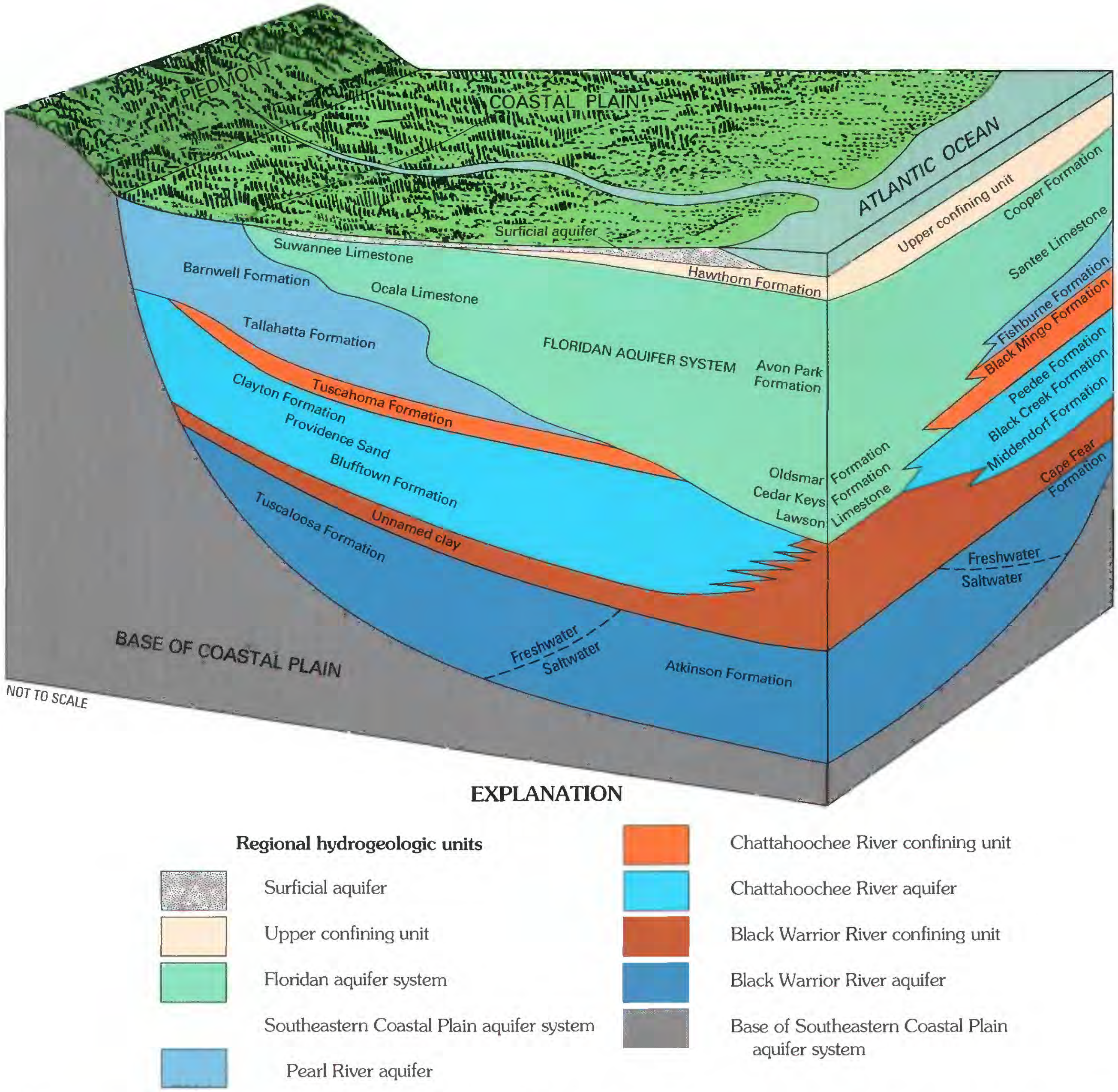


FIGURE 17.—Relations among major aquifers and confining units of the Southeastern Coastal Plain and the Floridan aquifer system.

wide correlation. Accordingly, determination of regional equivalency is more easily established.

A major purpose of this report is to describe the complex nature of Southeastern Coastal Plain sediments and to explain how a host of tectonic elements, sea-level changes, and depositional factors affect physical properties, character, and extent of the rocks. Given the highly varied distribution of marine, marginal-marine, and nonmarine rocks through geologic time and an inherited rock-stratigraphic nomenclature largely created to describe only outcropping beds, it is impractical to apply the existing formational or local-aquifer nomenclature to regional aquifers and confining units that are delineated in this report. Hydrogeologic units defined herein commonly encompass several local aquifers, local confining units, formations, or parts of formations (figs. 18 and 19). Many of the rock-stratigraphic names currently used are defined on the basis of specific lithologic and biostratigraphic criteria, applicable only where the named rocks crop out. The subsurface boundaries of aquifers and

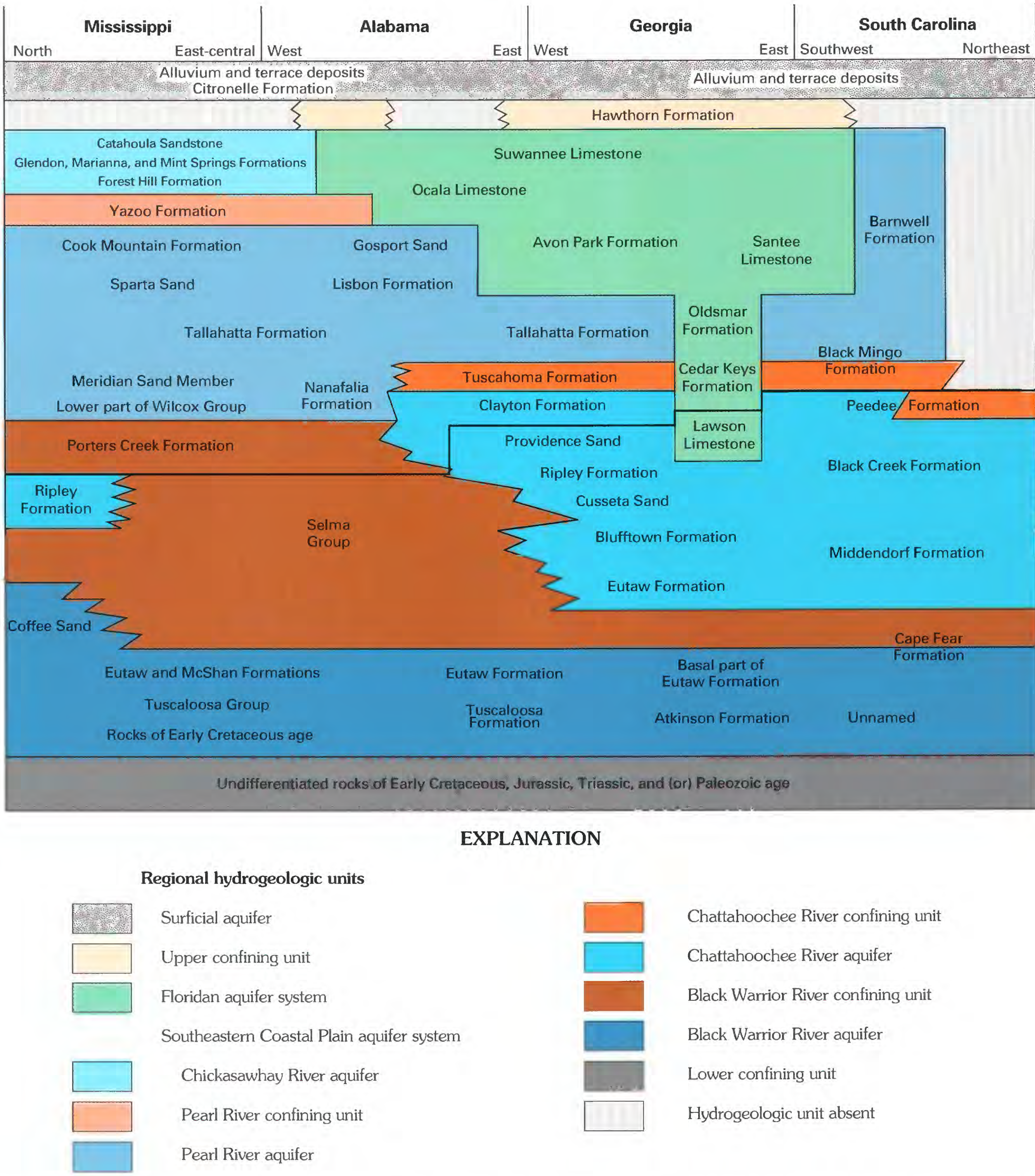


FIGURE 18.—Relations among regional hydrogeologic units and selected rock-stratigraphic units in the Southeastern Coastal Plain (modified from Renken, 1984). Exact correlation of geologic units is not implied.

confining units described in this report have been defined, in part, on the basis of a qualitative appraisal of rock lithology, porosity, and permeability as they can be determined from geophysical borehole log and lithologic sample data. In many places, aquifer and confining unit boundaries did not correspond with formational

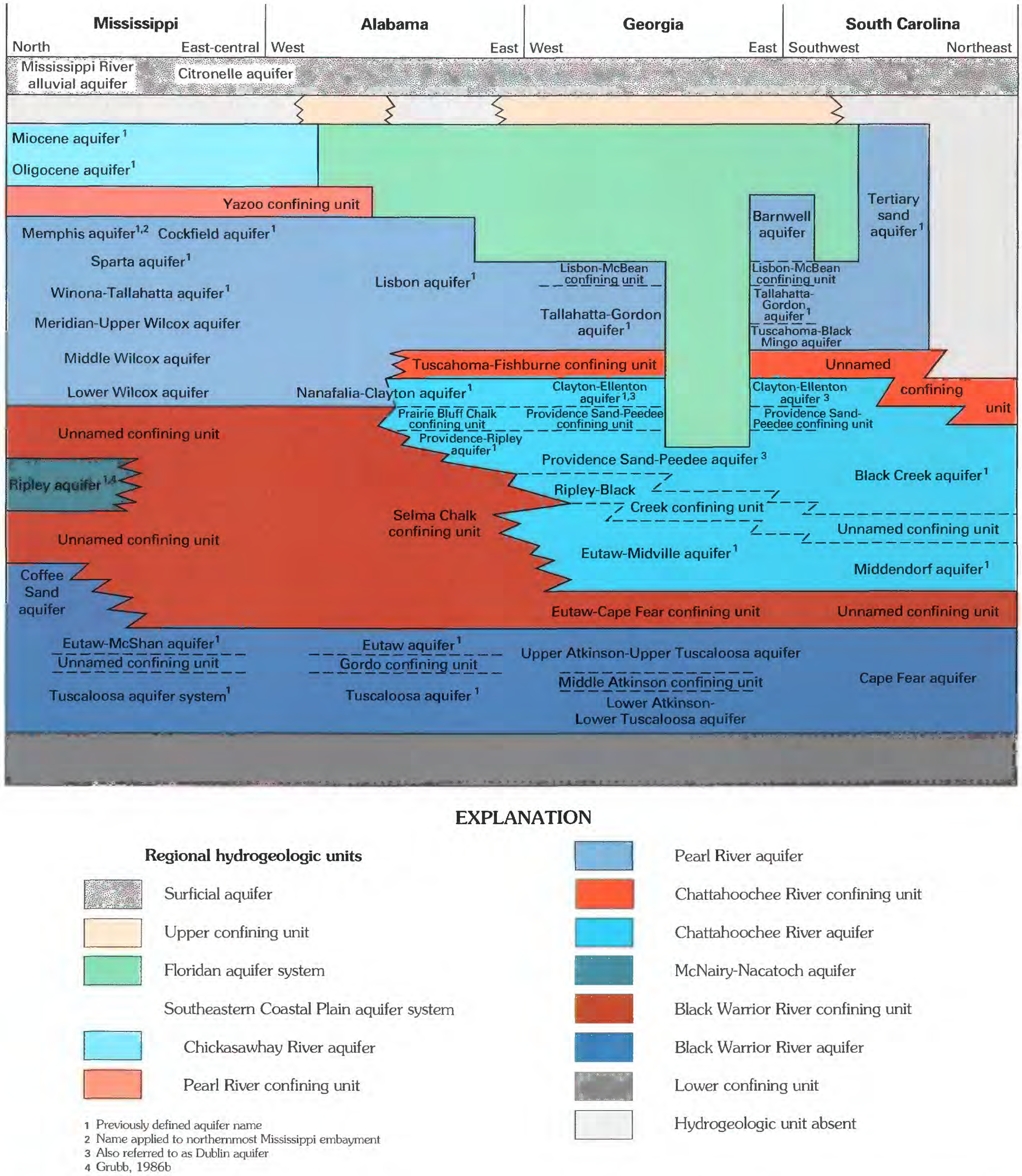


FIGURE 19.—Relations among regional and subregional hydrogeologic units in the Southeastern Coastal Plain aquifer system (modified from Miller and Renken, 1988).

boundaries. Application of a time-stratigraphic terminology to characterize regionally extensive beds of high or lowpermeability that were deposited at different times is equally difficult.

Previous reports of this RASA study (Renken, 1984; Barker, 1985; Wait and others, 1986; Renken and others, 1989) used an alphanumeric terminology to describe the seven different regional hydrogeologic units for simulation purposes. More recently, the alphanumeric designations were replaced by names proposed by Miller and Renken (1988). Each of the four regional aquifers is named for a major river in the study area. Each selected name refers to a river that cuts across the outcrop of the regional aquifer, and part of the aquifer is exposed along the river. Regional confining units that separate the regional aquifers are named the same as the regional aquifer they overlie, largely to avoid introduction of additional names.

The regional aquifers consist mainly of quartzose, coarse to fine sand that is variously glauconitic, feldspathic, calcareous, and fossiliferous to nonfossiliferous, but they locally contain sandstone, gravel, and minor limestone beds. Confining units that bound and separate the regional aquifers are composed of clay, mudstone, siltstone, shale, and chalk. Except where they are covered by younger strata, the aquifers and confining units that make up the Southeastern Coastal Plain aquifer system crop out in adjacent bands that extend from Mississippi to South Carolina (fig. 20) and extend into the subsurface either in a seaward direction or westward toward the Mississippi River. Where the regional aquifers that make up this system are covered by low-permeability rocks, the aquifers contain water under confined conditions everywhere. In outcrop areas, discrete water-bearing horizons within a given aquifer may be locally separated by beds of clay, shale, mudstone, and marl; water may occur under confined conditions in these areas as well. Nowhere in the entire study area is ground water found that contains less than 10,000 mg/L of dissolved solids below depths of 4,500 ft below sea level (Cushing, 1966; Gandl, 1982; Lee and others, 1986; Strickland and Mahon, 1986).

SURFICIAL AQUIFER

The surficial aquifer is the uppermost hydrologic unit that occurs within the Southeastern Coastal Plain. However, the surficial aquifer is not considered to be part of the Southeastern Coastal Plain aquifer system nor the adjoining Floridan aquifer system; the aquifer is considered hydrologically important because it functions as a source of recharge to, and discharge from, underlying flow systems.

In Florida, southern Alabama, southern and southeastern Georgia, and southern South Carolina, the surficial aquifer is underlain by the Floridan aquifer system and its upper confining unit (figs. 19 and 20). In Mississippi, southwestern Alabama, and eastern South Carolina, the aquifer extends well beyond the northern and western margin of the Floridan aquifer system and overlies three aquifers of the Southeastern Coastal Plain aquifer system. In southern Mississippi and southwestern Alabama, the surficial aquifer (named locally the Citronelle aquifer) overlies the Southeastern Coastal Plain aquifer system's uppermost Chickasawhay River aquifer. In a 500-mi^2 area of northwestern and westernmost Mississippi, the surficial aquifer (named locally the Mississippi River alluvial aquifer (Dalsin, 1978)) overlies the Pearl River aquifer. In eastern South Carolina, the surficial aquifer overlies both the Chattahoochee River aquifer and the Chattahoochee River confining unit.

The surficial aquifer is a relatively permeable sand and gravel unit and contains lesser amounts of clay that range from Pliocene to Holocene in age. In southern Mississippi and southwestern Alabama, the surficial aquifer consists mostly of quartz sand, chert, gravel, and clay lenses of the Citronelle Formation that occur as hilltop erosional outliers. The thickest part of the aquifer occurs near the coast, rarely exceeding 100 ft. The surficial aquifer of northwestern Mississippi is divided into three layers: a lower gravel and sand layer, a middle sand layer, and a discontinuous, upper, silty clay layer. The thickness of the aquifer that occurs in these areas ranges from less than 50 to more than 200 ft and is greatest where alluvium infills former stream channels. Coastal terrace deposits make up the surficial aquifer in South Carolina and consist of sand, shell debris, and clay that are less than 40 ft thick, except where they infill channel deposits.

The surficial aquifer is recharged by rainfall and mostly contains water under unconfined conditions. Infiltrating rainfall percolates downward through the surficial aquifer, recharging permeable rock within the Southeastern Coastal Plain or Floridan aquifer systems or quickly discharging water to adjoining streams and rivers. The surficial aquifer is only partially saturated in most areas of Mississippi and southwestern Alabama. The hydraulic conductivity of the surficial aquifer in northwestern Mississippi is reported to range from 170 to 190 ft/d (Dalsin, 1978); in southern Mississippi, the hydraulic conductivity of the aquifer ranges from 82 to 200 ft/d (Boswell, 1979a). In South Carolina, the surficial aquifer is relatively thin and commonly unsaturated, as it lies above the local water table.

CHICKASAWHAY RIVER AQUIFER

The thick, seaward-dipping sequence of clastic and minor limestone beds of Oligocene and Miocene age present in Mississippi and Alabama has been designated

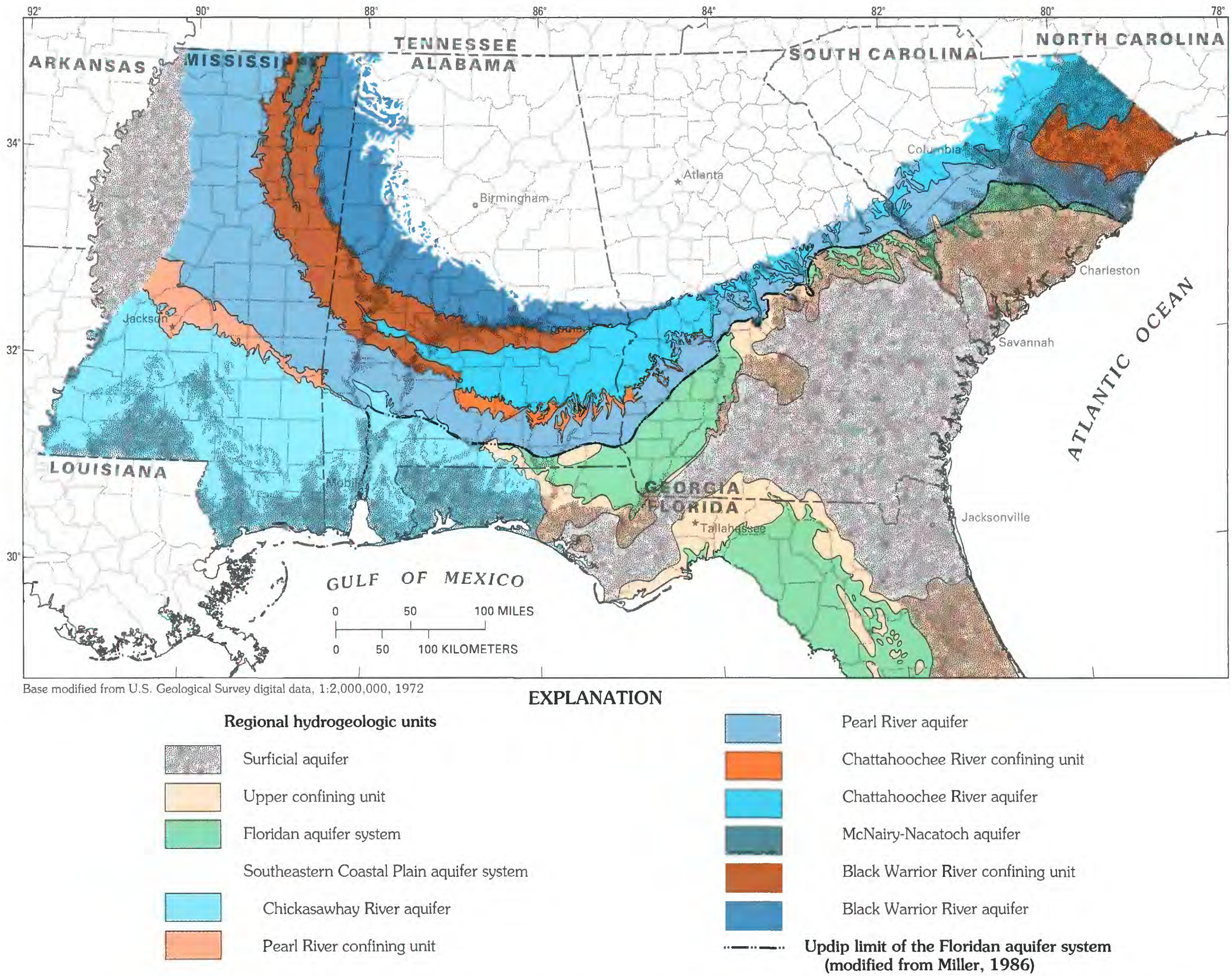


FIGURE 20.—Outcrop extent of regional aquifers and confining units of the Southeastern Coastal Plain aquifer system (modified from Renken and others, 1989).

the Chickasawhay River aquifer. This aquifer crops out as a 30- to 60-mi-wide band in southern Mississippi and southwestern Alabama and extends into Louisiana, where it has been considered part of the coastal lowland aquifer system studied by the Gulf Coastal Plain RASA team (Grubb 1986a, b). It is overlain in western Alabama and Mississippi by a veneer of sand and gravel of Pliocene, Pleistocene, and Holocene age that is part of a surficial aquifer that extends westward from Florida. In southwestern Alabama, the Chickasawhay River aquifer overlaps, and in places is hydraulically interconnected with, the Floridan aquifer system. The Chickasawhay River aquifer overlies calcareous marine clay of late Eocene and Oligocene age (Yazoo and Red Bluff Formations, pl. 2) in Mississippi and westernmost Alabama that together constitute the Pearl River confining unit (fig. 21, pl. 19).

The Chickasawhay aquifer is a highly interbedded sequence of sand, clay, and minor limestone beds that were deposited in fluvial to marine environments. The shallowest water-bearing units contain ground water under water table conditions. Deeper horizons contain water under confined conditions. Recharge to the aquifer occurs by precipitation falling directly on outcrop areas or by downward leakage from overlying permeable units in the surficial aquifer.

ROCKS OF MIOCENE AGE

Miocene strata in Mississippi and southwestern Alabama collectively form prolific water-bearing units whose uppermost water-bearing sands are developed for water supply. Deeper water-bearing sands remain untapped largely due to the sufficient supply of ground water from shallower horizons. The average transmissivity of the water-bearing units within the Miocene sediments in Mississippi is reported (Newcome, 1975) to be 13,000 ft^2/d, and the average hydraulic conductivity is 95 ft/d.

Water-bearing sands of the Pascagoula and Hattiesburg Formations and the Catahoula Sandstone collectively constitute the upper part of the Chickasawhay River aquifer where the regional aquifer crops out in Mississippi. Because of the high degree of lithologic variability associated with these units as they extend into Alabama or into the subsurface of both States (fig. 21, pl. 19), local water-bearing units are difficult to correlate over any great distance.

ROCKS OF OLIGOCENE AGE

Rocks of the Byram, Glendon, Marianna, and Mint Springs Formations of the Vicksburg Group combine with sandy strata of the Forest Hill Formation to form the "Oligocene aquifer system" discussed by Gandl (1979) in Mississippi. The Oligocene aquifer system makes up the lower part of the Chickasawhay River aquifer of this report. The Red Bluff Formation and Chickasawhay Limestone are included as part of the "Oligocene aquifer system" where they contain local sand lenses or highly developed solution channels. Beds in Alabama and Florida equivalent to these permeable Oligocene units are included as part of the Floridan aquifer system. The Oligocene part of the Chickasawhay River aquifer is only 100 to 200 ft thick and contains water with less than 1,000 mg/L of dissolved solids. The reported transmissivity of this part of the regional aquifer ranges from 120 to 3,300 ft^2/d, and the estimated hydraulic conductivity ranges from 3 to 60 ft/d (Gandl, 1979, 1982).

PEARL RIVER CONFINING UNIT

The Pearl River confining unit underlies the Chickasawhay River aquifer and extends from western Mississippi into westernmost Alabama as a 30- to 40-mi-wide outcrop band. Its width of outcrop decreases in Alabama, as it is overlapped by the Chickasawhay River aquifer. The Pearl River confining unit extends westward into Louisiana and was included as the Vicksburg-Jackson confining unit in the Gulf Coastal Plain regional aquifer system (Grubb, 1986b). In the subsurface, the Pearl River confining unit thins as it extends eastward into Alabama, grading from a poorly permeable, clastic marine unit to a highly permeable, carbonate platform and bank sequence that includes the Ocala Limestone, the Bumpnose Formation, and the Suwannee Limestone that are all part of the Floridan aquifer system (fig. 22, pl. 20).

Three formations of late Eocene and early Oligocene age (the Red Bluff, Yazoo, and Moodys Branch Formations) combine to form the Pearl River confining unit in Mississippi (figs. 21, 23; pls. 19, 21). In general, these three formations are not considered to be productive water-bearing units, as can be readily determined by their clayey, marly texture. Gandl (1982) reports, however, that the Cocoa Sand Member of the Yazoo Formation forms a 40-ft-thick aquifer locally in Clarke and Wayne Counties, Miss. Similarly, the Moodys Branch Formation locally yields water in sufficient quantities for domestic use.

PEARL RIVER AQUIFER

A thick section of unconsolidated to poorly consolidated sand, sandstone, gravel, and minor limestone beds of Paleocene to late Eocene age forms the Pearl River aquifer, named for the Pearl River transecting the aquifer in Mississippi. Local sand beds of Late Cretaceous age in South Carolina (equivalent to part of the Peedee Formation) are also included as part of the Pearl

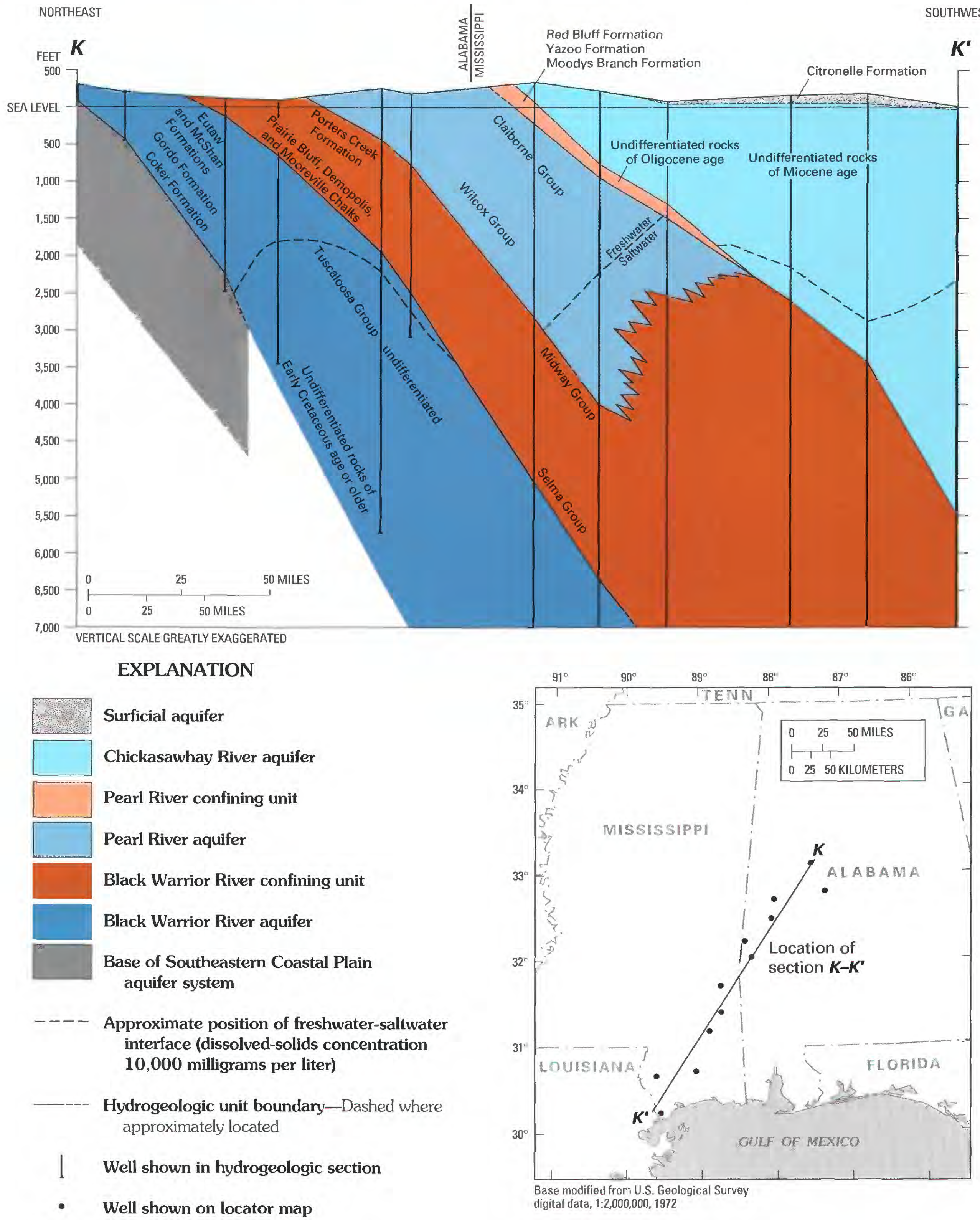


FIGURE 21.—Generalized hydrogeologic section *K–K'* from Tuscaloosa County, Ala., to Hancock County, Miss.

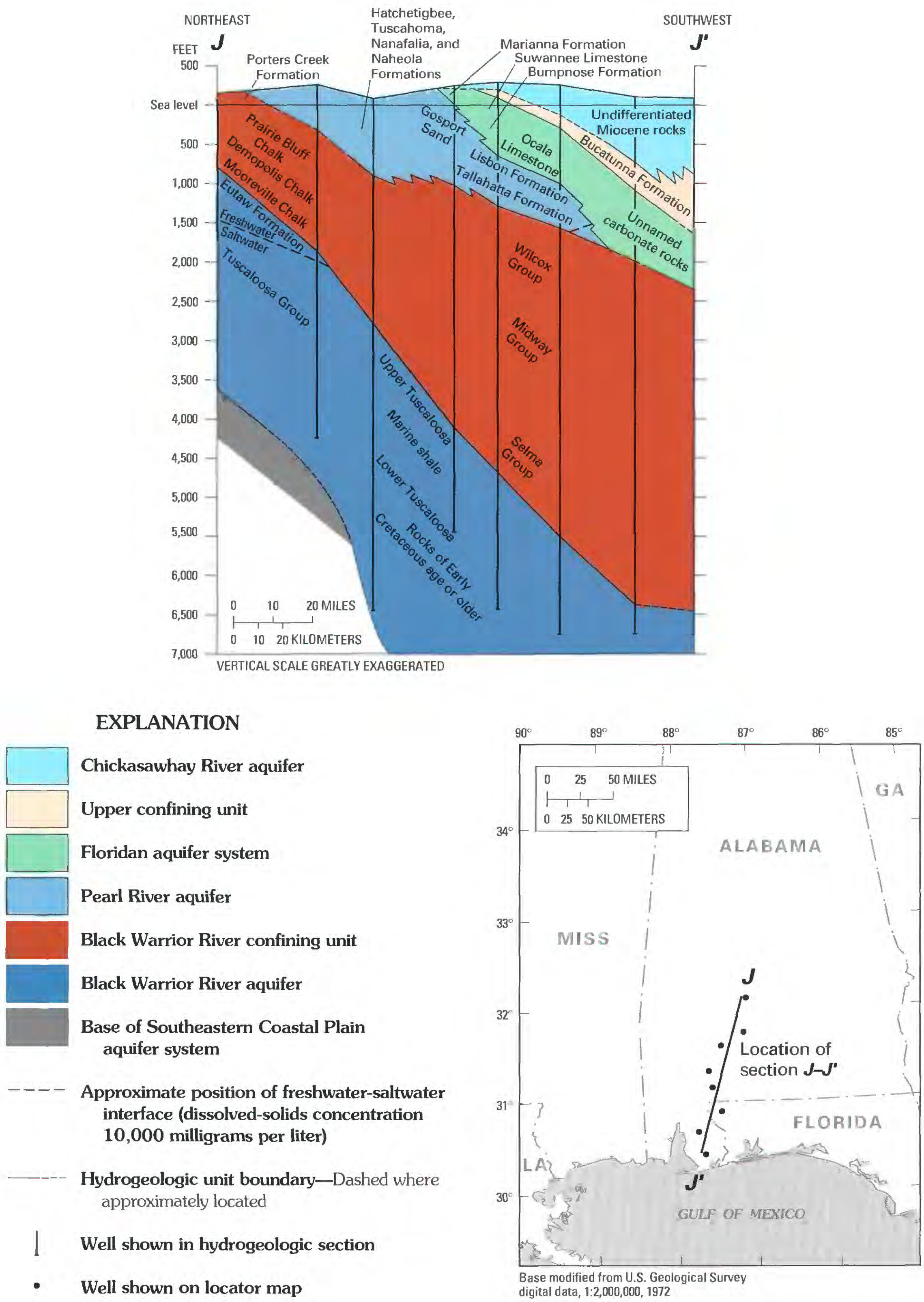


FIGURE 22.—Generalized hydrogeologic section *J–J'* from Dallas County to Baldwin County, Ala.

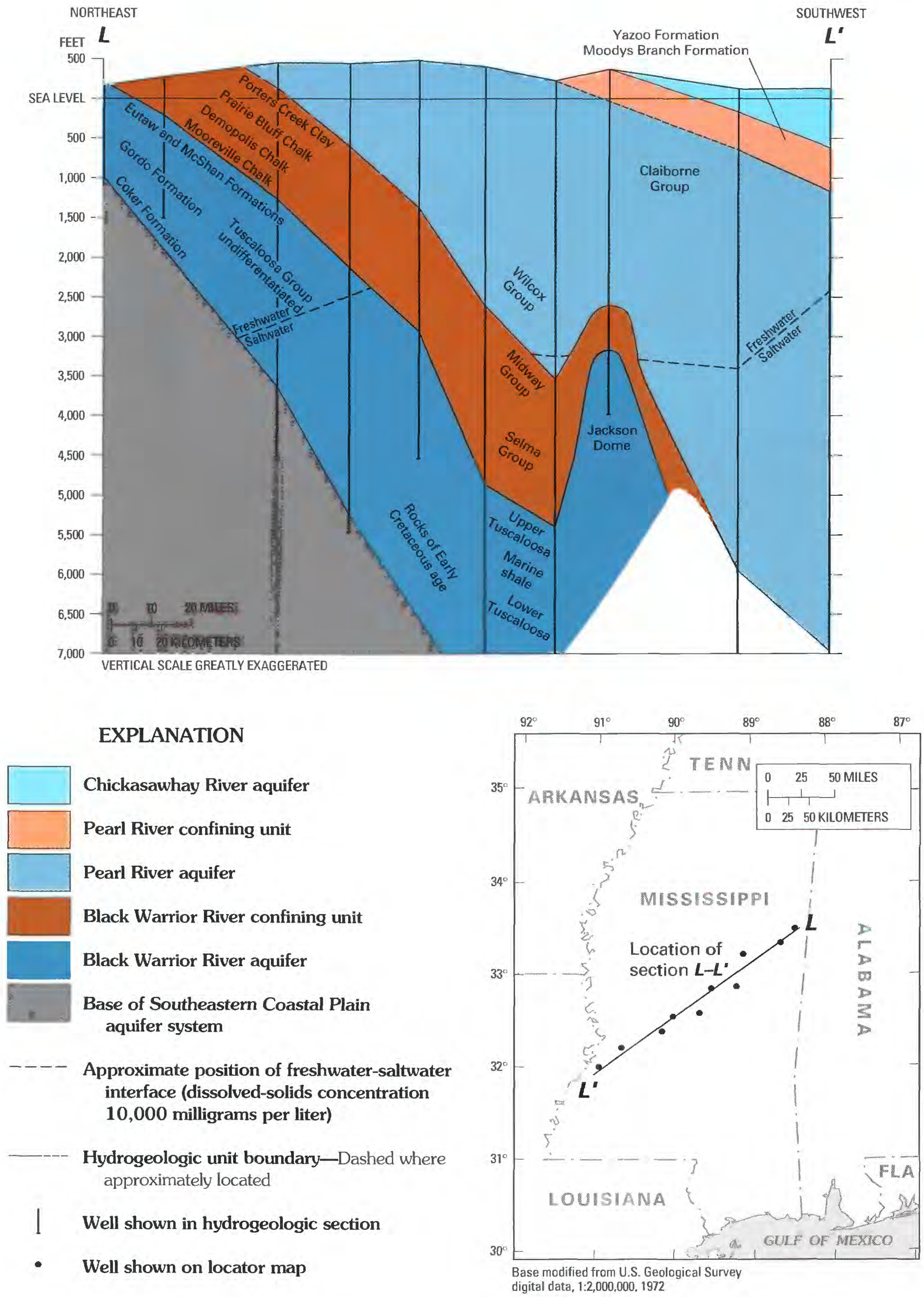


FIGURE 23.—Generalized hydrogeologic section *L–L'* from Lowndes County to Claiborne County, Miss.

River aquifer (fig. 24, pl. 22). Sediments of the Pearl River aquifer were largely deposited under marginal-marine conditions except in Mississippi, where they are dominated by a thick fluvial sequence. The Pearl River aquifer is composed largely of fine to coarse, massive to thinly bedded sand, but contains glauconitic and feldspathic sand in places. Interbedded and interlaminated clay, shale, marl, and mudstone stratify the Pearl River aquifer in some localities and form important local confining beds; several are described in greater detail below.

The Pearl River aquifer extends from northern Mississippi to central South Carolina. West of central Mississippi, the Pearl River aquifer becomes part of the thick, extensive Mississippi embayment aquifer system studied by the Gulf Coastal Plain RASA team (Grubb, 1986a, b) and can be mapped as far west as Texas. The Pearl River aquifer crops out as a 20- to 30-mi-wide band in central South Carolina but decreases in width to a 10- to 20-mi band throughout Georgia and central Alabama; its width of outcrop expands to about 30 to 60 mi across Mississippi and western Alabama (fig. 25, pl. 23). In north-central Georgia, the Pearl River aquifer overlaps deeper water-bearing strata and crops out adjacent to the Fall Line. The Pearl River aquifer dips seaward in South Carolina, Georgia, and eastern Alabama at a gradient of about 10 to 30 ft/mi; in Mississippi, this gradient increases to about 30 to 45 ft/mi and the sediments dip to the south, southwest, and west (pl. 23). Where the Pearl River aquifer is overlain by alluvial materials that are part of a surficial aquifer in northwestern Mississippi, the top of the Pearl River aquifer is nearly flat because it represents an erosional flood-plain surface created by the ancestral Mississippi River (figs. 25, 26; pls. 23, 24).

In most places, the Pearl River aquifer grades seaward from porous sand, sandstone, gravel, and limestone beds into low-permeability clay, shale, mudstone, chalk, and chalky limestone that mark its downdip limit. In central and eastern Alabama, southern Georgia, and southwestern South Carolina, however, the Pearl River aquifer grades into, or is overlain by, stratigraphically equivalent and hydraulically interconnected permeable limestone and dolomite units that are part of the Floridan aquifer system (figs. 24, 27–33; pls. 22, 25–31). The boundary between the two aquifers represents a transitional or facies boundary, separating carbonate rocks of the Floridan aquifer from underlying clastic strata of the Pearl River aquifer. Consequently, the configuration of the top of the Pearl River aquifer is largely coincident with the base of the Floridan aquifer system (Miller, 1986) where the two units are juxtaposed. The "transgression" of this facies boundary across time-stratigraphic lines, shown on many of the hydrogeologic sections presented in this report, explains the diversity of the rocks that constitute the top of the Pearl River aquifer.

The Pearl River aquifer is underlain by sedimentary rocks of Paleocene and Cretaceous age that are part of two different regional confining units (Chattahoochee River and Black Warrior River confining units). A more detailed description of these two confining units follows in a later section. A shallow confining unit underlies the Pearl River aquifer in central and eastern Alabama, Georgia, and South Carolina but grades to more permeable beds that are water-bearing units in western Alabama. Deeper, low-permeability rocks form a confining unit that underlies the aquifer in Mississippi and western Alabama. The Pearl River aquifer is considerably thicker to the west in Mississippi than from central Alabama eastward (fig. 34; pls. 32, 33).

The northern limit of water in the Pearl River aquifer having concentrations of dissolved solids greater than 10,000 mg/L is shown in figure 25 and plates 23 and 32. The equal concentration line of 10,000 mg/L was derived largely from the work of Boswell (1976a, b), Spiers (1977a, b), and Sprinkle (1982). Nearly the entire aquifer contains freshwater (water containing less than 10,000 mg/L of dissolved solids) in eastern Alabama, Georgia, and South Carolina. The thickness of the freshwater column exceeds 3,000 to 4,000 ft in a band that extends from northeastern Leake and northwestern Neshoba County, Miss., to southern Clarke County, Ala. The freshwater column is considerably thinner in the eastern half of the study area, only locally exceeding 500 ft in thickness in southernmost Georgia and panhandle Florida.

ROCKS OF JACKSONIAN AGE

Rocks of late Eocene (Jacksonian) age form the uppermost part of the Pearl River aquifer in middip and downdip areas of southwestern Alabama and where the aquifer crops out and lies in the shallow subsurface of eastern Georgia and western South Carolina (pl. 23). In the latter areas, rocks of Jacksonian age consist of deep-red, fine to coarse, arkosic quartz sand (Barnwell Formation and equivalents); in southwestern Alabama, they consist of unnamed calcareous, glauconitic sand and interbedded clay, considered equivalent to the outcropping Moodys Branch Formation.

Tobacco Road Sand, Barnwell Formation, and Clinchfield Sand

Specific information regarding the water-bearing capability of the Tobacco Road Sand is limited; until recently, it had been grouped as part of the "Barnwell aquifer" of local usage. The "Barnwell aquifer," a complexly interbedded sequence of transitional-marine to

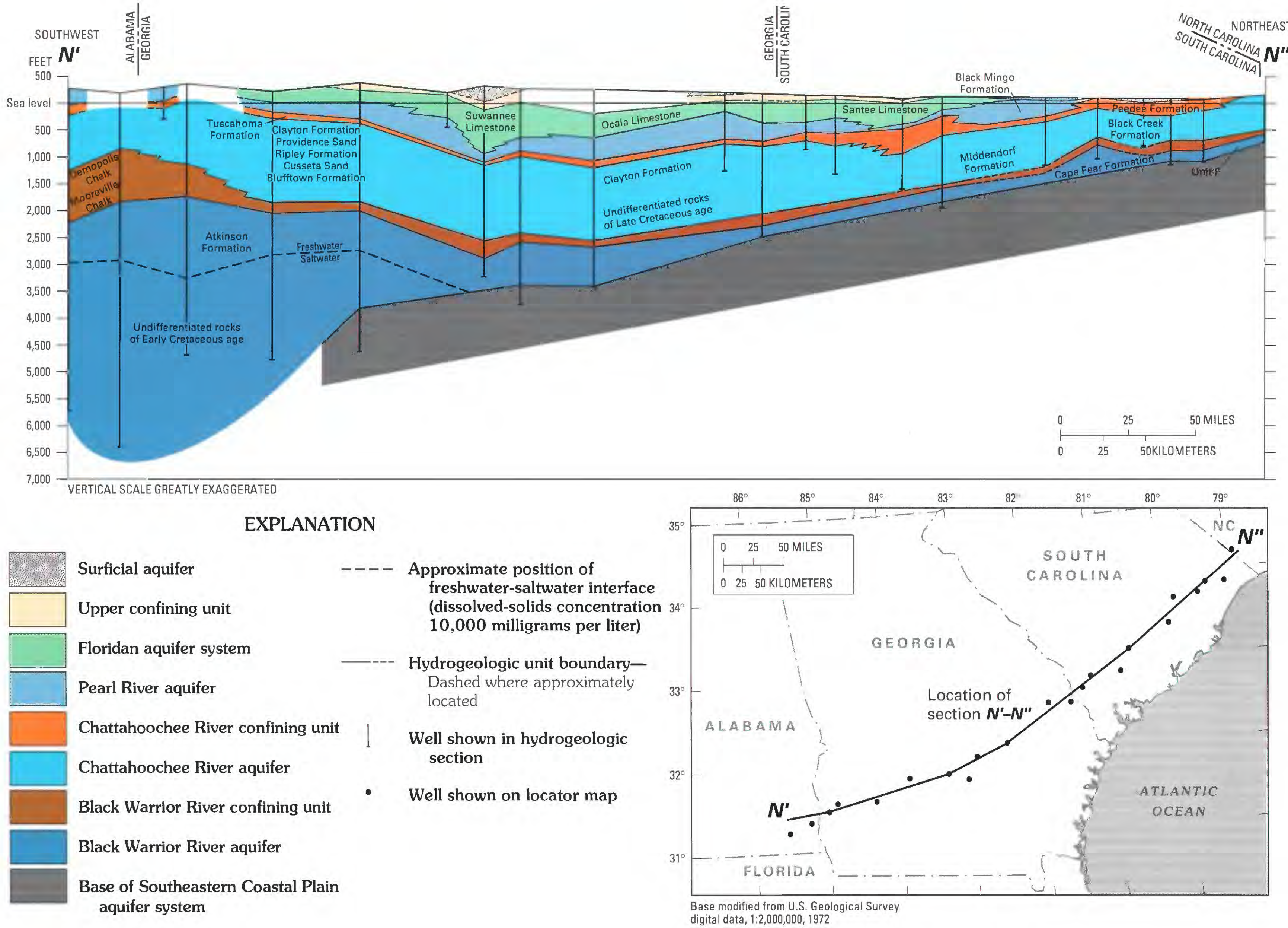


FIGURE 24.—Generalized hydrogeologic section N'–N'' from Houston County, Ala., to Columbus County, N.C.

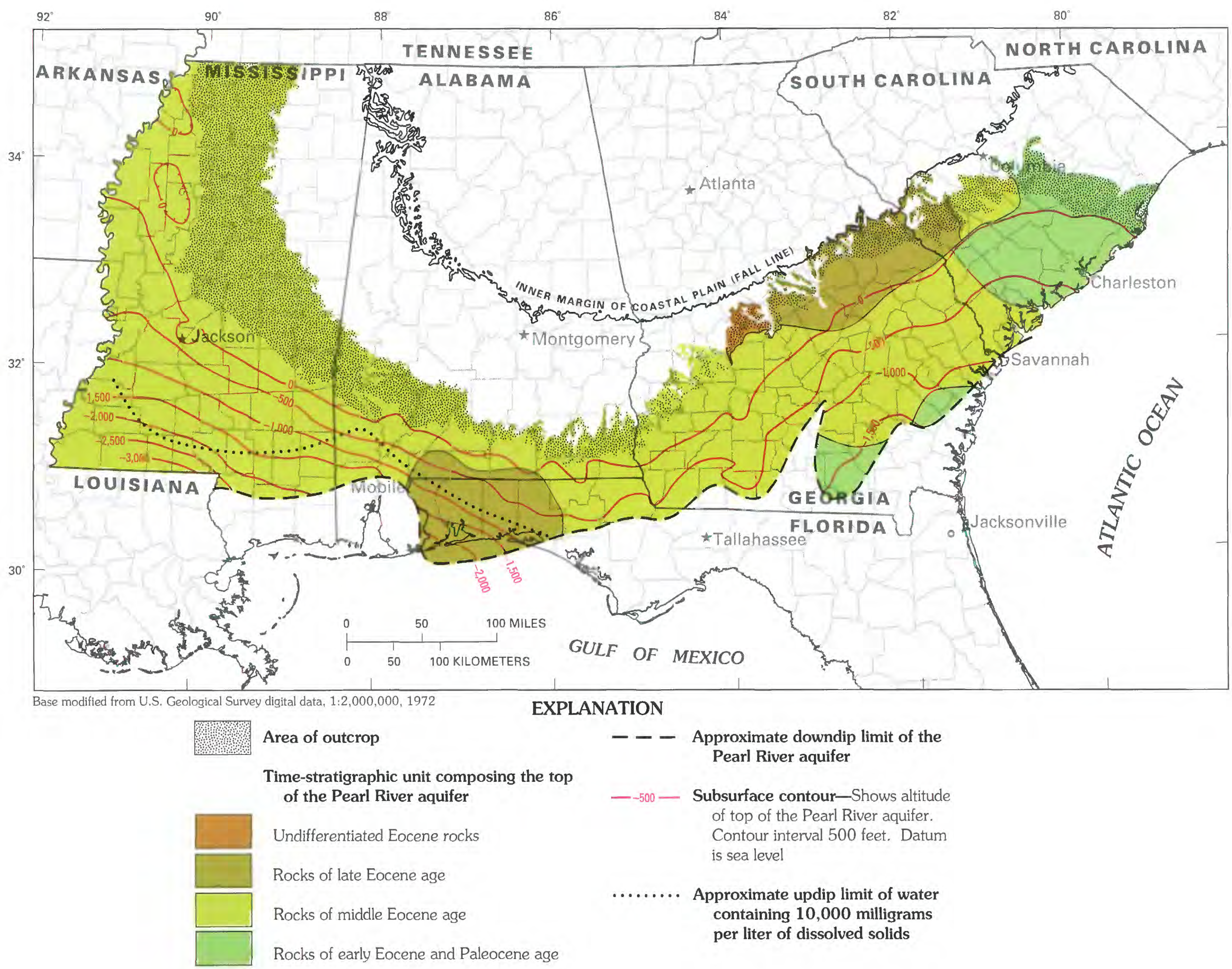


FIGURE 25.—Geology and configuration of the top of the Pearl River aquifer.

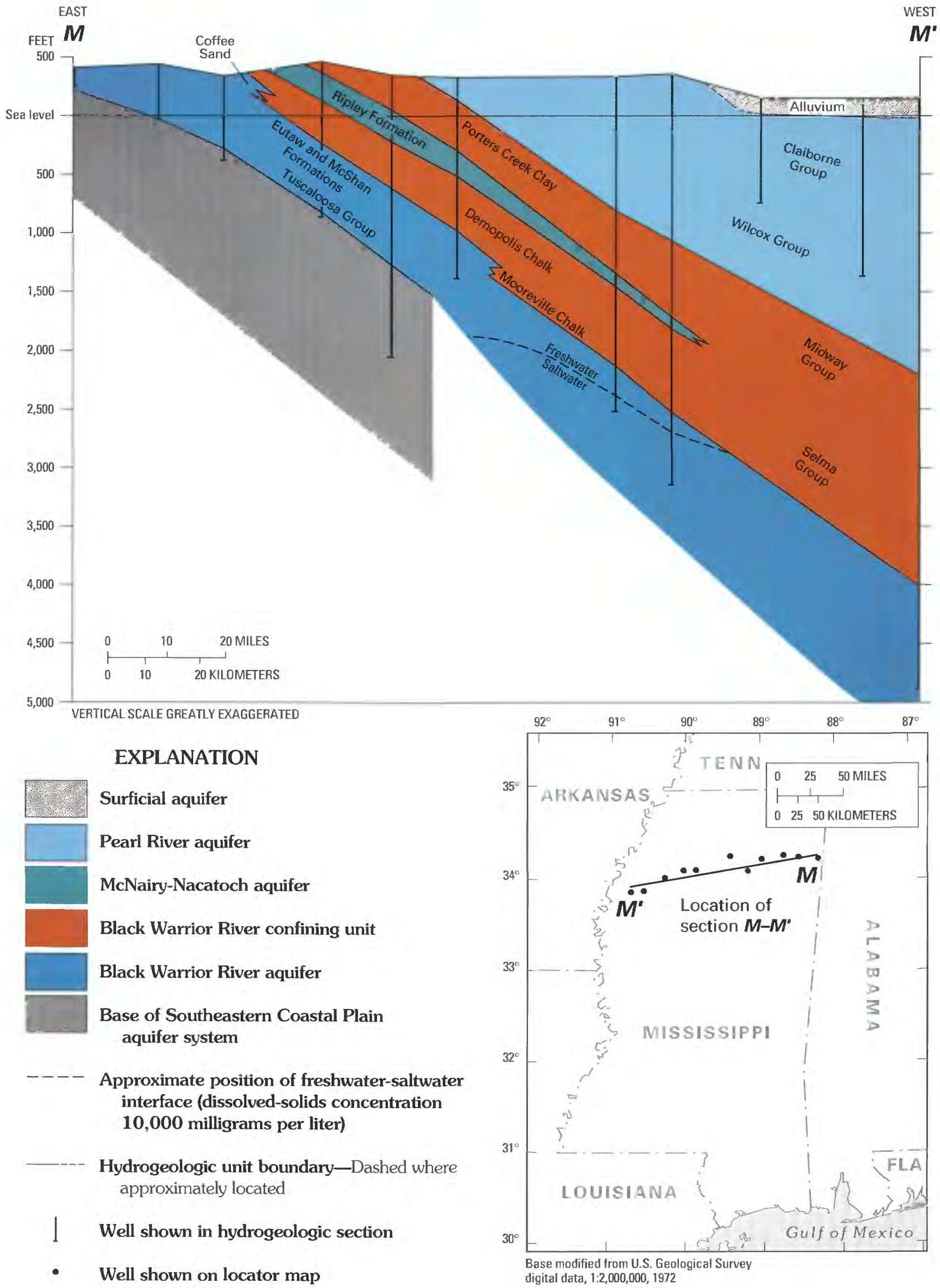


FIGURE 26.—Generalized hydrogeologic section *M–M'* from Itawamba County to Bolivar County, Miss.

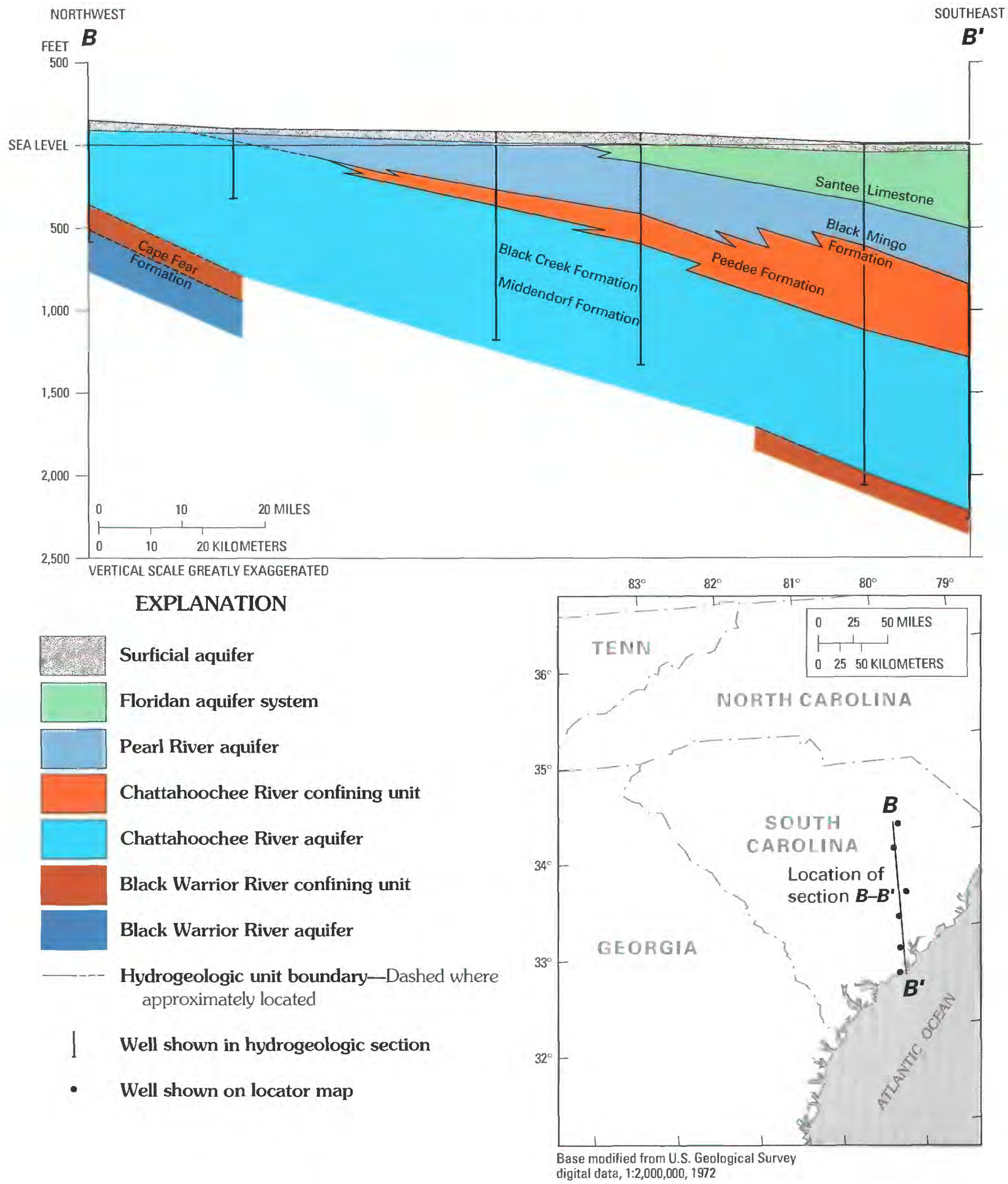


FIGURE 27.—Generalized hydrogeologic section *B–B'* from Florence County to Charleston County, S.C.

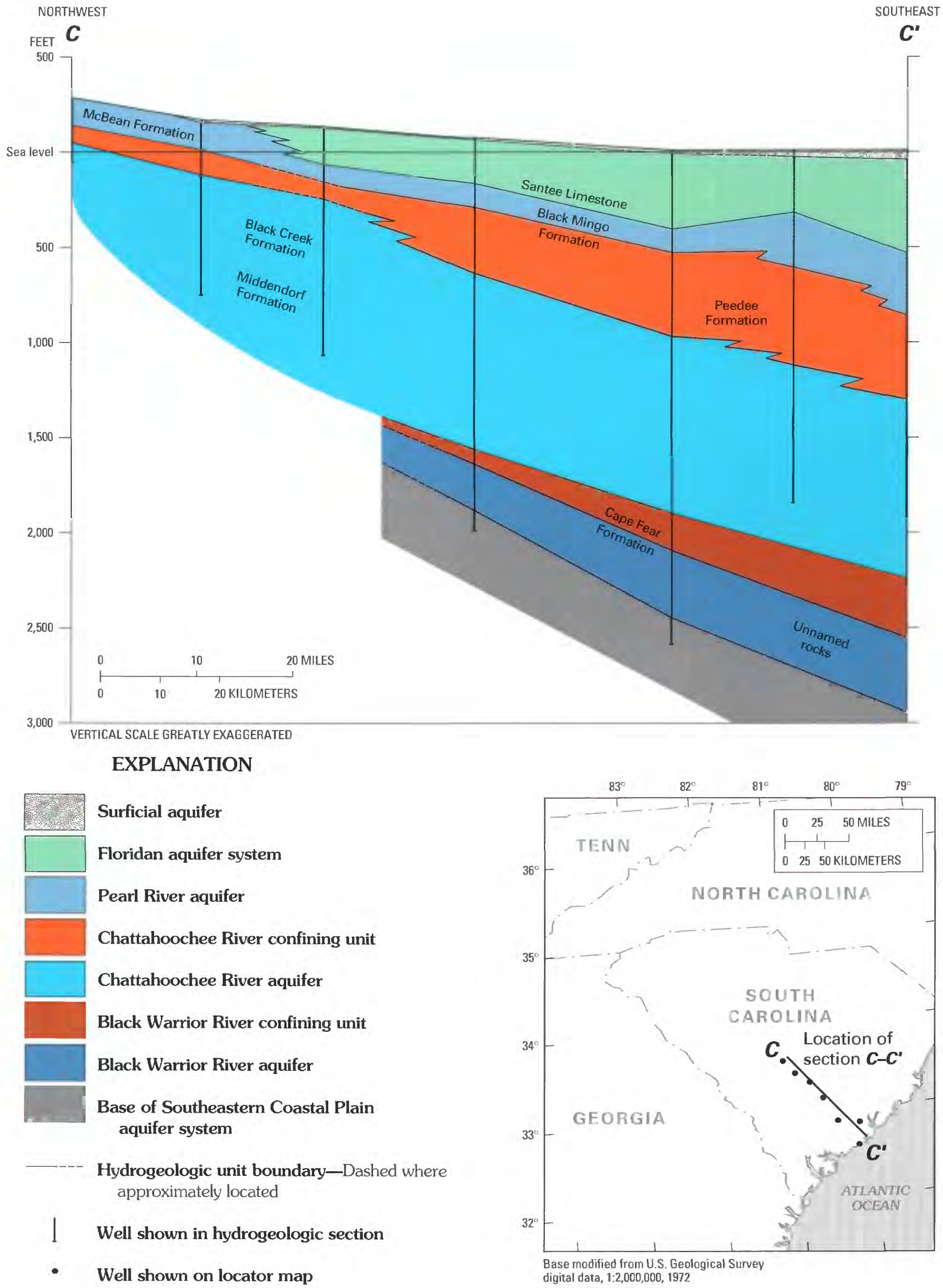


FIGURE 28.—Generalized hydrogeologic section C–C' from Orangeburg County to Charleston County, S.C.

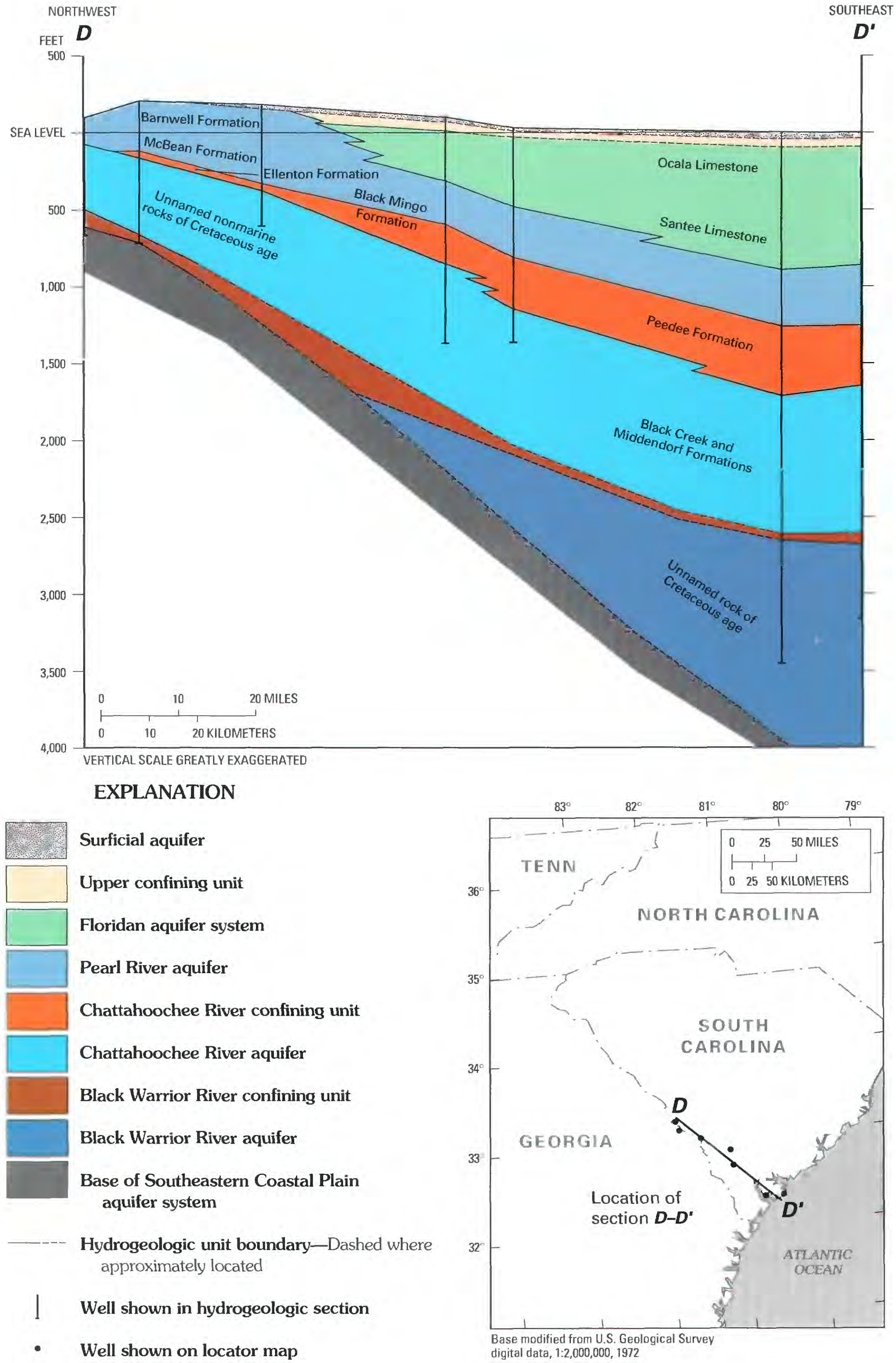


FIGURE 29.—Generalized hydrogeologic section *D–D'* from Aiken County to Beaufort County, S.C.

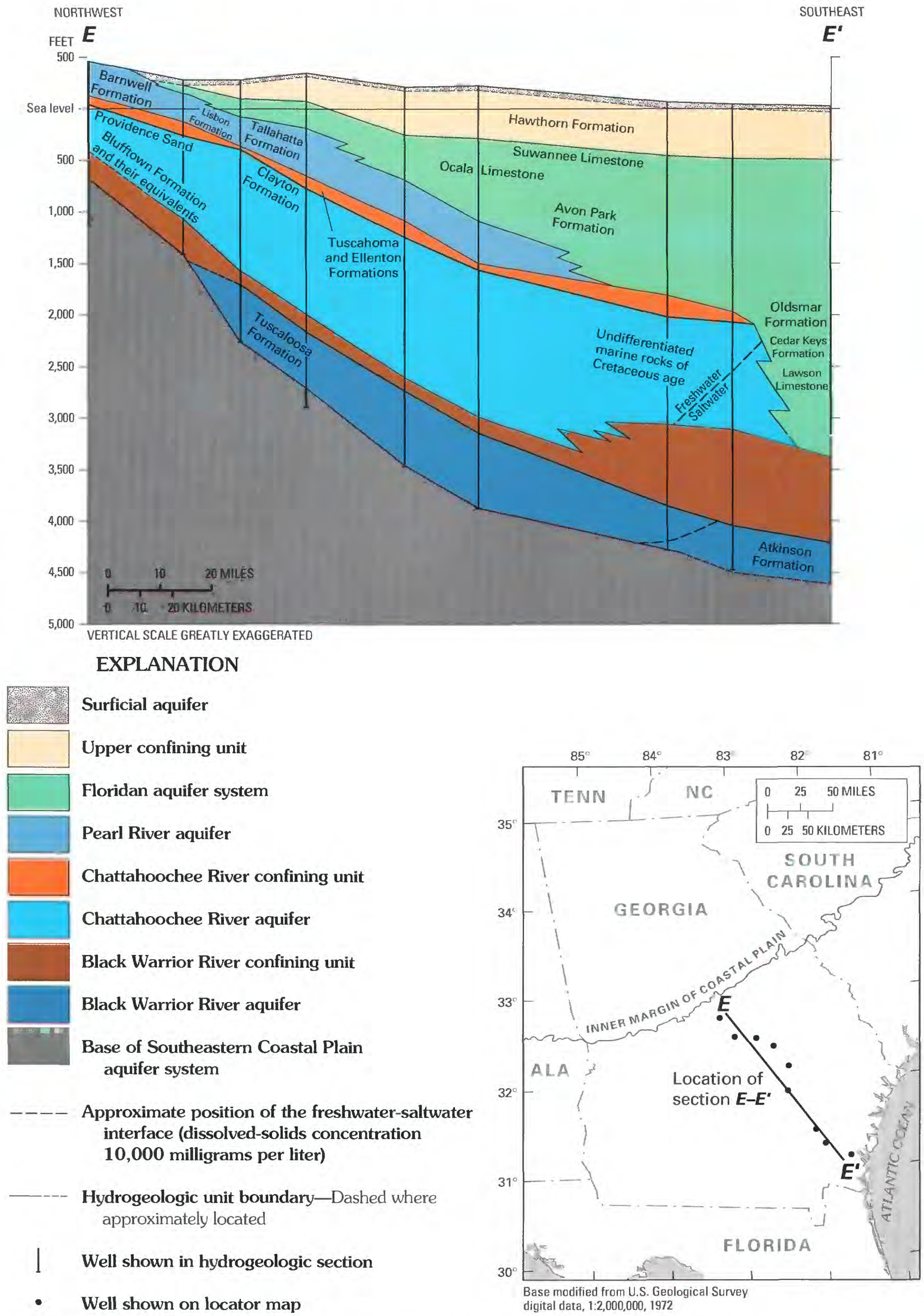


FIGURE 30.—Generalized hydrogeologic section *E–E'* from Wilkinson County to Glynn County, Ga.

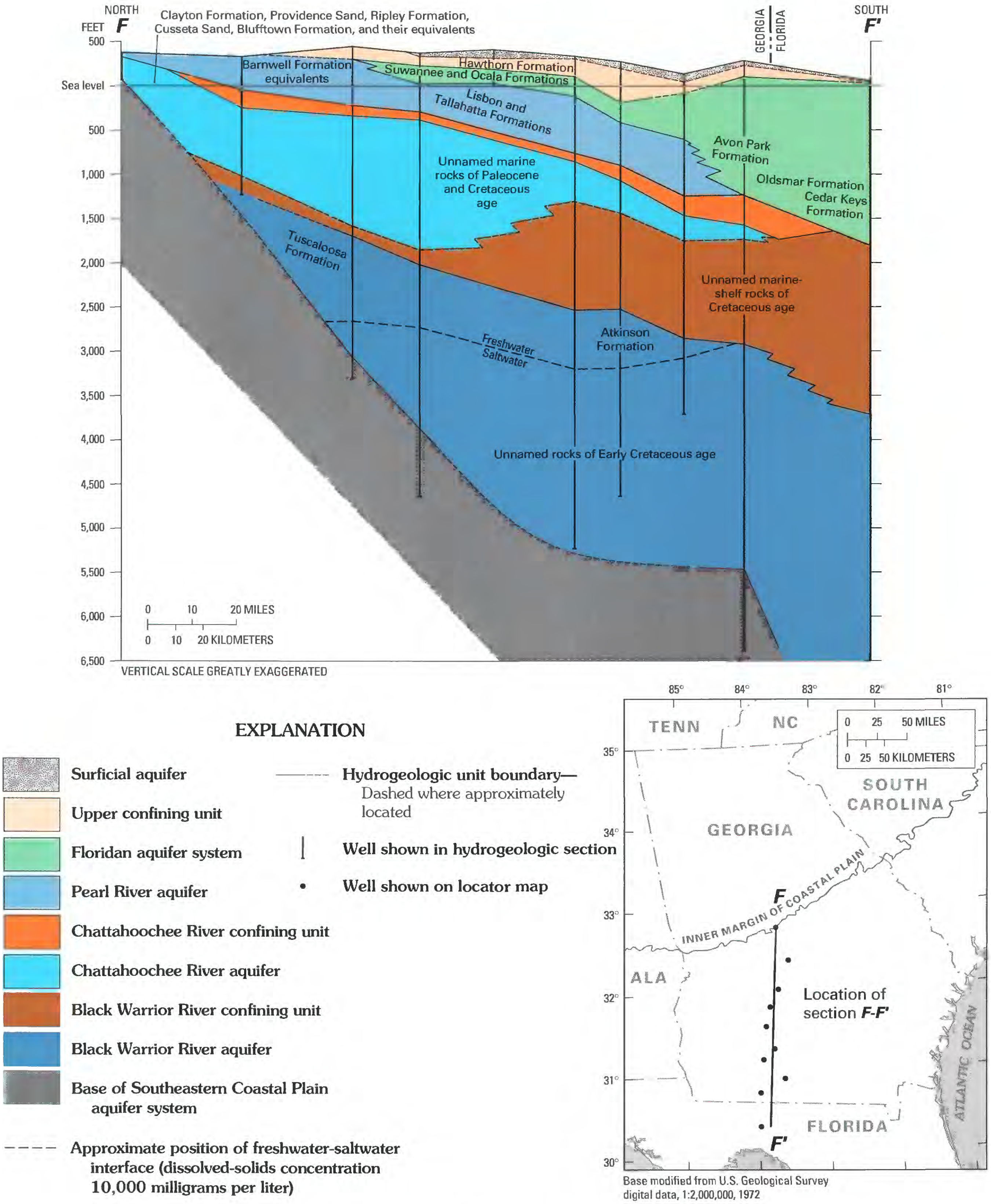


FIGURE 31.—Generalized hydrogeologic section *F–F′* from Bibb County, Ga., to Jefferson County, Fla.

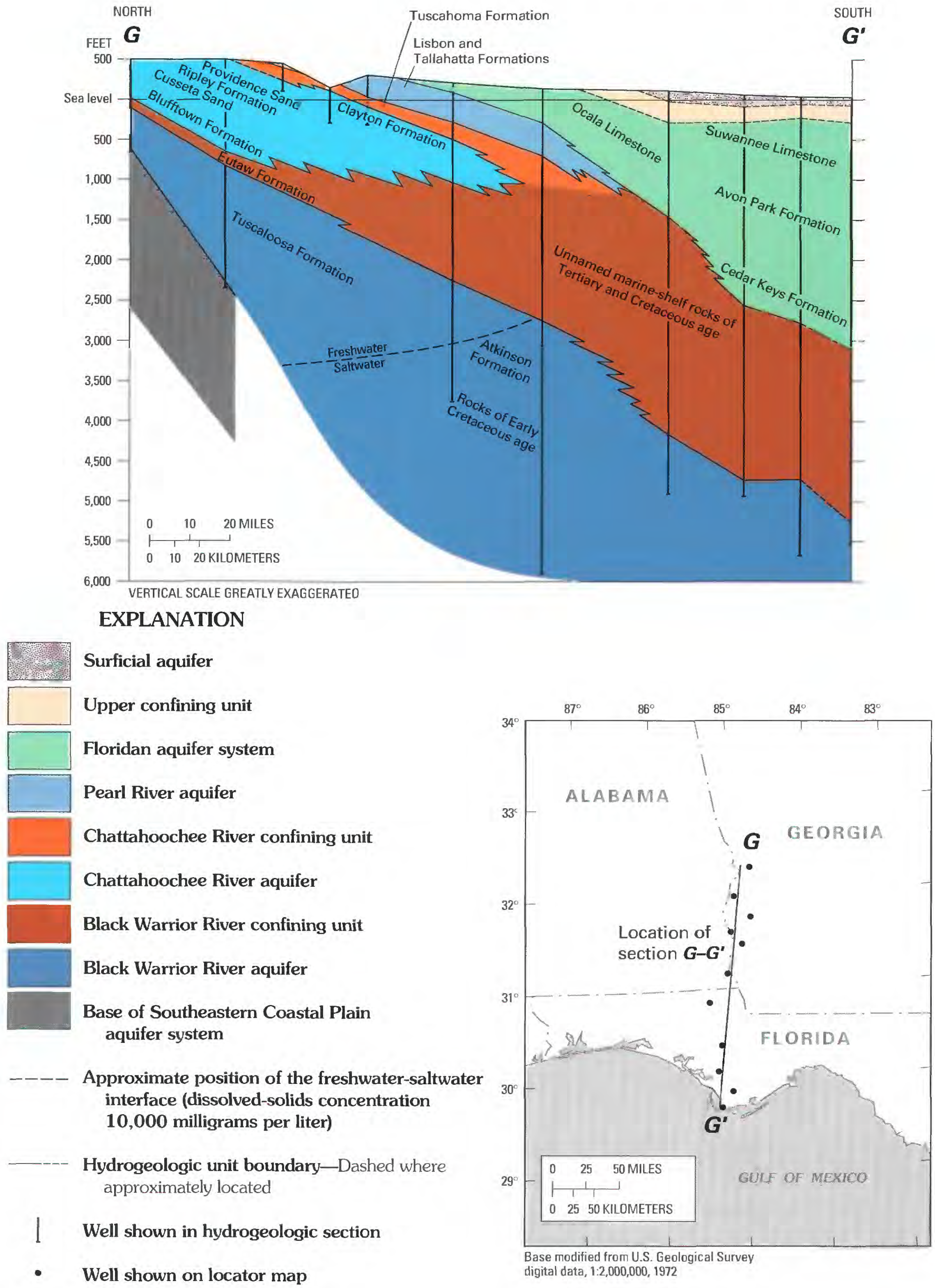


FIGURE 32.—Generalized hydrogeologic section *G–G'* from Chattahoochee County, Ga., to Gulf County, Fla.

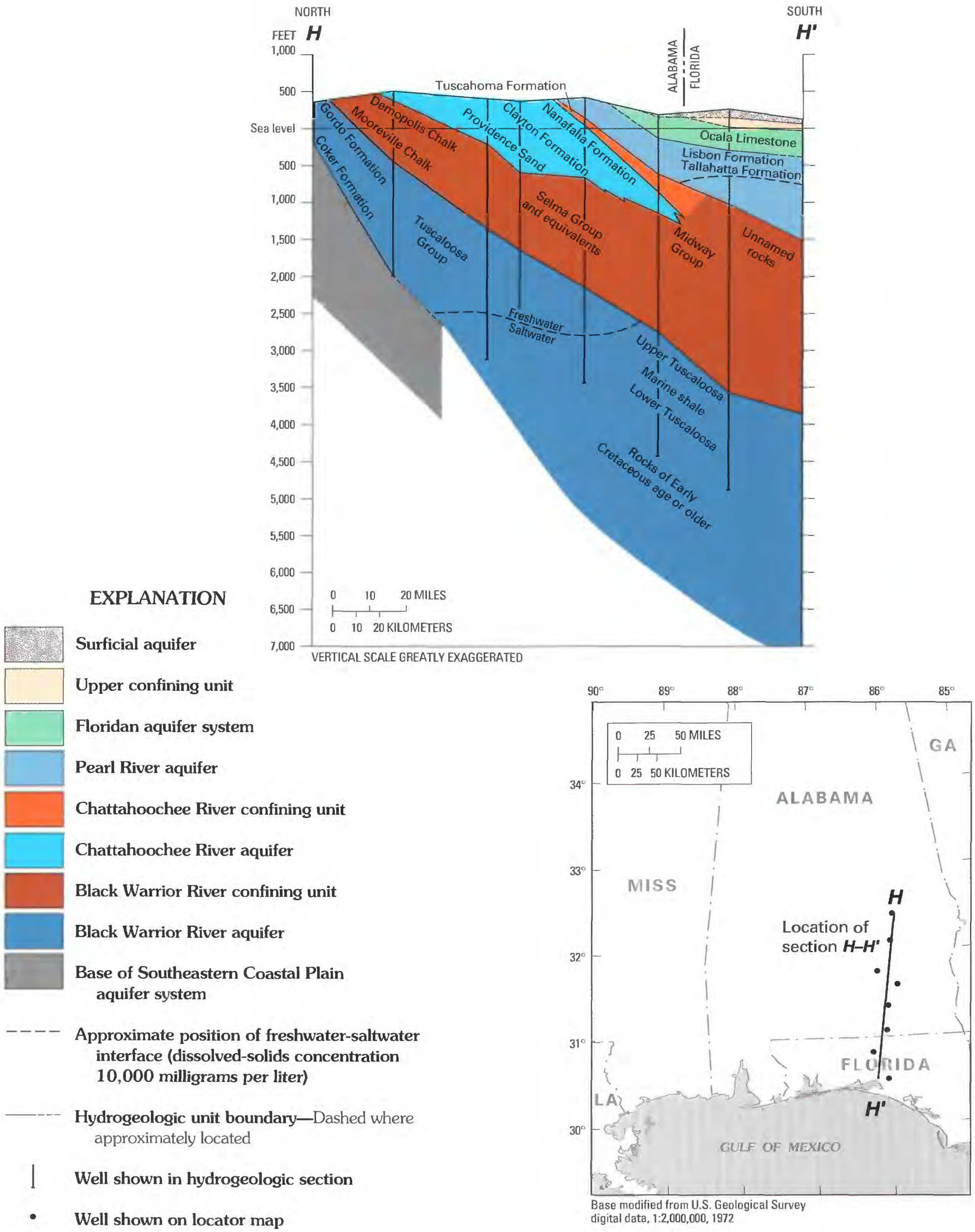


FIGURE 33.—Generalized hydrogeologic section *H–H'* from Macon County, Ala., to Walton County, Fla.

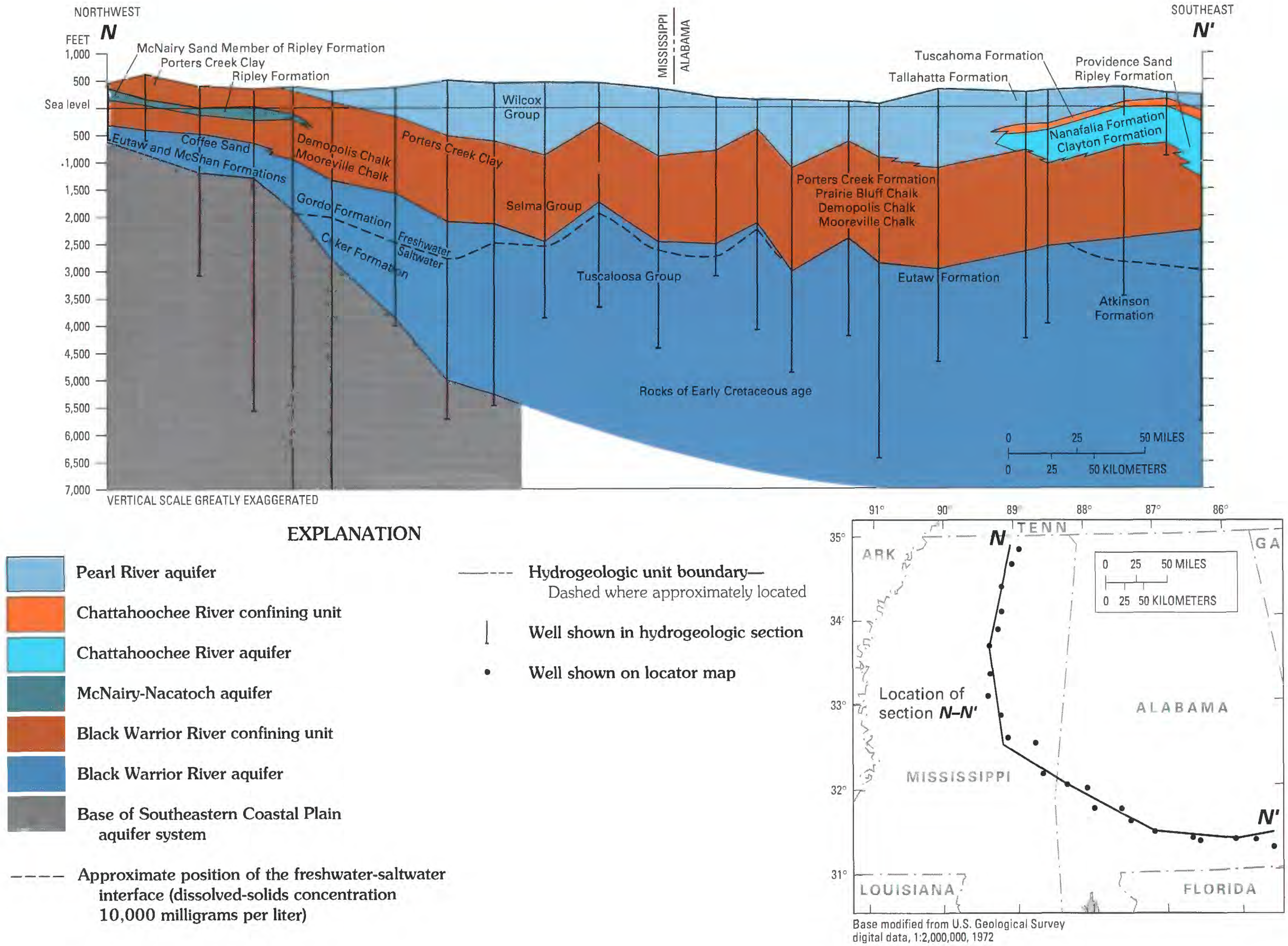


FIGURE 34.—Generalized hydrogeologic section N–N' from Tippah County, Miss., to Houston County, Ala.

marine sand, clay, and minor limestone beds, forms the updip part of the Pearl River aquifer in eastern Georgia and western South Carolina. Although less important than the Clinchfield Sand, the Irwinton Sand Member of the Barnwell Formation is a source for local domestic and stock water supplies. The Twiggs Clay Member of the Barnwell Formation is not considered to be a permeable unit. However, LaMoreaux (1946b) reports that a few wells produce limited quantities of water from the Twiggs in east-central Georgia. For the most part, the Twiggs has low permeability and serves as a local confining unit, separating underlying water-bearing units of Claibornian age or older from shallower water-bearing units. The Clinchfield Sand ranges in thickness from 16 to 35 ft and provides adequate water supplies for farm and domestic use.

ROCKS OF CLAIBORNIAN AGE

Permeable strata of Claibornian age mark the top of the Pearl River aquifer at outcrop and in the subsurface in a continuous band from southwestern South Carolina into northern Mississippi. Claibornian strata consist of massive to thinly bedded, fine- to coarse-grained, fossiliferous to sparsely fossiliferous glauconitic quartz sand that is, in places, interbedded with silty, carbonaceous, micaceous, fossiliferous marl, minor limestone beds, mudstone, and clay. Claibornian rocks deposited largely under marine conditions were found in South Carolina, Georgia, and Alabama. They grade westward to a thick, fluviodeltaic, massively bedded quartz sand sequence in Mississippi that closely resembles the Sabinian rocks that lie beneath the sand. Where these Claibornian beds crop out in western Georgia and southern Alabama, they are overlain by a thin residuum of varicolored, very fine to coarse sand and fossiliferous chert.

COCKFIELD AND COOK MOUNTAIN FORMATIONS

The Cook Mountain Formation is not generally considered to be an important permeable unit in Mississippi. This formation grades to a sandier facies in northern Mississippi, however, allowing greater interconnection between the more permeable, underlying Sparta Sand and overlying Cockfield Formation. For the most part, local clay beds within the upper part of the Cockfield Formation combine with overlying clay of Jacksonian age (Yazoo and Moodys Branch Formations) that separates water-bearing sand within the Cockfield from shallower aquifers. On the basis of 27 aquifer tests, a median transmissivity of 4,600 ft^2/d and a hydraulic conductivity of 50 ft/d are reported for the "Cockfield aquifer" in Mississippi (Spiers, 1977a). The large range of transmissivity (80 to 21,000 ft^2/d) and hydraulic conductivity (1 to 120 ft/d) reported from these aquifer tests reflects the highly variable, fluviodeltaic depositional nature of the Cockfield. Water-bearing units having the greatest permeability are probably associated with more massive channel-sand deposits.

SPARTA SAND, ZILPHA CLAY, AND WINONA SAND

The transmissivity of the Sparta Sand varies considerably and is highest where the thickness of the Sparta exceeds 100 ft (Payne, 1968). Newcome (1976) found that the transmissivity of the Sparta Sand in Mississippi ranges from 330 to 13,000 ft^2/d and hydraulic conductivity ranges from 6 to 130 ft/d.

The Zilpha Clay forms an effective local confining unit that separates the "Winona-Tallahatta aquifer" from overlying water-bearing strata of the Sparta Sand. The hydraulically interconnected Winona Sand and underlying Neshoba Sand Member of the Tallahatta Formation (pl. 2) combine to form the locally named "Winona-Tallahatta aquifer" in Mississippi (Spiers, 1977b). In northwestern counties in Mississippi, the low-permeability beds of the Basic City Shale Member of the Tallahatta grade to a micaceous, fine-grained sandy facies and are included as part of this "Winona-Tallahatta aquifer." The Winona Sand is not considered to be an important water-bearing unit, however, relative to the more permeable, prolific water-bearing units that lie above and below it. The transmissivity of the "Winona-Tallahatta aquifer" as reported from two aquifer tests (Gandl, 1982) ranges from 1,200 to 6,300 ft^2/d.

LISBON FORMATION

Toulmin and others (1951), Cagle and Newton (1963), and Carter and others (1949) considered the medium to very coarse glauconitic sand that forms the basal part of the Lisbon Formation in Choctaw and Escambia Counties, Ala., to be a permeable unit that can yield 100 to 750 gal/min to wells. In southeastern Alabama, wells completed in water-bearing units consisting of glauconitic sand of the Lisbon Formation have been reported to yield 100 to 450 gal/min. Recently, Williams and others (1986b) formally defined the Lisbon as an "aquifer" (fig. 19); however, the term Lisbon as they described it does not refer strictly to water-bearing beds of that formation but also includes water-bearing beds equivalent to the Ocala Limestone, Moodys Branch Formation, Gosport Sand, and the Tallahatta, Hatchetigbee, and Bashi Formations. The permeable water-bearing parts of the Lisbon Formation, however, make up the bulk of these water-bearing units. The water-bearing nature of the Lisbon Formation in Alabama contrasts greatly with its less permeable nature in parts of Georgia. In Georgia, calcareous glauconitic sand, clayey sand, and clay beds of the Lisbon combine to form the lower confining unit of the Floridan aquifer system (Miller, 1986). In the shallow subsurface of east-central Georgia, the Lisbon Formation combines with the McBean Formation to form a massive, glauconitic marl and clay bed separating Georgia's "Gordon aquifer" (fig. 19) (Brooks and others, 1985) from overlying permeable, clastic rocks of Jacksonian age.

McBean and Congaree Formations

Siple (1967) found that basal marl of the McBean Formation and the upper clay of the Congaree Formation combine to form a local confining bed in the Aiken–Barnwell County, S.C., area, separating water-bearing units in both formations. These water-bearing units, however, are not considered important in this area, particularly when compared with the more prolific underlying aquifers in Cretaceous rocks. Siple (1967) reported the transmissivity of the water-bearing units within the McBean and Congaree Formations to be from 7,800 to 13,400 ft^2/d, with a hydraulic conductivity ranging from 10 to 130 ft/d.

Tallahatta Formation

A number of water-bearing units that are separated by local confining units make up the Tallahatta Formation in Mississippi. As the Tallahatta extends into Tennessee, it grades to a sandier sequence and combines with overlying sand of the Cockfield Formation, Cook Mountain Formation, Sparta Sand, and Zilpha Clay (which is sandy in these localities) to form the Memphis aquifer (fig. 19). The Meridian Sand Member, the fine- to coarse-grained lowermost member of the Tallahatta Formation in Mississippi, is screened in wells, together with the underlying, hydraulically interconnected, locally named "Upper Wilcox aquifer." The Meridian Sand Member is separated from overlying water-bearing beds of the Neshoba Sand Member by the Basic City Shale Member.

Water-bearing beds of fine- to medium-grained clayey sand that are equivalent to the Tallahatta Formation in Georgia combine with the older Hatchetigbee Formation (Sabinian) and younger Lisbon Formation to form the "Gordon aquifer" (fig. 19) in Georgia (Brooks and others, 1985). Tallahatta equivalents make up the bulk of the "Gordon aquifer"; however, sand and kaolinitic clay that are part of the Huber Formation are also part of this water-bearing unit. The "Gordon aquifer" in Pulaski and Screven Counties, Ga., has a reported transmissivity ranging from 3,500 to 9,800 ft^2/d (Brooks and others, 1985).

ROCKS OF SABINIAN AND MIDWAYAN AGE

Rocks of late Paleocene and early Eocene age (Sabinian Stage) make up the upper surface of the Pearl River aquifer in northeastern Mississippi, west-central Alabama, southeastern Georgia, and southwestern South Carolina. Littoral to estuarine, fine- to coarse-grained, fossiliferous, argillaceous, glauconitic quartz sand that is part of the Black Mingo Formation makes up the Pearl River aquifer where these rocks crop out and extend into the South Carolina subsurface. Rocks of similar age and lithology are found in the Pearl River aquifer in southeastern Georgia, but these are more indurated and are typically interbedded with fossiliferous marl and sandy limestone. In western Alabama and northern Mississippi, equivalent water-bearing strata crop out that consist of a thick fluviodeltaic sequence containing massive to thinly bedded, fine to coarse quartz sand and lignitic clay that are part of the Wilcox Group.

Fishburne and Black Mingo Formations

The Fishburne Formation serves as a confining unit of limited extent in coastal areas of southern South Carolina. Locally it occurs within the larger, more regionally extensive Pearl River aquifer, but elsewhere it forms a confining unit separating the Floridan aquifer system and Pearl River aquifer.

Park (1984) considered the Black Mingo Formation to be the most productive water-bearing unit of early Tertiary age in South Carolina. Collectively, the Black Mingo consists of fine to medium sand, silty sand, interlaminated clay, and interbedded limestone. Sandier beds within the upper 100 ft of the formation serve as the principal water-bearing units. Hayes' (1979) "lower permeable zone" in Beaufort, Colleton, Hampton, and Jasper Counties, S.C., however, may be equivalent to the lower (Midwayan) part rather than the upper (Sabinian) part of the Black Mingo Formation. The lithologic character of the Black Mingo grades from the clastic facies noted above to an indurated, siliceous, slightly glauconitic limestone. Reported transmissivities of the Black Mingo ranged from 500 to 5,000 ft^2/d in northern Colleton and northeastern Hampton Counties and averaged about 4,000 ft^2/d in southern Colleton County. Hayes (1979) estimated that the hydraulic conductivity varied between 75 and 100 ft/d in these areas.

Wilcox Group and Equivalents

Hosman and others (1968) and Boswell (1976a, b) recognized two hydrogeologic units within the Wilcox Group: (1) a "lower Wilcox aquifer" consisting mostly of the Nanafalia Formation but including the Midwayan Naheola Formation and (2) a "Meridian–upper Wilcox aquifer" that consists of the water-bearing uppermost sands of the Wilcox Group and the lowermost water-bearing beds of the overlying Meridian Sand Member of the Tallahatta Formation of Claibornian age. Both reports consider these different lithostratigraphic units as a single aquifer because of their lithologic character and hydraulic interconnection. The "upper and lower Wilcox aquifers" are separated in Mississippi by a confining bed consisting of local beds or lenses of clay (equivalent to the Tuscahoma Formation) that this author has found quite difficult to map over any great distance. Cleaves (1980) considered the contact between the upper and lower Wilcox units to be a subjective and arbitrary pick. In fact, the sandier lenses of this confining bed combine with the lower beds of the Hatchetigbee Formation to make up Gandl's (1982) "middle Wilcox aquifer," which is productive locally in a band that extends from Grenada to Lauderdale County, Miss. There, middle Wilcox strata consist of lenticular sand beds and interlaminated clay and silt, whereas to the north, clay beds predominate. The "middle Wilcox aquifer" described by Gandl is not used extensively for water supply due to the prolific nature of the sandy water-bearing units ("Meridian–upper Wilcox and lower Wilcox aquifers") that overlie and underlie it. Where the uppermost beds of the Wilcox Group consist of less permeable, deltaic sandy clay and clay deposits in northern Mississippi, the Meridian Sand Member of the Tallahatta Formation constitutes the bulk of the Wilcox water-bearing units. To the south, the Meridian Sand Member thins and is less important as part of the Meridian–upper Wilcox water-bearing units.

The complexly bedded nature of the water-bearing units within the Wilcox Group includes rocks deposited as massive channel sand, fine-grained overbank deposits, and deltaic sand and clay. Understanding this depositional setting helps explain the highly varied hydraulic nature of these rocks, as they change lithology within relatively short distances. Gandl (1982) reported hydraulic conductivity of the "lower Wilcox aquifer," for example, to range between 25 and 470 ft/d (median of 100 ft/d); transmissivity ranged between 670 and 51,000 ft^2/d (median of 5,300 ft^2/d).

In western Alabama, the sandier parts of the Nanafalia Formation are used as a water-producing zone and are often screened in wells together with sandy beds of the upper part of the underlying Naheola Formation and basal part of the overlying Tuscahoma Formation (LaMoreaux and others, 1957). Davis and others (1983) reported a transmissivity of 4,000 ft^2/d for a sand bed that is part of the Nanafalia Formation in Choctaw County, Ala.

The Bashi Formation is not generally considered to be a permeable zone. LaMoreaux and others (1957) observed, however, that the Bashi Formation is capable of supplying water to domestic and farm wells in Wilcox County, Ala. In Alabama, productive water-bearing strata that are part of the Hatchetigbee Formation combine with younger beds that are part of the "Lisbon aquifer" described by Williams and others (1986b). In Georgia, beds equivalent to the Hatchetigbee and Tuscahoma Formations form the "Gordon aquifer" and the underlying confining unit (Brooks and others, 1985).

CHATTAHOOCHEE RIVER CONFINING UNIT

The configuration of, and stratigraphic units constituting, the upper surface of low-permeability rocks that collectively separate the Pearl River aquifer from underlying aquifers is shown on plate 34. As discussed earlier, the Pearl River aquifer is underlain by two different, but regionally extensive, confining units. The shallower confining unit, known as the Chattahoochee River confining unit, underlies the Pearl River aquifer in about two-thirds of the study area and, in general, dips gently southward at a gradient of about 15 to 30 ft/mi. The Chattahoochee River confining unit extends from Horry and Marion Counties in eastern South Carolina, across Georgia, and westward into Pike and Coffee Counties in central Alabama. It crops out as a narrow but continuous 5- to 10-mi-band across Alabama and crops out discontinuously in western Georgia (pl. 35). The Chattahoochee River confining unit is not exposed anywhere in eastern Georgia and westernmost South Carolina because the unit pinches out, and the underlying aquifer is overlapped by the shallower Pearl River aquifer (figs. 27, 29; pls. 25, 27). In eastern South Carolina, the Chattahoochee River confining unit crops out or subcrops as a 30- to 50-mi-wide band. In updip sections of northeastern Georgia and northwestern South Carolina where the regional confining unit is absent, the Pearl River aquifer is directly connected to underlying, massive, nonmarine, feldspathic quartz sand beds of Cretaceous age that are part of the Chattahoochee River aquifer. The Chattahoochee River confining unit averages 100 to 200 ft in thickness over a major part of the study area. Its greatest thickness occurs in coastal areas of South Carolina and Georgia, where the low-permeability clay, marl, and shale that constitute it exceed 300 to 400 ft in thickness.

A deeper confining unit, called the Black Warrior confining unit, underlies the Pearl River aquifer in central Mississippi and western Alabama. The Chattahoochee River aquifer is absent in these places because the permeable rocks that constitute it elsewhere have passed by facies change into low-permeability clay, chalk, and mudstone (fig. 34, pl. 33).

ROCKS OF PALEOCENE AGE

In south-central and southwestern South Carolina, the Chattahoochee River confining unit is considered to be of Paleocene age (Sabinian and Midwayan) and includes beds of low permeability that are equivalent, in places, to the Black Mingo Formation and, elsewhere, to the Ellenton Formation. The Chattahoochee River confining unit in South Carolina is characterized as either a (1) gray to greenish-gray, locally fossiliferous, marine arenaceous shale; siliceous mudstone; and sandy clay (Black Mingo Formation) or (2) lignitic micaceous clay (Ellenton Formation). Where these beds are found in the shallow subsurface or crop out in South Carolina, the Black Mingo Formation grades to a sandier facies, and the confining unit is accordingly absent. In the shallow subsurface to the west in the vicinity of the Georgia–South Carolina State line, the Ellenton Formation forms a major part of this confining unit. The Ellenton is not known to crop out except in a small stream that cuts along Hollow Creek in Aiken County, S.C. (Prowell and others, 1985).

The Chattahoochee River confining unit is largely equivalent to the Tuscahoma Formation of Paleocene age (Sabinian) in western Georgia and eastern Alabama, but it also includes rocks equivalent to the lowermost part of the Huber Formation in central and eastern Georgia. In these areas, the Chattahoochee River confining unit consists of blocky, silty, carbonaceous to kaolinitic clay or marl; common minor constituents include lignite, glauconite, mica, and pyrite. Downdip, these strata grade to poorly permeable, gray to greenish-gray, calcareous, glauconitic, arenaceous shale, and nonfossiliferous limestone. The relatively low permeability of the Tuscahoma Formation increases to the west as the formation grades to more permeable, fine-grained, glauconitic sand and interbedded silty clay that are part of the Pearl River aquifer. This change in lithology can best be explained by the poorly permeable, marine, quiet-water lagoon, and tidal-flat nature of the Tuscahoma strata in eastern Alabama and western Georgia, in contrast with the more permeable, fluvial to delta-plain sequence that constitutes the Tuscahoma Formation and Wilcox Group of Mississippi and western Alabama.

ROCKS OF LATE CRETACEOUS AGE

The Chattahoochee River confining unit consists of calcareous sandy mudstone, muddy, very fine sand, and marl of Late Cretaceous age (Navarroan) in central South Carolina. There, this regional confining unit consists entirely of strata that are equivalent to the lower part of the outcropping Peedee Formation. The characteristically low permeability of this part of the Peedee can be attributed to its deposition in an open-marine, shallow-shelf environment below the effective wave-base level, thereby limiting the removal of finer sediments. To the west, equivalent rocks grade to a transitional-marine and nonmarine sequence that is considerably more permeable and is included as part of the Chattahoochee River aquifer (figs. 24, 28; pls. 22, 26).

CHATTAHOOCHEE RIVER AND McNAIRY-NACATOCH AQUIFERS

Sand, sandstone, gravel, and minor limestone beds that are locally interbedded and interlaminated with clay, shale, marl, mudstone, and chalk together constitute the Chattahoochee River aquifer (fig. 35, pl. 36). Rocks of the Chattahoochee River aquifer were deposited in a wide range of environments that include shallow-marine to nonmarine conditions during the Late Cretaceous (Austinian) to late Paleocene (Sabinian) (pl. 2). The bedding character, texture, and lithology of this aquifer are highly varied as a result of these diverse depositional conditions. Water-bearing zones within the aquifer consist largely of fine to coarse quartz sand that is glauconitic and feldspathic in places and occurs as massive, thin, or lenticular beds. In addition, many of these water-bearing zones tend to be fossiliferous, calcareous, carbonaceous, and micaceous; locally, they are nonfossiliferous and ferruginous. Sandy, glauconitic, highly permeable limestone beds are also part of the Chattahoochee River aquifer in some areas.

The Chattahoochee River aquifer extends as a continuous unit from central Alabama to western South Carolina. In east-central Mississippi and western Alabama, however, the aquifer is absent. A correlative clastic permeable unit, hydraulically disconnected from the main body of the Chattahoochee River aquifer, is present in northern Mississippi and extends northward and northwestward to Tennessee, Kentucky, Illinois, Missouri, and Arkansas. Locally named the "Ripley aquifer" (Boswell, 1963) in northern Mississippi, the McNairy-Nacatoch aquifer is being investigated as part of the Gulf Coastal Plain RASA Program (Grubb, 1986b). The McNairy-Nacatoch aquifer consists of permeable strata of Late Cretaceous age that are part of the McNairy Sand of Tennessee and the Nacatoch Sand of Arkansas, Louisiana, and Texas. As the McNairy-Nacatoch aquifer is both physically disconnected and lithologically distinctive, it is discussed here merely to provide a more uniform description of permeable strata that are found within the Southeastern Coastal Plain.

The Chattahoochee River aquifer crops out in two areas (fig. 35, pl. 36): a 25- to 60-mi-wide band extends southwestward from eastern to western South Carolina; a second band about 15 to 40 mi wide extends westward into Alabama from central Georgia. A very narrow outcrop (2 to 15 mi wide) of the McNairy-Nacatoch aquifer extends southward from Tennessee into northern Mississippi. In western South Carolina and eastern Georgia, the Chattahoochee River aquifer mostly is covered by the Pearl River aquifer; consequently, the Chatta-

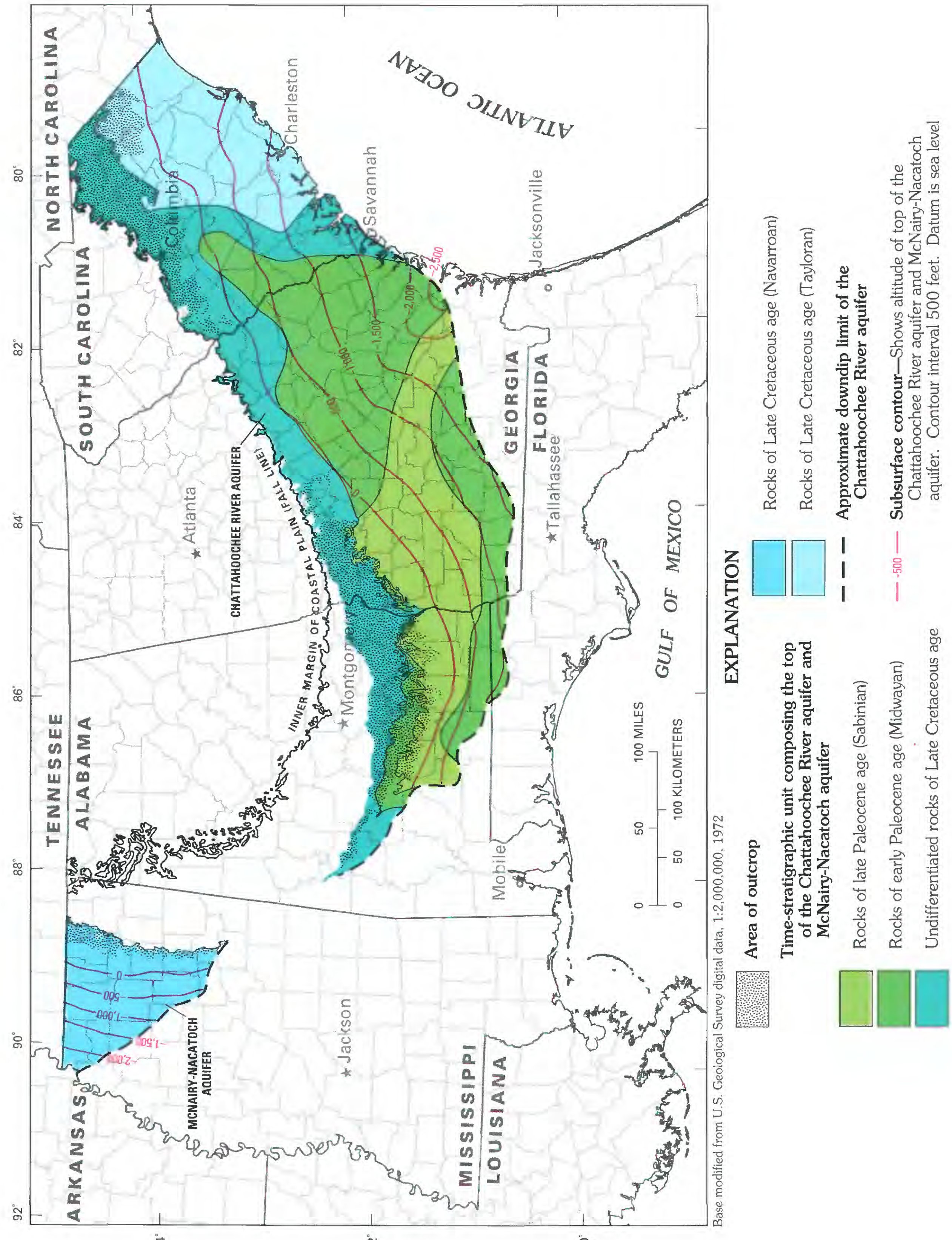


FIGURE 35.—Geology and configuration of the top of the Chattahoochee River aquifer and the McNairy-Nacatoch aquifer.

hoochee River aquifer crops out only as discontinuous outliers that are exposed where shallower strata have been eroded.

The landward limit of the Chattahoochee River aquifer occurs at or near the Fall Line (inner Coastal Plain margin) in South Carolina and Georgia. In Alabama, the aquifer lies coastward from the inner Coastal Plain margin. In Mississippi, the landward limit of the McNairy-Nacatoch aquifer is westward of the inner Coastal Plain margin. The upper surface of the Chattahoochee River aquifer slopes gently coastward at a gradient of 15 to 20 ft/mi in South Carolina, Georgia, and Alabama. The top of the McNairy-Nacatoch aquifer dips westward in Mississippi at a steeper gradient of 30 to 40 ft/mi (pl. 36). The hydraulic conductivity of the water-bearing zones within the Chattahoochee River and the McNairy-Nacatoch aquifers diminishes at depth as the sandy strata grade into calcareous shale and chalk; the permeable parts of these aquifers thin greatly seaward as a result of facies changes (figs. 26, 31–33; pls. 24, 27–29). This is not true everywhere. For example, the Chattahoochee River aquifer grades into permeable limestone that is part of the Floridan aquifer system in southeastern Georgia (fig. 30, pl. 28).

The westward extent of the McNairy-Nacatoch aquifer in Mississippi differs from that previously shown by Boswell (1979b). Data suggest that the aquifer grades to a calcareous, sandy marl and clay in places in the subsurface where Boswell described the Ripley as water bearing. As discussed below, this author chose not to extend the downdip limit of the McNairy-Nacatoch aquifer as far westward as has been previously shown.

The thickness of the Chattahoochee River aquifer is greatest (1,000 to 1,500 ft) in a wide band that extends westward from southern South Carolina to western Georgia (pl. 37). The aquifer thins as it extends northeastward into South Carolina, ranging from 500 to 750 ft in thickness in much of the State, and thinning landward to a featheredge. A similar thickness occurs in eastern Alabama, whereas the McNairy-Nacatoch aquifer is only 100 to 200 ft thick in northern Mississippi.

The Chattahoochee River aquifer is believed to contain freshwater throughout, as shown in figure 35 and plates 36 and 37. As noted previously, Boswell (1979b) believed that his "Ripley aquifer" could be mapped farther to the west than this author has chosen to extend it in light of more current lithologic data. The position of Boswell's (1979b, sheet 1) freshwater-saltwater interface in his "Ripley aquifer" (NcNairy-Nacatoch aquifer) corresponds to the same area in plate 36 where the equivalent beds have very low permeability that should be considered as a confining unit rather than an aquifer. In southern Georgia, saline ground water occurs in beds equivalent to the Chattahoochee River aquifer (Brown and others, 1979) but occurs coastward of the southern limit of permeability of the aquifer.

ROCKS OF PALEOCENE AGE

Sand and limestone beds of Paleocene age form the uppermost part of the Chattahoochee River aquifer in a fairly wide band that extends coastward from outcrop areas in central Alabama to central Georgia, as well as in a more limited area of the subsurface in South Carolina. These beds represent the youngest rock units associated with the Chattahoochee River aquifer. The youngest of these are fossiliferous, glauconitic quartz sand of the Nanafalia Formation and its fluvial and estuarine equivalent, the Baker Hill Formation (both of Sabinian age), which are found in the middip areas of Alabama and western Georgia. These permeable strata grade coastward by facies change to a calcareous shale sequence. Paleocene limestone of the Clayton Formation (Midwayan age) marks the uppermost part of the Chattahoochee River aquifer in downdip areas of southwestern Georgia and southeastern Alabama. The Clayton largely consists of coarsely glauconitic, fossiliferous limestone beds that are karstic, crystalline, and sandy in places, but also include calcareous, glauconitic quartz sand. The limestone beds are hydraulically interconnected with underlying, permeable, clastic beds of Tertiary and Cretaceous age but are separated from limestone beds of the Floridan aquifer system by sand and clay of the overlying Pearl River aquifer and Chattahoochee River confining unit. The Clayton carbonate beds grade into an unnamed arenaceous facies of calcareous, fine- to coarse-grained, fossiliferous quartz sand in central and eastern Georgia that may be equivalent to the Ellenton Formation. These unnamed sandy beds combine with underlying Cretaceous water-bearing units to form the "Dublin aquifer" in Georgia (Clarke and others, 1985).

In eastern Alabama, wells tapping the Nanafalia Formation are usually screened in combination with the Clayton Formation as well as lower parts of the overlying Tuscahoma Formation (Scott and others, 1984). Elsewhere, the Nanafalia Formation and its equivalents consist of silty to kaolinitic clay that are part of the overlying Chattahoochee River confining unit. Massive, recrystallized limestone is the part of the Clayton Formation most often tapped by wells in western Georgia, except in Dougherty County, Ga., where the upper Clayton and lowermost Sabinian sands combine to form important water-bearing units. Transmissivity of the Clayton Formation ranges from 400 to 11,000 ft^2/d in western Georgia (Clarke and others, 1984). The permeability of the Clayton Formation is not as great in Dale County, Ala. (Scott and others, 1984), as it is to the east in Clay County, Ga. (Stewart, 1973), in spite of its similar lithologic character; this contrast can be attributed to the lack of limestone dissolution in Dale County. In combination with the uppermost part of the Providence Sand, the Nanafalia Formation, and the basal part of the Tuscahoma Formation, however, the Clayton Formation is commonly a highly transmissive unit. Scott and others (1984) report a transmissivity of 7,800 ft^2/d for the Clayton at Fort Rucker.

ROCKS OF LATE CRETACEOUS AGE

Most of the outcropping and subsurface beds that form the Chattahoochee River aquifer consist primarily of Upper Cretaceous, nonmarine to transitional-marine, fine- to coarse-grained sand, sandstone, gravel, and interstratified clay, mudstone, and marl.

The McNairy-Nacatoch aquifer, a part of the Gulf Coastal Plain regional aquifer system in Mississippi (Grubb, 1986b), consists primarily of marine, glauconitic, quartz sand (Ripley Formation). Fluvial, crossbedded sands, present locally in the Ripley Formation in Mississippi, are more common north in Tennessee. Several Cretaceous rock units make up the Chattahoochee River aquifer in Alabama, Georgia, and South Carolina. The lithologic character of these rocks is more variable in these three States, where the aquifer commonly includes several rock units that form a variable mix of shallow-marine to nonmarine, feldspathic to locally glauconitic, quartz sand and gravel beds that are interbedded in places with ferruginous, kaolinitic, or carbonaceous clay. Rock-stratigraphic units that are part of the Chattahoochee River aquifer in Georgia and easternmost Alabama include the Providence Sand, Ripley Formation, Cusseta Sand, Blufftown Formation, and local beds that are considered to be equivalent to the upper part of the Eutaw Formation (pl. 2). In South Carolina, the Chattahoochee River aquifer consists partly of massively bedded, fluviodeltaic, feldspathic quartz sand of the Middendorf Formation. This highly permeable succession of sand and gravel and less permeable kaolinitic clay grades coastward to, and is overlain by, a complexly interbedded sequence of marginal marine, lenticular to thinly bedded, water-bearing units that are interbedded and interlaminated with carbonaceous, silty clay commonly referred to as the Black Creek Formation. Water-bearing units within the Black Creek combine with the Middendorf Formation to make up a major part of the Chattahoochee River aquifer in South Carolina. Nonmarine beds stratigraphically equivalent to the poorly permeable Peedee Formation are important local water-bearing rocks in western South Carolina.

Many of the Cretaceous siliciclastic deposits that make up the Chattahoochee River aquifer in eastern Georgia and western South Carolina consist of nonmarine to marginal marine deposits that are not easily differentiated. In these areas, Cretaceous water-bearing rocks consist primarily of fine to coarse, glauconitic to feldspathic sand, interbedded or interstratified with beds of silty, carbonaceous to kaolinitic clay similar to beds assigned to the Middendorf or Black Creek Formations to the east. Siple (1967, 1975, 1984) thought these beds were part of the Tuscaloosa Formation. Given the uncertain correlation of these beds with Cretaceous strata to the east or west, Clarke and others (1985) assigned the water-bearing strata in Georgia to the locally named "Dublin aquifer" or to the underlying "Midville aquifer." Collectively, these Cretaceous rocks are considered to be some of the most permeable clastic water-bearing units in the Chattahoochee River aquifer. Aquifer-test analyses for wells screened in these strata indicate that the transmissivity ranges from 2,200 to 35,000 ft^2/d (Clarke and others, 1985).

PROVIDENCE SAND, RIPLEY FORMATION, CUSSETA SAND, AND BLUFFTOWN FORMATION

A thick sequence of siliciclastic marine to nonmarine beds of Late Cretaceous age crops out and extends into the subsurface in eastern Georgia and western Alabama and makes up most of the Chattahoochee River aquifer in these two areas. These beds are more easily separated into distinct lithologic units than their dominantly nonmarine equivalents in eastern Georgia. The most important water-bearing units are usually associated with the Providence Sand, the Ripley Formation, the Cusseta Sand, and the Blufftown Formation (pl. 2). Water-bearing units within these formations do not form a continuous vertical sequence of permeable sand and gravel; several local confining units stratify the regional aquifer, separating it into local water-bearing units.

Permeable beds of the Providence Sand constitute the youngest Cretaceous strata of the Chattahoochee River aquifer. Throughout much of western Georgia, the sandier part of the Providence is separated locally from the overlying Clayton Formation (Paleocene) by a clayey sand and clay layer that is part of both formations. However, in many updip areas of western and central Georgia and eastern Alabama, permeable beds of the Providence and Clayton combine to form a single water-bearing unit. In western Georgia, the Providence Sand is separated from the underlying Cusseta Sand by fine sand, silt, and clay of the lower part of the Providence in combination with poorly permeable beds of the underlying Ripley Formation. This confining unit is of local significance only and grades to sandier beds or is missing to the east, south, and west. In southeastern Alabama, the Providence Sand is usually developed in combination with water-bearing units that are part of the Nanafalia and Ripley Formations (Scott and others, 1984).

Water-bearing units of the Providence Sand, Ripley Formation, and Cusseta Sand are considered to be the least productive of the Southeastern Coastal Plain aquifers in Alabama (Williams and others, 1986a). Clarke and others (1983) reported a transmissivity of 930 ft^2/d for the Providence Sand in Clay County, Ga. The Ripley Formation is not considered to be a productive water-bearing zone in western Alabama and east-central Mississippi; there, it grades by facies change to sandy clay and chalk that are part of the extensive Black Warrior River confining unit. In northern Mississippi, more permeable, sandy beds of the McNairy Sand and Chipawa Members of the Ripley Formation serve as the most important source of water within the McNairy-Nacatoch aquifer. Aquifer tests indicate that the transmissivity of these water-bearing zones ranges from 270 to 800 ft^2/d, and hydraulic conductivity ranges from 50 to 75 ft/d (Newcome, 1974; Wasson and Tharpe, 1975).

The Blufftown Formation is not considered to contain major water-bearing zones in Alabama. It grades to a sandier facies as it extends eastward into Georgia.

Black Creek and Middendorf Formations

Water-bearing units within the Black Creek Formation serve as the principal source of ground water in coastal and middip areas of South Carolina. Unlike the thick, massively bedded strata of the Middendorf Formation at outcrop and in the shallow and middip subsurface, water-bearing units within the Black Creek Formation tend to be thinner and more lenticular and to contain more clay. Discrete water-bearing units range from thin, laminated sand and clay to medium-bedded sandy units, none of which can be mapped over any great distance. Accordingly, water-bearing units within the Black Creek Formation tend to act hydraulically more independently when subjected to pumping from wells (Zack, 1977). The transmissivity of the Black Creek Formation is, in general, much less than that of the underlying Middendorf Formation. Aucott and Newcome (1986) reported that the transmissivity of the Black Creek ranges from 200 to 6,000 ft^2/d, and the hydraulic conductivity ranges from 4 to 133 ft/d. The unit is more permeable in the northwestern South Carolina Coastal Plain, where it grades to a nonmarine lithology similar to that of the Middendorf Formation. The Black Creek Formation is least permeable along the South Carolina coast. Strata equivalent to the basal part of the Black Creek Formation in shallow subsurface areas along the Georgia–South Carolina border are largely of nonmarine character and form the uppermost part of the locally named "Midville aquifer" in Georgia (Clarke and others, 1985). The water-bearing units of the Black Creek Formation combine with deeper, sandy strata that are equivalent to the Middendorf. Wells tapping the uppermost water-bearing units of the Chattahoochee River aquifer of eastern Georgia and western South Carolina are commonly screened in combination with shallower water-bearing zones, making it difficult to assess hydraulic properties of individual units. It is likely, however, that the transmissivity and hydraulic conductivity of these water-bearing units are similar to those reported for the Middendorf Formation in eastern South Carolina.

The fluvial Middendorf Formation has been considered by some workers as the most important and productive permeable zone in the South Carolina Coastal Plain sediments (Siple, 1975, 1984; Park, 1980). Water-bearing units that are part of this formation serve as the principal source of water to many counties adjacent to the inner Coastal Plain margin. The permeability and transmissivity of these water-bearing units are greatest where they crop out or lie in the shallow subsurface. Aquifer-test data collected from wells screened in the Middendorf Formation in South Carolina (Aucott and Newcome, 1986) indicate that the transmissivity ranges from 2,500 to 18,000 ft^2/d. The hydraulic conductivity of these water-bearing units is reported to range from 25 to 266 ft/d. In extreme northeastern South Carolina, the transmissivity and hydraulic conductivity of the Middendorf Formation are lower, due to the higher concentration of intermixed and interstratified kaolinitic clay, and range from 400 to 900 ft^2/d and from 10 to 25 ft/d, respectively. The transmissivity of the Middendorf decreases markedly to the southeast (probably due to gradational facies change to a clayey and silty sand that is thinly to thickly interlaminated and interbedded with clay and silt), ranging from 400 to 4,000 ft^2/d; hydraulic conductivity ranges from 10 to 50 ft/d.

The overlying Peedee Formation is not considered to be a water-bearing unit, except locally. Its lithologic character changes as equivalent beds extend into the western South Carolina and Georgia subsurface, where they form the lower part of the "Dublin aquifer" described by Clarke and others (1985). In that area, rocks equivalent to the Peedee Formation grade to a marginal-marine and nonmarine lithology and have a permeability similar to that of the Black Creek and Middendorf Formations. Because many of the wells drilled in eastern Georgia are screened in many different formations, the transmissivity and hydraulic conductivity of the rocks equivalent to the Peedee Formation are not known.

BLACK WARRIOR RIVER CONFINING UNIT

A thick marine sequence of low-permeability chalk, shale, clay, and mudstone of Cretaceous and Paleocene age forms the Black Warrior River confining unit, the thickest and most widespread confining unit of the

Southeastern Coastal Plain aquifer system. The Black Warrior River confining unit crops out in Mississippi and Alabama but is overlapped by the overlying Pearl River aquifer in Georgia and South Carolina. The configuration of the upper surface of the Black Warrior River confining unit, which is the same as the basal surface of the Chattahoochee River aquifer in South Carolina, Georgia, easternmost Alabama, and northern Mississippi, is shown on plate 38. Where the Chattahoochee River aquifer is absent in central Mississippi and western Alabama, the Black Warrior River confining unit separates the shallower Pearl River aquifer from the Black Warrior River aquifer; therefore, the configuration of the confining unit in those areas is the same as that shown for the base of the Pearl River aquifer (pl. 34). In northern Mississippi, the Black Warrior River confining unit both overlies and underlies the McNairy-Nacatoch aquifer (Ripley Formation), thus separating the confining unit into an upper and lower zone (fig. 34, pl. 33). The deeper Black Warrior River aquifer underlies the confining unit in most of the study area (pl. 2). However, this aquifer is absent in much of the northeast Georgia–northwest South Carolina Coastal Plain. In these areas, the Black Warrior confining unit immediately overlies the lower confining unit, a basal confining zone that underlies the Southeastern Coastal Plain aquifer system and consists of low-permeability crystalline and sedimentary rocks of Paleozoic and early Mesozoic age.

The Black Warrior River confining unit is thickest in Mississippi and western Alabama where the Chattahoochee River aquifer is missing, and these low-permeability beds separate the Pearl River aquifer from the underlying Black Warrior River aquifer (pl. 39). Although the thickness of this confining unit exceeds 3,000 ft in southern Mississippi, this is considered an unusual case. Only in a limited area of Mississippi and western Alabama does the Black Warrior River confining unit separate the freshwater parts of the Pearl River aquifer from the underlying freshwater parts of the Black Warrior River aquifer. In these areas, the Black Warrior River confining unit is generally less than 1,500 to 1,700 ft thick (figs. 21–23; pls. 19–21). The Black Warrior River confining unit thins considerably to the east and averages less than 250 ft in thickness in much of eastern Georgia and South Carolina, although it is as thick as 500 to 1,000 ft in southern Georgia.

The thick section of low-permeability rock that forms the Black Warrior River confining unit includes a number of Cretaceous and Paleocene rock-stratigraphic units that together form an extremely effective confining unit. As might be expected of a confining unit containing such a diverse collection of rock units, the Black Warrior River confining unit contains a highly variable lithology. Highly oxidized, nonmarine, sandy and silty clay that makes up the confining unit in the shallow updip areas of South Carolina and northeastern Georgia grades coastward and westward into marginal-marine and shelfal-marine calcareous clay, shale, mudstone, marl, or chalk.

ROCKS OF PALEOCENE AGE

Marine, micaceous, calcareous to carbonaceous clay and shale of Paleocene age that are locally interbedded with minor limestone and fine glauconitic sand constitute the upper part of the Black Warrior River confining unit in extreme southwestern Georgia. Equivalent beds that form the uppermost part of the regional confining unit throughout Alabama and Mississippi are considered to be stratigraphically equivalent to the Porters Creek and Clayton Formations of early Paleocene age (Midwayan).

ROCKS OF CRETACEOUS AGE

An extensive clay that forms the Black Warrior River confining unit in the shallow subsurface of South Carolina and in adjacent counties of North Carolina is considered equivalent, in part, to the outcropping beds of the Cape Fear Formation or the lower part of the Middendorf Formation (figs. 27, 28, 36; pls. 25, 26, 40). There, the confining unit is made up of nonmarine (fluviodeltaic), noncalcareous, sparsely fossiliferous, mottled reddish-brown to greenish-gray, sandy to silty clay that is interlaminated with fine micaceous sand; minor constituents include hematite, limonite, and siderite. In the deeper subsurface of South Carolina and southeastern North Carolina, the Black Warrior River confining unit consists of a moderately thick succession of marginal-marine to nearshore-marine sandy clay beds that are quite similar lithologically to the Black Creek Formation. There, the confining unit embodies gray clay that is interlaminated with fine-grained, micaceous sand and lignite; glauconite, phosphate, pyrite, shell material, Foraminifera, and Ostracoda are common minor constituents.

The low-permeability beds that form the Black Warrior River confining unit in much of Georgia are considered equivalent to the clay of the Eutaw Formation or to the lower part of the Blufftown Formation, both of Late Cretaceous age (figs. 24, 30–32; pls. 22, 28–30). The formations that make up the Black Warrior confining unit in much of Georgia include chalky, micaceous, calcareous, carbonaceous clay that is silty and sandy in places. Minor amounts of glauconite, phosphate, and chlorite are locally present.

Chalk, shale, and clay that are part of the Selma Group and its equivalents make up a large part of the Black Warrior River confining unit in Mississippi, Alabama, Georgia, and panhandle Florida. In these areas, the confining unit includes gray to brown marl, chalky marl,

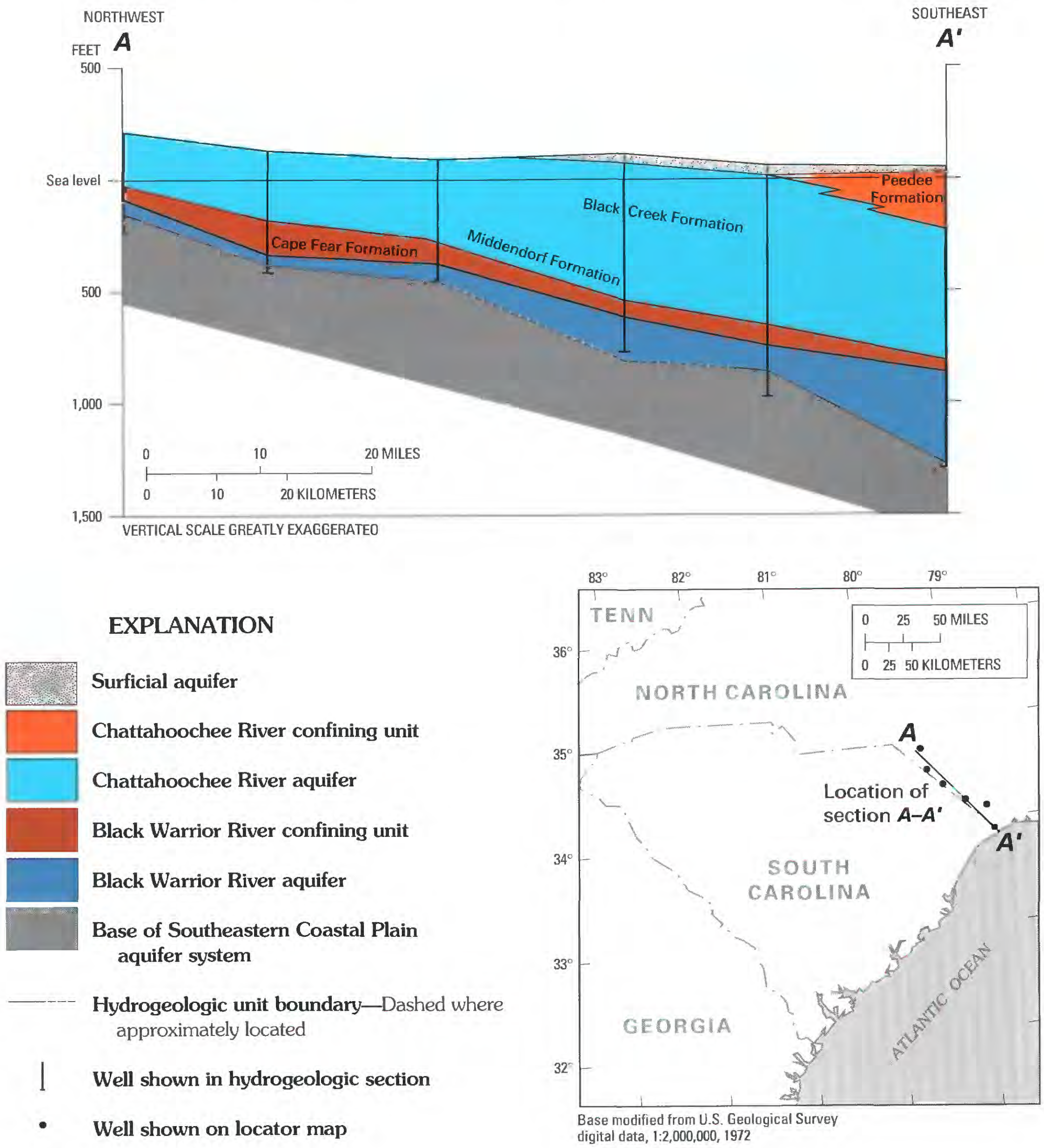


FIGURE 36.—Generalized hydrogeologic section *A–A'* from Scotland County to Brunswick County, N.C.

chalk, and calcareous shale and clay that are locally micaceous, fossiliferous, and sandy.

BLACK WARRIOR RIVER AQUIFER

The Black Warrior River aquifer is the most extensive clastic aquifer of the Southeastern Coastal Plain (fig. 37, pl. 41). Sandy strata that are part of this aquifer extend in the subsurface or crop out as far north and west as Tennessee and as far east as central North Carolina. The upper surface of the Black Warrior River aquifer slopes gently seaward at a gradient of 15 to 30 ft/mi in Georgia, northern Florida, South Carolina, and adjacent counties of North Carolina but dips more steeply in Alabama and Mississippi (30 to 50 ft/mi or greater). The landward limit of the outcrop area of the Black Warrior River aquifer marks the inner margin of Coastal Plain sediments (Fall Line) in western Georgia, Alabama, and Mississippi. From a 40- to 50-mi-wide outcrop band in eastern Mississippi and western Alabama, the width of its outcrop decreases gradually as it extends into eastern Alabama and western Georgia. The Black Warrior River aquifer is completely covered in eastern and central Georgia by onlapping rocks of Late Cretaceous and Tertiary age but crops out locally along the Cape Fear River in North

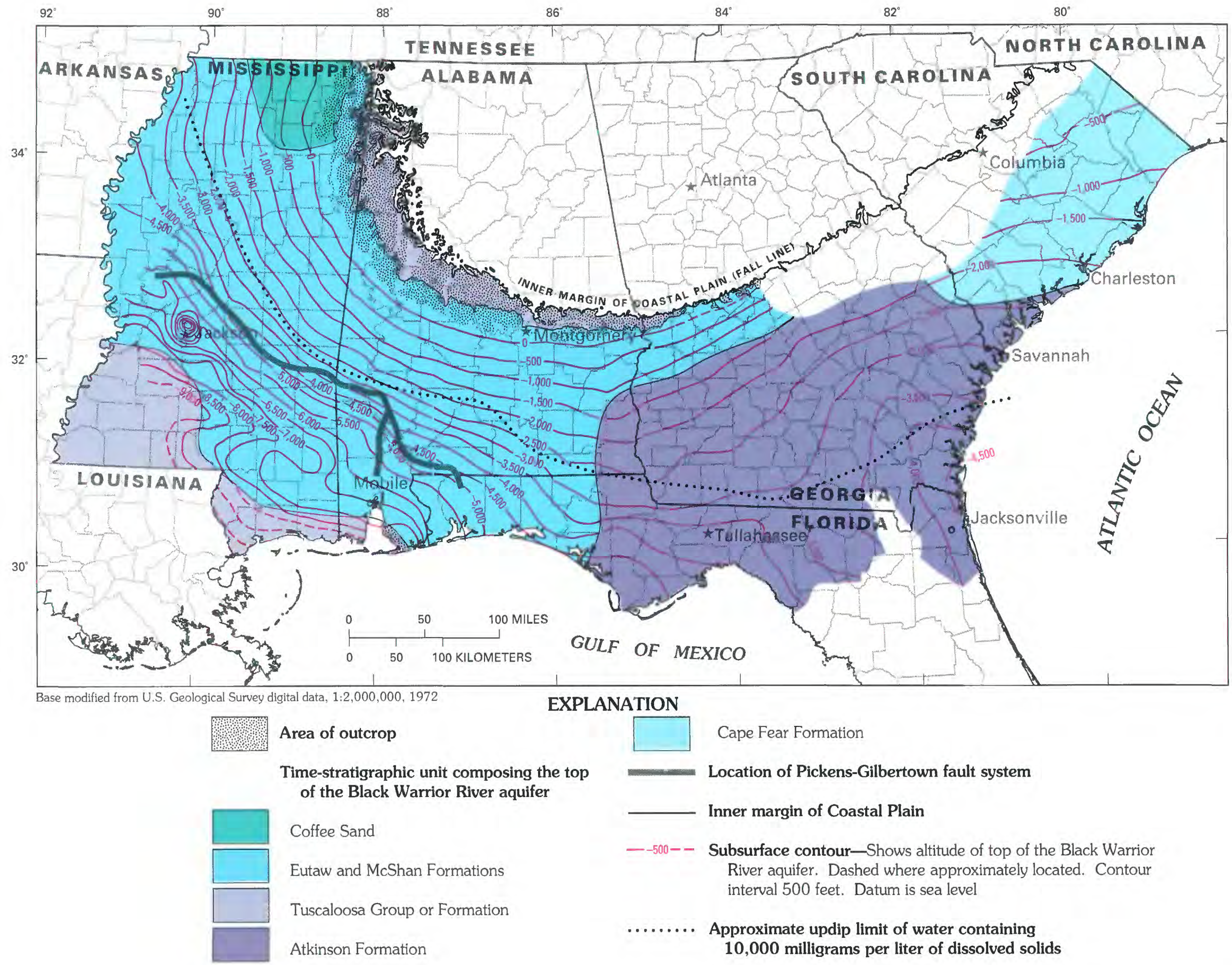


FIGURE 37.—Geology and configuration of the top of the Black Warrior River aquifer.

Carolina. The updip limit of this aquifer occurs well south of the Fall Line in eastern Georgia and South Carolina, probably due to nondeposition of equivalent beds. The Black Warrior River aquifer is missing along the axis of the Peninsular arch in northeastern Florida and southeastern Georgia.

The northernmost extent of ground water containing concentrations of greater than 10,000 mg/L of dissolved solids in the uppermost part of the Black Warrior River aquifer is shown on figure 37 and plate 41. An interesting feature of the occurrence of saline water in the aquifer is that fresh ground water extends farther downdip and lies at much greater depths in eastern Alabama, Georgia, and South Carolina than in western Alabama and Mississippi. Cross sections presented in this report as well as a map (fig. 38) showing the altitude of saline water within the aquifer (Strickland and Mahon, 1986) reflect the nonuniform lithologic and hydraulic properties of the aquifer and locations of ground-water recharge and discharge in the study area. Three factors control the position and character of the freshwater-saltwater transition zone.

Meisler and others (1984) studied the effect of Pleistocene sea-level changes on the position of similar freshwater-saltwater transition zones in the northern Atlantic Coastal Plain, observing that in New Jersey, saltwater occurs at greater depths near the coast than farther inland. By use of a cross-sectional ground-water flow model, they concluded that the freshwater-saltwater transition zone in New Jersey reflects sea levels that were probably 50 to 100 ft below present sea level. Meisler and others (1988) also observed that the freshwater-saltwater transition zone is shallower and does not extend as far offshore in southeastern Virginia and North Carolina. They concluded that the position of the transition zone there reflected higher average sea levels to the south than to the north (Meisler and others, 1988).

The permeability and transmissivity of the Black Warrior River aquifer are much greater in western Alabama and in Mississippi than to the east. However, the depth to the transition zone is much deeper in Georgia than in Mississippi and western Alabama. The contrasting depths to the transition zone may reflect differences in the transmissivity of the aquifer. As the sea level rose from its most recent Pleistocene lowstand, the position of the transition zone responded by shifting landward. The fact that this zone extends farther landward in the west may reflect higher transmissivity, allowing a more rapid landward movement of saltwater in response to higher heads. Conversely, the more coastward extent of fresh ground water to the east may reflect the lower transmissivity there that did not permit landward movement of saltwater to occur as quickly from a rising sea.

Another factor controlling the position of the freshwater-saltwater interface is related to the discharge of ground water to rivers and streams. The Black Warrior River aquifer does not crop out in South Carolina and most of Georgia and is under confined conditions. To the west, the aquifer is cut by a number of deeply entrenched river drains that intersect the ground-water flow system and capture recharge that might otherwise percolate into the deeper parts of the aquifers. The influence of this natural drainage system is largely reflected by a relatively shallow depth to saline ground water in the west. Saline ground water occurs within the Black Warrior River aquifer as shallow as 1,450 ft below sea level in places such as central Alabama. In Georgia, where the aquifer is isolated from regional river drains, saline water does not occur at depths shallower than 2,700 ft below land surface.

The Black Warrior River aquifer is thickest in east-central Mississippi and west-central Alabama, where it exceeds 5,000 ft in thickness in downdip localities (pl. 42). However, the maximum thickness of the freshwater column (that is, the entire thickness of the aquifer that contains ground water with less than 10,000 mg/L of dissolved solids) exceeds 2,500 ft only locally in central Alabama. Coastward, the freshwater column thins toward the saltwater-freshwater transition zone and also thins to a featheredge as it extends to aquifer outcrop areas. The thickness of the freshwater column in the Black Warrior River aquifer averages less than 750 ft in northern Mississippi. However, in South Carolina and eastern Georgia, it averages less than 500 ft.

ROCKS OF LATE CRETACEOUS AGE

Coffee Sand

Outcropping and subsurface beds that are part of the Coffee Sand form the uppermost part of the Black Warrior River aquifer in several northeastern Mississippi counties. These strata consist of marine, fine- to medium-grained, loosely consolidated, glauconitic quartz sand, commonly laminated with silt and clay; other sand beds are finely crossbedded to massive. To the south and southwest, these strata grade to less permeable chalk, shale, and clay of the Mooreville and Demopolis Chalks that are part of the Black Warrior River confining unit. Permeable strata of the Coffee Sand are hydraulically linked to the underlying Eutaw Formation north of Lee County, Miss. To the south, they are separated from underlying water-bearing units by a tongue of the Mooreville Chalk. The Coffee Sand is separated from overlying water-bearing rocks everywhere in northeastern Mississippi by the “transitional clay” of the Ripley Formation. The transmissivity of the Coffee Sand ranges from 930 to

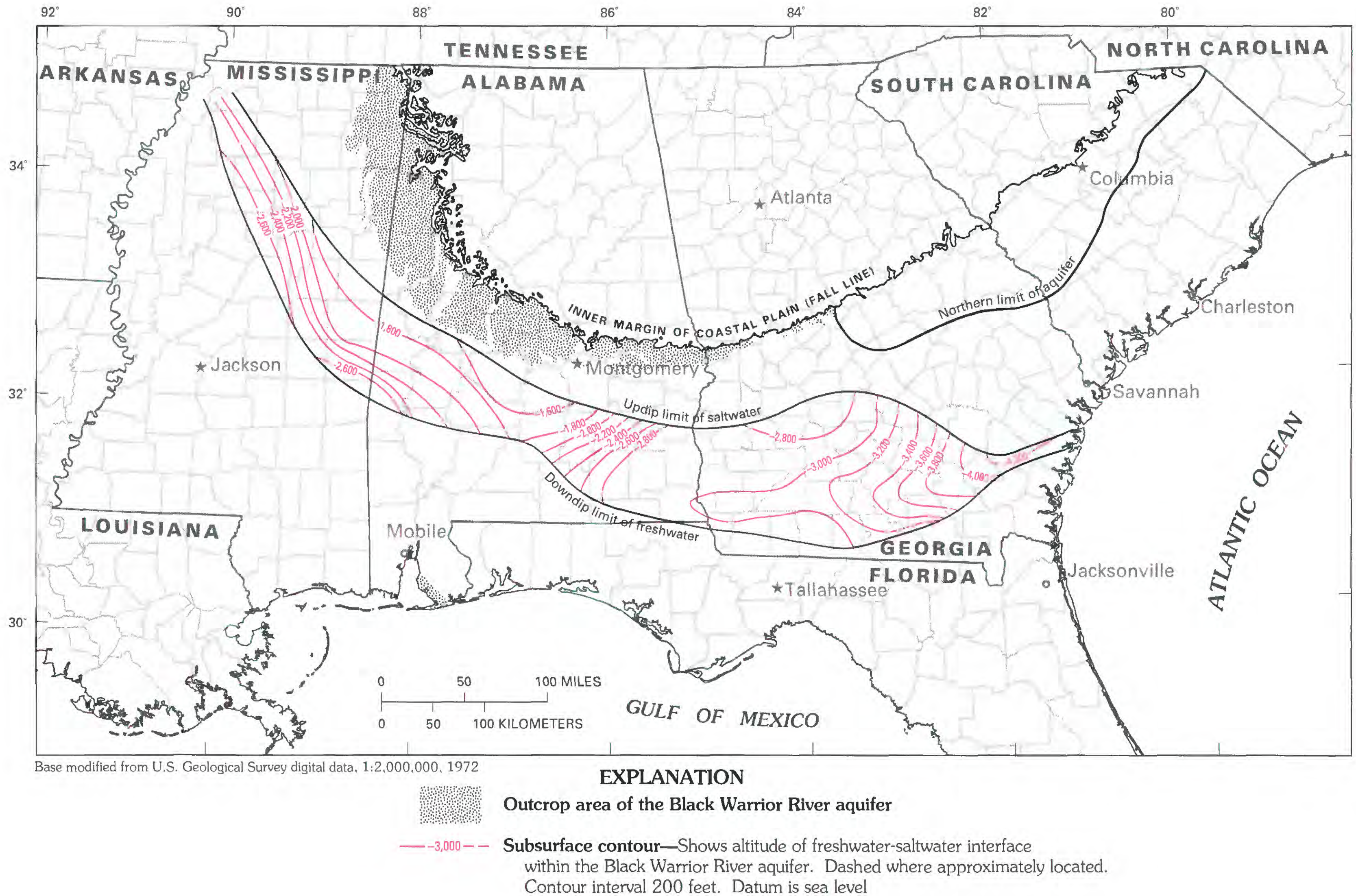


FIGURE 38.—Altitude of saline water within the Black Warrior River aquifer (modified from Strickland and Mahon, 1986).

1,200 ft^2/d; the hydraulic conductivity of these same strata ranges from 9 to 20 ft/d (Newcome, 1974; Wasson and Tharpe, 1975).

Cape Fear Formation

Poorly sorted, nonmarine, mottled red to reddish-brown, fine to coarse feldspathic quartz sand, considered in part equivalent to the outcropping Cape Fear Formation and in part equivalent to "Unit F" of Brown and others (1972), forms the uppermost part of the Black Warrior River aquifer in South Carolina and adjacent counties of North Carolina. This sand is commonly cyclically stratified with interbedded mudstone and noncalcareous clay; siderite, hematite, and pyrite are common minor constituents. In coastal areas of South Carolina, older rocks, possibly Eaglefordian in age, are included as part of the Black Warrior River aquifer. Few data are available to ascertain the hydraulic character of these older strata. Judging by the marginal- to shallow-marine character of these sediments, the transmissivity of the aquifer is probably low. The same is true for the poorly transmissive, clayey Cape Fear Formation and "Unit F" beds. The water-transmitting capabilities of these units are low compared with those of the overlying, highly permeable Middendorf Formation. Relatively few aquifer-test analyses have been reported from the Cape Fear Formation, possibly attesting to its low transmissivity. Shallower, more permeable water-bearing units are used for water supply instead. A transmissivity of 900 ft^2/d and a hydraulic conductivity of 18 ft/d are reported for the Cape Fear Formation in Darlington County, S.C. (Aucott and Newcome, 1986). Age-equivalent rocks in the shallow subsurface of east-central Georgia form part of the Black Warrior River confining unit underlying the Chattahoochee River aquifer (in Georgia, locally named "Midville aquifer").

Atkinson Formation

Subsurface strata that represent the upper and lower sands of the Atkinson Formation, in combination with underlying rocks of Early Cretaceous age, form the Black Warrior River aquifer in the subsurface of southeastern Alabama, Georgia, and northern Florida. In these areas, rocks that form the upper part of the aquifer consist largely of marine sediments but include nonmarine strata as they merge with the Tuscaloosa Formation of western Georgia. The Atkinson part of the Black Warrior River aquifer typically consists of very fine to medium-grained quartz sand and sandstone, interbedded with siltstone, shale, and minor limestone beds; the sand tends to be more feldspathic in shallow updip regions of western Georgia.

Eutaw and McShan Formations

In most of Mississippi and Alabama and in the northwestern Georgia Coastal Plain, strata equivalent to the Eutaw or the combined Eutaw and McShan Formation(s) make up the upper part of the Black Warrior River aquifer. In these localities, the aquifer consists of sparsely fossiliferous, greenish-gray to yellowish-brown, fine to coarse glauconitic sand that is interbedded with gray, micaceous to carbonaceous shale. The uppermost part of the Eutaw, the Tombigbee Sand Member, is massive, whereas the lower part of the Eutaw and the underlying McShan Formation include laminated sand and clay and, locally, crossbedded sand.

The lowermost sands of the Eutaw Formation and sand of the McShan Formation, where present, tend to be more productive water-bearing strata than the Tombigbee Sand Member. Boswell (1963) observed that, although the Tombigbee Sand Member was capable of yielding small quantities of water, its calcareous, silty, fine-grained nature makes it a less productive water-bearing unit that is usually cased off in water wells. Boswell considered the lower part of the Eutaw Formation and the deeper McShan Formation to function as a single water-bearing unit, noting that the sands of both units were interconnected when mapped regionally. The two formations are hydraulically separated from deeper aquifers of the Tuscaloosa Group by an intervening clay bed that extends as far north as Lee County, Miss. This low-permeability bed extends into western Alabama but does not occur in the eastern half of the State. It is likely that in Alabama, as in northern Mississippi, this uppermost clay in the Tuscaloosa (Gordo Formation) is missing in some localities, and both the Eutaw and Tuscaloosa Formations function as a single hydrologic unit. The uppermost beds of the Eutaw Formation are directly overlain in most of Mississippi and Alabama by the thick Black Warrior River confining unit that consists of chalk, clay, and shale. In northern Mississippi, however, uppermost Eutaw beds are overlain by, and are hydraulically connected to, permeable water-bearing units that are part of the Coffee Sand. South of Lee County, Miss., however, they are separated from the Coffee by an interfingering tongue of the Mooreville Chalk. In eastern Alabama and western Georgia, the Mooreville Chalk grades to the more permeable Blufftown Formation that forms the lowermost part of the Chattahoochee River aquifer. In these areas, a clay confining bed forms the uppermost part of the Eutaw Formation and the lower part of the Blufftown Formation, and separates the Black Warrior River and Chattahoochee River aquifers.

Although they are less permeable than the underlying Tuscaloosa strata, water-bearing rocks of the Eutaw Formation form an important aquifer in Mississippi because of water quality considerations (a smaller iron content). Based on 41 aquifer tests, the transmissivity of these strata was found to range from 200 to 4,900 ft^2/d and the hydraulic conductivity to have a median value of 13.4 ft/d (Boswell, 1977). Hydraulic data are lacking from wells screened specifically in the Eutaw Formation in Alabama and Georgia. In general, however, the hydraulic conductivity and thickness of these beds appear to diminish as they extend eastward across Alabama; therefore, the transmissivity probably decreases also.

Facies changes similar to those described above occur as the Eutaw and McShan strata extend coastward into southwestern Mississippi. There, the permeability of these rocks diminishes due to a gradational lithic change. Rocks equivalent to the Eutaw and McShan Formations consist of chalk and argillaceous shale that form the basal part of the Black Warrior River confining unit (fig. 21, pl. 19). Accordingly, the upper part of the Black Warrior River aquifer here is probably equivalent to the uppermost part of the Tuscaloosa Group.

Tuscaloosa Group or Formation

Several important water-bearing units within the Tuscaloosa part of the Black Warrior River aquifer include (1) nonmarine, highly crossbedded, fine to coarse, ferruginous quartz sand and cherty gravel deposits of the Gordo Formation; (2) fluvial and nearshore-marine glauconitic quartz sand deposits of the Coker Formation; and (3) nonmarine, massively bedded, medium to coarse quartz sand of the Massive sand unit in the subsurface of Alabama, western Georgia, and northern Mississippi. The transmissivity of this unit in the Tuscaloosa Group (Formation) ranges from 590 ft^2/d in Bullock County in eastern Alabama to 510 ft^2/d in Chattahoochee County in western Georgia (Faye and McFadden, 1986). These values are lower than those reported for the same beds that lie to the west.

Interbedded, dark, micaceous, marine shale separates the Tuscaloosa Group in middip localities of Mississippi and western Alabama. Permeable rocks that are part of the Gordo Formation form an upper water-bearing unit. Water-bearing units of Early Cretaceous age combine with the Coker Formation and the Massive sand unit to form a lower part of the Tuscaloosa Group in the Black Warrior River aquifer. In Mississippi, the transmissivity of this lower part of the formation ranges from 762 to 80,200 ft^2/d, whereas that of the upper part ranges from 535 to 21,400 ft^2/d. The Tuscaloosa Group has an average hydraulic conductivity of 42.8 ft/d (Boswell, 1978).

ROCKS OF EARLY CRETACEOUS AGE AND OLDER

Permeable clastic rocks of Early Cretaceous age (Washitan and Fredericksburgian) form the base of the Black Warrior River aquifer in middip and downdip localities of Mississippi, Alabama, Georgia, and northern Florida but are not known to crop out in the Southeastern Coastal Plain. These rocks consist of red to reddish-brown sand, sandstone, and gravel that were deposited under nonmarine conditions. Interlaminated marine and nonmarine shale, siltstone, and minor limestone beds are also present. Rocks of Early Cretaceous age contain ground water with greater than 10,000 mg/L of dissolved solids in most of the study area and generally are not considered part of the freshwater flow system. Some water-bearing units of Early Cretaceous age contain freshwater locally; these beds represent the oldest Coastal Plain sedimentary strata that contain fresh ground water. They occur in east-central Mississippi and extend across Alabama and western Georgia as a narrow band close to their updip extent. A much wider band extends across central and eastern Georgia.

Boswell (1963) identified a thick, nonmarine sand and gravel unit of Early Cretaceous age containing fresh ground water of a chemical quality similar to that of the overlying Tuscaloosa Group in the northwestern Mississippi Counties of Calhoun, Clay, Oktibbeha, Lowndes, and Noxubee. Although this unit does not crop out, its likely source of recharge is by downward leakage from the overlying Tuscaloosa Formation. M.E. Davis (U.S. Geological Survey, oral commun., 1986) reported that similar conditions exist in northwestern Alabama. Estimates as determined by analyzing electric log data (Brown and others, 1979) indicate that rocks of Early Cretaceous (Comanchean) age in subsurface areas of Georgia also contain ground water with less than 10,000 mg/L of dissolved solids.

BASE OF THE AQUIFER SYSTEM

Pre-Cretaceous rocks form a nearly impermeable base to the Southeastern Coastal Plain aquifer system. The base of the system consists of five major categories of rock, including (1) undifferentiated crystalline rocks, (2) saprolite, (3) sedimentary red beds, basalt, and diabase of early Mesozoic age, (4) sedimentary rocks of Jurassic age, and (5) sedimentary rocks of Paleozoic age.

Jurassic sedimentary rocks were excluded from the Southeastern Coastal Plain aquifer system because they are not known to contain ground water with dissolved-solids concentrations of less than 10,000 mg/L. It is assumed that very little movement of water occurs in these deeply buried rocks. Triassic sedimentary rocks were excluded from the Southeastern Coastal Plain aquifer system unit because they are considered to be nearly impermeable, the hydraulic conductivity ranging from 1.48×10^{-3} to 3.3×10^{-7} ft/d (Marine and Siple, 1974) in the buried Triassic Dunbarton Basin of South Carolina.

A 100-ft-thick weathered zone of tripolitic chert derived from limestone and sandstone of Paleozoic age occurs in northeastern Mississippi and northwestern Alabama, forming a locally productive aquifer that is in hydraulic contact with overlying Cretaceous aquifers (Boswell and others, 1965; J.V. Brahana, written commun., 1974; Wasson and Tharpe, 1975; Gandl, 1982). The highly variable hydraulic conductivity associated with these Paleozoic rocks (1.6 to 134 ft/d; mean of 71 ft/d) is due in large part to their weathered and fractured nature. These strata are not water productive except locally, such as in Tishomingo County, Miss. (Boswell, 1978).

Fracturing resulting from tectonic forces can increase the secondary porosity and permeability of crystalline Paleozoic strata but, as Snipes and others (1986) found, fractures may locally tend to be clogged by clay gouge or healed by secondary mineralization. In and near the Southeastern Coastal Plain aquifer system study area, the reported hydraulic conductivity of unfractured crystalline rocks ranges from 0.14 to 5×10^{-6} ft/d (Stewart, 1964).

Stewart (1964) reported that aquifer and laboratory tests of saprolitic materials developed on metamorphic rocks in northern Georgia show that the greatest hydraulic conductivities are in the saprolite parallel to the strike of the parent rock. Hydraulic conductivities of the saprolite range from 2.7×10^{-3} to 7.6 ft/d. Siple (1964) studied saprolitic beds buried beneath Coastal Plain sedimentary rocks in Aiken and Barnwell Counties, S.C. On the basis of hydraulic head and water quality differences, Siple concluded that the saprolite functioned as a confining bed in these areas.

STRATIGRAPHIC AND STRUCTURAL CONTROLS ON PERMEABILITY AND TRANSMISSIVITY OF THE SEDIMENTS

The extent and thickness of the major aquifers and confining units within the Southeastern Coastal Plain aquifer system are primarily functions of gradational changes in permeability of the delineated sediments. The regional changes in facies within the rocks that make up the Southeastern Coastal Plain overwhelmingly dominate the extent, composition, textural character, and hydraulic character of water-bearing strata. The following discussion summarizes these factors and their control on the distribution, geometry, and character of the major aquifers and confining units of the Southeastern Coastal Plain aquifer system.

Sedimentary rocks in the Southeastern Coastal Plain can be broadly categorized as either clastic or carbonate. Included as part of the latter group is the thick sequence of carbonate-platform deposits that cover the entire Florida peninsula and part of the Florida panhandle region, as well as less extensive areas of Alabama, Georgia, and southern South Carolina (Miller, 1986). Having a hydraulic character distinct from the clastic rocks that in places adjoin and elsewhere underlie them, these carbonate rocks may be treated as a single hydrogeologic system. The hydraulic character of the carbonate rocks is partly controlled by the original depositional character of the strata, but unlike clastic Coastal Plain deposits, their hydraulic nature is also influenced by subsequent diagenesis and especially dissolution that may increase or decrease their hydraulic conductivity.

As discussed previously, siliciclastic rocks of the Southeastern Coastal Plain aquifer system can be further divided into three major depositional types: (1) those deposited under nonmarine conditions, (2) those deposited under marine conditions, and (3) those deposited under transitional- or marginal-marine conditions. Nonmarine strata make up the most permeable and productive aquifers; the bulk of the nonmarine rocks were laid down under fluvial to deltaic conditions. Highly crossbedded to graded, fine to coarse sand and gravelly sand were deposited as channel lag and fill, point bars, levees, and terraces. Occasionally, erratic lenses or layers of clay that formed in oxbow or shallow flood-plain lakes and swamps are also found. These deposits were all laid down by meandering and, in some instances, anastomosing river and stream systems that carried sediment downstream from an elevated land mass to the north. The Tuscaloosa Group or Formation and the Middendorf Formation are the best examples of dominantly nonmarine rocks that form prolific, highly permeable water-bearing units. Delta-plain deposits include interdistributary mudstone beds commonly associated with lignitic deposits and channel-fill sand beds. The pattern of sand beds associated with these deltaic conditions reflects shifting stream channels, marshes, and swamps that typically are found in a delta plain.

Clastic strata deposited under marine conditions, particularly those deposited in open-marine-shelf conditions, combine to form some of the thicker, regionally extensive confining beds. As compared with the more localized shoreline, tidal, delta, and fluvial environments, marine-shelf areas of deposition are widespread and largely reflect low-energy conditions because they mostly remain below the effective wave base except during occasional storm surges. The term "marine shelf" implies a depositional environment that is areally widespread. Shelf materials consist dominantly of clayey silt and silty clay; coarser grained sediment is localized and concentrated as sandy "ribbons" or "waves" by longshore currents or occasional storm surges. Shelf deposits in the Southeastern Coastal Plain show an increase in sediment grain size in a shoreward direction. They tend to be increasingly calcareous as they extend southward toward the Florida peninsula. The sea covered much of Mississippi and Alabama during much of Late Cretaceous time (Austinian to Navarroan), raising the erosional base level, decreasing the size and elevation of the landmass available for erosion, and thus resulting in a retreat of the shoreline. Effectively isolated from an influx of coarse terrigenous sediment, a thick sequence of low-permeability chalk, chalky shale, and shale was deposited.

Marginal- or transitional-marine rocks represent the third major clastic rock type and include rocks that were deposited under estuarine, tidal-flat, strand-plain, and barrier-island conditions. Many rock types are associated with these varied depositional conditions, due to the complex mix of high- and low-energy environments that occur in close proximity to one another. Many of the coarser grained, moderately to well-sorted sandy rocks tend to be interbedded, interlaminated, or interstratified with finer grained clay and silt. Strand-plain and barrier-island sands form as "shoestrings." They grade landward to less permeable, clayey, lagoonal, tidal-flat, and marsh deposits, or coastward to silty clay and clayey silt shelf deposits. As in the case of barrier-island sand, these strata tend to be localized. A highly permeable water-bearing unit that may prove to be an extremely important local aquifer can grade progressively over a short distance to a local confining unit. The hydraulic interconnection of the more permeable parts of these transitional rock types can vary considerably from place to place and is largely dependent on their juxtaposition with overlying or underlying permeable beds. Therefore, one can expect individual water-bearing units of marginal-marine origin to be more hydraulically isolated than water-bearing units in more uniform nonmarine water-bearing rocks.

The lithology of clastic Coastal Plain rocks and their depositional origin not only control permeability but also are important criteria in delineating the boundaries of regionally extensive water-bearing units. For example, the Pearl River aquifer is overlain by, and is lithologically and hydraulically interconnected with, the highly permeable Floridan aquifer system in Florida, southern Alabama, southern Georgia, and southwestern South Carolina. The boundary between the two regional aquifers represents a lithologic separation of carbonate rocks from clastic beds as well as a significant contrast in permeability. The permeability of the Floridan is one or more orders of magnitude larger than that of the underlying Pearl River aquifer. The position of the boundary between the two aquifers is largely dependent on the northward shift of the carbonate facies during Late Cretaceous to Tertiary time. Therefore, the boundary between the two regional aquifers transgresses geologic time.

In much of the Southeastern Coastal Plain, hydraulic and initial hydrologic conditions were not well known prior to this study. There are few or no field data available to help assess regional recharge rates, streambed conductance, or confining unit leakance. The transmissivity of many of the water-bearing units, as determined from aquifer tests, is known for fewer than 500 sites in a 120,000-mi^2 study area. More important, most of the test analyses are representative of the transmissivity of specific, screened water-bearing intervals and do not represent the entire thickness of the extensive, lithologically variable, regional hydrogeologic units that are described in this report. Given a lack of definitive data needed to construct a digital computer model of regional ground-water flow, an indirect approach was selected using iterative trial-and-error estimates for the various input model parameters (Barker and Pernik, 1994). The transmissivity estimate used for each aquifer was derived from values that appear to best represent observed conditions. In combination with other estimated hydraulic parameters, transmissivity estimates were used to calibrate the digital flow model by matching observed hydraulic head data and ground-water discharge rates against simulated head and discharge values.

The transmissivity and hydraulic conductivity of an aquifer are directly influenced by particle size and shape, sorting, sedimentary fabric, degree of packing, amount of interstitial matrix material, and cementation of the rock material composing the aquifer. These factors are, in part, a reflection of the depositional history of the rock.

Hydraulic conductivity distributions can be estimated in an aquifer from maps of rock lithofacies and aquifer thickness, by assuming that a direct correlation exists between rock type and aquifer permeability. This assumption was confirmed by comparing estimated transmissivity, regional facies, and total aquifer thickness maps of the Southeastern Coastal Plain aquifer system. Ranges of transmissivity based on the final calibrated model for the Pearl River–Lower Floridan aquifer; Chattahoochee River and McNairy-Nacatoch aquifers; and Black Warrior River aquifer are shown in figures 39–41 (Barker and Pernik, 1994). A direct comparison is not easily accomplished between model-derived transmissivity and field-estimated transmissivity as determined from aquifer tests, thickness of aquifer, and rock type. It is particularly difficult to compare the transmissivity values of aquifers that contain water-bearing rocks that encompass several different stratigraphic units, and whose upper and lower boundaries transgress geologic time.

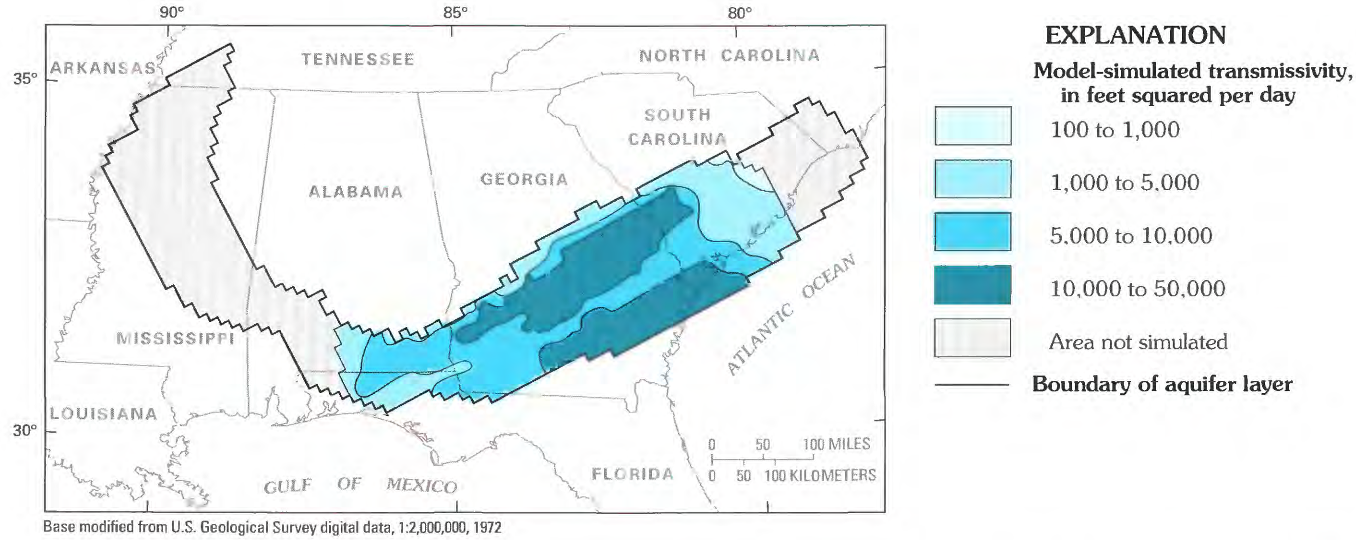


FIGURE 39.—Simulated transmissivity values for the Pearl River aquifer and Lower Floridan aquifer of the Floridan aquifer system (modified from Barker and Pernik, 1994).

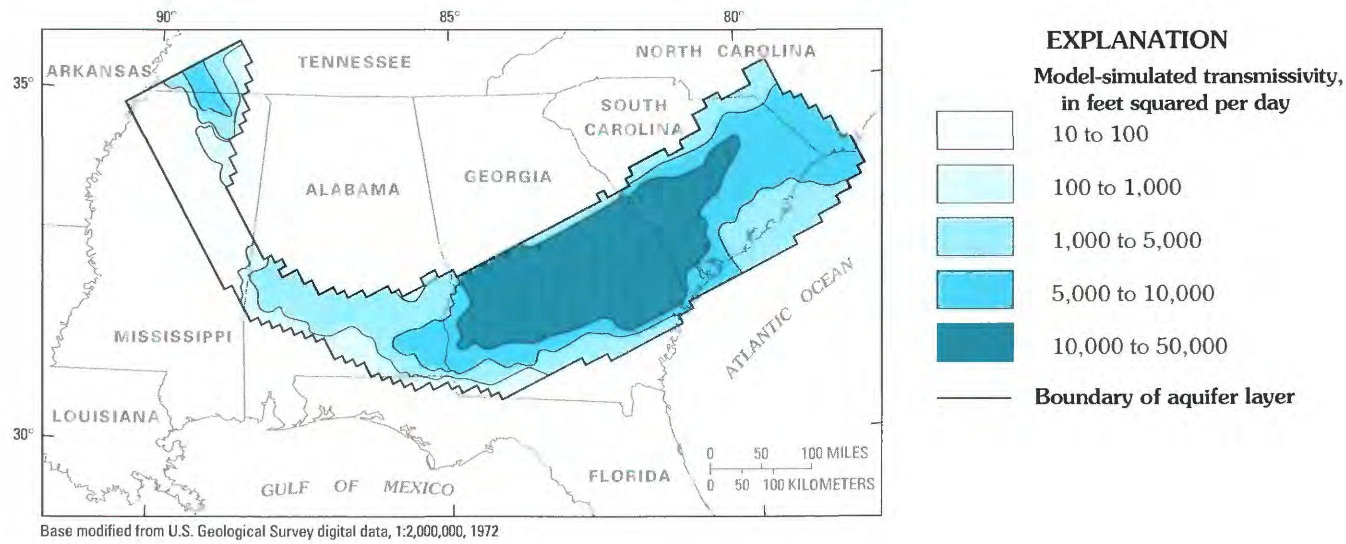


FIGURE 40.—Simulated transmissivity values for the Chattahoochee River aquifer and the McNairy-Nacatoch aquifer (modified from Barker and Pernik, 1994).

The Pearl River aquifer is the shallowest aquifer actively simulated as part of the regional ground-water-flow model. Although they represent units of contrasting permeability, the Pearl River aquifer and Lower Floridan aquifer of the Floridan aquifer system generally act as a single hydrologic unit with predominantly lateral ground-water flow in southern Georgia (fig. 30). These aquifers were combined into a single model layer to simulate the hydraulic interconnection between the Floridan and the Southeastern Coastal Plain aquifer systems. Therefore, the characteristics of this uppermost model layer (such as transmissivity) and those of the Pearl River aquifer do not directly correspond everywhere. A similar departure between the regional hydrogeologic framework and model simulation is found in Mississippi and Alabama; in these areas, the Pearl River aquifer was simulated as part of a source-sink boundary condition.

In spite of some lack of correspondence between model layers and major hydrogeologic units, a comparison of simulated transmissivity values can be made with the major Paleocene and Eocene lithofacies that make up the Pearl River aquifer (compare figs. 11–13 with fig. 39). Lowest simulated transmissivity values (1,000 to 5,000

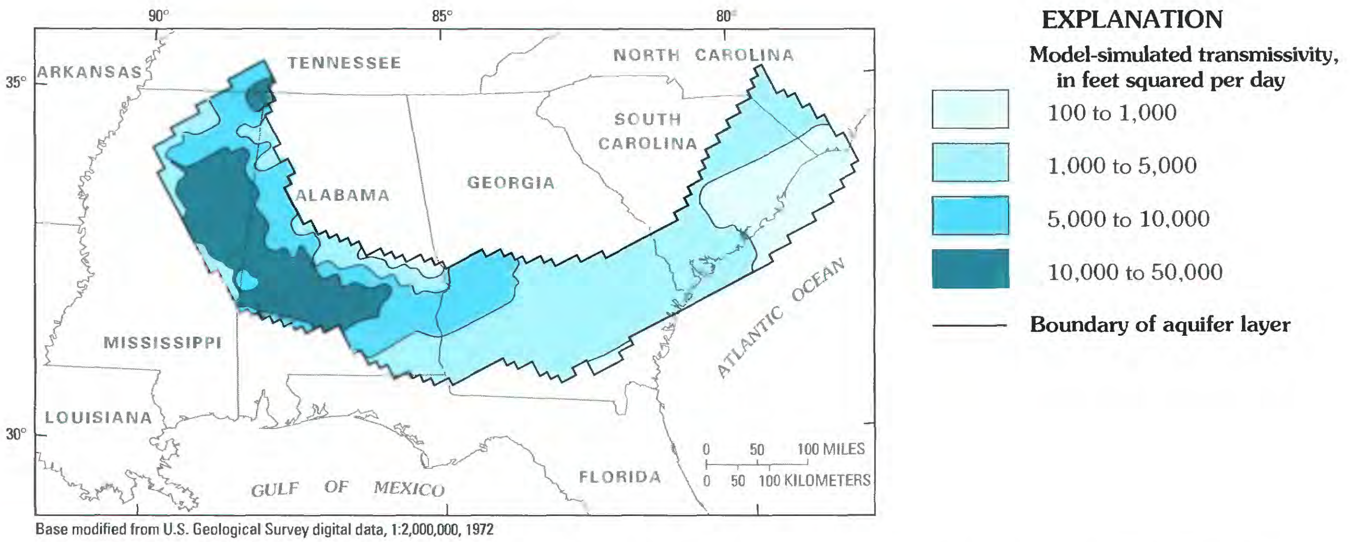


FIGURE 41.—Simulated transmissivity values for the Black Warrior River aquifer (modified from Barker and Pernik, 1994).

ft^2/d) occur, in general, where these strata grade from marginal- and transitional-marine sediments to rock types that were deposited under neritic conditions. In South Carolina, for example, the Pearl River aquifer consists largely of rocks of Midwayan to Claibornian age that are sandy in outcrop but quickly grade to less permeable marl, muddy sand, and shelly limestone as they extend into the subsurface. A similar occurrence is found in central and eastern Alabama, where rocks of Claibornian to Sabinian age grade coastward to less permeable, deeper marine rocks.

Simulated transmissivity values for the model layer representing the Pearl River and Lower Floridan aquifers are greater (5,000 to 50,000 ft^2/d) in Georgia than in either Alabama or South Carolina; the areas with the largest transmissivity values (10,000 to 50,000 ft^2/d) extend across Georgia in a northeast-southwest direction as two parallel bands. The transmissivity distribution shown in figure 39 for these two aquifers includes carbonate rocks that interfinger with, and overlie, the clastic marine strata, all of which range from Claibornian to Sabinian in age. Interbedded sandy limestone and limy sandstone beds that overlie the less permeable glauconitic sand, clay, and sandy marl contribute greatly to the large transmissivity values. A band of rocks having less transmissivity (5,000 to 10,000 ft^2/d) is attributed to the influence of the Gulf trough on the Lower Floridan aquifer. Miller (1986) observed that low-permeability rocks were downdropped within the Gulf trough and are now positioned adjacent to the high-permeability rocks of the Floridan aquifer system. The lower transmissivity of the Floridan in the Gulf trough is related to a reduction in thickness of limestone by faulting (Gelbaum, 1978; Miller, 1986).

The Chattahoochee River aquifer has the largest transmissivity (10,000 to 50,000 ft^2/d) in an area that underlies most of Georgia and in a smaller area of western South Carolina (fig. 40). These highly transmissive areas correspond to nonmarine deposits that are shown on the Austinian, Tayloran, and Navarroan facies maps (compare fig. 40 with figs. 8–10). In northeastern South Carolina, the transmissivity of the Chattahoochee River aquifer decreases (to 5,000 to 10,000 ft^2/d) despite the nonmarine character of the lower part (Middendorf Formation) of the aquifer. This decrease can be explained by the gradational change of younger Tayloran strata (Black Creek Formation) to less permeable marginal-marine deposits and by a general thinning of the aquifer as it extends eastward. This thinning is controlled partly by the structurally positive Cape Fear arch and partly by the absence of permeable Navarroan and Midwayan strata that are part of the aquifer to the east. Low transmissivity values (1,000 to 5,000 ft^2/d) extending as a narrow band across the inner margin of the Coastal Plain are also associated with nonmarine, dominantly feldspathic, quartz sands. Given their dominantly nonmarine character, the estimated transmissivity may appear surprisingly low, but the aquifer is thin as it extends to outcrop or lies as shallow subcrop. The other controlling factor is lithology. This low-transmissivity band corresponds to kaolin belt deposits. Kaolinitic clay occurs as massive beds throughout the area, but more important, it occurs as interstitial material, thus lowering the permeability of the water-bearing rocks (see discussion of the Middendorf Formation under the Chattahoochee River and McNairy-Nacatoch aquifers).

The relatively high transmissivity values (10,000 to 50,000 ft^2/d) that characterize much of the Chattahoochee

River aquifer in Georgia extend well beyond the limits shown for nonmarine deposition on the Austinian, Tayloran, and Navarroan facies maps. The reason that transmissivities remain relatively high is twofold. The Chattahoochee River aquifer is thickest in central Georgia and consists of moderately permeable, marginal- or transitional-marine rocks. These rocks are, in turn, overlain by a highly productive carbonate-clastic sequence of Midwayan rocks that includes the highly transmissive, biohermal Clayton Formation (fig. 11). Farther south in Georgia and to the west in Alabama, the transmissivity of the Chattahoochee River aquifer decreases (to 100 to 5,000 ft^2/d) as the strata grade to marine-shelf clays, chalks, and shale of Cretaceous and earliest Tertiary age. Very low transmissivity values (10 to 100 ft^2/d) occur in Mississippi, where more permeable strata grade to chalk, chalky shale, and shale of the Selma Group. In northernmost Mississippi, the McNairy-Nacatoch aquifer consists of prodelta, delta, and fluvial sands that are part of the Ripley Formation and McNairy Sand. Interestingly, the highest transmissivities in the McNairy Sand Member of the Ripley Formation (5,000 to 10,000 ft^2/d) do not occur at their landwardmost extent or in the shallow subsurface; rather, they occur in the middip areas of northernmost Mississippi and into Tennessee. A possible explanation may be related to the fluvial to deltaic origin of these strata. In combination with a slightly thicker sequence of strata there, it is suggested that the highest transmissivity values in the McNairy Sand Member may be associated with river or tidal channel deposits.

The largest simulated transmissivity values (10,000 to 50,000 ft^2/d) associated with the Black Warrior River aquifer occur in central Mississippi and in Alabama, where a major part of the aquifer consists of a thick sequence of fluvial strata (Tuscaloosa Group or Formation) and marginal marine beds (Eutaw and McShan Formations). The aquifer is less transmissive (1,000 to 10,000 ft^2/d) as it thins landward to a featheredge along the inner Coastal Plain margin (compare fig. 41 and pl. 42). The transmissivity of the Black Warrior River aquifer decreases to similar values (1,000 to 10,000 ft^2/d) in northernmost Mississippi owing partly to thinning of the aquifer there, but also because of the pinchout of deeper, nonmarine Tuscaloosa rocks (fig. 7). In this area, the Black Warrior River aquifer consists primarily of rocks deposited under marginal-marine conditions (Eutaw and McShan Formations and Coffee Sand). The simulated transmissivity of the Black Warrior River aquifer decreases as it extends eastward across eastern Alabama and Georgia, probably due to the more permeable Tuscaloosa Group or Formation and Eutaw Formation merging with the less permeable Atkinson Formation. In South Carolina, the transmissivity of the aquifer is small (100 to 5,000 ft^2/d) partly due to its low permeability or its relative thinness.

The thickness of regional aquifer and confining units and the pattern of contours on their upper or lower surface in large part reflect changes in permeability. For example, the Chattahoochee aquifer grades coastward from porous sand, sandstone, and minor limestone in updip localities to low-permeability chalk and calcareous shale in the deep subsurface of southeastern and southwestern Alabama (figs. 32–34; pls. 30–31, 33). Consequently, the permeable parts of the Chattahoochee River aquifer thin seaward greatly (pl. 36). Hydrogeologic sections *F–F′* and *H–H′* (pls. 29, 31) also show that permeable rocks of Tertiary age extend farther downdip than the underlying permeable Cretaceous rocks that make up the Chattahoochee River aquifer. This is in contrast to southeastern Georgia, where clastic Cretaceous strata of the Chattahoochee River aquifer grade seaward to permeable limestone (Lawson Limestone) that is part of the Floridan aquifer system (fig. 30; pl. 28). Such major permeability variations overshadow the influence of minor structural features and account for many local highs and lows drawn on the maps of the different regional hydrogeologic units. For example, an apparent anticlinal feature has been mapped on the base of the Chattahoochee River aquifer in Colquitt and Grady Counties in southwest Georgia. This “anticline” is not related to postdepositional folding or faulting, and its alignment with the position of the Gulf trough (fig. 6; pls. 17, 38) is considered coincidental. The contour pattern only reflects local changes in permeability and the facies of rocks that make up the aquifer. The “anticlinal high” is an area where less permeable rocks are flanked by more permeable rocks that lie deeper in the subsurface.

In spite of the poor correspondence between hydrogeologic and stratigraphic units of the Southeastern Coastal Plain, large- and small-scale structural features are subtly reflected on the top of the major hydrogeologic units. Major embayments that appear on maps of some of the aquifer units include the Southeast Georgia, Southwest Georgia, and Mississippi embayments. The Southeast Georgia embayment is centered and best defined in coastal counties of southeastern Georgia and is evident on the map showing the surface of the Black Warrior River aquifer (fig. 37, pl. 41). The Southwest Georgia embayment forms the dominant structural element in the southern tier of counties in Georgia and the central Florida panhandle; it is strongly reflected by the contour pattern shown on the Black Warrior River aquifer map. There is no evidence to suggest, however, that the Southwest or Southeast Georgia embayments influence regional ground-water movement within any of the regional aquifers. The Mississippi embayment, however, with its north-trending axis that is nearly coincident with the Mississippi River, strongly controls the western and southwestern dip of beds in western Mississippi. This embayment also forms a major regional ground-water drain that greatly influences the direction of ground-water movement within the Pearl River aquifer.

The Cape Fear and Peninsular arches, two major positive structures in the Southeastern Coastal Plain, are responsible for the absence of Tertiary clastic rocks in eastern South Carolina as well as the absence of basal Cretaceous sands in southeastern Georgia and northeastern Florida. The Cape Fear arch has also raised permeable strata of the Chattahoochee River aquifer to the surface, where they are partly eroded and exposed, thus forming a major recharge area. The effect of the Wiggins anticline in southeastern Mississippi is limited to deep subsurface strata that constitute the saline part of the Black Warrior River aquifer. Shallower overlying clastic aquifers (Pearl River and Chattahoochee River) were not influenced by this structural feature. The Jackson dome, near Jackson, Miss., forms a positive feature that strongly controls the structural configuration of both the Pearl River and Black Warrior River aquifers. Flow within local water-bearing strata that are part of the Pearl River aquifer (Sparta Sand) is influenced by this feature, forming a local potentiometric high (Spiers, 1979).

Small- and large-scale faults associated with the Pickens-Gilbertown fault zone bound graben-type structures that displace sediments downward in varying degrees. Their influence on the regional ground-water flow system is difficult to demonstrate. Ground water containing less than 10,000 mg/L of dissolved solids that occurs in rocks of Cretaceous age does not extend as far south as this fault zone. Displacement of the aquifers in Tertiary rocks (Pearl River aquifer) by this fault zone is much less than displacement of the older aquifers. Displacement of Claibornian rocks in Jasper County, Miss., for example, is usually less than 50 to 100 ft (DeVries and others, 1963). These downdropped graben-type blocks have not significantly affected the regional ground-water movement; in some instances, the fault blocks have provided additional interconnection of water-bearing strata normally separated by local confining units. Elsewhere, permeable beds have been displaced adjacent to beds of lesser permeability. Downwarping or faulting associated with the Gulf trough (Herrick and Vorhis, 1963; Gelbaum, 1978) in southern Georgia is inferred on the basis of limited well control and is mapped on the upper surface of the Pearl River aquifer. However, structural evidence for the Gulf trough is not discernible at the base of the Pearl River aquifer, and its depositional and tectonic influence may have been limited to post-Sabinian time. Likewise, the postulated Millet fault of Faye and Prowell (1982) is not recognizable at the top of any of the aquifers, confining units, or stratigraphic unit maps shown herein. The Millet fault, which supposedly displaced Upper Cretaceous rocks and affected the potentiometric surface of two aquifers in Burke County, Ga., and Allendale and Barnwell Counties, S.C., has been shown by subsequent drilling (Bechtel Corporation, 1982) not to exist.

An unnamed northwest-trending structural lineament or possible fault centered in Marion and Dillon Counties, S.C., and Robeson County, N.C., is inferred on the basis of an anomalous change in dip on the upper surface of the Black Warrior River aquifer (pl. 41). There is subparallel alignment of this postulated structural component with the so-called "Florence Basin" of Triassic age (Popenoe and Zietz, 1977; Daniels and others, 1983), possibly indicating that border faulting associated with the Florence Basin continued from Triassic into Late Cretaceous time. However, information is not available to confirm the effect of this feature on the regional ground-water flow system.

SUMMARY

Clastic sedimentary rocks of Cretaceous and Tertiary age in Mississippi, Alabama, Georgia, South Carolina, and adjacent areas of northern Florida and southeastern North Carolina make up a major aquifer system called the Southeastern Coastal Plain aquifer system. This system can be subdivided into seven major hydrogeologic units. Massive to thinly bedded, fine- to coarse-grained, glauconitic and feldspathic quartz sand, and minor sandstone, gravel, and occasional limestone beds make up four major regional aquifers that are separated by less permeable chalk, clay, mudstone, and shale as confining units. Except where they are covered by younger strata, the regional aquifers and confining units crop out in adjacent bands from Mississippi to South Carolina and extend into the subsurface at a gentle dip of 1 degree or less. The aquifers contain water under unconfined conditions where they crop out. The water is confined where the aquifers lie in the subsurface and are covered or separated from overlying water-bearing units by less permeable confining units. The Chickasawhay River, Pearl River, Chattahoochee River, and Black Warrior River aquifers that constitute the Southeastern Coastal Plain aquifer system all extend beyond the study area and are parts of adjoining aquifer systems. Siliciclastic Tertiary and Cretaceous sediments grade southward into age-equivalent carbonate strata in southern Georgia, southwestern South Carolina, and Florida that are considered to be part of the Floridan aquifer system. In these areas, the Southeastern Coastal Plain aquifer system is overlain by, and is hydraulically interconnected with, the Floridan aquifer system.

Southeastern Coastal Plain rocks form a thick wedge of unconsolidated to poorly consolidated, dominantly clastic strata that dip gently coastward from a featheredge near the Fall Line, except in Mississippi, where subsidence within the Mississippi embayment has caused them to dip westward. Southeastern Coastal Plain rocks are typically nonmarine to marginal marine at their northernmost extent, and they grade to deeper marine deposits as they extend into the deep subsurface. In some localities, such as southern Mississippi and southwestern Alabama, Coastal Plain rocks lie at depths that exceed 7,000 ft below sea level. Differential movement within the Coastal Plain and its floor has resulted in a number of large- and small-scale structural features. Large-scale structures of the Southeastern Coastal Plain include the Mississippi, Southwest Georgia, and Southeast Georgia embayments; Cape Fear and Peninsular arches; and Pickens-Gilbertown fault zone. Small-scale features include the Jackson dome, Wiggins anticline, Gulf trough, and Ocala uplift.

The vertical and horizontal boundaries of regional hydrogeologic and time- or rock-stratigraphic units do not everywhere correspond; the hydraulic connection of stratigraphically equivalent rocks changes from place to place. A major reason for this poor correspondence is that most of the siliciclastic units that make up the regional aquifers were deposited in alluvial or transitional- to marginal-marine environments and are accordingly restricted in areal extent. It is not uncommon to find age-equivalent strata functioning as an aquifer in one area but as a confining unit in another. Hydrogeologic units described in this report were defined on the basis of a qualitative appraisal of rock lithology, porosity, and permeability as determined from borehole geophysical logs, well cuttings, and cores. The complex stratigraphic and hydrologic nature of the Southeastern Coastal Plain was greatly generalized to simplify the hydrogeologic framework. Hydrogeologic units defined herein encompass several formations or parts of formations. Some of the boundaries of the different hydrogeologic units transgress geologic time. The regional aquifers and confining units that together make up the Southeastern Coastal Plain aquifer system each contain a series of sand and clay beds that form discrete water-bearing or confining units, many of which are named at the State or local level. A new aquifer nomenclature was proposed to avoid confusion between rock- and time-stratigraphic names and local aquifer terminology currently in use.

A fundamental requirement of all subsurface geologic mapping is establishing the time equivalency of the different rock units. Numerous changes in the pattern of geologic facies occur as rock units in the Southeastern Coastal Plain extend along outcrop and into the subsurface. The high degree of lithologic variability within the Coastal Plain sedimentary section is the direct result of fluctuating depositional conditions due to regional uplift, subsidence, and sea-level changes. Provincial Gulf Coast stages were used for mapping time-synchronous geologic units to help ascertain their regional equivalency as well as that of the regional hydrogeologic units. Cross sections and structure, isopach, and facies maps of Tertiary and Cretaceous time-stratigraphic units were constructed to examine the relations among these units, rock-stratigraphic units, and the different regional aquifers and confining units. Used in combination, these maps and cross sections illustrate regionwide variations in permeability within the major aquifer and confining units. They also help explain how depositional and tectonic events directly control the character and nature of the hydrogeologic units and indirectly influence the ground-water flow system.

Pre-Cretaceous rocks form a nearly impermeable base of the Southeastern Coastal Plain aquifer system consisting of five major rock types: undifferentiated crystalline rocks of Paleozoic age, saprolite, folded and flat-lying sedimentary rocks of Paleozoic age, sedimentary rocks of Jurassic age, and Mesozoic red beds, basalts, and diabase. Many of these rocks represent a southward extension of rocks of the Piedmont physiographic province and the Appalachian Mountains and are almost impermeable except where they are fractured or faulted. Some Coastal Plain sediments of Cretaceous age that are permeable are not considered part of the aquifer system because they lie at depths well below the base of fresh ground water.

Most of the rocks that make up the Southeastern Coastal Plain aquifer system are Cretaceous in age. The oldest of these, the Lower Cretaceous Coahuilan and Lower and Upper Comanchean beds, do not crop out. Consisting of coarse-grained, well- to poorly consolidated sandstone, and interbedded clay and siltstone of nonmarine origin in much of the study area, they are often difficult to differentiate due to a lack of diagnostic microfauna or extensive marker beds. The vast majority of these rocks are found at great depths and mostly contain saline ground water. Gulfian strata form the bulk of the Cretaceous rocks that are part of the regional aquifer system. These rocks are divided into five chronostratigraphic units in Louisiana and Texas, but in the eastern Gulf and southern Atlantic Coastal Plains, basal Gulfian strata (Woodbinian to early Austinian age) are dominated by nonmarine sand, gravel, clay and shale that, like the underlying Comanchean and Coahuilan strata, are not easily differentiated. Chronostratigraphic breaks marking the top of Eaglefordian or Woodbinian strata coincide, in places, with lithostratigraphic breaks but elsewhere lie within major lithostratigraphic units.

In the case of the Tuscaloosa Group or Formation, for example, separation of major lithostratigraphic units on the basis of lithologic criteria has led to poor correlation of these strata and improper use of rock unit names.

Rising sea level during the latter half of the Late Cretaceous (late Austinian, Tayloran, and Navarroan time) caused widespread deposition of lithologically uniform, deeper marine deposits. These beds contain diagnostic fauna and extensive marker horizons that are easier to correlate. Two major areas of nonmarine to transitional-marine deposition prevailed during this time. At the northern end of the Mississippi embayment, permeable fluvial rocks were deposited; they grade to less permeable, glauconitic quartz sand of deltaic and prodelta origin as they extend southward into Mississippi. A second site of fluvial deposition is found in central to eastern Georgia and in South Carolina. Nearshore- and marginal-marine deposits of glauconitic quartz sand, calcareous and lignitic clay, silt, and marl occur near the present coast and rim a feldspathic quartz sand and gravel sequence of fluvial origin. Chalk, clay, and minor limestone beds were deposited farther southward and westward in Alabama and Mississippi in a marine shallow-shelf environment. Fluctuating sea level and tectonic uplift have resulted in numerous local to regional unconformities that have been used by some workers to separate many of the major lithostratigraphic units. Elsewhere, contacts separating these rock-stratigraphic units are gradational and difficult to identify.

Although Oligocene, Miocene, and Pliocene rocks occur in the study area, the Tertiary rocks that constitute much of the Southeastern Coastal Plain aquifer system are predominantly of Paleocene to Eocene age. These lower Tertiary strata can be divided into two major facies. A carbonate-evaporate platform facies occurs mostly in peninsular Florida but also extends to adjacent States; Eocene carbonate rocks extend much further northward than the underlying Paleocene rocks. A siliciclastic Paleocene to Eocene marine to nonmarine facies extends from Mississippi to South Carolina. Deposition of fluvial sediments was far less extensive in eastern Alabama, Georgia, and South Carolina during the Paleocene and Eocene than during the latter part of Gulfian time. In Mississippi, however, poorly consolidated to unconsolidated fluvial strata of Sabinian (late Paleocene to early Eocene) and Claibornian (middle Eocene) age cover a wide area and contain important clastic aquifers. Carbonate-platform deposits were at their greatest landward extent during late Eocene and Oligocene time, and rocks deposited during this time form a major part of the Floridan aquifer system. Nonmarine to marginal-marine deposition prevailed in the study area during the Neogene and Quaternary. Water-bearing strata within these rocks form the Chickasawhay River aquifer in southwestern Mississippi; less permeable (Miocene) strata form the upper confining unit of the Floridan aquifer system.

The uppermost regional aquifer of the Southeastern Coastal Plain aquifer system is the Chickasawhay River aquifer. It consists of a sequence of clastic and minor limestone beds of Miocene and Oligocene age that crops out in southern Mississippi and western Alabama. The Chickasawhay River aquifer is overlain by a veneer of sand and gravel of Pliocene and Quaternary age that is part of a surficial aquifer that extends eastward across Florida, southern Georgia, and South Carolina. The Chickasawhay River aquifer overlaps, and in places is interconnected with, the Floridan aquifer system in western Alabama.

The Pearl River confining unit underlies the Chickasawhay River aquifer and extends from Louisiana eastward into western Alabama, where it thins and grades to a highly permeable carbonate sequence that is part of the Floridan aquifer system. The Pearl River confining unit consists of clay and marl beds of marine origin having very low permeability except for isolated, minor water-bearing strata.

An underlying section of unconsolidated to poorly consolidated sand, sandstone, gravel, and minor limestone beds of Paleocene to late Eocene age forms the Pearl River aquifer. The Pearl River aquifer is quite extensive and occurs from central South Carolina to northern Mississippi; equivalent water-bearing rocks occur as far west as Texas. The Pearl River aquifer grades seaward from permeable clastic beds of sand and gravel that crop out or lie in the shallow subsurface into less permeable clay, shale, chalk, and chalky limestone that mark its downdip limit. In central and eastern Alabama, southern Georgia, and southwestern South Carolina, it grades seaward into, or is overlain by, stratigraphically equivalent and hydraulically connected permeable limestone and dolomite of the Floridan aquifer system. The boundary between the two aquifers represents a facies boundary that transgresses several time-stratigraphic units.

The Pearl River aquifer is underlain by low-permeability strata that are part of two different regional confining units. The shallower confining unit, the Chattahoochee River confining unit of Navarroan to Sabinian age, separates the Pearl River aquifer from deeper permeable strata in eastern Alabama, Georgia, and South Carolina. Low-permeability beds of marine arenaceous shale, siliceous mudstone, and sandy to lignitic to kaolinitic clay combine to form the Chattahoochee River confining unit; these beds grade to a more permeable facies in Mississippi and western Alabama that is considered part of the Pearl River aquifer. In Mississippi and Alabama, the Pearl River aquifer is underlain by more deeply buried, low-permeability rocks that make up the Black Warrior River confining unit.

The Chattahoochee River aquifer underlies the Chattahoochee River confining unit in South Carolina, Georgia, and eastern Alabama. In updip areas of eastern Georgia and western South Carolina, the Chattahoochee aquifer is in hydraulic contact with the Pearl River aquifer. Upper Cretaceous (Austinian) to upper Paleocene (Sabinian) feldspathic to glauconitic quartz sand, sandstone, gravel, and minor limestone beds locally interbedded with clay, shale, marl, mudstone, and chalk combine to make up this regional aquifer. In much of eastern Georgia and western South Carolina, the Chattahoochee River aquifer crops out only as discontinuous outliers, present only where erosion has removed shallower beds. Nonmarine to marginal-marine strata make up the bulk of the more permeable beds within the Chattahoochee River aquifer, particularly in the updip areas. The Chattahoochee River aquifer progressively grades to less permeable shale and chalk of marine-shelf origin in downdip localities and along outcrops or in the shallow subsurface of central Alabama. The permeable parts of the Chattahoochee River aquifer thin greatly seaward as a result. This is not true everywhere. In southeastern Georgia, the Chattahoochee River aquifer grades to a permeable limestone unit that is the lowermost permeable zone of the Floridan aquifer system. In east-central Mississippi and in western Alabama, the Chattahoochee River aquifer is absent. A correlative clastic aquifer (McNairy-Nacatoch aquifer, a term used by the Gulf Coast RASA team), not hydraulically connected to the Chattahoochee River aquifer, occurs in northern Mississippi and extends northward into the northern part of the Mississippi embayment.

The Black Warrior River confining unit forms an effective hydrologic barrier that prevents vertical ground-water movement, except through leakage between the Chattahoochee River aquifer and the underlying Black Warrior River aquifer in eastern Alabama, Georgia, and South Carolina. Where the Chattahoochee River aquifer is absent in Mississippi and Alabama, the Black Warrior River confining unit separates the overlying Pearl River aquifer from the underlying Black Warrior River aquifer. In northern Mississippi, low-permeability rocks enclose permeable strata of the McNairy-Nacatoch aquifer that separate the Black Warrior River confining unit into an upper and lower zone. The Black Warrior River confining unit consists largely of marine to marginal-marine beds of clay, shale, marl, and chalk except in local areas of middip South Carolina, where nonmarine sandy clay beds make up the confining unit.

The Black Warrior River aquifer, the most extensive and lowermost regional clastic aquifer within the Southeastern Coastal Plain aquifer system, thickens greatly in the subsurface from its outcrop in a wide band adjacent to the inner margin of the Coastal Plain from Tennessee to eastern Georgia. It does not crop out in eastern and central Georgia or in South Carolina but occurs in the subsurface, where it is covered by younger Cretaceous and Tertiary rocks. A series of discrete water-bearing rocks together make up the Black Warrior River aquifer, which consists mostly of Cretaceous (Woodbinian to Austinian age) nonmarine sand, sandstone, and gravel beds, interbedded with nonmarine to marginal-marine clay, mudstone, and shale. As these strata extend coastward into southern Mississippi and Alabama or eastward into central Georgia, they grade to less permeable transitional- or marginal-marine rocks. Although the vast majority of Black Warrior River aquifer rocks are of Late Cretaceous age, some Lower Cretaceous nonmarine beds that contain freshwater occur locally in the shallow and middip subsurface of Mississippi, Alabama, and western Georgia. These Cretaceous rocks are the oldest clastic Coastal Plain deposits of the Black Warrior River aquifer.

The landward extent of water within the Black Warrior River aquifer that contains concentrations of dissolved solids greater than 10,000 mg/L is controlled by variations in permeability within the aquifer and the location of ground-water discharge areas, especially of deeply incised rivers. The transition zone between saltwater and freshwater extends farther downdip in eastern Alabama, Georgia, and South Carolina than to the west. The fact that the transition zone extends farther landward in Mississippi and western Alabama may reflect the fact that sedimentary rocks in these areas have a higher hydraulic conductivity value and result in a more rapid landward movement of saltwater in response to the most recent Pleistocene sea-level rise. A contributing factor may be the occurrence of a greater number of deeply entrenched rivers in Mississippi and Alabama. Ground-water discharge to these rivers results in lower heads in the aquifer, which in turn can cause the equilibrium position of the saltwater-freshwater transition zone to be farther inland and shallower.

The pattern of changes in the regional geologic facies determines the extent, composition, textural character, and hydraulic character of the water-bearing strata within the Southeastern Coastal Plain aquifer system. Nonmarine sand strata constitute the most permeable and productive aquifers. Conversely, clastic beds deposited under marine conditions, particularly marine-shelf conditions, form the thicker, more extensive confining beds. The hydraulic character of marginal- or transitional-marine rocks is most difficult to characterize; these rocks reflect a complex mix of both high- and low-energy conditions that occur in close proximity to one another. Water-bearing rocks tend to be localized and grade to confining units over a short distance. Discrete water-bearing units within the rocks formed in these transitional-marine environments tend to be more hydraulically isolated, and their hydraulic interconnection is largely dependent on their juxtaposition with permeable overlying or underlying beds.

Regional lithofacies and aquifer thickness are closely related to aquifer transmissivity as derived from the regional ground-water flow model. The highest transmissivity values within the Black Warrior River aquifer occur in central Mississippi and Alabama, where a major part of the aquifer consists of a thick fluvial sequence. The transmissivity of the aquifer decreases where the aquifer thins, such as where it extends as a featheredge along the Fall Line and in the deeper subsurface, where the aquifer merges with less permeable, marginal-marine deposits.

Like the Black Warrior River aquifer, the most transmissive part of the Chattahoochee River aquifer occurs in areas in Georgia and South Carolina where nonmarine conditions prevailed during Austinian to Navarroan time. The least transmissive parts of the Chattahoochee River aquifer are where the aquifer thins, such as across the structurally positive Cape Fear arch in easternmost South Carolina, or where it grades into, or is interbedded with, less permeable marginal-marine deposits. A low-transmissivity band extending across the inner Coastal Plain margin in eastern Georgia and in South Carolina is attributed to the abundant kaolinitic clay deposits.

The Pearl River aquifer and Lower Floridan aquifer of the Floridan aquifer system were combined and treated as a single layer in a digital-computer model to simulate the hydraulic interconnection between the Southeastern Coastal Plain and Floridan aquifer systems; accordingly, the simulated transmissivity map represents aquifers of both systems. A comparison of the transmissivity distribution of these two combined units with Paleocene and Eocene lithofacies maps indicates that the lowest simulated transmissivity values occur in areas where the strata grade from marginal- and transitional-marine rock types to sediments that were deposited under neritic conditions. The highest transmissivity values occur in an area that extends as parallel bands across central Georgia. These high values are for highly permeable carbonate rocks of the Floridan aquifer system that interfinger with, and overlie, the less permeable clastic beds of the Pearl River aquifer. These parallel bands are separated by a band of low transmissivity in the Gulf trough that is related to a reduction in the thickness of the limestone by faulting.

Although regional lithofacies strongly control transmissivity patterns within the regional aquifers, it can be seen that, as in the case of the influence of the Gulf trough on the ground-water flow of the Floridan aquifer system, structural features can also influence the ground-water flow system. The Mississippi embayment not only strongly controls the west and southwest dip of beds in the Southeastern Coastal Plain aquifer system but, in combination with the Mississippi River that closely parallels the axis of the embayment, forms a major regional ground-water discharge area controlling the direction of ground-water movement within the Pearl River aquifer. A major recharge area occurs atop the Cape Fear arch in southeastern North Carolina where permeable beds of the Chattahoochee River aquifer are uplifted and exposed at the surface. Other structurally positive features play only minor roles in influencing the ground-water flow patterns within the Southeastern Coastal Plain aquifer system. The Jackson dome, for example, forms a positive feature in western Mississippi, and flow within local water-bearing strata of the Pearl River aquifer radiates outward from a potentiometric high that coincides with the dome. For the most part, however, structural controls on water movement are indirect and are related more to the influence of tectonism on deposition and the resulting hydraulic character of the sediments.

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