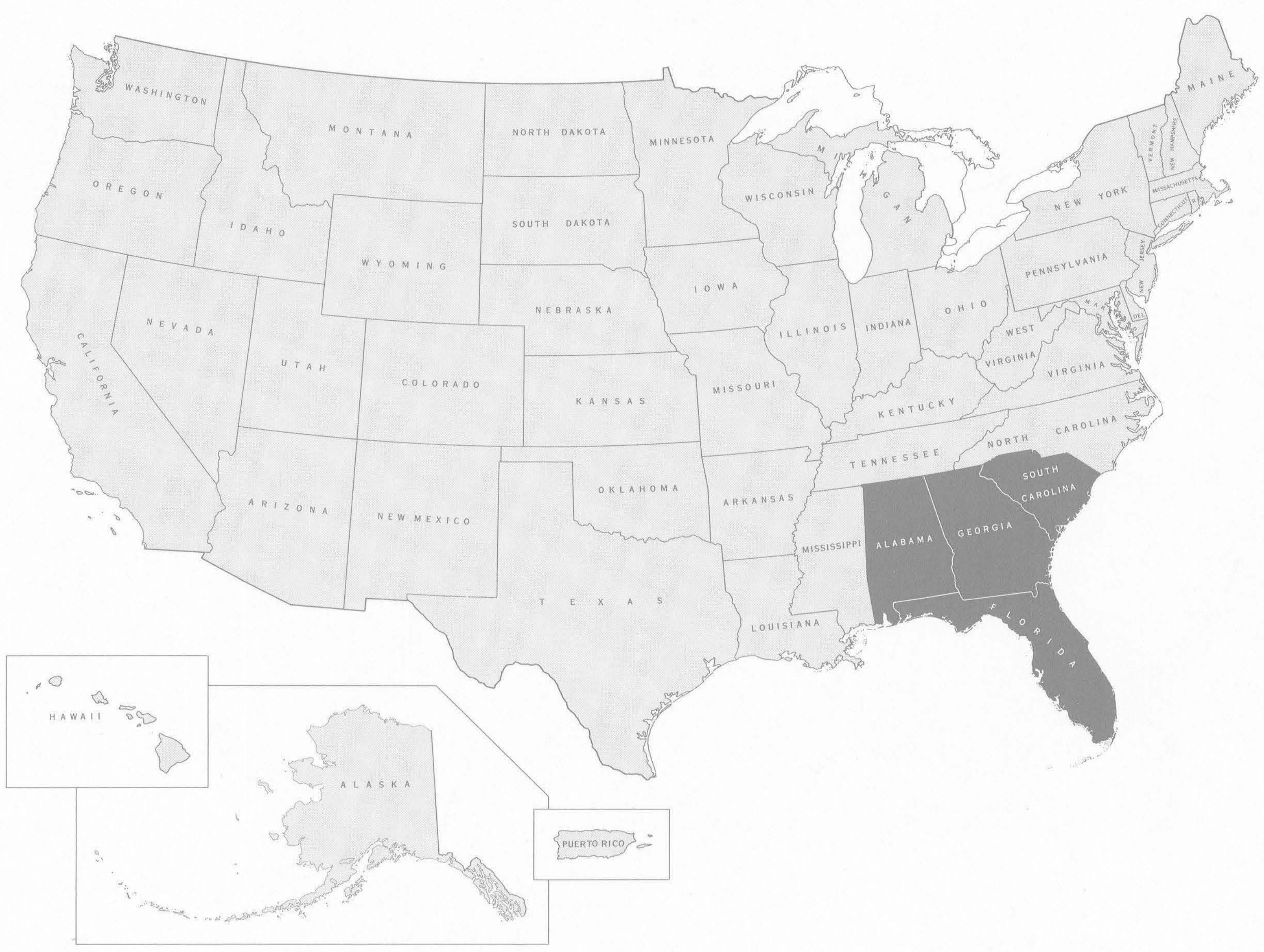
GROUND WATER ATLAS OF THE UNITED STATES

SEGMENT 6

Alabama
Florida
Georgia
South Carolina



HYDROLOGIC INVESTIGATIONS ATLAS 730-G

U.S. Geological Survey

GROUND WATER ATLAS OF THE UNITED STATES

Hydrologic Investigations Atlas 730-G

FOREWORD

The Ground Water Atlas of the United States presents a comprehensive summary of the Nations's ground-water resources, and is a basic reference for the location, geography, geology, and hydrologic characteristics of the major aquifers in the Nation. The information was collected by the U.S. Geological Survey and other agencies during the course of many years of study. Results of the U.S. Geological Survey's Regional Aquifer-System Analysis Program, a systematic study of the Nation's major aquifers, were used as a major, but not exclusive, source of information for compilation of the Atlas.

The Atlas, which is designed in a graphical format that is supported by descriptive discussions, includes 13 chapters, each representing regional areas that collectively cover the 50 States and Puerto Rico. Each chapter of the Atlas presents and describes hydrogeologic and hydrologic conditions for the major aquifers in each regional area. The scale of the Atlas does not allow portrayal of minor features of the geology and hydrology of each aquifer presented, nor does it include discussion of minor aquifers. Those readers that seek detailed, local information for the aquifers will find extensive lists of references at the end of each chapter.

An introductory chapter presents an overview of ground-water conditions Nationwide and discusses the effects of human activities on water resources, including saltwater encroachment and land subsidence.

Dallas L. Peck

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., *Secretary*

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

CONVERSION FACTORS

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

Multiply inch-pound units	*By*	*To obtain metric units*
	Length	
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
foot squared per day (ft²/d)	0.0929	meter squared per day (m²/d)
cubic foot per second (ft³/s)	0.02832	cubic meter per second (m³/s)
mile (mi)	1.609	kilometer (km)
square mile (mi²)	2.590	square kilometer (km²)
	Volume	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m³/s)
billion gallons per day (Bgal/d)	3.785	million cubic meters per day (Mm³/d)
	Temperature	
degree Celsius (°C)	9/5(°C)+32=°F	degree Fahrenheit (°F)

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'.

ATLAS ORGANIZATION

The Ground Water Atlas of the United States is divided into 14 chapters. Chapter A presents introductory material and nationwide summaries; chapters B through M describe all principal aquifers in a multistate segment of the conterminous United States; and chapter N describes all principal aquifers in Alaska, Hawaii, and Puerto Rico.

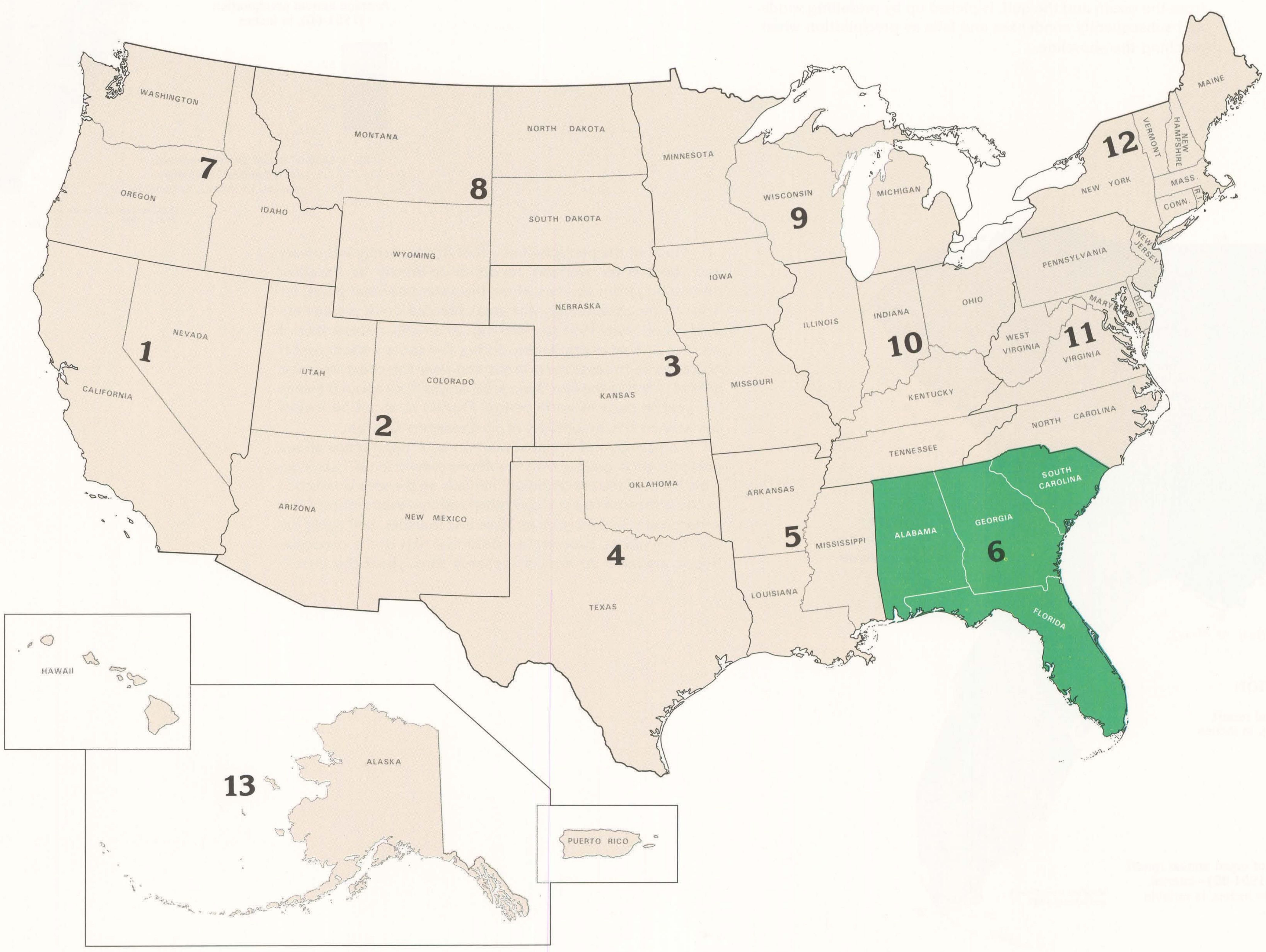
Segment Number	*Chapter content*	*Hydrologic Atlas Chapter*
–	Introductory material and nationwide summaries	730-A
1	California, Nevada	730-B
2	Arizona, Colorado, New Mexico, Utah	730-C
3	Kansas, Missouri, Nebraska	730-D
4	Oklahoma, Texas	730-E
5	Arkansas, Louisiana, Mississippi	730-F
6	Alabama, Florida, Georgia, South Carolina	730-G
7	Idaho, Oregon, Washington	730-H
8	Montana, North Dakota, South Dakota, Wyoming	730-I
9	Iowa, Michigan, Minnesota, Wisconsin	730-J
10	Illinois, Indiana, Kentucky, Ohio, Tennessee	730-K
11	Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia	730-L
12	Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont	730-M
13	Alaska, Hawaii, Puerto Rico	730-N

Ground Water Atlas of the United States

Segment 6

Alabama, Florida, Georgia, and South Carolina

By James A. Miller



CONTENTS

Regional summary

INTRODUCTION

The four States—Alabama, Florida, Georgia, and South Carolina—that comprise Segment 6 of this Atlas are located adjacent to the Atlantic Ocean or the Gulf of Mexico, or both. These States are drained by numerous rivers and streams, the largest being the Tombigbee, Alabama, Chattahoochee, Suwannee, St. Johns, Altamaha, and Savannah Rivers. These large rivers and their tributaries supply water to cities such as Columbia, S.C., Atlanta, Ga., and Birmingham, Ala. However, the majority of the population, particularly in the Coastal Plain which comprises more than one-half of the four-State area, depends on ground water as a source of water supply. The aquifers that contain the water are mostly composed of consolidated to unconsolidated sedimentary rocks, but also include hard, crystalline rocks in parts of three of the States. This chapter describes the geology and hydrology of each of the principal aquifers throughout the four-State area.

Precipitation is the source of all the water in the four States of Segment 6. Average annual precipitation (1951-80) ranges from about 48 inches per year over a large part of central South Carolina and Georgia to about 80 inches per year in mountainous areas of northeastern Georgia and western South Carolina. (**fig. 1**) In general, precipitation is greatest in the mountains (because of their orographic effect) and near the coast, where water vapor, which has been evaporated primarily from the ocean and the gulf, is picked up by prevailing winds and subsequently condenses and falls as precipitation when reaching the shoreline.

Figure 1. *Average annual precipitation (1951-80) ranges from about 48 to about 80 inches.*

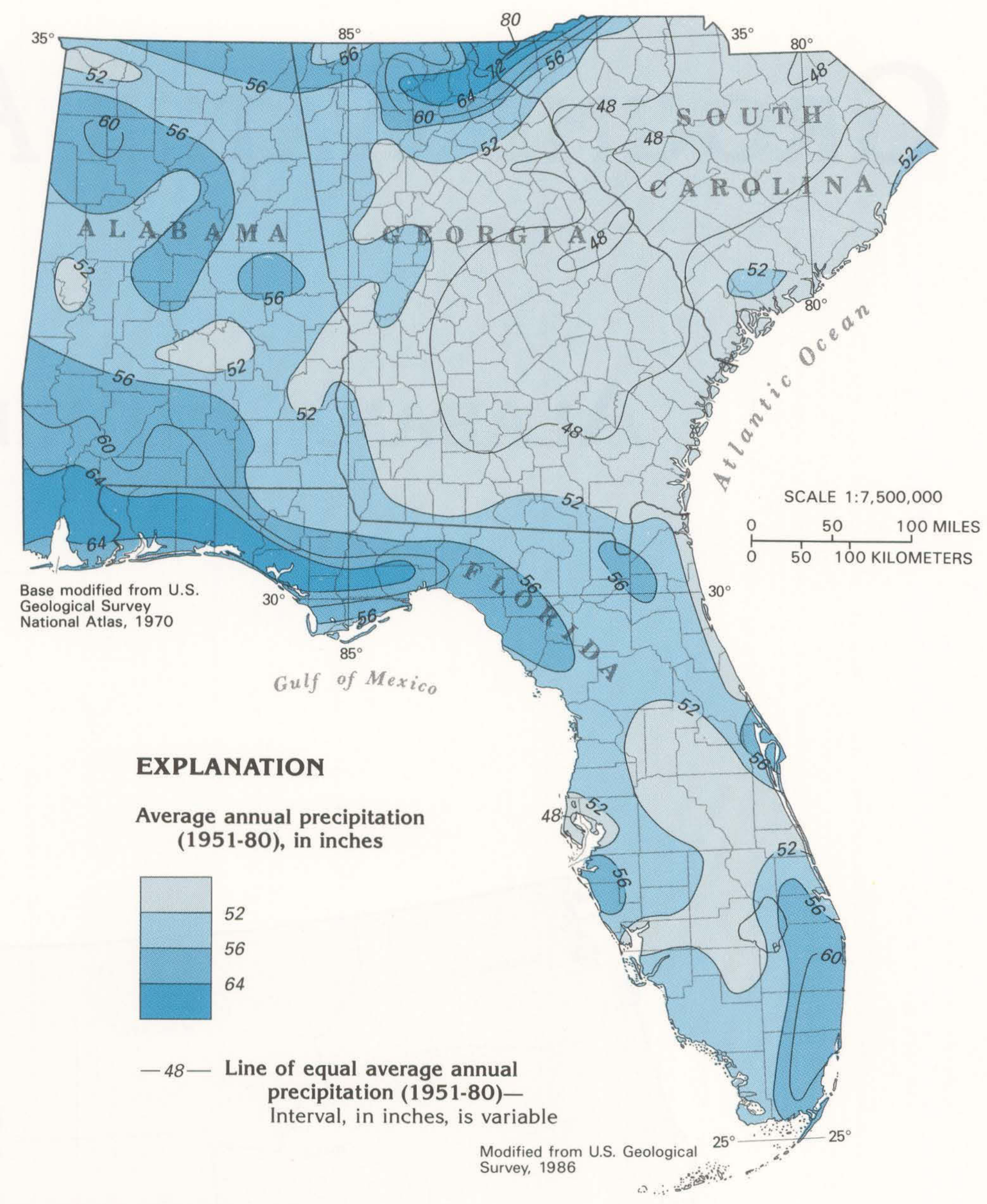
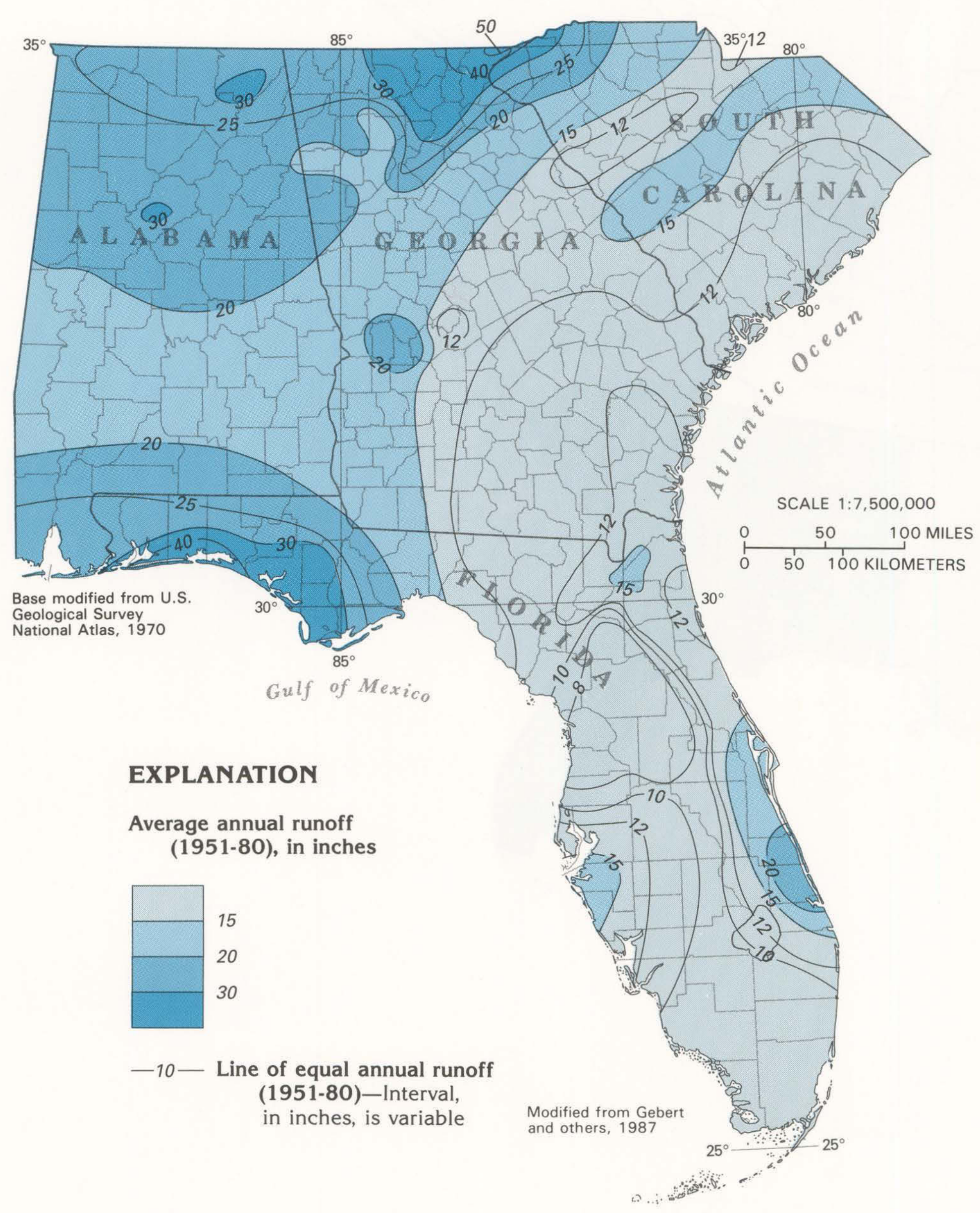


Figure 2. *Average annual runoff (1951-80) generally has the same areal distribution as precipitation; that is, runoff is greater where precipitation is greater.*



Much of the precipitation either flows directly into rivers and streams as overland runoff or indirectly as baseflow discharging from aquifers where the water has been stored for a short time. Accordingly, the areal distribution of average annual runoff from 1951 to 1980 (**fig. 2**) directly reflects that of average annual precipitation during the same period; runoff is greater in mountainous areas and near the coast. Average annual runoff in the four-State area ranges from about 8 inches per year in parts of north-central Florida to about 50 inches per year in the mountains of northeastern Georgia.

Comparison of the precipitation and runoff maps shows precipitation is greater than runoff everywhere in the four-State area. Much of the precipitation that falls on the area is returned to the atmosphere by evapotranspiration—evaporation from surface-water bodies, such as lakes and marshes, and transpiration from plants. However, a substantial part of the precipitation is available for aquifer recharge throughout the area.

MAJOR AQUIFERS

There are numerous aquifers in Segment 6, that range in composition from unconsolidated sand of the surficial aquifer system to hard, crystalline rocks of the Piedmont and Blue Ridge aquifers. These aquifers are grouped into nine major aquifers or aquifer systems on the basis of differences in their rock types and ground-water flow systems. An aquifer system consists of two or more aquifers that are hydraulically connected—that is, their flow systems function similarly, and a change in conditions in one aquifer affects the other aquifer(s).

The areas where eight major aquifers are exposed at land surface are shown in **figure 3** (see opposite page). Many of these aquifers extend underground far beyond the limits of outcrop, and, accordingly, may be used for water supply in much larger areas than the size of their outcrop may indicate. In places, deeper aquifers that contain freshwater underlie the major aquifers mapped here. For example, in southeastern South Carolina, the surficial aquifer system shown on the map is underlain by the Floridan aquifer system, which in turn is underlain by the Southeastern Coastal Plain aquifer system, all of which contain mostly freshwater. In other places, such as the areas where aquifers of the Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateaus physiographic provinces are mapped, deeper aquifers are nonexistent. In places in Alabama, Georgia, and Florida, a clayey confining unit that overlies the Floridan aquifer system is exposed at land surface, and wells need to be drilled through this clayey confining unit to penetrate the underlying aquifer.

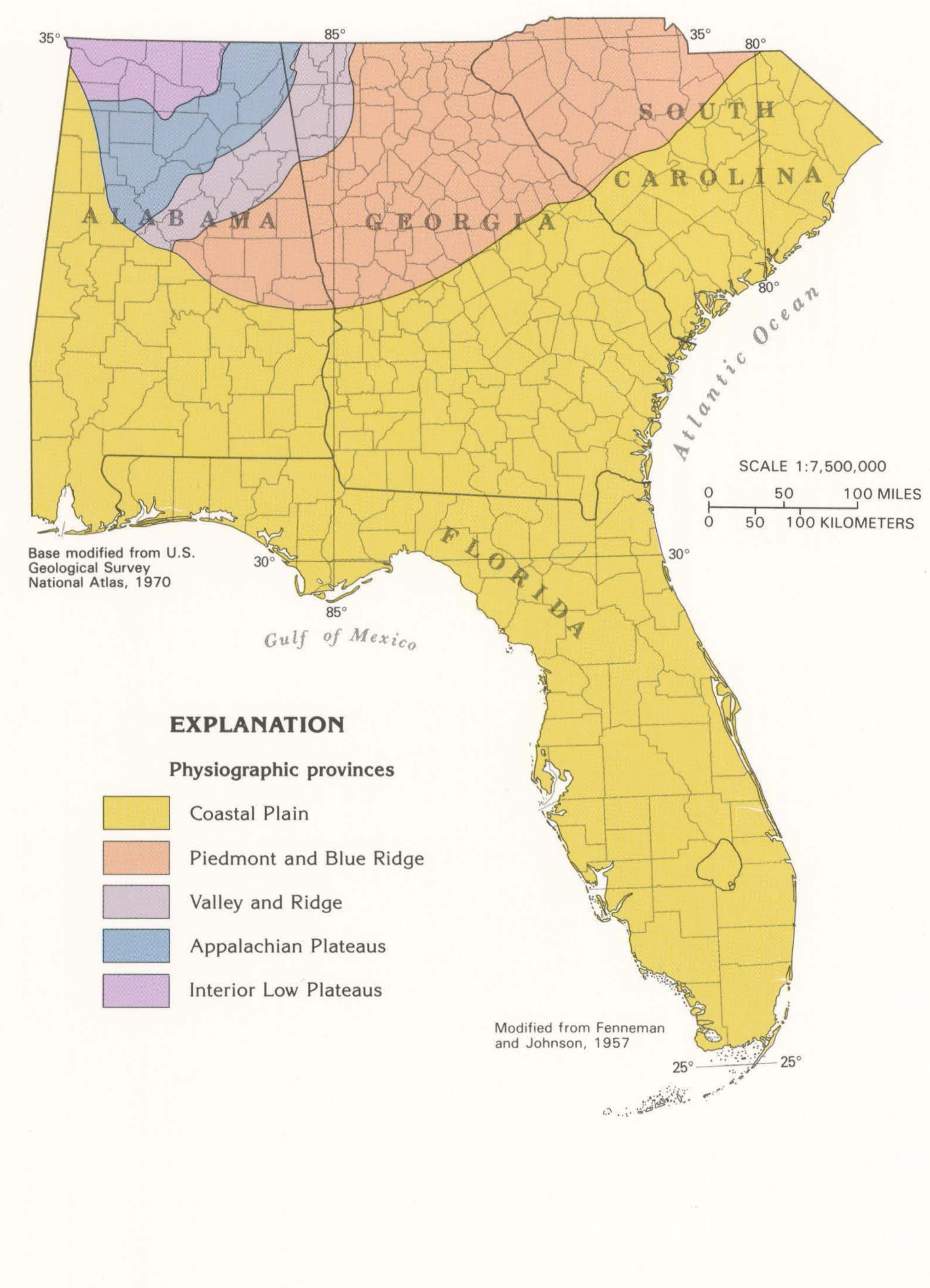
The surficial aquifer system consists mostly of unconsolidated sand, but also contains a few beds of shell and limestone. The sand and gravel and Biscayne aquifers are separately recognized parts of the surficial aquifer system that consist of distinctive rock types. The sand and gravel aquifer consists of complexly interbedded lenses and layers of coarse sand and gravel, and the Biscayne aquifer consists predominantly of limestone. The intermediate aquifer system consists of sand and limestone and lies between the surficial aquifer system and the Floridan aquifer system. The intermediate aquifer system does not crop out, and, accordingly, is not shown on the map.

The Floridan aquifer system consists of limestone and dolomite, and is the most productive of the aquifers in the mapped area, in terms of total water yield. The Southeastern Coastal Plain aquifer system consists of four regional aquifers that are predominately sand, but these aquifers also contain some beds of gravel and limestone. All the aquifers from the surficial aquifer system down through the Southeastern Coastal Plain aquifer system are present in the Coastal Plain physiographic province (**fig. 4**). Water in all of the Coastal Plain aquifers is present primarily in intergranular pore spaces. However, solution openings in carbonate rocks of the Biscayne aquifer and Floridan aquifer system yield large volumes of water.

Piedmont and Blue Ridge aquifers consist of indurated metamorphic rocks, such as gneiss and schist, and igneous rocks, such as granite, that underlie the rolling hills of the Piedmont physiographic province and the mountains of the Blue Ridge physiographic province. Water is present in these rocks in fractures, but locally a large volume of water is stored in the regolith, or blanket of weathered material that overlies the rock.

Folded Paleozoic rocks underlie the Valley and Ridge physiographic province, and flatlying Paleozoic rocks underlie the combined Appalachian Plateaus and Interior Low Plateaus physiographic provinces. In these three provinces, the Paleozoic rocks consist of indurated sedimentary rocks; the major aquifers consist of limestone. However, the ground-water flow system is different where these rocks are folded and where they are not.

Figure 4. *Six physiographic provinces are present in Segment 6. Two of these provinces—Piedmont and Blue Ridge—have been combined in this chapter because of similarity in geology and hydrology.*



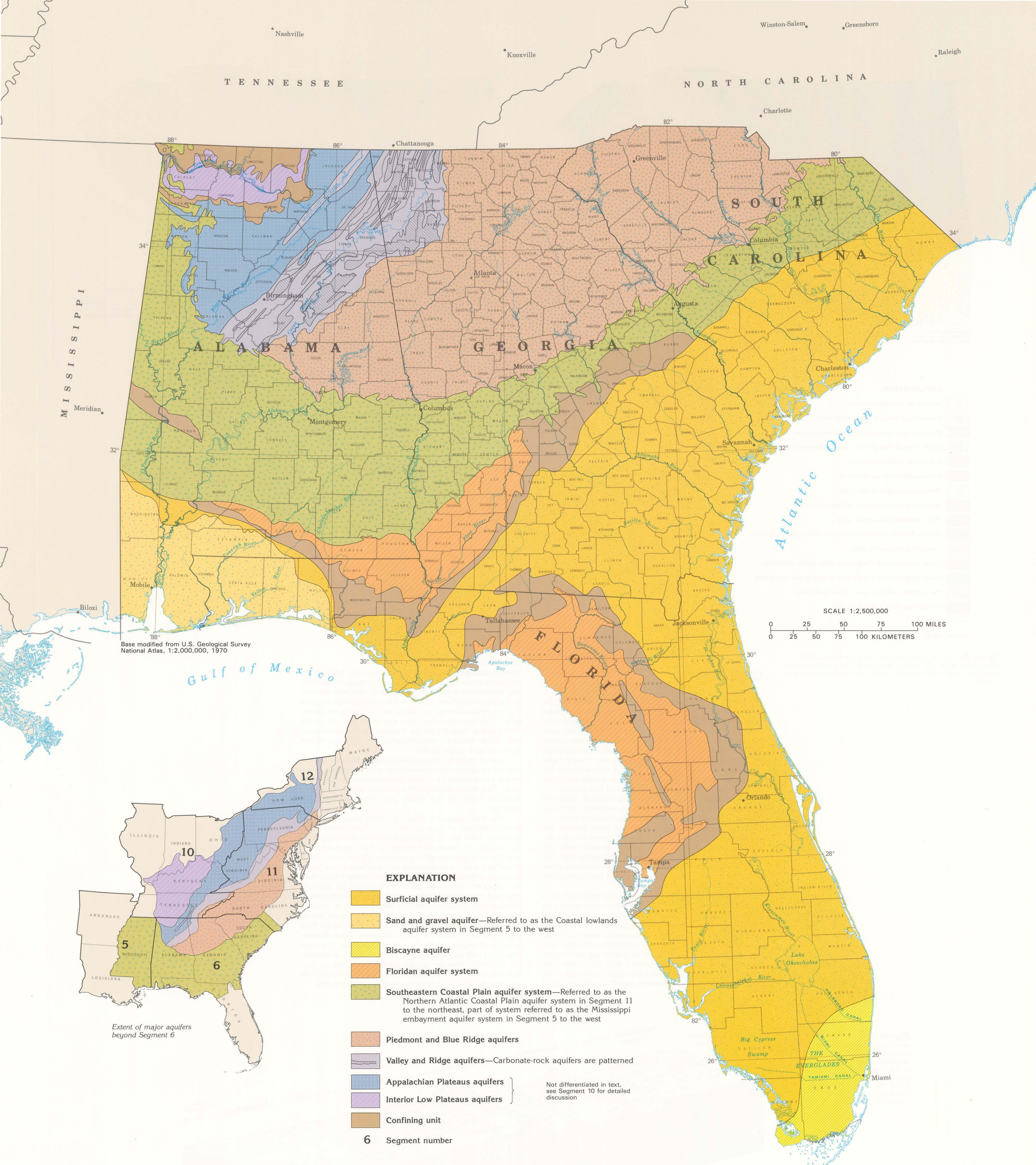


Figure 3. *The numerous aquifers in Segment 6 can be grouped into nine major aquifers or aquifer systems. The extent of eight of these major aquifers or aquifer systems at the land surface is mapped here. One aquifer, the intermediate aquifer system, is not exposed at the land surface.*

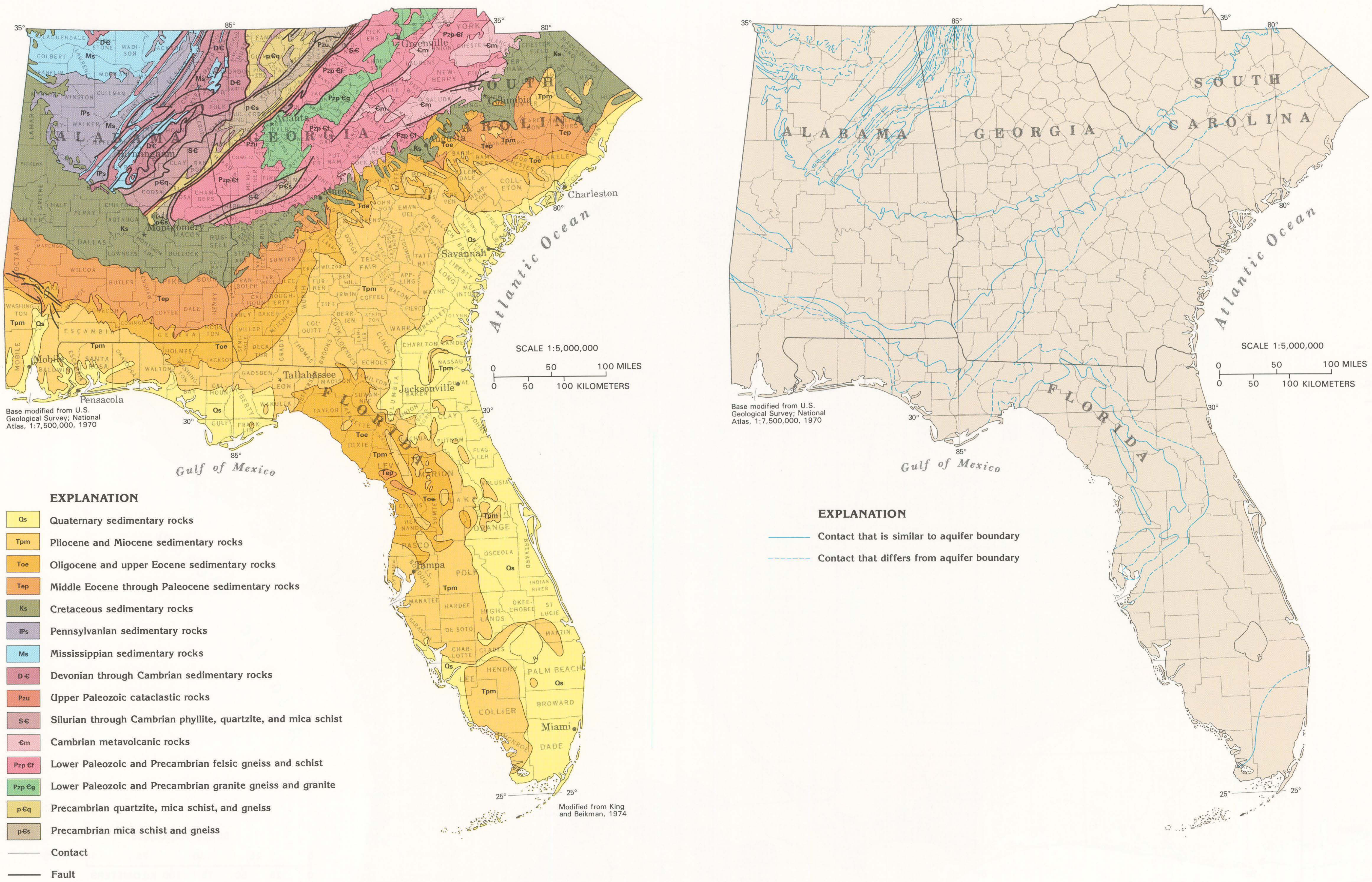


Figure 5. A simplified geologic map (above) shows the extent of the major rock units in Segment 6. The parallel between the geologic units and the major aquifers is shown on the map to the right.

GEOLOGY

Two categories of sedimentary rocks comprise most of the rocks underlying the four States of Segment 6: well-indurated rocks of Paleozoic age and poorly indurated to unconsolidated rocks of Cretaceous age and younger. The Paleozoic sedimentary rocks crop out in northern Alabama and northwestern Georgia; whereas, the Cretaceous and younger rocks underlie the Coastal Plain and form a broad, arcuate, coast-parallel band. Both categories have been divided into numerous formations, as shown on correlation charts in the discussions of the major aquifers in following sections of this chapter.

The majority of the water-yielding Paleozoic rocks are limestone; however, some water also is obtained from sandstone and, locally, from chert beds and fractured shale.

Most Coastal Plain strata are clastic rocks; however, the carbonate rocks of the Floridan aquifer system also are important. Triassic, Jurassic, and Lower Cretaceous rocks are present only in the deep subsurface of the Coastal Plain and do not form aquifers except in a local area in Alabama where Lower Cretaceous rocks form a small part of the Southeastern Coastal Plain aquifer system.

The geologic map (**fig. 5**) shows the distribution of rocks by major age category and also shows that an extensive area is underlain by crystalline rocks. These are metamorphic and igneous rocks that crop out in a broad, northeast-trending band that widens from eastern Alabama into eastern Georgia and western South Carolina. The crystalline rocks are hard, and generally are more resistant to weathering and erosion than sedimentary rocks. The gently rolling hills of the Piedmont physiographic province and the rugged mountains of the Blue Ridge physiographic province were formed as a result of these crystalline-rock characteristics. Radiometric dating of the crystalline rocks has determined that they range in age from late Precambrian to Permian. Locally, they have been intruded by diabase dikes of Late Triassic to Early Jurassic age. Detailed mapping shows that the crystalline rocks are complex; for example, they have been separated into about 90 units on the 1976 geologic map of Georgia. Because the crystalline rocks have similar hydraulic characteristics, they are mapped and discussed as a single aquifer.

Several major faults are shown in **figure 5**. Some of these faults form boundaries between major rock categories; for example, a fault marks the contact between metamorphic rocks of the Blue Ridge physiographic province and tightly folded Paleozoic rocks of the Valley and Ridge physiographic province.

The area mapped in **figure 5** can be divided into four broad categories of geologic structure. From northwest to southeast, these are: (1) flatlying Paleozoic sedimentary rocks that underlie the combined Appalachian Plateaus and Interior Low Plateaus physiographic provinces; (2) the same rocks folded into a series of anticlines and synclines in the Valley and Ridge physiographic province, where resistant rocks form the ridges and soft rocks underlie the valleys; (3) intensely deformed metamorphic rocks of the Piedmont and Blue Ridge physiographic provinces that have been intruded by small to large bodies of igneous rocks; and (4) gently dipping, poorly consolidated to unconsolidated sediments of the Coastal Plain physiographic province. The block diagram in **figure 6** shows the general relations of the four major categories. The combination of rock type and geologic structure largely determines the hydraulic character of the rocks. These factors, plus topography and climate, determine the characteristics of the ground-water flow system throughout the mapped area.

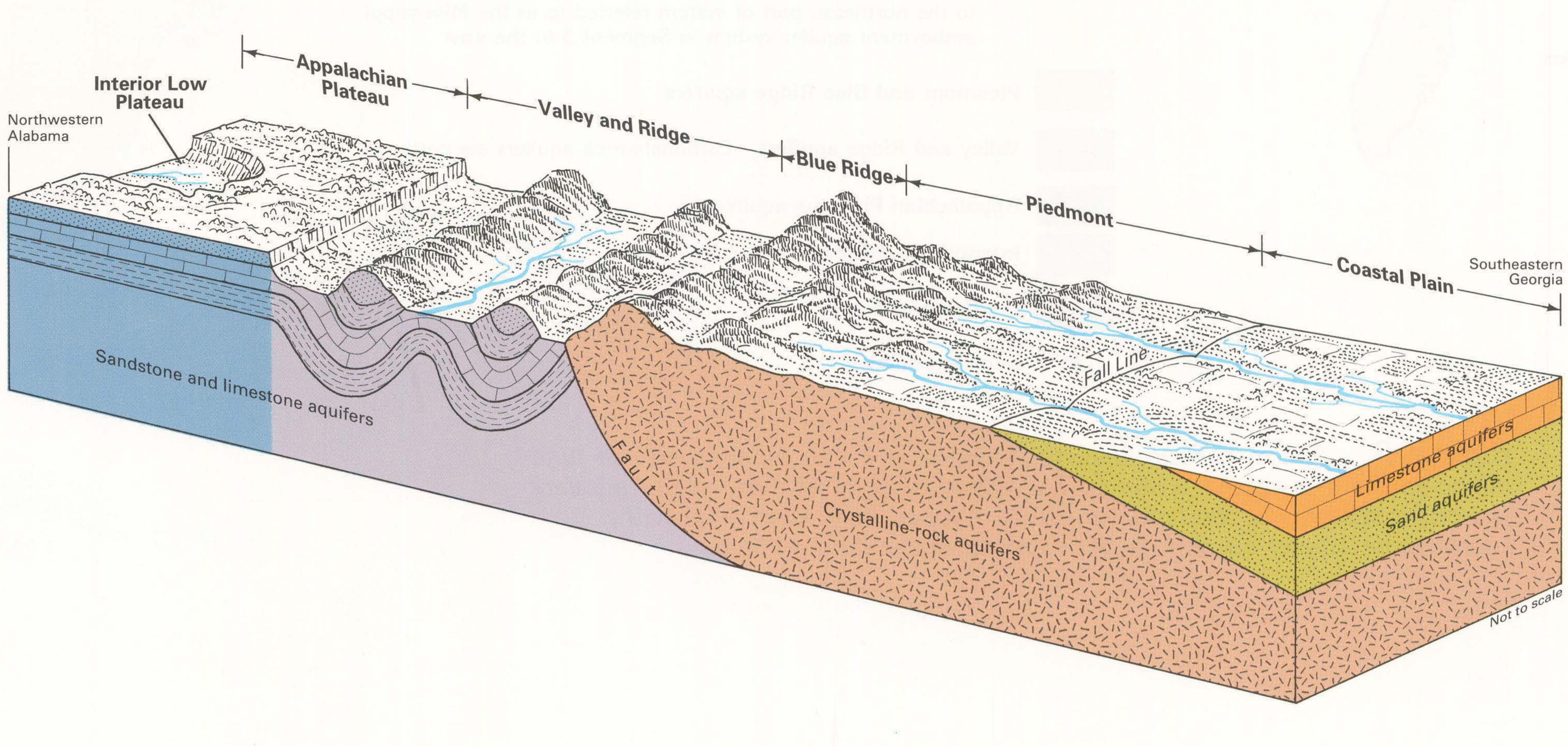


Figure 6. The Paleozoic rocks range from flatlying to intensely folded. They are separated from crystalline rocks of the Piedmont and Blue Ridge physiographic provinces by faults. The Coastal Plain strata that overlie older rocks are nearly flat.

VERTICAL SEQUENCE OF AQUIFERS

Some of the major aquifers and aquifer systems in Segment 6 lie atop others. For example, the Biscayne aquifer in southern Florida overlies the Floridan aquifer system, but the two are separated by a thick, clayey confining unit (**fig. 7**). Water is able to move vertically between some of these aquifers. Movement is in the direction of decreasing hydraulic head, and occurs most easily where the confining units separating the aquifers are absent, thin, or leaky.

The sequence of maps on this page shows the extent of each aquifer or aquifer system. Comparison of the maps shows the places where aquifers are stacked upon each other. The three uppermost aquifers in the Coastal Plain are shown in **figure 8**. These aquifers, the surficial aquifer system, sand and gravel aquifer, and Biscayne aquifer are all the same geologic age (primarily Pleistocene and younger), and all contain water mostly under unconfined (water table) conditions. However, even though these aquifers are lateral equivalents, the lithology and permeability of each are different. The surficial aquifer system is a thin, widespread layer of unconsolidated sand beds that commonly contains a few beds of shell and limestone. This aquifer system generally yields small volumes of water, and primarily is used for domestic supplies. The sand and gravel aquifer consists largely of interbedded layers of coarse sand and gravel that were deposited by streams. Thin clay beds in this aquifer locally create semiconfined conditions. The sand and gravel aquifer yields moderate volumes of water, and is an important source of supply for several counties in westernmost panhandle Florida and southwestern Alabama. Westward, in Mississippi, the sand and gravel aquifer grades into the Coastal lowlands aquifer system. The Biscayne aquifer, the source of water supply for several large cities along the southeastern coast of Florida, is a highly permeable sequence of mostly carbonate rocks that were deposited in marine waters.

The intermediate aquifer system (**fig. 9**) underlies the surficial aquifer system and overlies the Floridan aquifer system. The intermediate aquifer system is bounded above and below by clayey confining units. The system is not exposed at land surface and is recharged primarily by downward leakage from overlying aquifers. Sand beds and limestone lenses comprise the permeable parts of the system. The intermediate aquifer system is an important source of municipal supply in Sarasota, Charlotte, and Glades Counties, Fla.; elsewhere, it primarily is used for domestic supplies.

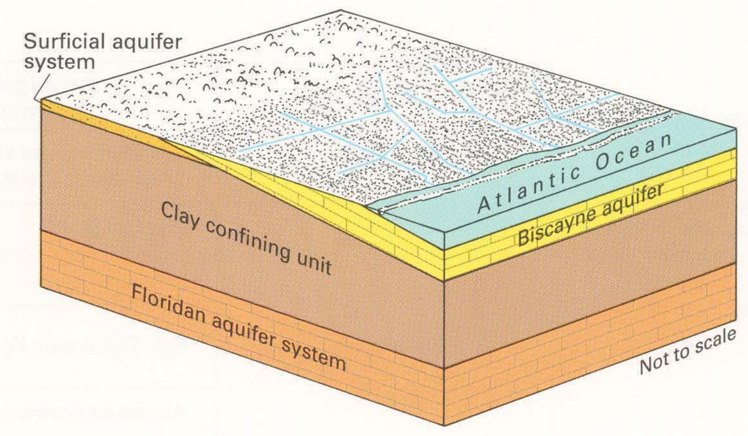


Figure 7. In places, some major aquifers overlie others. In south Florida, for example, the freshwater-yielding Biscayne aquifer is separated from the underlying Floridan aquifer system, which contains saltwater, by a thick, clayey confining unit.

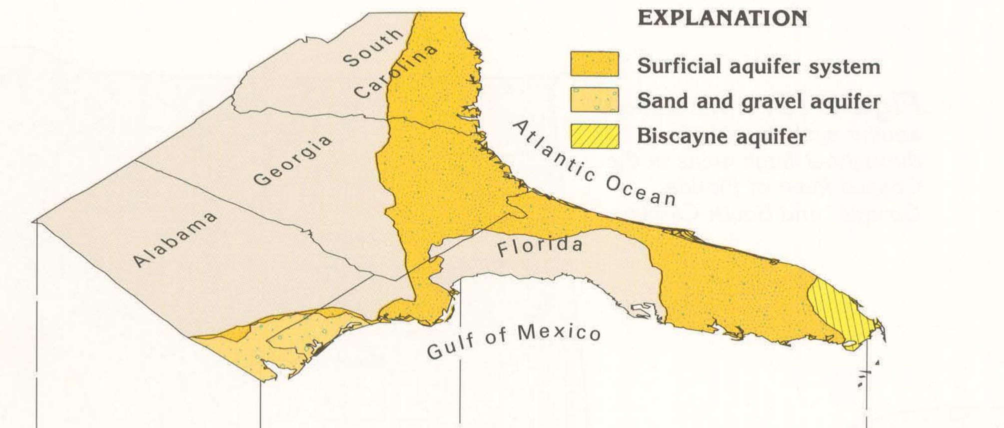


Figure 8. The uppermost Coastal Plain rocks are divided into three aquifers, all consisting of strata of the same age. The surficial aquifer system is a thin blanket of sand and shell beds that yields small volumes of water, the sand and gravel aquifer is a thick sequence of coarse clastic rocks that yields moderate volumes of water, and the Biscayne is a carbonate-rock aquifer that yields large volumes of water.

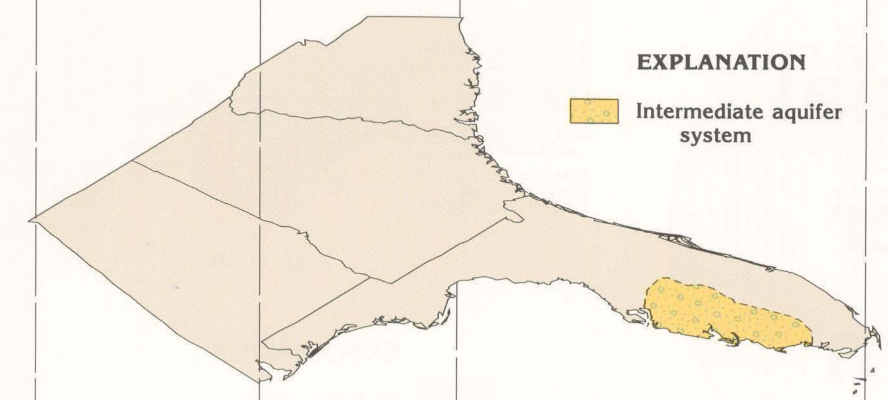


Figure 9. The intermediate aquifer system underlies the surficial aquifer system in southwestern Florida and consists mostly of sand, which yields small volumes of water, with some limestone beds, which yield large volumes of water.

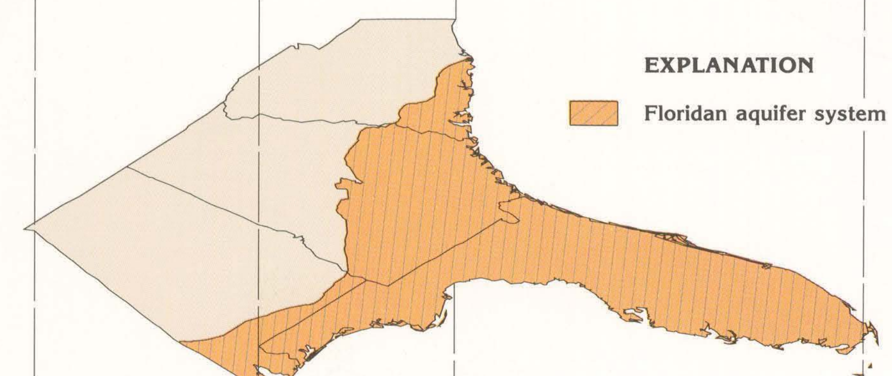


Figure 10. The Floridan aquifer system consists of carbonate rocks and is the most productive water-yielding unit in Segment 6. The Floridan is overlain by the intermediate aquifer system and also by the three younger aquifers shown in figure 8. In most places, the Floridan is separated from these overlying aquifers by a clayey confining unit.

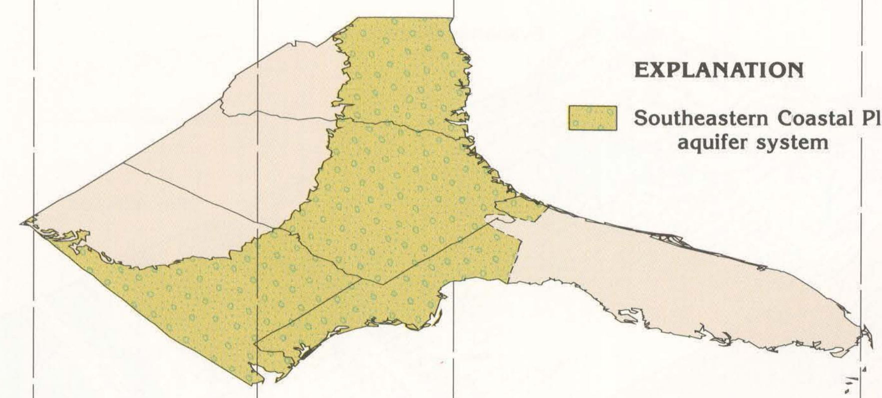


Figure 11. The clastic rocks of the Southeastern Coastal Plain aquifer system yield moderate volumes of water. The clastic rocks underlie the Floridan aquifer system in places, and grade laterally into the Floridan in other places. A clayey confining unit separates the two systems in Alabama and western Georgia.

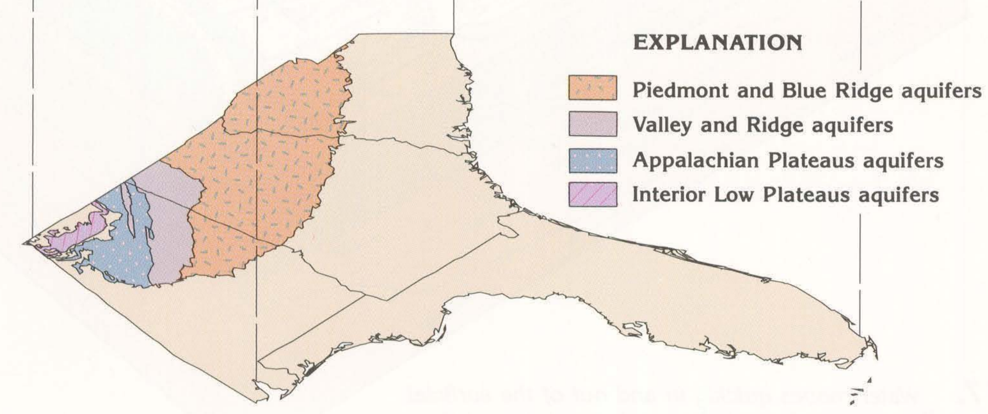


Figure 12. Crystalline rocks, such as granite, gneiss, and schist, comprise aquifers in the Piedmont and Blue Ridge provinces; indurated sedimentary rocks comprise aquifers in the Valley and Ridge province and in the combined Appalachian and Interior Low Plateaus provinces. All of the aquifers shown on this figure generally yield small volumes of water, and extend under the Southeastern Coastal Plain aquifer system, but are little used where the greater yielding Coastal Plain rocks cover them.

The Floridan aquifer system (**fig. 10**) consists of a thick sequence of carbonate rocks and is the most productive aquifer in Segment 6. The Floridan underlies the intermediate aquifer system where the latter is present; it also underlies the surficial aquifer system, the sand and gravel aquifer, and the Biscayne aquifer, but is separated from them practically everywhere by a thick, clayey confining unit. Where the surficial aquifer system overlies the Floridan, the clayey confining unit between the systems is thick in some places and thin or absent in other places. The Floridan supplied more than 3 billion gallons of water per day during 1985, primarily for municipal and agricultural purposes.

The Southeastern Coastal Plain aquifer system (**fig. 11**) underlies the Floridan aquifer system in some places (mostly in western Georgia and westward) and grades laterally into the Floridan in other places (mostly in southeastern Georgia and southwestern South Carolina). The upper part of the Southeastern Coastal Plain aquifer system grades laterally into the Mississippi embayment aquifer system in western Alabama (**fig. 3**). The Southeastern Coastal Plain aquifer system consists of four regional aquifers that are primarily sand beds, but which contain some gravel and limestone. The four regional aquifers generally yield large volumes of water in updip areas, where they are mostly sand, but the aquifers are less permeable in a coastward direction due to increasing clay content toward the coast. The system is an important source of water supply for all purposes throughout the inner part of the Coastal Plain.

Although rocks of the Piedmont, Blue Ridge, Valley and Ridge, and the combined Appalachian Plateaus and Interior Low Plateaus physiographic provinces (**fig. 12**) extend under the Southeastern Coastal Plain aquifer system, these rocks generally are not used as aquifers there because water can be more readily obtained from the shallower, unconsolidated Coastal Plain sediments. Piedmont and Blue Ridge aquifers consist of a complex sequence of metamorphic and igneous rocks, and primarily supply domestic or agricultural wells. Well yields generally are small; the water is obtained from fractures in the unweathered crystalline rock and from the mantle of regolith (weathered materials, soil, and alluvium) that overlies it. Major fault systems separate the Piedmont and Blue Ridge aquifers from the Valley and Ridge aquifers to the northwest.

The Valley and Ridge and the combined Appalachian Plateaus and Interior Low Plateaus aquifers consist of indurated sedimentary rocks of Paleozoic age. Water is obtained primarily from limestone in these provinces and secondarily from sandstone, chert beds, or fractured shale. In the Valley and Ridge province, these sedimentary rocks have been tightly folded into a sequence of northeast-trending anticlines and synclines that have been displaced by thrust faults in many places. Ground-water circulation extends to greater depths in these folded rocks than in the Appalachian Plateaus and Interior Low Plateaus provinces to the northwest where the same rocks are almost flatlying. In the Appalachian Plateaus province, the flatlying beds are topped with a resistant cap of sandstone; in the Interior Low Plateaus province, the sandstone has been dissected by erosion, and underlying limestone beds are exposed. The contact between the Valley and Ridge and Appalachian Plateaus provinces is distinct in some places where it follows faults and is gradational from nearly horizontal strata to folds in other places.

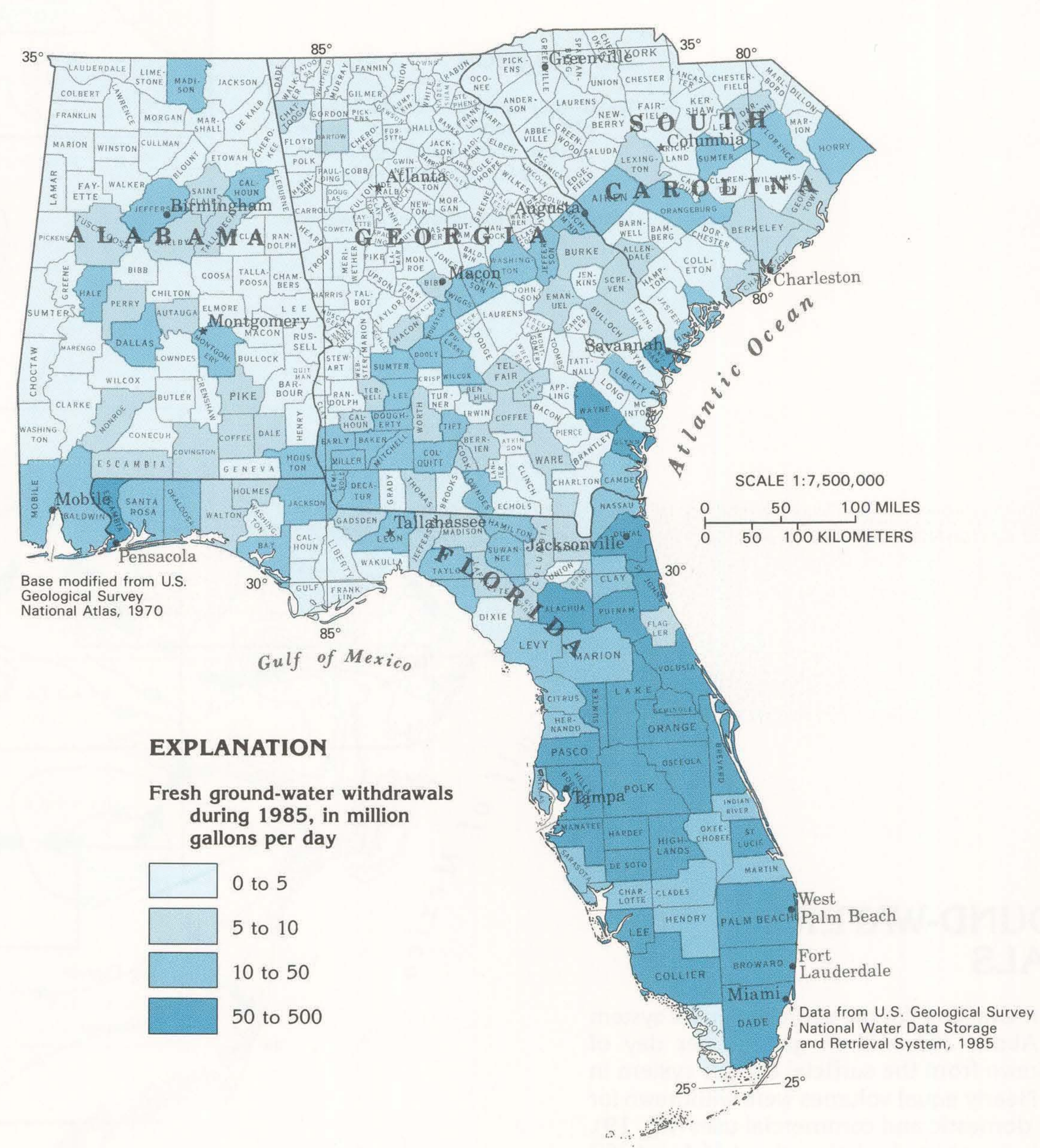


Figure 13. Fresh ground-water withdrawals were greatest in Florida during 1985 because the large population centers and extensive areas of agricultural water use in the State rely primarily on ground water for their water supplies.

FRESH GROUND-WATER WITHDRAWALS

Ground water is the source of water supply for almost 11 million people, or about 73 percent of the population in the four-State area.

About 5,600 million gallons per day was withdrawn from all the principal aquifers during 1985; 46 percent was used in rural areas for domestic and commercial supplies and for agricultural supplies. Withdrawals for public supply were somewhat less, accounting for 35 percent of the total water withdrawn.

Total withdrawals of fresh ground water, by county, are shown in **figure 13**. Counties with the largest withdrawals are those that have large population centers except for south-central Florida, where combined agricultural and mining uses account for most of the withdrawals. Fresh ground-water withdrawals for most water use categories are increasing, according to a recent (1990) nationwide compilation of water-use data by the U.S. Geological Survey.

Total withdrawals of freshwater during 1985 from each of the principal aquifers in four-State area are shown in **figure 14**. About 3,181 million gallons per day was withdrawn from the Floridan aquifer system, almost four times as much water as was withdrawn from the second most used aquifer, the Biscayne aquifer (786 million gallons per day), and almost twice as much water as was withdrawn from all the other principal aquifers combined. More water was withdrawn from the Biscayne aquifer, although it only extends throughout a small area in the southeastern tip of Florida, than from either the Southeastern Coastal Plain aquifer system (574 million gallons per day) or the surficial aquifer system (361 million gallons per day), even though both have a much larger areal extent. This is because the Biscayne is the source of supply for several large cities, including Miami, West Palm Beach, and Fort Lauderdale, along the southeast coast of Florida. About 298 million gallons per day was withdrawn from the intermediate aquifer system, about 150 million gallons per day from the sand and gravel aquifer, and about 149 million gallons per day from the combined Valley and Ridge, Appalachian Plateaus, and Interior Low Plateaus aquifers. Only about 100 million gallons per day, or about 2 percent of the total freshwater withdrawn, was obtained from the Piedmont and Blue Ridge aquifers because surface water is the primary source of supply in the area underlain by these aquifers.

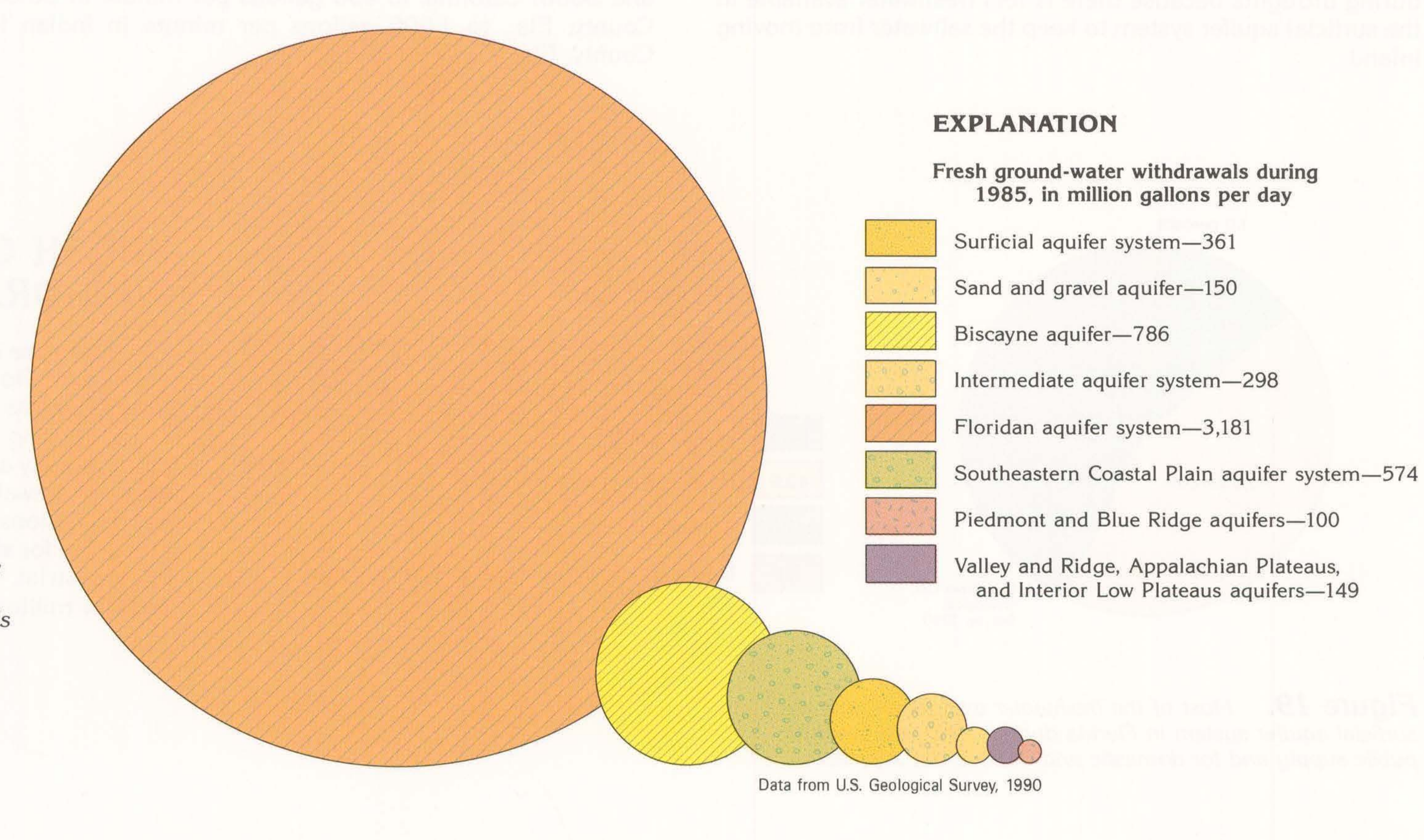


Figure 14. The Floridan aquifer system was the source of about 57 percent of the fresh ground-water withdrawals in the four-State area during 1985; about 14 percent of the fresh water was withdrawn from the Biscayne aquifer, the second most used aquifer.

Surficial aquifer system

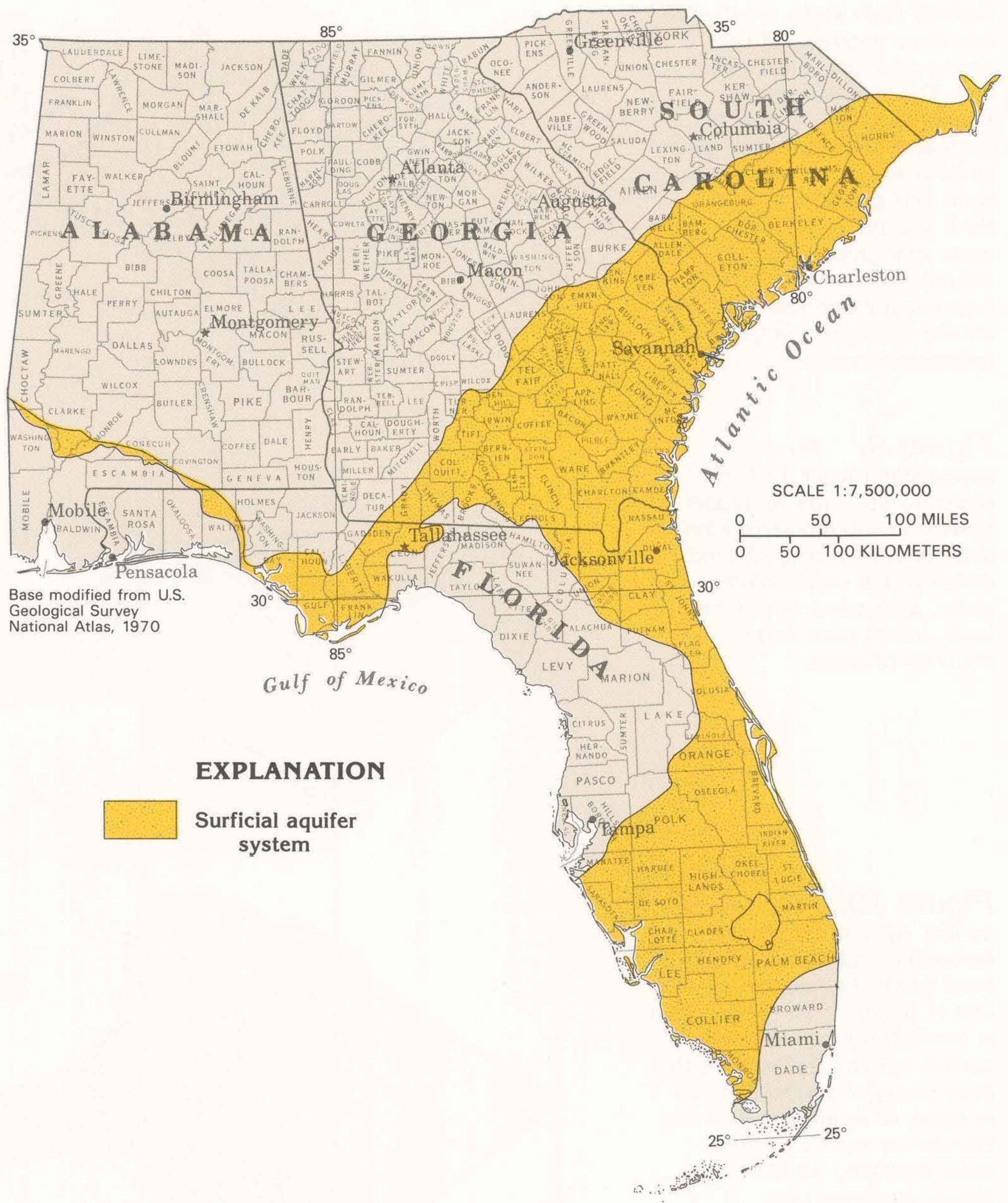


Figure 15. The surficial aquifer system extends throughout large areas in the Coastal Plain of Florida, Georgia, and South Carolina.

INTRODUCTION

The surficial aquifer system (**fig. 15**) in the southeastern United States includes any otherwise undefined aquifers that are present at the land surface. Even though the sand and gravel aquifer of Florida and southwestern Alabama, and the Biscayne aquifer of southern Florida are present at the land surface and are the lateral equivalents of the surficial aquifer system, they are treated separately in this Atlas because of their importance as water sources. The sand and gravel, and the Biscayne aquifers supply large municipalities; the surficial aquifer system, although used by a large number of people, principally is used only for domestic, commercial, or small municipal supplies.

The thickness of the surficial aquifer system is typically less than 50 feet, but its thickness in Florida is as much as 400 feet in Indian River and St. Lucie Counties; 250 feet in Martin and Palm Beach Counties; and 150 feet in eastern St. Johns County. In southeastern Georgia, thicknesses of about 60 feet have been mapped for the system. The system generally thickens coastward.

HYDROGEOLOGIC UNITS

The surficial aquifer system consists mostly of beds of unconsolidated sand, shelly sand, and shell. Locally, in southwestern Florida, limestone beds form an important and highly permeable part of the system. In places, clay beds are sufficiently thick and continuous to divide the system into two or three aquifers; mostly, however, the system is undivided. Complex interbedding of fine- and coarse-textured rocks is typical of the system.

The rocks that comprise the surficial aquifer system range from late Miocene to Holocene in age. Although **figure 16** shows that nine geologic formations are part of the system at different places in Florida, the entire sequence of formations is not present at any one location. The formations are thin and mostly lens-like, and it is unusual for more than three or four of them to comprise the surficial aquifer system at any place. Many of the geologic formations shown interfinger with each other, and some of them, such as the Caloosahatchee Marl, are not particularly productive aquifers. In Georgia and South Carolina, unnamed, sandy, marine terrace deposits of Pleistocene age and sand of Holocene age comprise the system. These sandy beds commonly contain clay and silt. In Alabama, a thin, unnamed sand of Holocene age comprises the system.

Limestone beds of the Tamiami and Fort Thompson Formations, mostly restricted to southern and southwestern Florida, are the most productive parts of the surficial aquifer system. Yields from these formations are especially large where large-scale openings have been developed by dissolution of part of the limestone. In places where the combined Pamlico Sand and overlying sand deposits of Holocene age are 40 feet or more thick, moderate yields are obtained; elsewhere, the system generally does not yield much water.

Figure 16. In Florida, rocks of late Miocene to Holocene age comprise the surficial aquifer system. In Alabama, Georgia, and South Carolina, a thin, unnamed sand sequence of Pleistocene and younger age comprises the system.

Series	Stratigraphic and hydrologic units		Lithology
Holocene	Undifferentiated alluvium and terrace deposits	Surficial aquifer system	Sand with local shell beds
Pleistocene[1]	Pamlico Sand		Fine to medium sand
	Miami Oolite		Oolitic limestone
	Fort Thompson Formation		Interbedded sand, shell, and limestone
	Anastasia Formation		Sandy limestone and marl
	Caloosahatchee Marl		Marl with minor sand and silt
Pliocene	Tamiami Formation		Marl with beds of fossiliferous limestone
	Bone Valley Formation		Phosphatic sand and clay
Miocene	Choctawhatchee Formation		Sand and limestone

[1](Stratigraphic units are equivalent in part. Order does not necessarily reflect relative age)

Modified from Healy, 1982

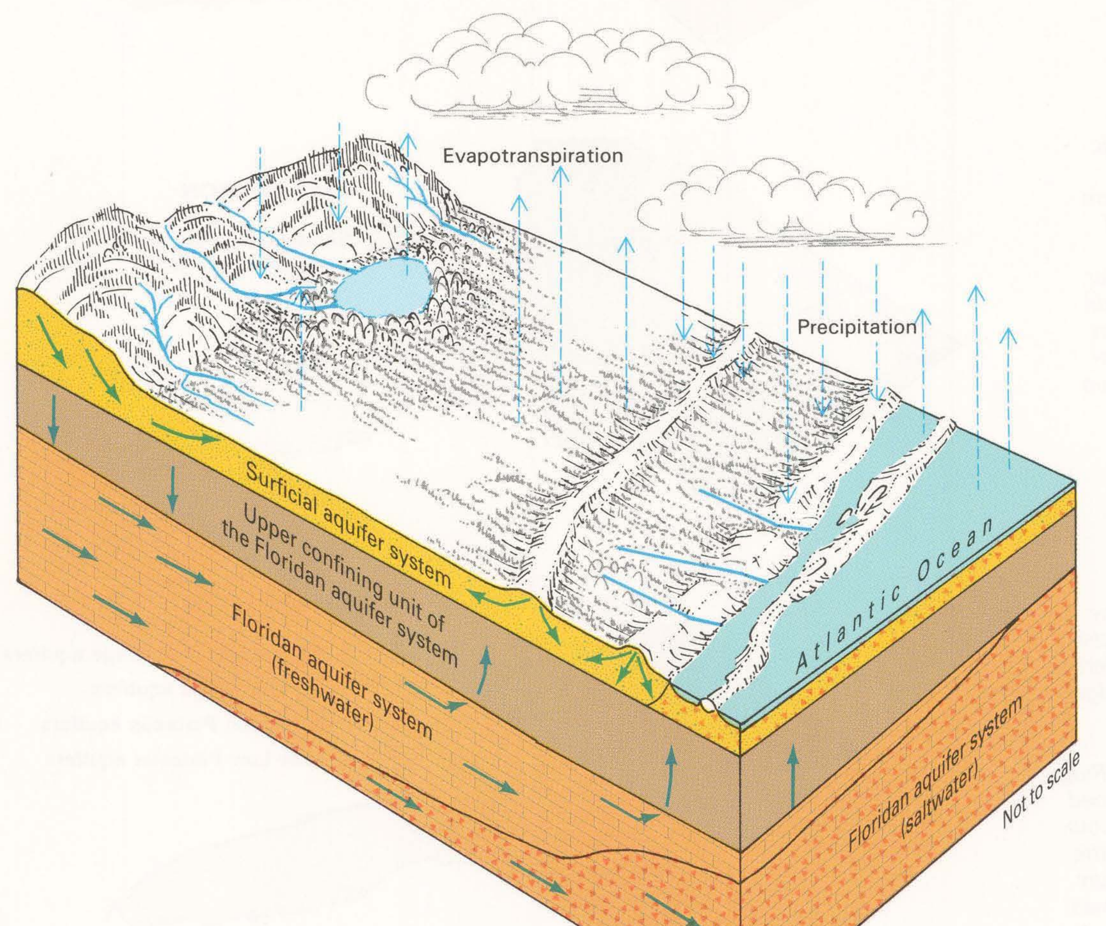


Figure 17. Water moves quickly in and out of the surficial aquifer system. Some water leaks between the system and the underlying Floridan aquifer system. The solid arrows show the general direction of ground-water movement.

GROUND-WATER FLOW

Ground water in the surficial aquifer system is under unconfined, or water-table, conditions practically everywhere. Locally, thin clay beds create confined or semiconfined conditions within the system. Most of the water that enters the system moves quickly along short flowpaths and discharges as baseflow to streams.

The general movement of water within the system is illustrated in **figure 17**, which is an idealized diagram representing hydrologic conditions in Indian River County, Fla. Water enters the system as precipitation. A large percentage of this water is returned to the atmosphere by evapotranspiration. Water that is not returned to the atmosphere by evapotranspiration, or that does not directly run off into surface-water bodies, percolates downward into the surficial aquifer system and then moves laterally through the system until it discharges to a surface-water body or to the ocean.

In places, some water leaks upward from the underlying Floridan aquifer system through the clayey confining unit separating the Floridan and surficial systems **(fig. 17)**. In other places, where the hydraulic head of the Floridan is lower than the water table of the surficial aquifer, leakage can occur in the opposite direction.

Because the surficial aquifer system extends seaward under the Atlantic Ocean, saltwater can encroach into the aquifer in coastal areas. Encroachment is more extensive during droughts because there is less freshwater available in the surficial aquifer system to keep the saltwater from moving inland.

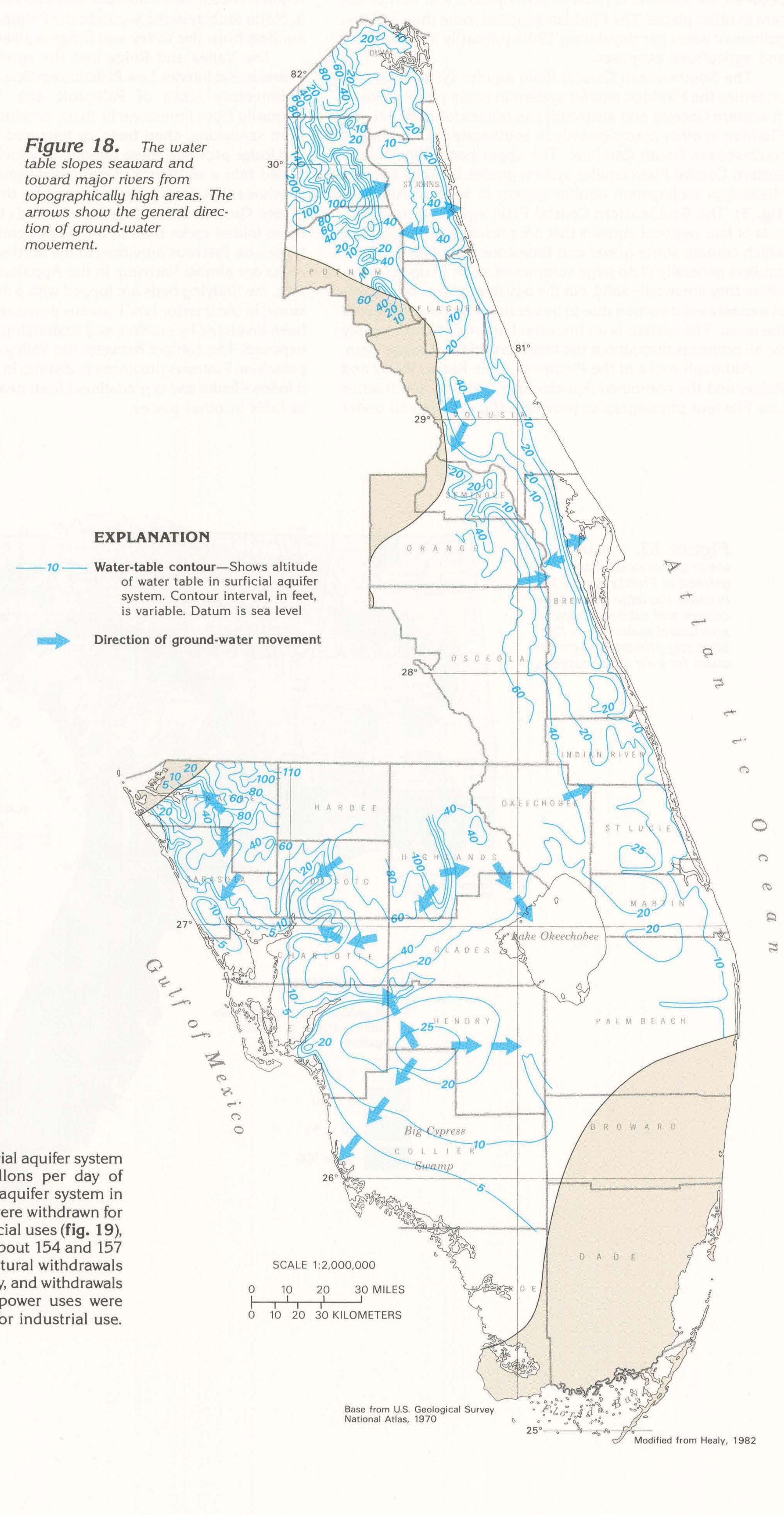
The configuration of the long-term, average water table of the surficial aquifer system, where it has been mapped in the eastern and southern part of the Florida peninsula, is shown in **figure 18**. The water-table configuration is generally a subdued reflection of the topography of land surface. Steep gradients occur between streams and ridges or hills, and gentle gradients occur in broad, flat interstream areas and under broad topographic highs.

The arrows in **figure 18** show that the general direction of ground-water movement is toward the Atlantic Ocean, the Gulf of Mexico, or toward major rivers. The water-table surface is complex, reflecting the fact that water in the surficial aquifer system moves quickly toward the nearest surface-water body. Accordingly, local directions of ground-water movement change markedly within short distances.

The wide spacing of the contours in Collier County and adjacent areas reflects two conditions: (1) the Big Cypress Swamp, which is virtually flat, is present throughout much of this area; and (2) the surficial aquifer system largely consists of highly permeable limestone in this area. Steeper gradients elsewhere are more typical of a sand aquifer in an area of gentle topography.

The transmissivity of the surficial aquifer system is extremely variable. Most reported values range from 1,000 to 10,000 feet squared per day; in places, values of 25,000 to 50,000 feet squared per day have been reported. The larger values are primarily for beds of shell or limestone. Well yields range from less than 50 gallons per minute in most of Georgia and South Carolina, to 450 gallons per minute in St. Johns County, Fla., to 1,000 gallons per minute in Indian River County, Fla.

Figure 18. The water table slopes seaward and toward major rivers from topographically high areas. The arrows show the general direction of ground-water movement.



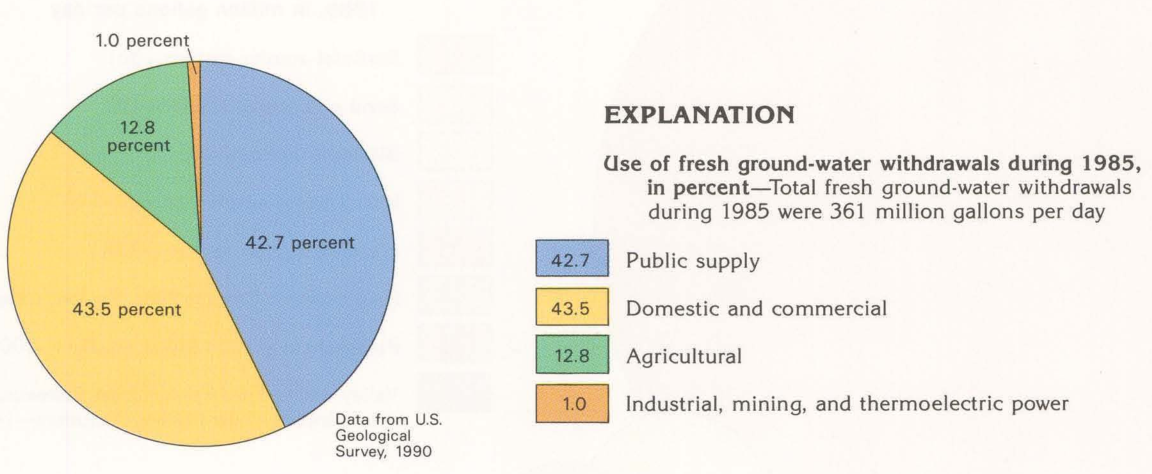
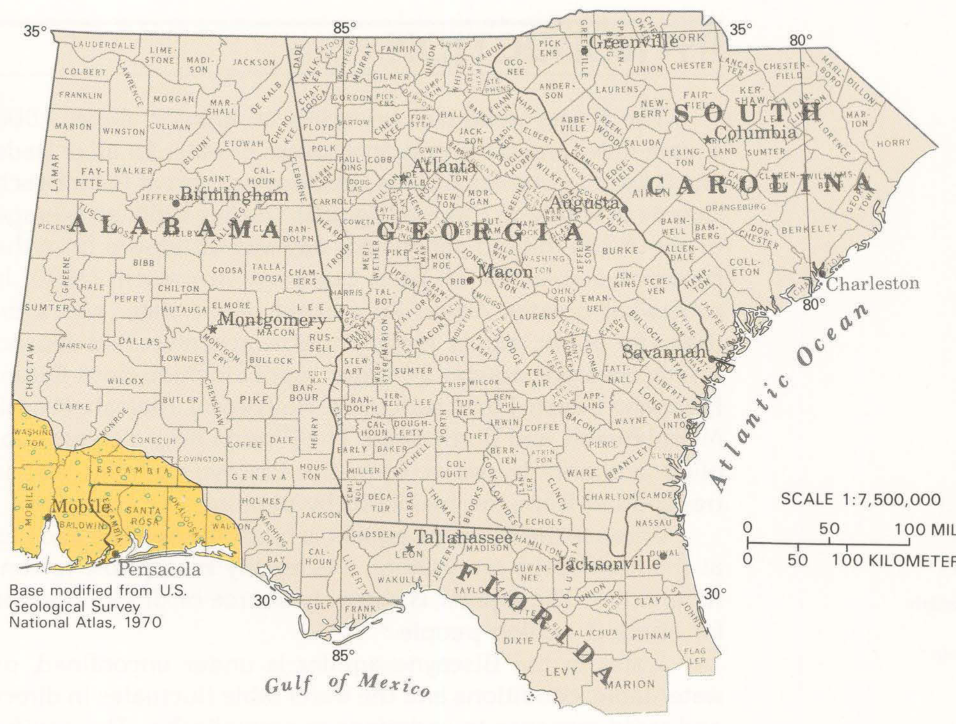


Figure 19. Most of the freshwater withdrawn from the surficial aquifer system in Florida during 1985 was used for public supply and for domestic and commercial supplies.

FRESH GROUND-WATER WITHDRAWALS

Water-use data are available for the surficial aquifer system only from Florida. About 361 million gallons per day of freshwater was withdrawn from the surficial aquifer system in Florida during 1985. Nearly equal volumes were withdrawn for public supply and for domestic and commercial uses **(fig. 19)**, with withdrawals for these categories being about 154 and 157 million gallons per day, respectively. Agricultural withdrawals accounted for about 13 million gallons per day, and withdrawals for industrial, mining, and thermoelectric-power uses were about 4 million gallons per day, primarily for industrial use.

Sand and gravel aquifer



EXPLANATION

Sand and gravel aquifer

Figure 20. The sand and gravel aquifer is an important source of water in southwestern Alabama and the westernmost part of panhandle Florida.

INTRODUCTION

The sand and gravel aquifer underlies an area of about 6,500 square miles in southwestern Alabama and the westernmost part of panhandle Florida (**fig. 20**). The aquifer is presently (1990) called the Miocene-Pliocene aquifer in Alabama; in the past, it has been called the Citronelle or Citronelle-Miocene aquifer in that State by some authors. In Mississippi, the sand and gravel aquifer grades laterally into part of the Coastal lowlands aquifer system that extends westward into southern Texas. The sand and gravel aquifer is the primary source of water in Baldwin, Washington, and western Escambia Counties, Ala., and in Santa Rosa and Escambia Counties, Fla. The aquifer also supplies most of the water used by small communities in the rural parts of Mobile County, Ala.; the city of Mobile in that county, however, is supplied by surface water. About 150 million gallons per day was withdrawn from the sand and gravel aquifer for all uses during 1985. About 80 percent was withdrawn in the Pensacola, Fla. area, and the majority of the remaining 20 percent was withdrawn in Mobile County, Ala.

As its name indicates, the sand and gravel aquifer consists largely of interbedded layers of sand and gravel. Clay beds and lenses are common in the aquifer and form local confining beds. Water in the aquifer is under unconfined conditions where the clay beds are thin or absent, and is under artesian conditions where such beds are thick. Movement of ground water is generally coastward.

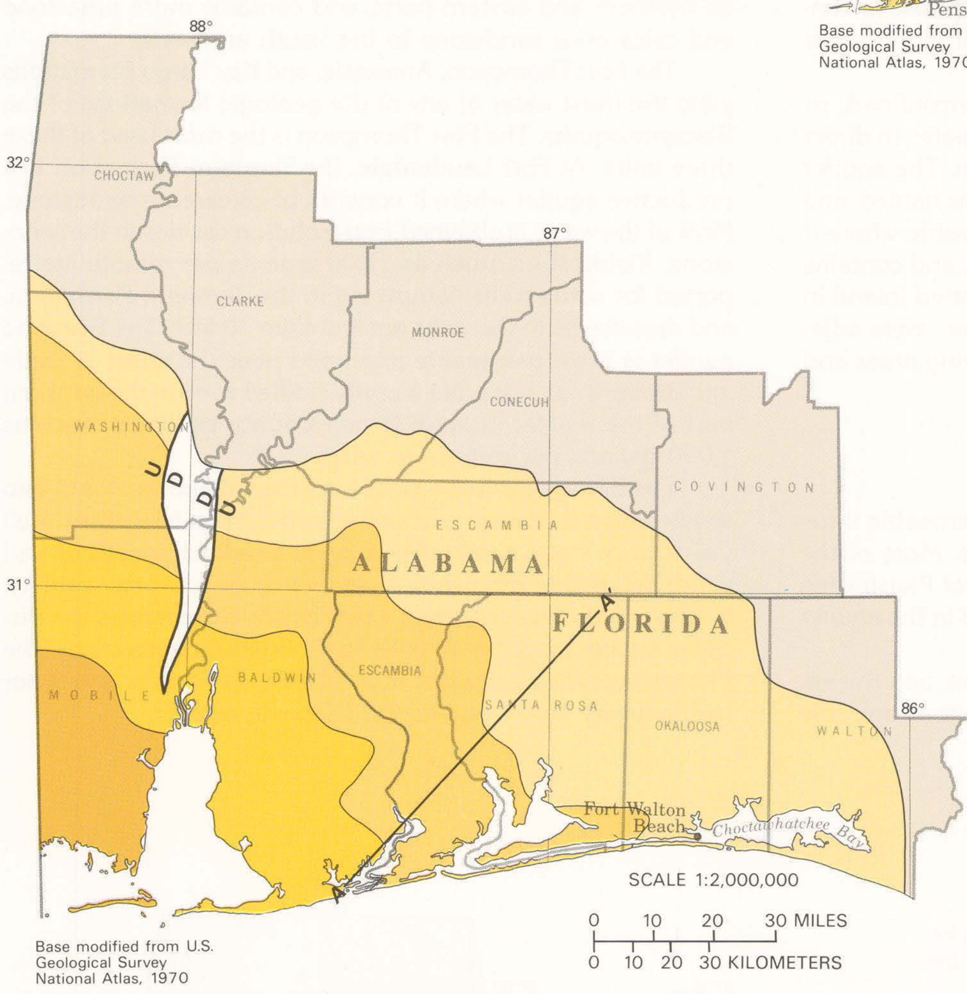
GEOLOGY

The sand and gravel aquifer consists of rocks ranging in age from middle Miocene to Holocene that were mostly deposited in a deltaic environment. In Alabama, Miocene rocks are all included in the undifferentiated Catahoula Sandstone, a thick, predominantly nonmarine sequence of sand and clay beds. The Miocene units shown in **figure 21** are overlain by the Citronelle Formation of Pliocene age. The Citronelle is mostly fine- to coarse-grained sand that is locally gravelly, and is the most important water-yielding formation in the upper part of the sand and gravel aquifer. The Citronelle locally contains layers of hardpan, or cemented iron oxide, that retard ground-water movement. The principal geologic units that comprise the aquifer in the westernmost part of the panhandle Florida are shown in **figure 21**. The Alum Bluff Group and the Choctawhatchee Formation, which were deposited in a more marine environment, are most easily recognizable near the coast. Northward, these beds grade into undifferentiated coarse sand and gravel, which comprise the major water-yielding unit of the lower part of the sand and gravel aquifer.

Series	Stratigraphic and hydrologic units			Lithology
Holocene and Pleistocene	Alluvium and terrace deposits		Sand and gravel aquifer	Undifferentiated silt, sand, and gravel, with some clay. Surficial zone of aquifer
Pliocene	Citronelle Formation		Sand and gravel aquifer	Sand, very fine to very coarse and poorly sorted. Hardpan layers in upper part
Miocene	Unnamed coarse clastics	Choctawhatchee Formation	Sand and gravel aquifer	Sand, shell, and marl
Miocene	Unnamed coarse clastics	Alum Bluff Group Shoal River Formation Chipola Formation	Sand and gravel aquifer	Sand with lenses of silt, clay, and gravel (includes unnamed coarse clastics and Alum Bluff Group). Main producing zone of aquifer
Miocene	Pensacola Clay		Confining unit	Dark to light gray sandy clay. Is basal confining unit in southern one-half of area
Miocene	St. Marks Formation		Floridan aquifer system	Limestone and dolomite--top of the Floridan aquifer system

Modified from Cushman-Roisin and Franks, 1982

Figure 21. Several geologic units of Miocene age and younger comprise the sand and gravel aquifer in the westernmost part of panhandle Florida. The aquifer extends to the land surface throughout its area of occurrence.



EXPLANATION

Thickness of sand and gravel aquifer, in feet

- Less than 400
- 400 to 800
- 800 to 1200
- Greater than 1200
- No data

D/U Fault—U, upthrown side, D, downthrown side

A——A′ Line of hydrogeologic section

Figure 22. The sand and gravel aquifer thickens to the southwest. In western Alabama, the aquifer is offset by a downdropped fault block called the Mobile graben.

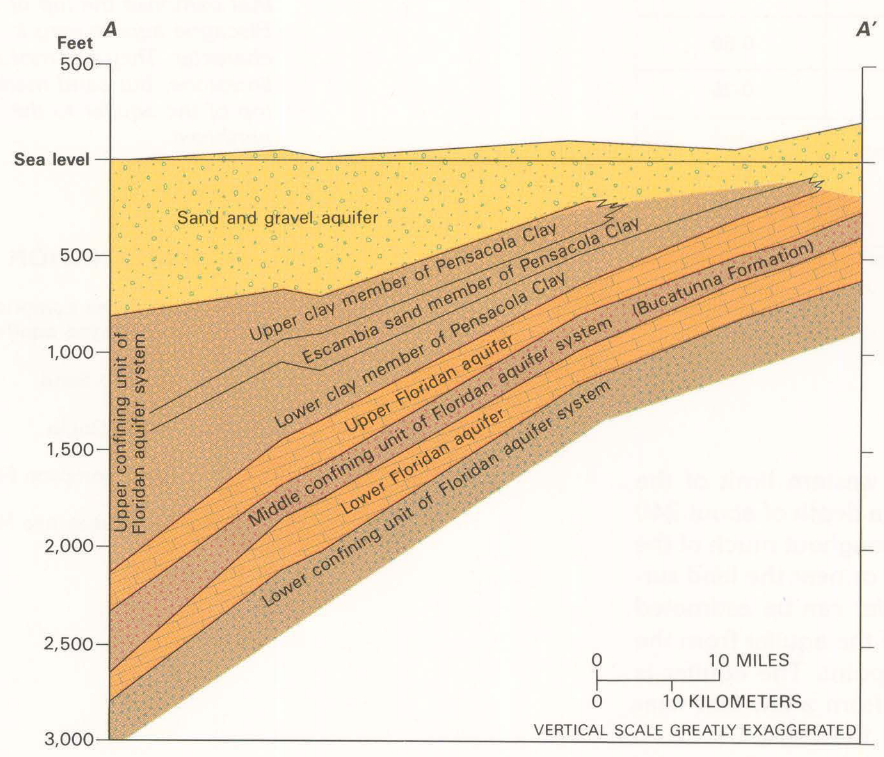


Figure 23. The base of the sand and gravel aquifer is formed by a thick series of clay beds to the southwest; however, the Upper Floridan aquifer is the base of the sand and gravel aquifer to the northeast. The line of the section is shown in figure 22.

THICKNESS

The sand and gravel aquifer is approximately wedge-shaped and thickens southwestward from a feather edge at its northern and eastern limit to about 1,400 feet in southwestern Alabama (**fig. 22**). Throughout the southern two-thirds of the area underlain by the aquifer, the confining unit forming the base of the aquifer consists of either the upper or lower clay members of the Pensacola Clay (**fig. 23**). Analysis of aquifer-test data, supplemented by the results of laboratory testing of cores from the Pensacola Clay, indicates that the permeability of this confining unit is so small that practically no water passes across it. To the northeast, the clay beds are absent and the sand and gravel aquifer is in direct contact with the Upper Floridan aquifer.

HYDROGEOLOGIC UNITS

In most places, the sand and gravel aquifer can be divided into two high-permeability zones, the upper surficial and lower main producing zones, separated by a less permeable sand and clay unit. The upper, or surficial, zone is mostly fine- to medium-grained sand, with gravel beds and lenses, and contains water that is mostly under unconfined conditions. This zone is recharged directly by precipitation, and ground-water flow in it is mostly lateral along short flowpaths to discharge points along small streams. Some of the water percolates downward and recharges the lower high-permeability zone. The upper zone consists mostly of the Citronelle Formation combined with stream-valley alluvium and terrace deposits. Along major streams, such as the Mobile River, alluvial deposits are as much as 150 feet thick and wells completed in them yield as much as 850 gallons per minute. The upper zone contains clay and hardpan layers that create local perched water tables or, in places, artesian conditions. The upper zone is mostly used for water supply in southern Mobile, southern Baldwin, and southwestern Escambia Counties, Ala., because the lower zone contains much clay in these counties, and, accordingly, yields less water. The hydraulic characteristics of the upper zone are extremely variable. Yields of as much as 1,000 gallons per minute are reported for wells completed in the upper zone, and a transmissivity of 11,000 feet squared per day was reported for the zone based on results of an aquifer test conducted in Escambia County, Ala.

In the westernmost part of panhandle Florida, the lower of the two high-permeability zones is called the "main producing zone" because most of the ground water used in Santa Rosa and Escambia Counties is withdrawn from this zone. This zone also is the main source of water supply for Washington, northern Mobile, northern Baldwin, and eastern Escambia Counties, Ala. The zone consists mostly of coarse sand and gravel beds, all of Miocene age. Water in this zone is confined everywhere. Recharge to the zone is by downward leakage from the upper zone; discharge is to major streams, bays, sounds, and the Gulf of Mexico. Yields of more than 1,000 gallons per minute are commonly reported for wells completed in this zone, and results of aquifer tests have indicated that the transmissivity of the zone is as much as 20,000 feet squared per day.

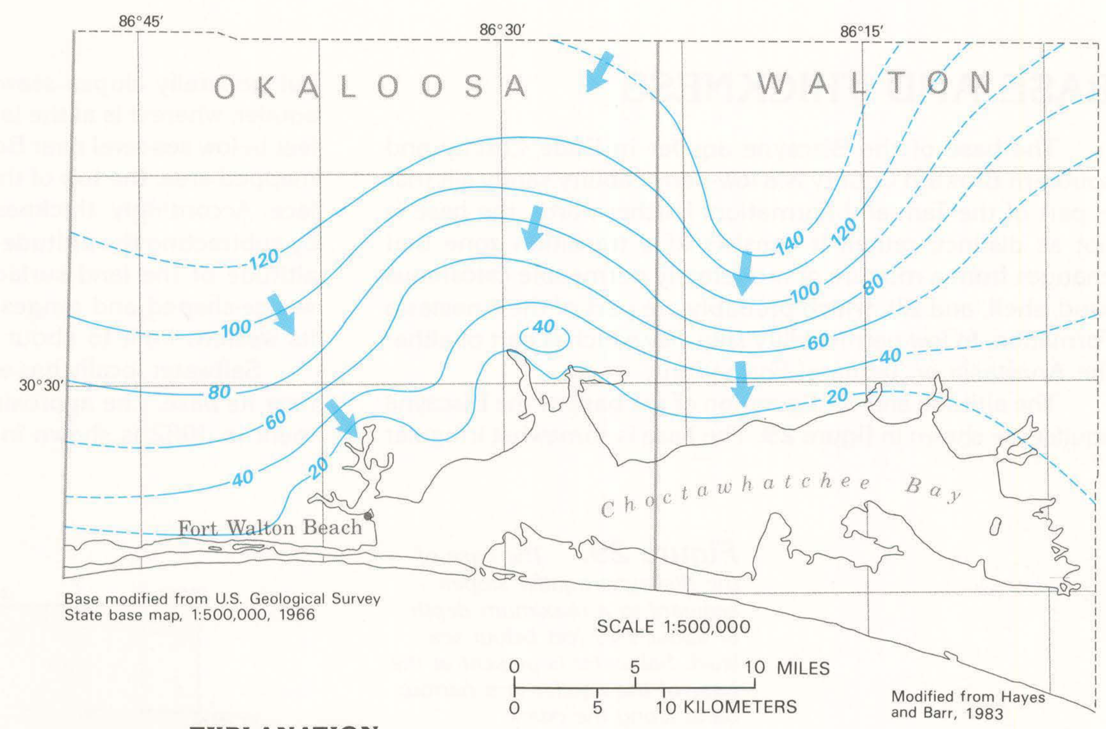
GROUND-WATER FLOW

Water enters the sand and gravel aquifer as recharge from precipitation, and moves generally downward and then either discharges to streams or moves coastward in the aquifer. Discharge is primarily to streams, bays, and sounds. Small volumes of water leak upward to the Gulf of Mexico and still smaller volumes are discharged by wells. Most of the well discharge is in Mobile County, Ala., and Escambia and Santa Rosa Counties, Fla.

Water movement in the upper zone of the aquifer is complex because this zone contains numerous discontinuous clay layers and some layers of iron oxide (hardpan). Because of the low permeability of the hardpan and the clay, and the confined conditions they produce, perched water-table conditions, artesian conditions, and true water-table conditions can all exist in one area. Such conditions prohibit drawing a representative map of the potentiometric surface of the aquifer, except for local areas. Where hardpan or clay beds are near the land surface, ponds may be perched on them or springs may issue at the top of such beds where they are exposed in small stream valleys. Some water percolates downward across all these confining beds to recharge deeper permeable zones in the aquifer. Water levels generally decrease with depth in the aquifer, a condition that allows downward leakage almost everywhere.

The saturated thickness of the aquifer is everywhere less than its total thickness because the water table ranges from a few feet to about 50 feet below land surface. The water table is just below land surface in low-lying areas and is deepest under hills and ridges.

The general coastward movement of water in the main producing zone of the sand and gravel aquifer is shown by the potentiometric contours in **figure 24**. The arrows show that the water is moving mostly toward Choctawhatchee Bay from recharge areas where water levels are highest. The contours are smooth and evenly spaced because the water in this zone is confined. A similar map for the surficial zone of the aquifer would show the same general seaward movement of water, but the contours would be convoluted because of the effects of topography and streams.



EXPLANATION

—60— Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 20 feet. Datum is sea level

→ Direction of ground-water movement

- - - - Boundary of study area

Figure 24. Water in the main producing zone of the sand and gravel aquifer moves toward the coast from inland recharge areas. The water levels were measured in March 1979.

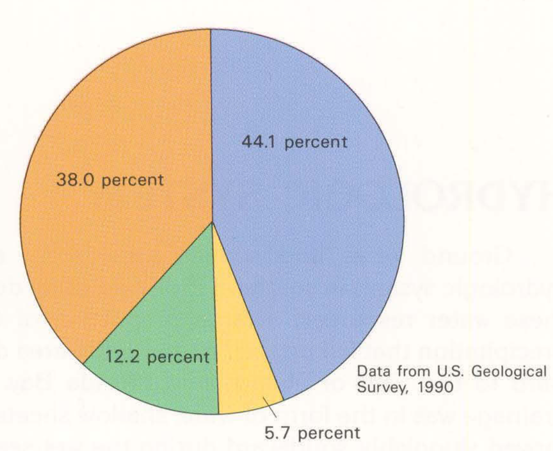
GROUND-WATER QUALITY

Water in the sand and gravel aquifer is suitable for drinking practically everywhere. The quartz-rich sediments that comprise the aquifer are practically insoluble; accordingly, water in the aquifer has concentrations of dissolved solids that ordinarily are less than 50 milligrams per liter. Chloride concentrations also are ordinarily less than 50 milligrams per liter everywhere except in a few locations near the coast and adjacent to large bays and sounds where there is a transition zone of freshwater and saltwater; there, chloride concentrations greater than 1,000 milligrams per liter are reported in water from some wells. Water in the aquifer is usually slightly acidic, with a pH of about 6.0; locally, the water is more acidic (pH 4.5). Dissolved-iron concentrations may locally be objectionable; concentrations as large as 4,300 micrograms per liter have been reported.

The sand and gravel aquifer, like other shallow aquifers, is readily susceptible to contamination. Contamination of the upper zone has occurred at several places in the three westernmost counties of Florida. One such place is a site near Pensacola where creosote waste products from a wood-preserving plant have been detected in a large part of the upper zone of the aquifer.

FRESH GROUND-WATER WITHDRAWALS

Withdrawals of freshwater from the sand and gravel aquifer totaled 150 million gallons per day during 1985. About 44 percent, or about 66 million gallons per day, was withdrawn for public supply (**fig. 25**). About 9 million gallons per day was withdrawn for domestic and commercial uses, and about 18 million gallons per day was withdrawn for agricultural uses. About 57 million gallons per day was withdrawn for industrial, mining, and thermoelectric-power uses.



EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent—Total fresh ground-water withdrawals during 1985 were 150 million gallons per day

- 44.1 Public supply
- 5.7 Domestic and commercial
- 12.2 Agricultural
- 38.0 Industrial, mining, and thermoelectric power

Figure 25. Most of the freshwater withdrawn from the sand and gravel aquifer during 1985 was used for public supply and industrial, mining, and thermoelectric-power purposes.

Floridan aquifer system

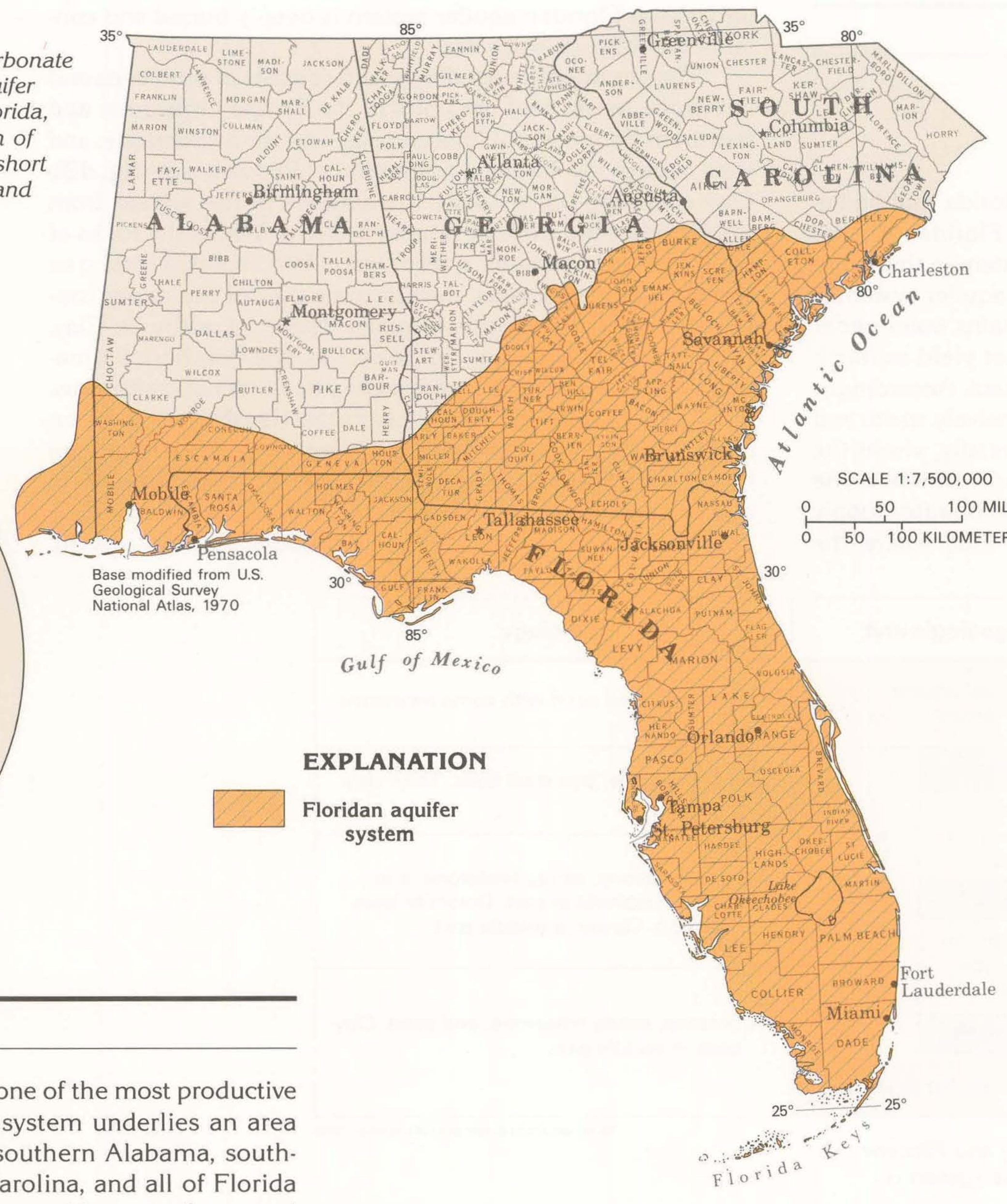


Figure 48. The carbonate rocks of the Floridan aquifer system underlie all of Florida, most of the Coastal Plain of Georgia, and extend for short distances into Alabama and South Carolina.

INTRODUCTION

The Floridan aquifer system is one of the most productive aquifers in the world. This aquifer system underlies an area of about 100,000 square miles in southern Alabama, southeastern Georgia, southern South Carolina, and all of Florida (**fig. 48**). The Floridan aquifer system provides water for several large cities, including Savannah and Brunswick in Georgia; and Jacksonville, Tallahassee, Orlando, and St. Petersburg in Florida. In addition, the aquifer system provides water for hundreds of thousands of people in smaller communities and rural areas. Locally, the Floridan is intensively pumped for industrial and irrigation supplies. During 1985, an average of about 3 billion gallons per day of freshwater was withdrawn from the Floridan for all purposes. Withdrawals during 1988 were somewhat greater. Despite the huge volumes of water that are being withdrawn from the aquifer system, water levels have not declined greatly except locally where pumpage is concentrated or the yield from the system is minimal.

The Floridan is a multiple-use aquifer system. Where it contains freshwater, it is the principal source of water supply. In several places where the aquifer contains saltwater, such as along the southeastern coast of Florida, treated sewage and industrial wastes are injected into it. Near Orlando, Fla., drainage wells are used to divert surface runoff into the Floridan. South of Lake Okeechobee in Florida, the aquifer contains saltwater. Some of this saltwater is withdrawn for cooling purposes and some is withdrawn and converted to freshwater by desalinization plants. Desalinization is especially important in the Florida Keys, which have no other source of freshwater except that which is imported by pipeline.

HYDROGEOLOGIC UNITS

A thick sequence of carbonate rocks (limestone and dolomite) of Tertiary age comprise the Floridan aquifer system. The thickest and most productive formations of the system are the Avon Park Formation and the Ocala Limestone of Eocene age (**fig. 49**). The Suwannee Limestone (Oligocene age) also is a principal source of water, but it is thinner and much less areally extensive than the Eocene formations. The Tampa Limestone of Miocene age is part of the Floridan in only a few places where it is sufficiently permeable to be an aquifer. Both the Suwannee and the Tampa Limestones are discontinuous. The lower part of the Avon Park Formation, the Oldsmar Formation of early Eocene age, and the upper part of the Cedar Keys Formation of Paleocene age also are included in the Floridan where they are highly permeable. Limestone beds in the lower part of the Hawthorn Formation of Miocene age are considered part of the Floridan by some, but are excluded from it in this Atlas because the permeability of these beds is thought to be minimal. The base of the aquifer system in much of Florida consists of nearly impermeable anhydrite beds in the Cedar Keys Formation. In northern peninsular Florida, the Paleocene and lowermost Eocene rocks contain sand and are much less permeable than the carbonate rocks of the Floridan. Due to the contrast in permeability, these sandy strata form the base of the Floridan aquifer system in this area. Locally, in south-central Georgia and northern peninsular Florida, evaporite minerals have filled the pore spaces in upper Eocene rocks, and these low-permeability beds comprise the base of the system.

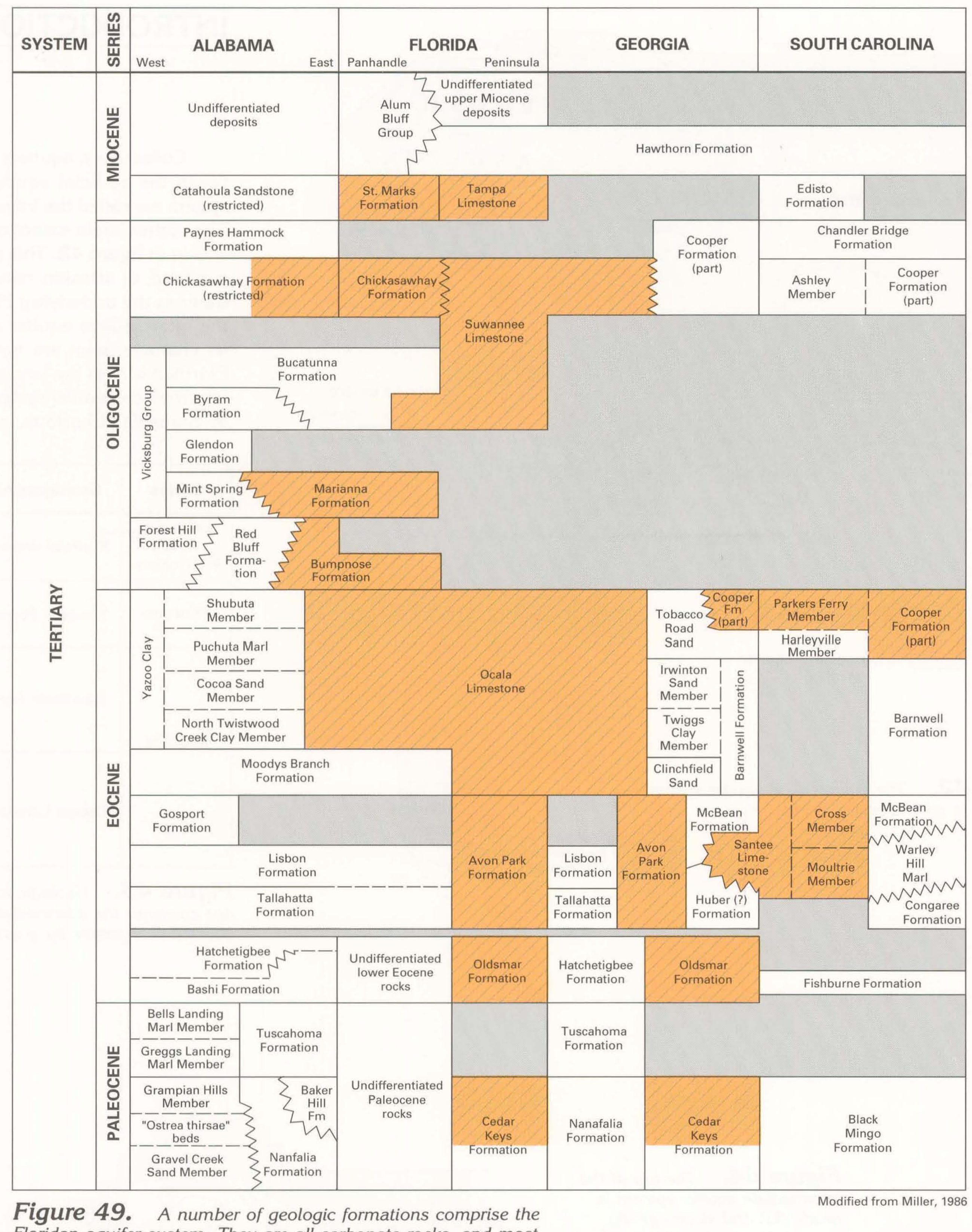


Figure 49. A number of geologic formations comprise the Floridan aquifer system. They are all carbonate rocks, and most of them are of Eocene age. In places, however, rocks as young as Miocene age and as old as Paleocene age are included in the system. The gray area represents missing rocks.

Aquifers and Confining Units

The Floridan aquifer system has been defined on the basis of permeability. In general, the system is at least 10 times more permeable than its bounding upper and lower confining units. The aquifer system is thick and widespread, and the rocks within it generally vary in permeability. In most places, as shown by the idealized layers in **figure 50**, the system can be divided into the Upper and Lower Floridan aquifers, separated by a less-permeable confining unit.

The geology and hydraulic properties of the Upper Floridan aquifer have been extensively studied, and this is the part of the system described by most reports. The Upper Floridan is highly permeable in most places and includes the Suwannee and Ocala Limestones, and the upper part of the Avon Park Formation. Where the Tampa Limestone is highly permeable, it also is included in the Upper Floridan. In most places, the Upper Floridan aquifer yields sufficient water supplies for most purposes, and there is no need to drill into the deeper Lower Floridan aquifer. The confining unit separating the Upper and Lower Floridan aquifers, informally called the middle confining unit (or semiconfining unit where it allows water to leak through it more easily), is present at different altitudes and consists of different rock types from place to place. The confining unit actually consists of seven separate, discrete units that are idealized into a single layer in **figure 50**. At some locations, the confining unit consists of clay; at others, it is a very fine-grained (micritic) limestone; at still other places, it is a dolomite with the pore spaces filled with anhydrite. Regardless of rock type, wherever the middle confining unit is present, it restricts the movement of ground water between the Upper and Lower Floridan aquifers.

The geologic characteristics and hydraulic properties of the Lower Floridan aquifer are not as well known as those of the Upper Floridan aquifer because the Lower Floridan is at greater depths, and, therefore, fewer borehole data are available. The Lower Floridan includes the lower part of the Avon Park Formation, the Oldsmar Limestone, and the upper part of the Cedar Keys Formation. Much of the Lower Floridan aquifer contains saltwater. Two important, highly permeable zones are present within the Lower Floridan. One of these is a partly cavernous zone in northeastern Florida and southeastern coastal Georgia, called the Fernandina permeable zone, named after the Fernandina Beach area of Nassau County, Fla. This zone is the source of a considerable volume of fresh to brackish water that moves upward through the middle semiconfining unit and ultimately reaches the Upper Floridan aquifer. The second zone is an extremely permeable cavernous zone in southeastern Florida, known as the Boulder Zone. This name is applied to the zone not because it consists of boulders, but because it is difficult to drill into, having the same rough, shaking, grabbing effect on the drill stem and drilling rig as boulders would. The Boulder Zone contains saltwater and is used as the receiving zone for treated sewage and other wastes disposed through injection wells in the Miami-Fort Lauderdale area. The zone is overlain in most places by a confining unit that prevents upward movement of the injected waste. The cavernous nature of the Fernandina permeable zone and the Boulder Zone was created by the vigorous circulation of ground water through the carbonate rocks in the geologic past, and does not result from the present ground-water flow system.

Thickness

The Floridan aquifer system generally thickens seaward from a thin edge near its northern limit. The variations in thickness of the aquifer system are shown in **figure 51**. The contours represent the combined thicknesses of the Upper and Lower Floridan aquifers, and the middle confining unit where it is present. Some of the large-scale features on the thickness map are related to geologic structures. For example, the thick areas in Glynn County, Ga., and in Gulf and Franklin Counties, Fla., coincide with two downwarped areas, the Southeast and Southwest Georgia embayments, respectively. In north-central peninsular Florida, the limestone units that comprise the aquifer system are thin over the upwarped Peninsular arch.

A series of small faults bounds downdropped, trough-like crustal blocks (grabens) in southern Georgia and southwestern Alabama (**fig. 51**). Within these grabens, respectively called the Gulf Trough and Mobile graben, clayey sediments have been downdropped opposite permeable limestone of the Floridan aquifer system. This juxtaposition creates a damming effect that restricts the flow of ground water across the grabens.

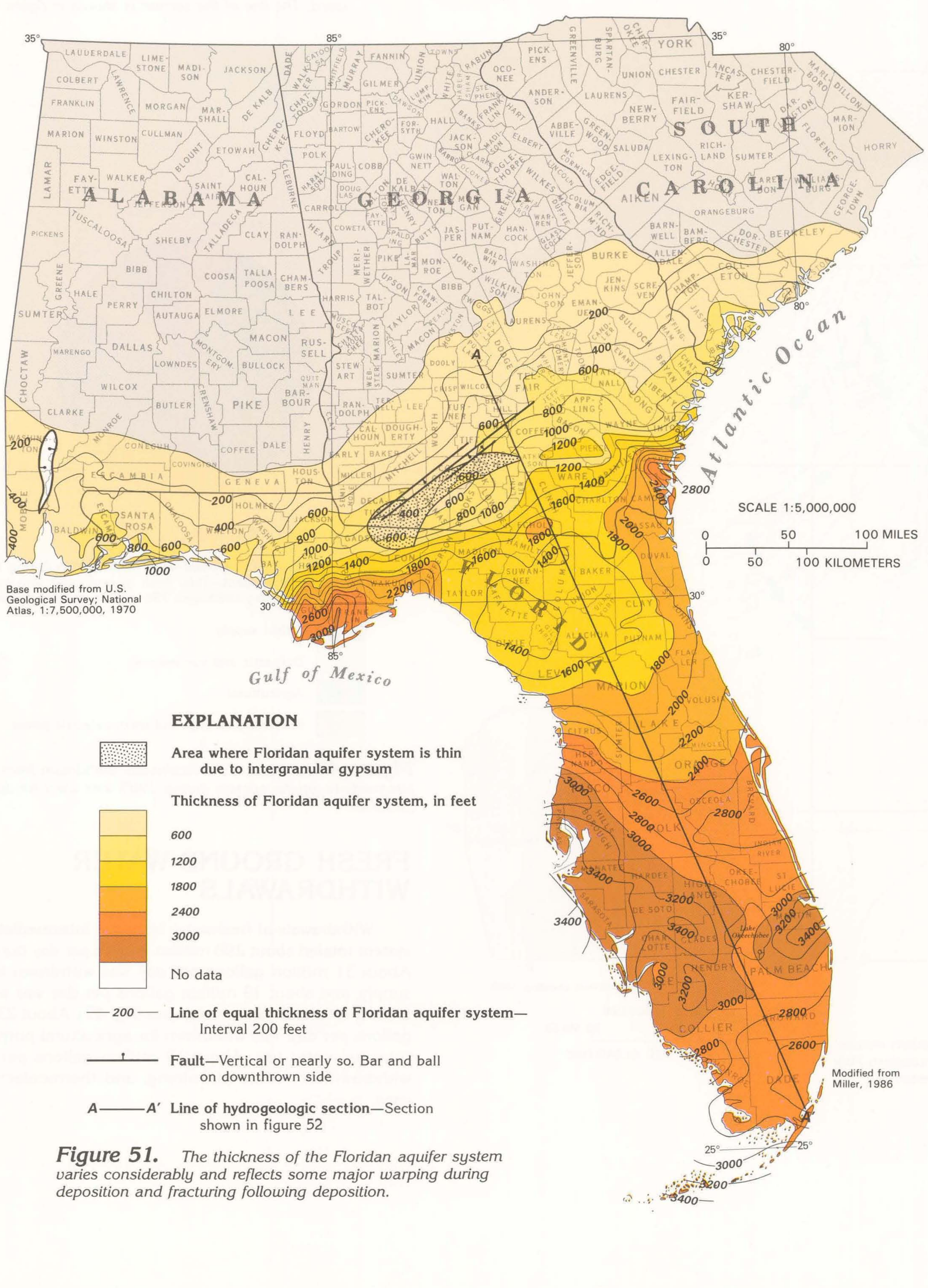


Figure 51. The thickness of the Floridan aquifer system varies considerably and reflects some major warping during deposition and fracturing following deposition.

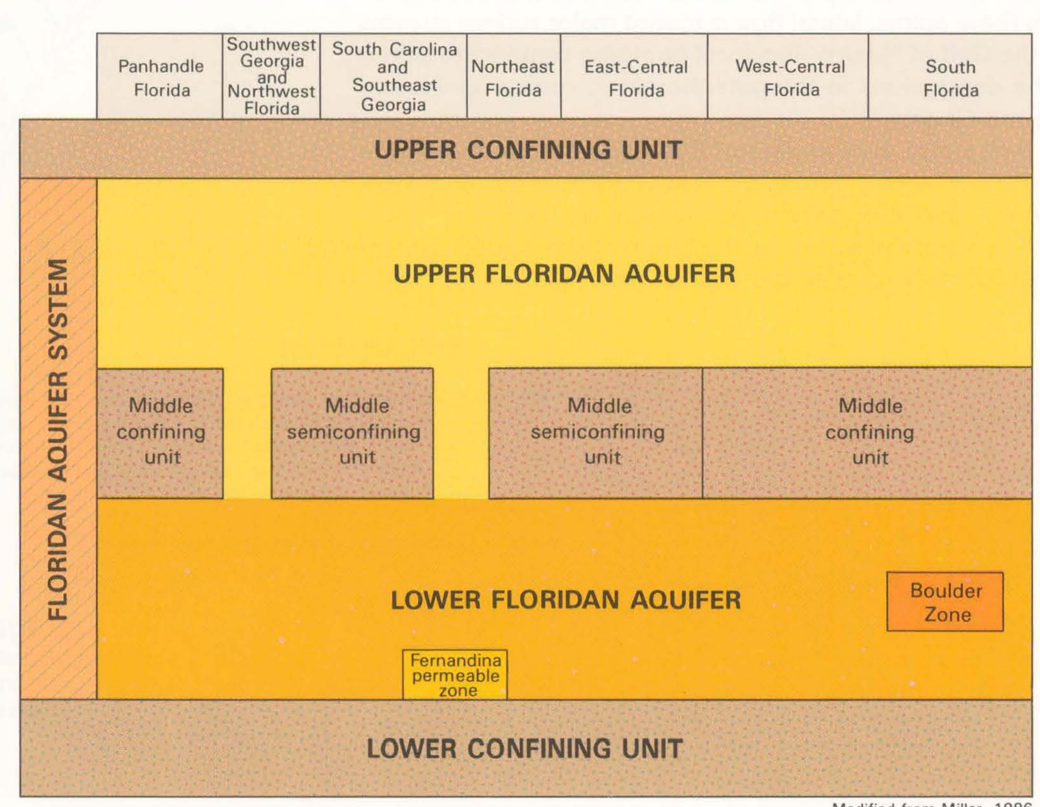
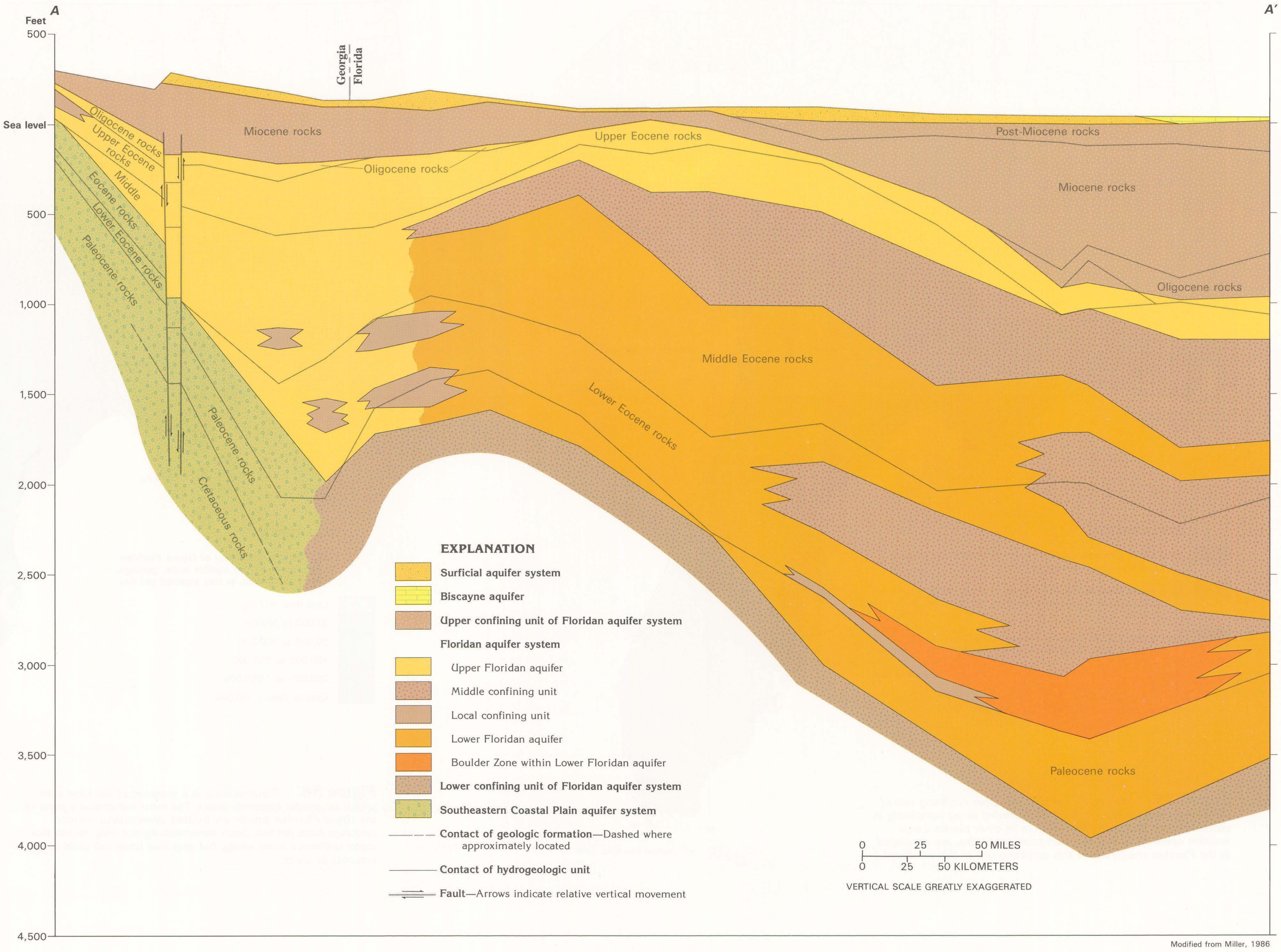


Figure 50. The Floridan aquifer system can generally be divided into an Upper Floridan aquifer and a Lower Floridan aquifer, separated by a less-permeable unit in most places and bounded above and below by confining units that are much less permeable. The Lower Floridan aquifer locally contains zones that are extremely permeable.

Figure 52. The Floridan aquifer system changes significantly from south-central Georgia to southern Florida. Aquifers and confining units in the system thicken and thin from well to well, and generally resemble complexly interfingering, lens-shaped bodies of rock. The line of the hydrogeologic section is shown in figure 51.



VARIATIONS IN THE FLORIDAN AQUIFER SYSTEM

The variations among and complexity of various parts of the Floridan aquifer system along a southeast-trending line from south-central Georgia to southern Florida are shown in **figure 52**. The most obvious variation is the substantial thickening of the aquifer system to the southeast. The left side of the figure, representing conditions in south-central Georgia, shows that the Floridan is only about 250 feet thick in this area. The right side of the figure, representing southern Florida, shows that the aquifer system is about 3,000 feet thick in places. The break in this gradual thickening, shown between the faults near the left side of the figure, is the graben known as the Gulf Trough. The downward movement of this crustal block produced a depression where a greater than average thickness of the clayey upper confining unit of the Floridan accumulated, thus restricting or partially damming the southward flow of ground water. This damming is reflected on maps of the potentiometric surface of the Floridan.

Another prominent feature shown in **figure 52** is the increasing complexity of the Floridan aquifer system toward the southeast. In south-central Georgia, where the system is thin, it contains only scattered, local confining units or none at all. In such areas, the system is hydraulically connected and generally functions as a single water-yielding unit, the Upper Floridan aquifer. Near the Georgia-Florida State line and southeastward, the aquifer system contains regionally-extensive middle confining units that separate it into two aquifers. In places, such as in southern Florida, two or three of these middle confining units are stacked. All of the regional and local confining units within the Floridan consist of carbonate rocks that are less permeable than the main, water-yielding parts of the aquifer system, and all of these confining units retard or partially restrict the movement of ground water in the system.

The Boulder Zone, a deeply-buried, cavernous zone filled with saltwater and used as a receiving zone for injected wastes, is shown near the right side of **figure 52** along with the confining bed that overlies it. Also shown in southern Florida is the Biscayne aquifer, which is separated from the Floridan aquifer system by a clayey confining unit that is about 1,000 feet thick in this area.

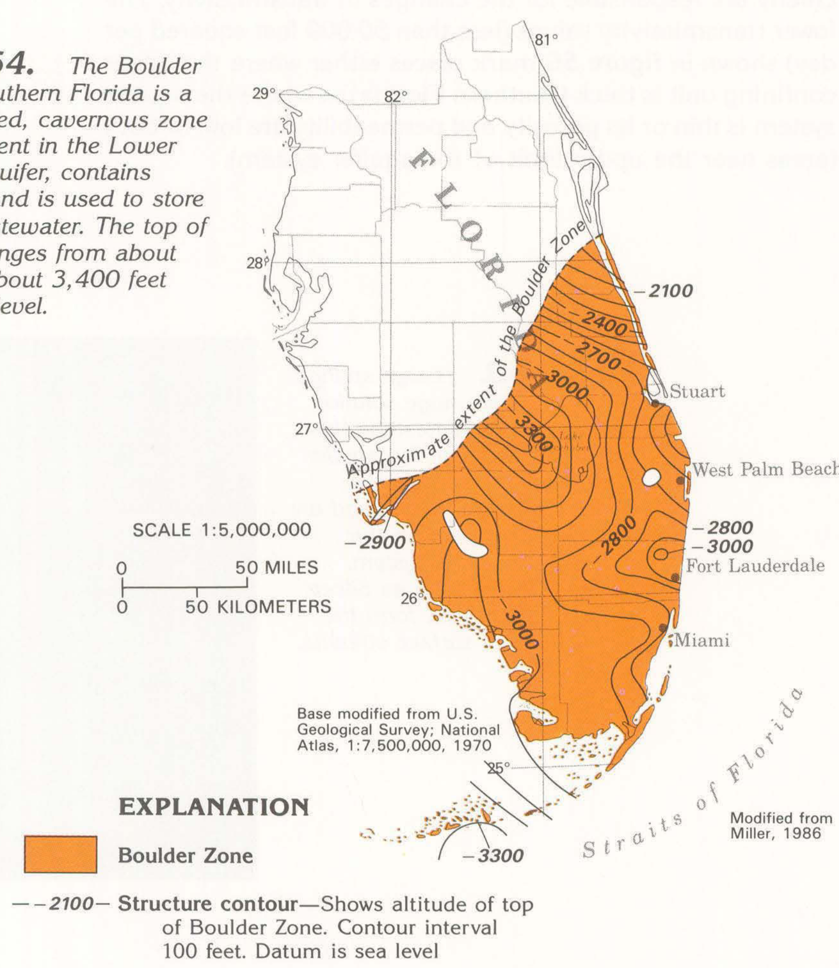
Near the left side of **figure 52**, the Southeastern Coastal Plain aquifer system is shown directly underlying the Floridan aquifer system. Throughout much of southern Georgia, these two aquifer systems are in direct contact, and ground water passes freely between them. The permeability of the aquifers in the Southeastern Coastal Plain aquifer system, however, is generally much lower than that of the aquifers in the Floridan aquifer system. The carbonate rocks of the Floridan either had substantial intergranular porosity when they were first formed, or pores in the rocks were enlarged by the dissolving action of circulating, slightly acidic ground water, or both (**fig. 53**). As these carbonate rocks grade northward into the predominantly clastic rocks of the Southeastern Coastal Plain system, the porosity and permeability of the rocks decreases and they yield less water than the more productive aquifers of the Floridan aquifer system.

Southeastward from about the Georgia-Florida State line, the confining unit that forms the base of the Floridan consists of beds of anhydrite in the Cedar Keys Formation of Paleocene age. These beds consist of calcium sulfate, which, when dissolved, contributes excessive concentrations of sulfate to the ground water. When the sulfate is chemically reduced to hydrogen sulfide, an objectionable, "rotten-egg" taste and odor are produced.

A. F. Randazzo, Gainesville, Florida

Figure 53. Slightly acidic ground water has dissolved part of the limestone of the Floridan aquifer system, creating large solution openings in the rock.

Figure 54. The Boulder Zone of southern Florida is a deeply buried, cavernous zone that is present in the Lower Floridan aquifer, contains saltwater, and is used to store treated wastewater. The top of the zone ranges from about 2,000 to about 3,400 feet below sea level.



BOULDER ZONE

The deeply buried zone of cavernous permeability, called the Boulder Zone, developed in fractured dolomite in the Lower Floridan aquifer, underlies a 13-county area in southern Florida (**fig. 54**). The Boulder Zone is not a single, simple, almost flatlying horizon of caves; rather, as shown by the contours in **figure 54**, its top is irregular and is as shallow as about 2,000 feet below sea level and as deep as about 3,400 feet below sea level. The zone is thought to represent caverns developed at several different levels and connected by vertical "pipes" or solution tubes similar to a modern cave system. A 90-foot high cavern reported in the subsurface in southern Florida probably is one of these vertical solution tubes rather than a large cavern.

The permeability of the Boulder Zone is extremely high because of its cavernous nature. This anomalous permeability, which prevents pressure buildup in injection wells, coupled with the fact that the Boulder Zone contains saltwater, makes it an ideal zone for receiving injected wastes. The Boulder Zone has been used for years to store vast quantities of treated sewage injected into it by Miami, Fort Lauderdale, West Palm Beach, and Stuart. Because the salinity and temperature of the water in the Boulder Zone are similar to those of modern seawater, the zone is thought to be connected to the Atlantic Ocean, possibly about 25 miles east of Miami where the sea floor is almost 2,800 feet deep along the Straits of Florida. The Boulder Zone is overlain by 500 to 1,000 feet of low-permeability limestone and dolomite, which retard the upward movement of injected fluids to shallower parts of the Floridan aquifer system that contain fresher although still brackish water.

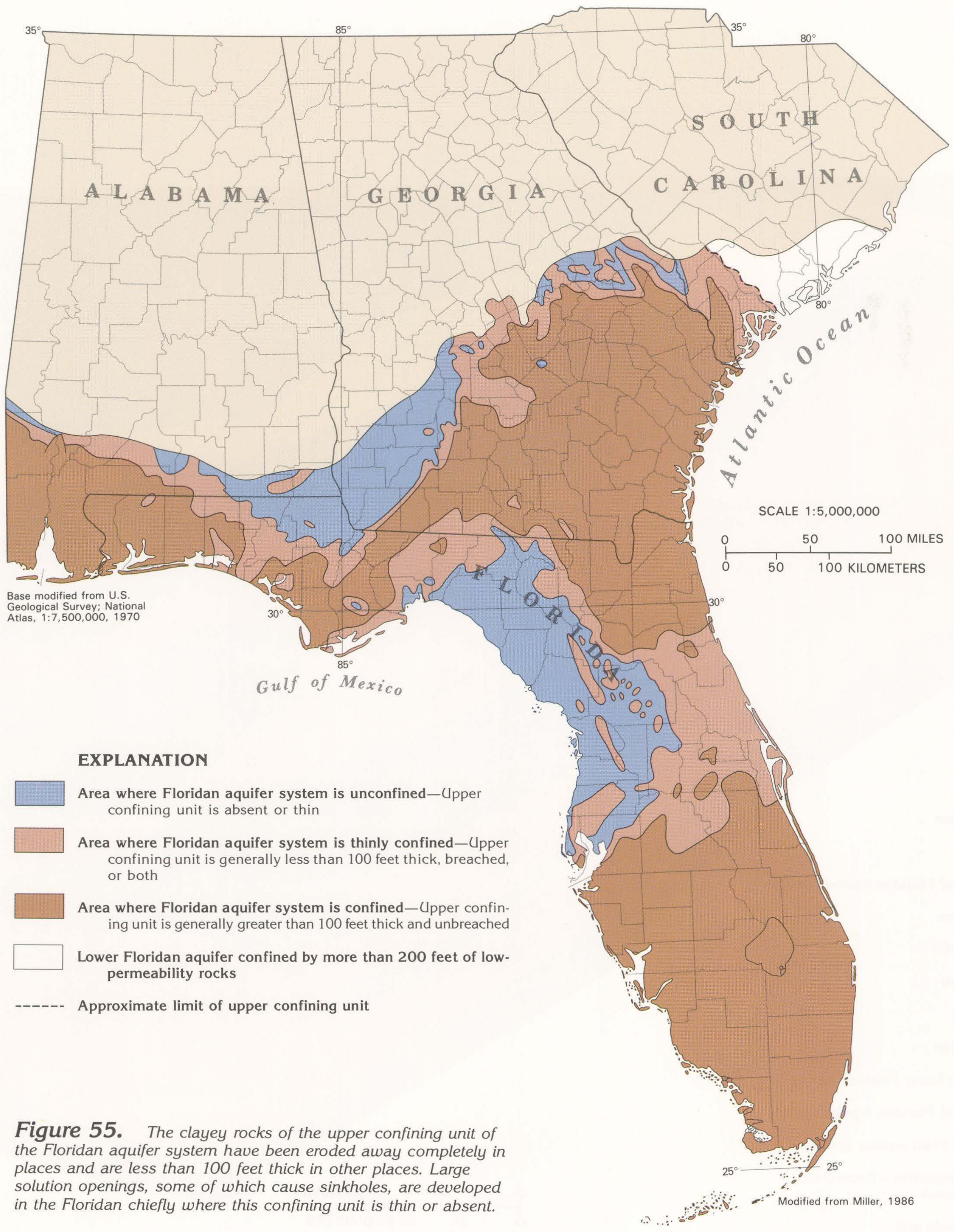


Figure 55. *The clayey rocks of the upper confining unit of the Floridan aquifer system have been eroded away completely in places and are less than 100 feet thick in other places. Large solution openings, some of which cause sinkholes, are developed in the Floridan chiefly where this confining unit is thin or absent.*

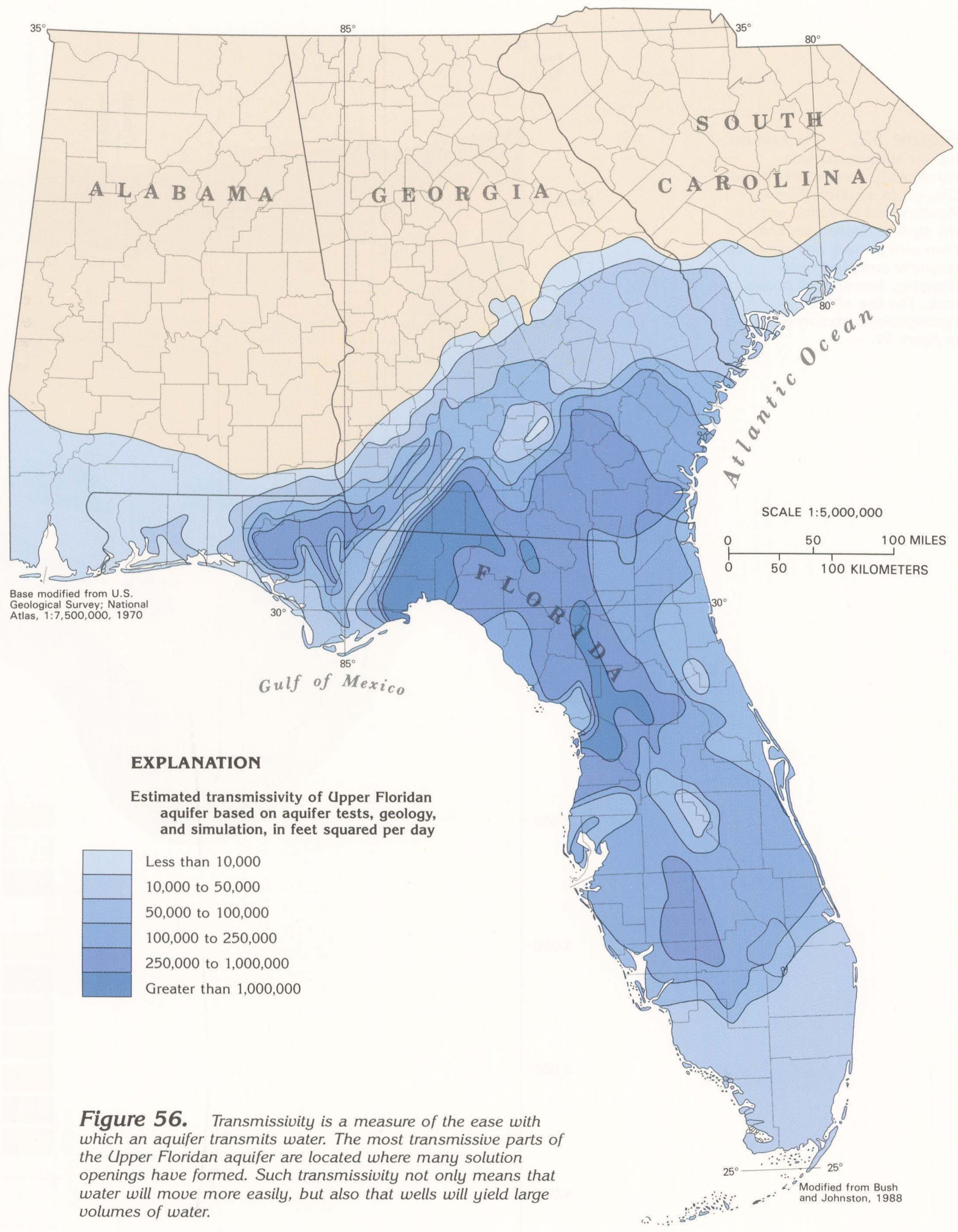


Figure 56. *Transmissivity is a measure of the ease with which an aquifer transmits water. The most transmissive parts of the Upper Floridan aquifer are located where many solution openings have formed. Such transmissivity not only means that water will move more easily, but also that wells will yield large volumes of water.*

EFFECTS OF CONFINEMENT

Effects on Dissolution

The carbonate rocks of the Floridan aquifer system are readily dissolved where they are exposed at land surface or are overlain by only a thin layer of confining material. Precipitation absorbs some carbon dioxide from the atmosphere as the precipitation falls and much more carbon dioxide from organic matter in soil as the precipitation percolates downward through the soil, thus forming weak carbonic acid. This acidic water dissolves the limestone and dolomite of the Floridan aquifer system, initially by enlarging pre-existing openings such as pores between grains of limestone or fractures (joints) in the rock. These small solution openings become larger as more of the acidic water moves through the aquifer; eventually the openings may be tens of feet in diameter. The end result of dissolution of carbonate rocks is a type of topography called karst, named for the Karst Plateau of Yugoslavia, that is characterized by caves, sinkholes, and other types of openings caused by dissolution, and by few surface streams.

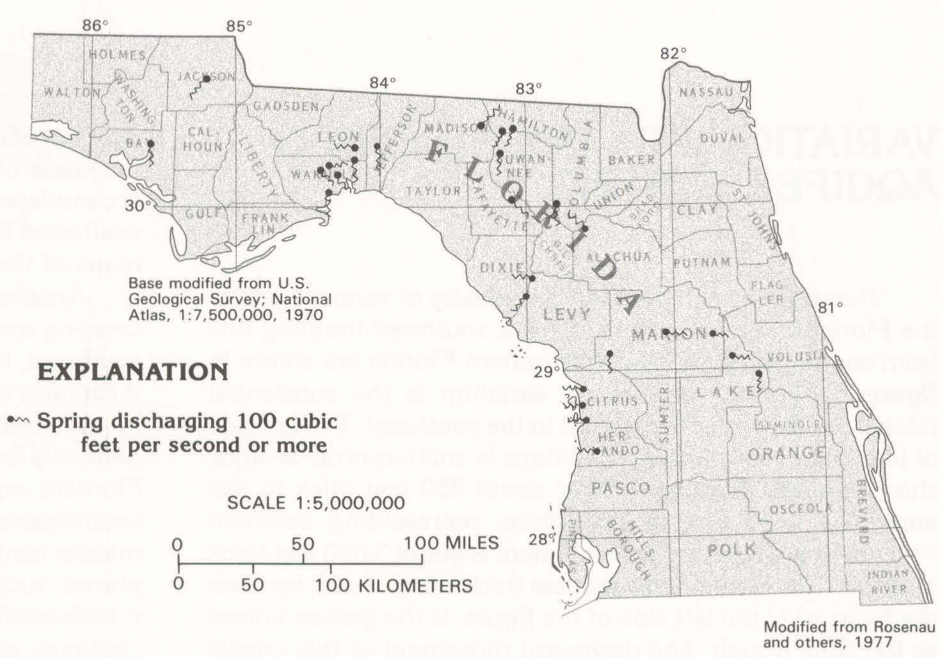
Dissolution of carbonate rocks is greatest where ground-water circulation is most vigorous. Water is able to enter, move through, and discharge from the Floridan aquifer system more readily and rapidly where it is unconfined or where the upper confining unit is thin. Such areas are shown in **figure 55**. In these unconfined areas, the aquifer is either exposed or, more commonly, is covered by a thin layer of sand or by clayey, residual soil. In adjacent areas, the Floridan is confined, but the upper confining unit is less than 100 feet thick (**fig. 55**). In these areas, sinkholes that locally breach the confining unit and allow precipitation to move quickly downward into the aquifer are common. Where the confining unit is thick and unbreached (**fig. 55**), there has been little dissolution of the aquifer system except in deeply buried zones of paleokarst, such as the Fernandina permeable zone of southeastern Georgia and northeastern Florida, and the Boulder Zone of southern Florida. However, these deeply buried zones chiefly formed in the geologic past, when the rocks comprising the zones were at or near the land surface, and are not the result of the modern ground-water flow system.

Effects on Transmissivity

The large-scale solution porosity that develops as a result of dissolution of the carbonate rocks in the Floridan aquifer system creates large conduits in some places that store and transmit ground water. These conduits, which include caves, solution channels, and sinkholes are like large-diameter pipes or channels in that they allow tremendous volumes of water to pass quickly through the aquifer with little resistance to flow. Transmissivity, or the capacity of an aquifer to transmit water, is one way of measuring the relative ease with which ground water moves. The greater the transmissivity, the more readily water is able to move through the aquifer.

The distribution of transmissivity values in the Upper Floridan aquifer, the best-known part of the Floridan aquifer system, is shown in **figure 56**. All of the area having a transmissivity greater than 1,000,000 feet squared per day and most of the area having transmissivity from 250,000 to 1,000,000 feet squared per day are where the upper confining unit of the Floridan aquifer system is less than 100 feet thick, or is absent (compare **figs. 55 and 56**). These areas are where large solution openings developed in the carbonate rocks allow water to be conveyed through the aquifer rapidly. Where the upper confining unit is greater than 100 feet thick, transmissivity values generally are lower and flow is not so rapid. Where the aquifer is more thickly confined and less affected by dissolution, variations in the original porosity of the aquifer chiefly are responsible for the changes in transmissivity. The lower transmissivity values (less than 50,000 feet squared per day) shown in **figure 56** mark places either where the upper confining unit is thick (southern Florida) or where the aquifer system is thin or its porosity and permeability are low, or both (areas near the updip limit of the aquifer system).

Figure 57. *Large springs issue from large solution openings developed where the upper confining unit of the Floridan aquifer system is thin or absent.*



Effects on Springs

Springs are places where ground water discharges through natural openings in the ground. Springs may vary greatly in the volume of water they discharge; some springs are small enough to be expressed only as seeps where water oozes slowly from the aquifer, whereas others are large enough to form the headwaters of large rivers. The water discharged by a spring may be from an aquifer that is unconfined (water-table conditions) or confined (artesian conditions). Springs issuing from an unconfined aquifer tend to have a small, extremely variable flow and are directly and quickly affected by variations in precipitation. These springs may cease flowing during periods of less than normal precipitation. In contrast, springs issuing from a confined aquifer have a more constant flow because their flow is supplied by a much greater replenishment area. Accordingly, such springs tend to be unaffected by variations in precipitation unless there is prolonged drought. Springs are common in areas of karst topography. Spring flow is controlled by the size of the replenishment area, the difference in altitude between the spring opening or openings and the water level in the aquifer, and the size of the opening or openings through which the springs issue. Factors that have lesser effects on spring flow include atmospheric-pressure changes, earth and oceanic tides, and pumping of wells located near springs.

Florida has 27 first-magnitude springs (springs with a flow of 100 cubic feet per second or more) out of a total of 78 in the entire Nation. The location of these springs is shown in **figure 57**. All of them issue from the Upper Floridan aquifer, and practically all of them are located in areas where the upper confining unit of the Floridan aquifer system either is less than 100 feet thick or is absent. The distribution of large springs discharging from the Floridan aquifer system, like the areas of greatest transmissivity within the aquifer system, is the direct result of dissolution of carbonate rocks, which results in the development of large conduits. Many of these caverns channel the ground water to the point where they are exposed at land surface and become the orifices of major springs (**fig. 58**).

Figure 58. *Large springs may issue from huge solution openings in the limestone that comprises the Floridan aquifer system. These springs are major discharge points, and are a dominant control on the ground-water flow system. Some of them, such as Silver Spring shown here, form the headwaters of surface streams.*

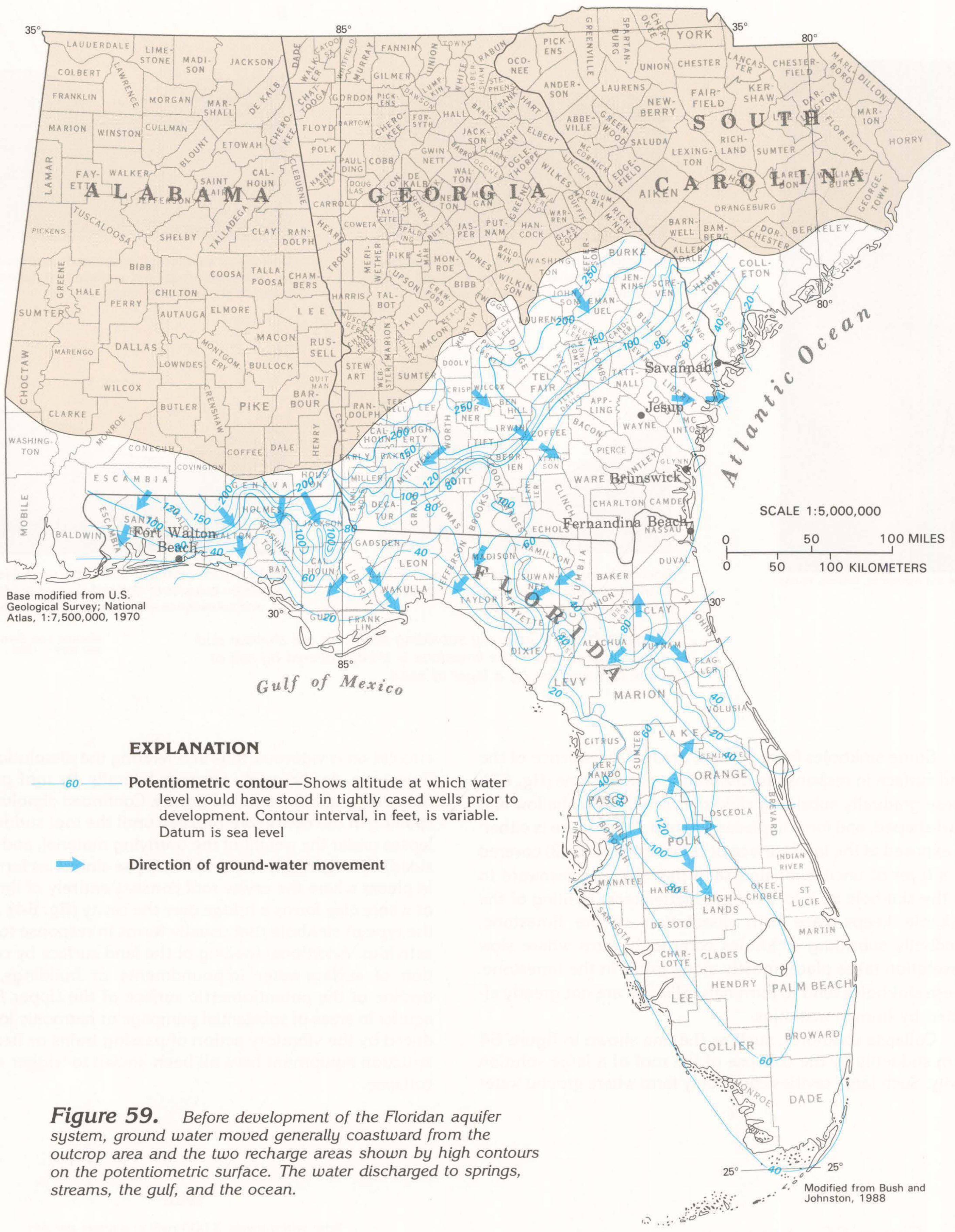


Figure 59. Before development of the Floridan aquifer system, ground water moved generally coastward from the outcrop area and the two recharge areas shown by high contours on the potentiometric surface. The water discharged to springs, streams, the gulf, and the ocean.

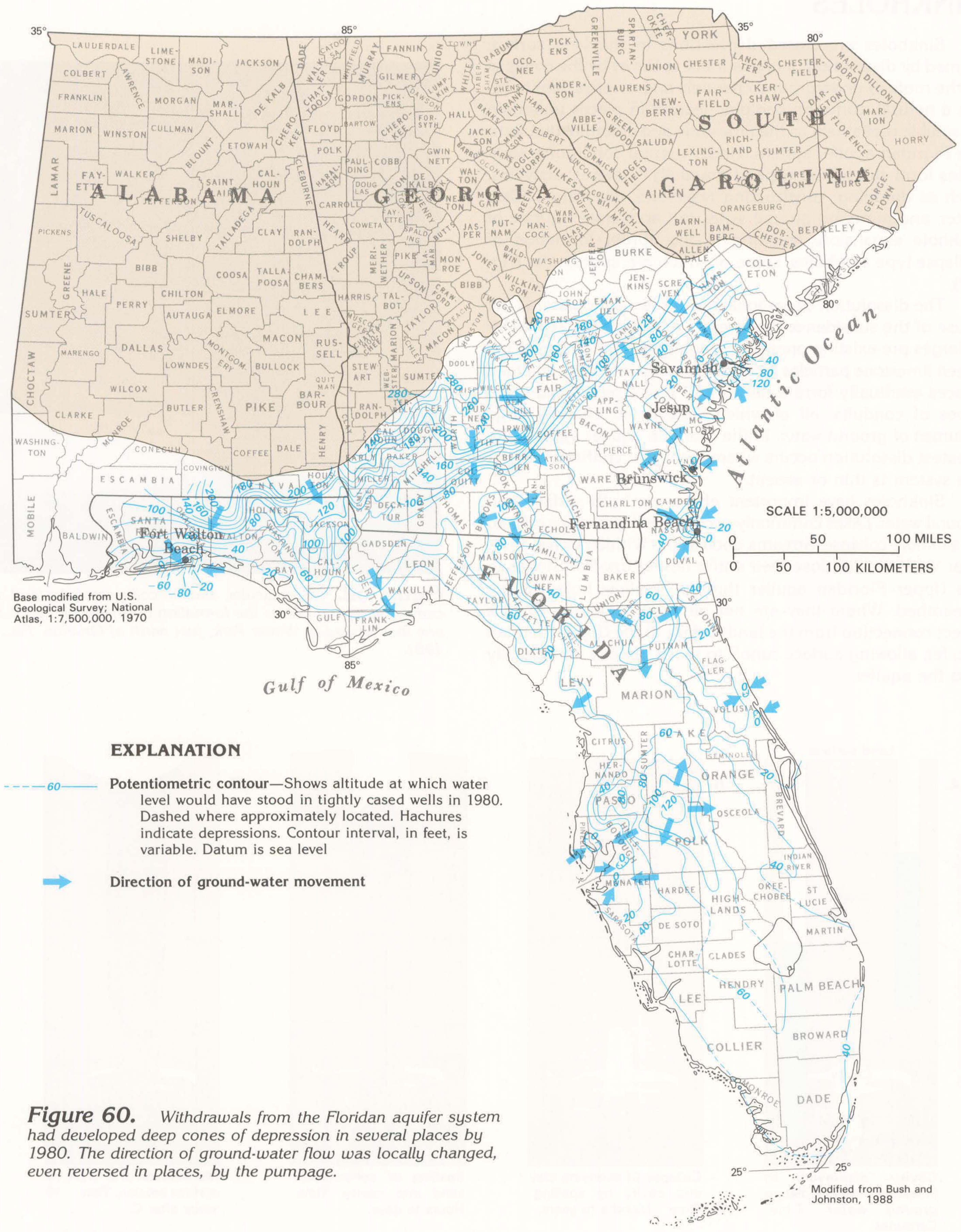


Figure 60. Withdrawals from the Floridan aquifer system had developed deep cones of depression in several places by 1980. The direction of ground-water flow was locally changed, even reversed in places, by the pumpage.

GROUND-WATER FLOW

The existence of a regional ground-water flow system in the Floridan aquifer system was first recognized in peninsular Florida in the 1930's and, by the 1940's, this system was known to extend into Georgia and South Carolina. The major features of this ground-water flow system can be illustrated by a map of the potentiometric surface of the Upper Floridan aquifer. The contours shown in **figure 59** represent the altitude and configuration of the potentiometric surface of the Upper Floridan aquifer before development (that is, the condition before substantial withdrawals from the aquifer began). The altitude and configuration of the potentiometric surface in 1980, when withdrawals had changed the configuration of the surface considerably, is shown in **figure 60**. In both figures, the contours represent lines of equal altitude of the potentiometric surface or water level. The arrows superimposed on the maps show the direction of ground-water movement, which generally is perpendicular to the contours.

Water in the Upper Floridan aquifer moves from high to low areas on the potentiometric surface. The highest areas on the Upper Floridan's potentiometric surface are located: (1) in a band where the aquifer is exposed at the land surface near its landward, updip limit and (2) in an area in central peninsular Florida (**figs. 59 and 60**). Water moves coastward from the outcrop area of the aquifer and outward in all directions from the potentiometric high in central Florida. Although recharge to the aquifer takes place throughout more than one-half of its area, recharge tends to be concentrated in outcrop areas and at potentiometric highs. Rates of recharge vary from less than 1 inch to more than 20 inches per year, depending on local geologic and hydrologic conditions. For example, in Lowndes County in south-central Georgia, the aquifer is hydraulically connected to the Withlacoochee River through swallow holes (sinkholes that develop in a bed of a stream) in the streambed and captures much or all of the streamflow during dry seasons. Recharge here is estimated to be between 10 and 20 inches per year. In contrast, little recharge (an estimated 1 to 5 inches per year) takes place at the potentiometric high in central peninsular Florida.

Before development, nearly 90 percent of the discharge from the Floridan aquifer system was to springs and streams. Upward leakage across confining units, especially in coastal areas, accounted for slightly more than 10 percent of the discharge. Discharge to offshore springs was common on both the gulf and ocean sides of the northern part of peninsular Florida where onshore hydraulic heads were 10 feet or less. Contours that extend offshore from coastal Georgia and adjacent northeastern Florida are based on freshwater heads measured during recent test drilling.

The degree of confinement of the Floridan aquifer system is the characteristic that most greatly affects the distribution of recharge and discharge, and is reflected in the character of the potentiometric surface. Where the system is unconfined or the upper confining unit is thin, there is substantial hydraulic connection between the aquifer and surface drainage. In such areas, the potentiometric surface is irregular, complex, and has many closed highs and lows. Contours are commonly distorted where they cross surface streams or where there are groups of springs. In areas of thick confinement, the aquifer is not affected by surface streams because of the intervening confining unit. Smooth contours are, accordingly, associated with confined conditions. Examples of such places are southeastern Georgia and South Carolina, western panhandle Florida, and southern peninsular Florida.

The band of closely spaced contours trending northeast across south-central Georgia (**fig. 59**) is located just upgradient from the Gulf Trough, a graben filled with a greater than average thickness of the clayey upper confining unit. Faults bounding this graben extend through the Floridan aquifer system and have allowed confining-unit material to be downdropped opposite the aquifer, thus impeding ground-water flow. This damming effect is represented by the closely spaced potentiometric contours.

The effect of ground-water withdrawals on the potentiometric surface of the Upper Floridan aquifer is illustrated by a map of that surface as it existed in 1980 (**fig. 60**). The major features of the potentiometric surface are the same as those of the predevelopment surface. That is, the direction of flow in South Carolina and Georgia was still east or southeast from outcrop areas to the Atlantic Ocean and Florida. In peninsular Florida, the general flow direction was still toward the gulf and ocean. However, the effect of withdrawals is shown by deep cones of depression at Savannah, Jesup, and Brunswick, Ga., and at Fernandina Beach and Fort Walton Beach, Fla. Also, hydraulic heads have been lowered 30 feet or more throughout a five-county area southeast of Tampa Bay on the west coast of Florida as a result of withdrawals for irrigation and industrial needs. Regional declines of more than 10 feet have occurred in three broad areas surrounding pumping centers (**fig. 61**): (1) southeastern Georgia and adjacent parts of northeastern Florida and southern South Carolina; (2) west-central peninsular Florida; and (3) western panhandle Florida. Predevelopment potentiometric gradients have been locally reversed in some coastal areas, creating the potential for encroachment of saltwater from the gulf or ocean or from deep parts of the aquifer that contain saltwater. However, saltwater encroachment was limited to a few localized areas as of 1986.

The major characteristics of the predevelopment flow system have not been greatly altered by ground-water development. The dominant form of discharge remains springflow and discharge to streams. The withdrawal of more than 3 billion gallons per day of freshwater during the early 1980's accounts for less than 20 percent of the total discharge of the Floridan aquifer system.

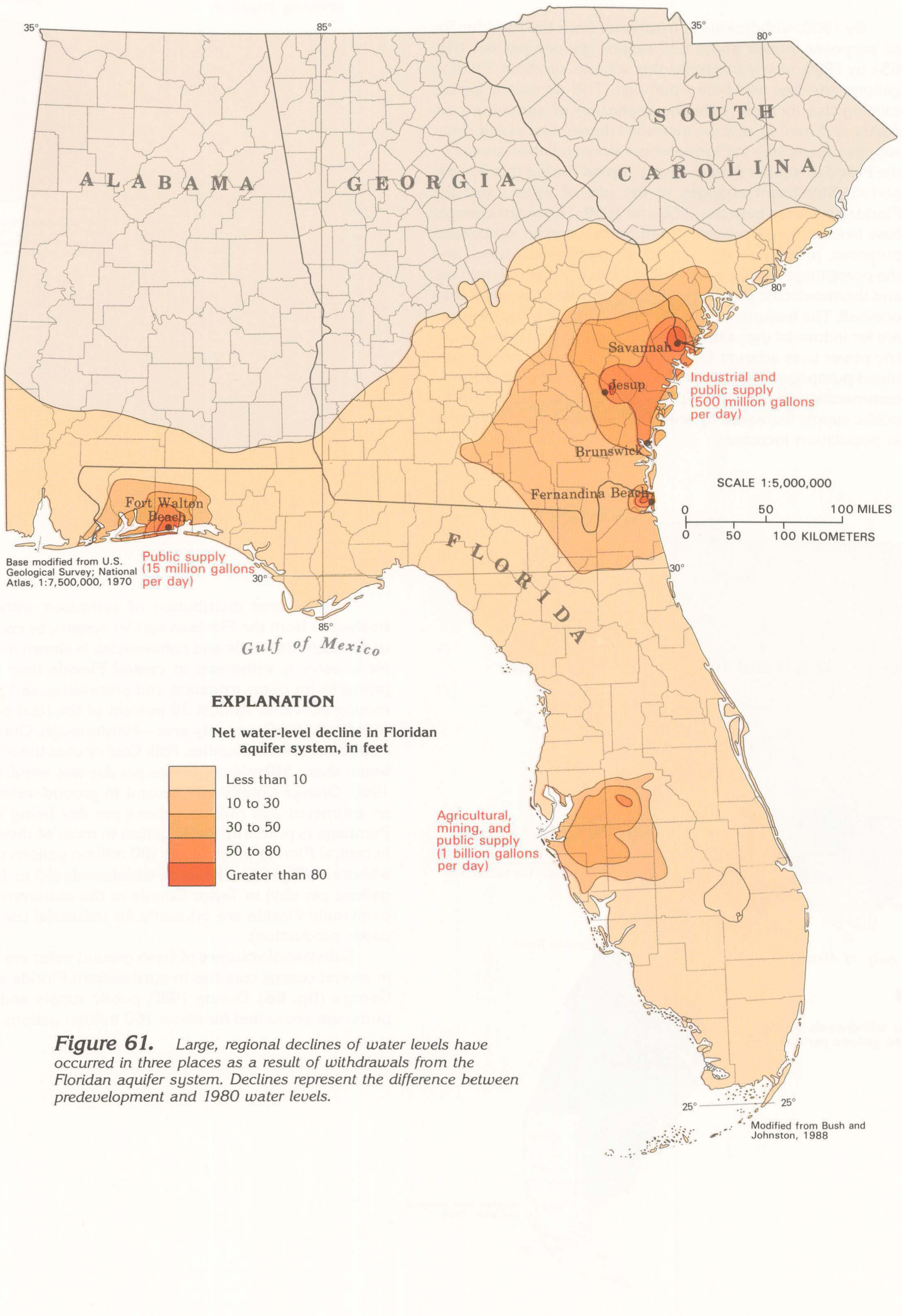


Figure 61. Large, regional declines of water levels have occurred in three places as a result of withdrawals from the Floridan aquifer system. Declines represent the difference between predevelopment and 1980 water levels.

SINKHOLES

Sinkholes are closed depressions in the land surface formed by dissolution of near-surface rocks or by the collapse of the roofs of underground channels and caverns. Sinkholes are a natural, common geologic feature in places underlain by soluble rocks such as the limestone and dolomite that form the Floridan aquifer system. Under natural conditions, sinkholes form slowly and expand gradually. However, activities, such as dredging, constructing reservoirs, diverting surface water, and pumping ground water can accelerate the rate of sinkhole expansion, resulting in the abrupt formation of collapse-type sinkholes, some of which are spectacular (**fig. 62**).

The dissolution of carbonate rocks by acidic water is the cause of the subsidence that creates all sinkholes. The water enlarges pre-existing openings ranging from pore spaces between limestone particles to fractures in the rock. The enlarged spaces eventually form a network of caves, pipes, and other types of conduits, all of which collect and channel large volumes of ground water. In the Floridan aquifer system, the greatest dissolution occurs where the upper confining unit of the system is thin or absent.

Sinkholes have important effects on both surface and ground water. Lakes commonly occupy the depressions created by sinkhole collapse. Streams, such as the Withlacoochee River near Valdosta, Ga., lose their entire flow at low-flow stages to the Upper Floridan aquifer through swallow holes in the streambed. Where they are not plugged, sinkholes form a direct connection from the land surface to the Upper Floridan aquifer, allowing surface runoff to move directly and quickly into the aquifer.

Jamal and Associates, Orlando, Florida

Figure 62. Spectacular, sudden collapse of the land surface commonly accompanies the formation of a sinkhole, such as this one that formed at Winter Park, just north of Orlando, Fla., in 1981.

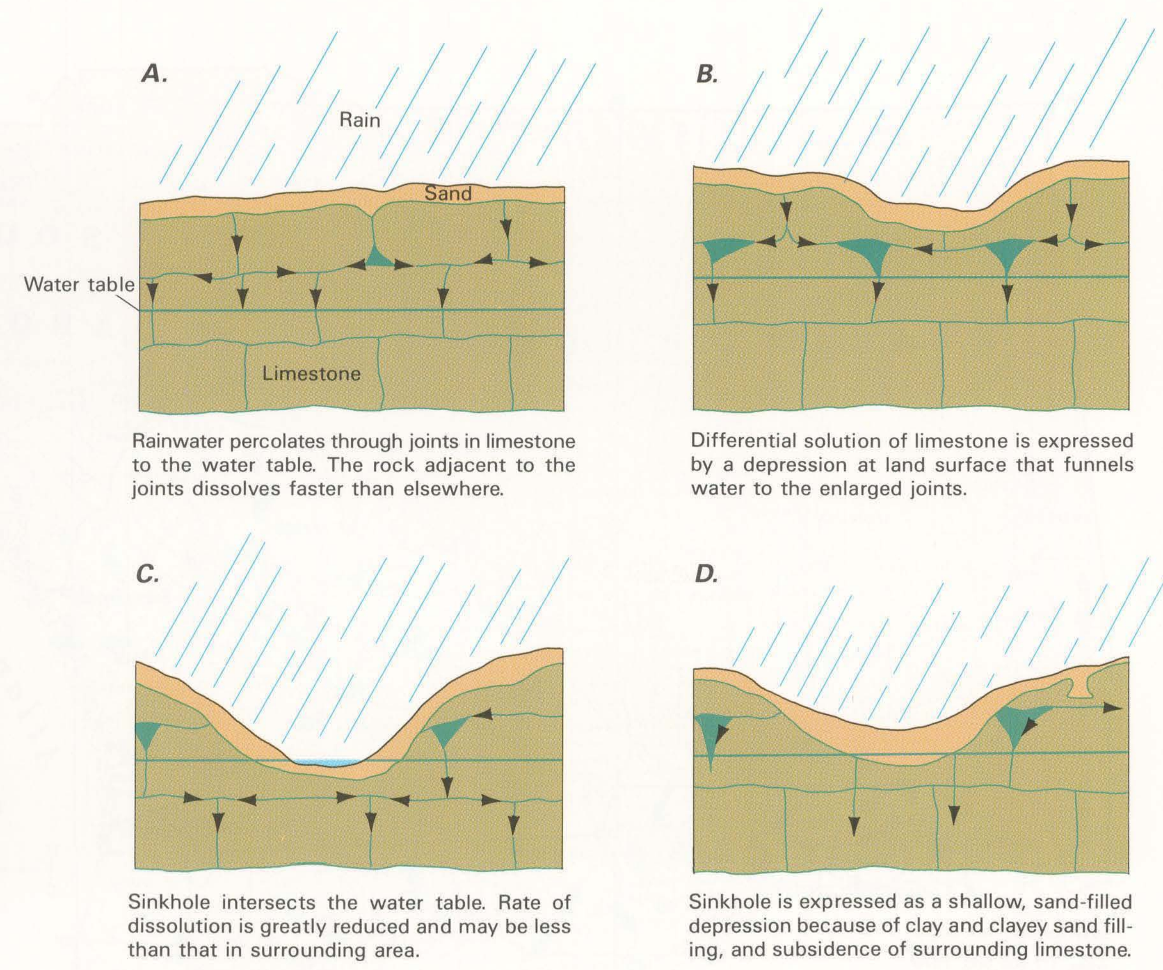
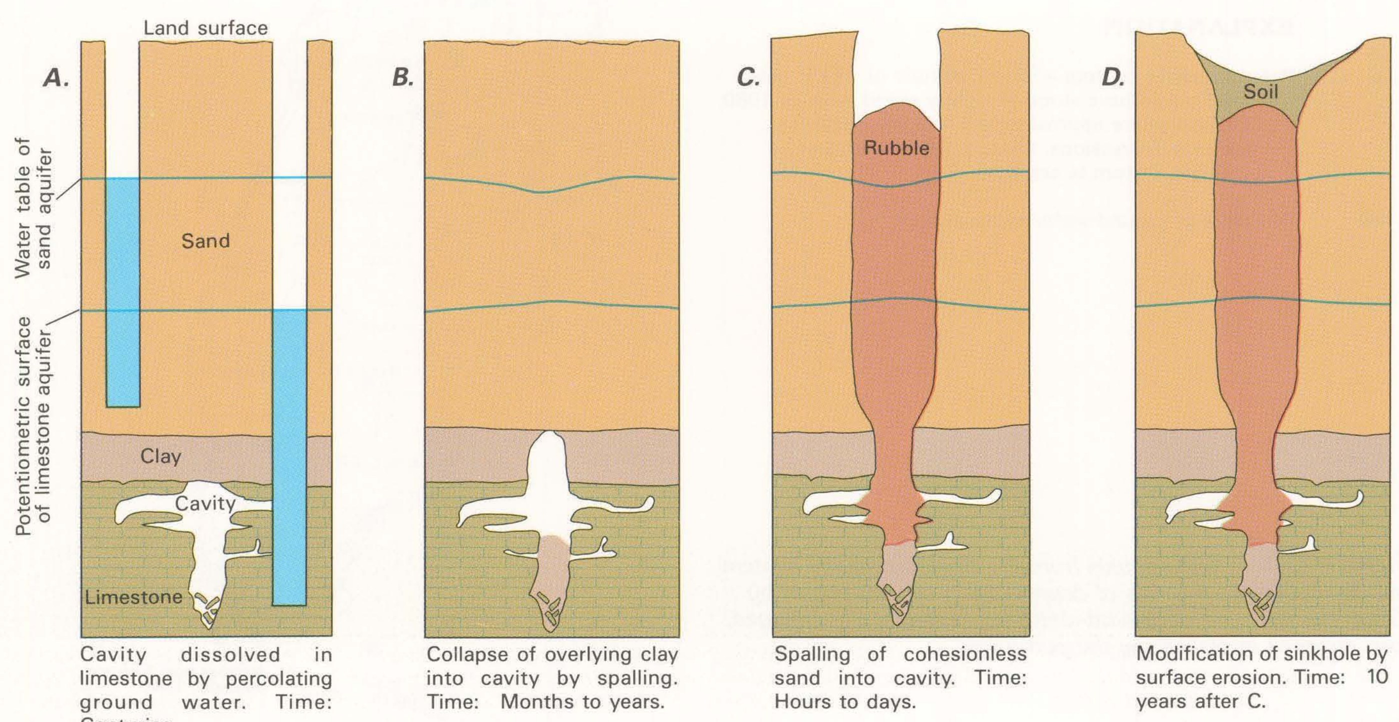


Figure 63. Gradually subsiding sinkholes are shallow and form at places where the limestone is thinly covered by soil or where it is overlain by a layer of sand.

Modified from Sinclair and others, 1985



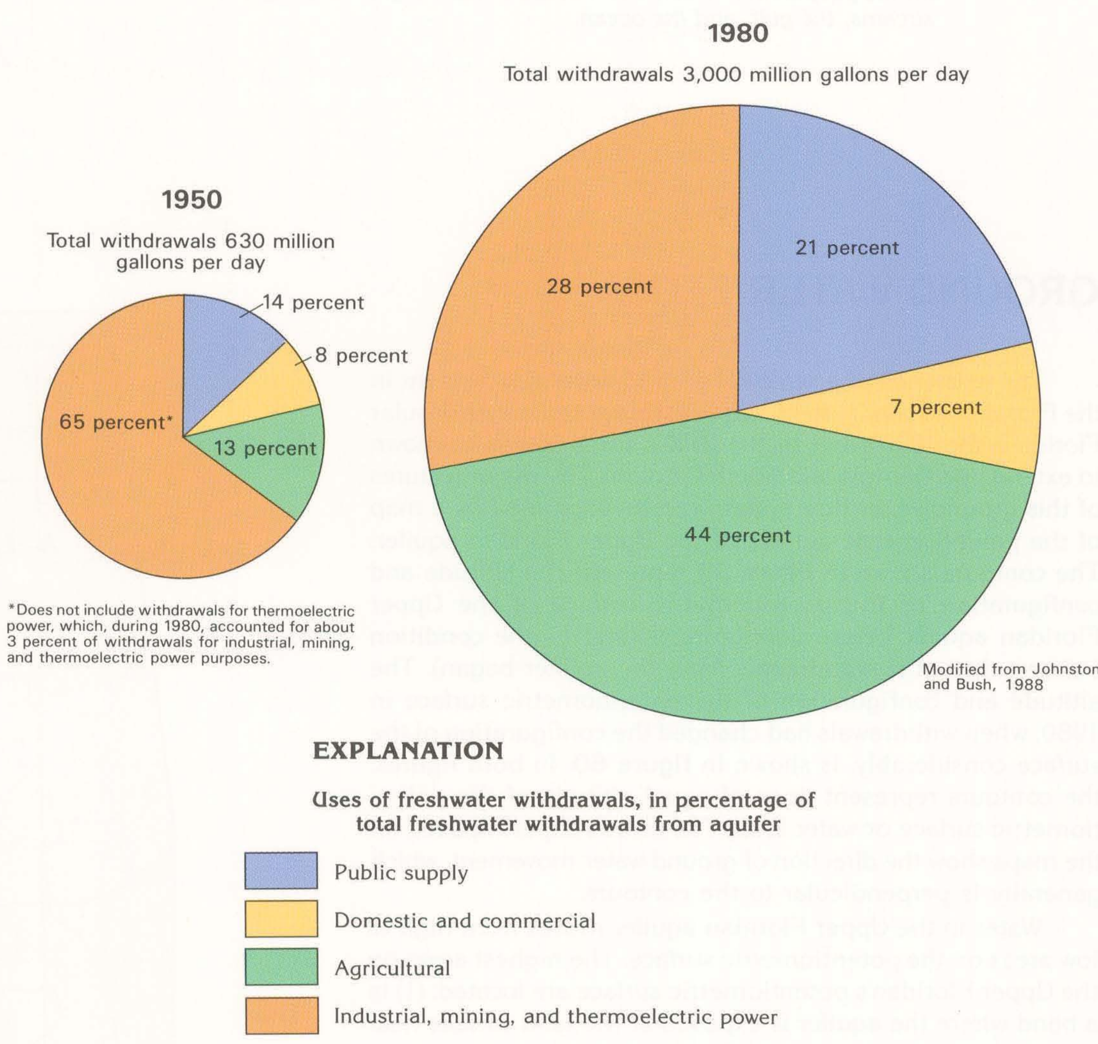
Modified from Beck and Sinclair, 1986

Figure 64. Collapse sinkholes form suddenly as a cavity roof collapses after dissolution of the limestone beneath the roof. The roof may consist either of clay, as shown here, or of limestone.

Some sinkholes form by slow, gradual subsidence of the land surface in response to dissolution of limestone (**fig. 63**). These gradually subsiding sinkholes are usually shallow and bowl-shaped, and form in places where the limestone is either: (1) exposed at the land surface or thinly covered or (2) covered by a layer of unconsolidated sand that slumps downward to fill the sinkhole as it forms. In the latter case, infilling of the sinkhole keeps pace with dissolution of the limestone. Gradually subsiding sinkholes commonly form where slow dissolution takes place, mostly along joints in the limestone. These sinkholes tend to form naturally and are not greatly affected by human activities.

Collapse sinkholes, such as the one shown in **figure 64** form suddenly by the collapse of the roof of a large solution cavity. Such large cavities commonly form where ground water circulation is vigorous, thus accelerating the dissolution of the limestone. As the cavity expands laterally, its roof gradually flakes off under the effect of gravity. Continued dissolution and spalling of the cavity roof proceed until the roof suddenly collapses under the weight of the overlying material, and a steep-sided, circular sinkhole forms. Collapse sinkholes form either in places where the cavity roof consists entirely of limestone, or where clay forms a bridge over the cavity (**fig. 64**); they are the type of sinkhole that usually forms in response to human activities. Additional loading of the land surface by construction of surface-water impoundments or buildings, abrupt decline of the potentiometric surface of the Upper Floridan aquifer in areas of substantial pumpage or harmonic loads produced by the vibratory action of passing trains or heavy construction equipment have all been known to trigger sinkhole collapse.

Figure 65. Withdrawals of freshwater from the Floridan aquifer system increased almost five-fold between 1950 and 1980. The most marked increases were for public supply and agricultural purposes, primarily irrigation.



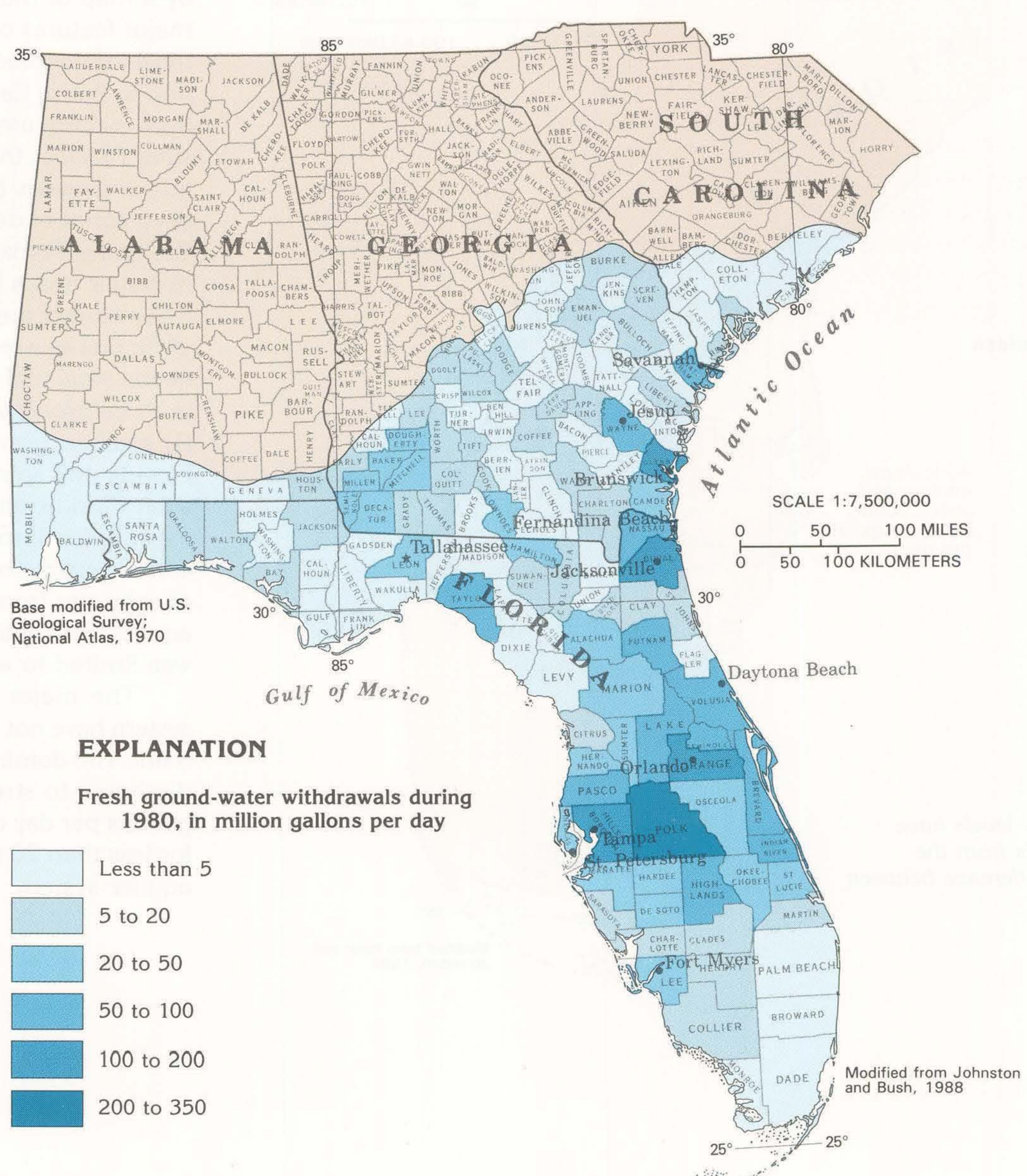
Modified from Johnston and Bush, 1988

GROUND-WATER DEVELOPMENT

Ground-water development of the Floridan aquifer system began in the 1880's when Savannah, Ga., and Jacksonville, Fla., first constructed wells for municipal supply. By the early 1900's, several other cities, including Brunswick, Ga., and Daytona Beach, Fernandina Beach, Fort Meyers, Orlando, St. Petersburg, Tallahassee, and Tampa, Fla., were obtaining water supplies from the Floridan. Many of these early wells flowed because hydraulic heads initially were high. However, increased use soon caused the hydraulic head in the Upper Floridan aquifer to decline until installation of pumps and deepening of supply wells became necessary. Starting in the 1930's, industrial withdrawals from the Floridan became an important factor as pulp- and paper-processing plants in southeastern Georgia and northeastern Florida, and phosphate mining and citrus-processing operations in west-central Florida, began to withdraw large volumes of ground water.

By 1950, withdrawals of freshwater from the Floridan for all purposes totaled about 630 million gallons per day (**fig. 65**); by 1980, nearly five times this volume, or about 3 billion gallons per day, was being pumped. The dominant factors causing this increase were the expansion of agriculture, industry, and mining, and the increased demand for public water supplies, especially in Florida where the population served by the Floridan aquifer system nearly tripled during this 30-year period. Significant changes in the use of water from the Floridan occurred between 1950 and 1980. The major changes have been in the percentage of withdrawal used for agricultural purposes, primarily irrigation, which more than tripled, and the percentage withdrawn for self-supplied industrial, mining, and thermoelectric power uses, which decreased by more than one-half. The majority of the withdrawals in the latter category are for industrial use; withdrawals for mining and thermoelectric power uses account for only about 3 percent of the combined pumpage. The percentage withdrawn for domestic and commercial uses remained practically the same, but that for public supply increased by one-third, directly reflecting trends in population increases.

Figure 66. The distribution of freshwater withdrawals from the Floridan aquifer system mostly reflects the water needs of population centers. However, irrigation and phosphate-mining activities account for much of the freshwater withdrawals in central peninsular Florida.



The regional distribution of estimated withdrawals of freshwater from the Floridan aquifer system, by county, for all uses except domestic and commercial, is shown in **figure 66**. More water is withdrawn in central Florida than elsewhere, primarily for citrus irrigation and processing, and phosphate-mining activities. Almost 30 percent of the total pumpage is withdrawn in a five-county area—Hillsborough, Orange, Pasco, Pinellas, and Polk Counties. Polk County uses the most ground water; about 310 million gallons per day was withdrawn during 1980. Orange County was second in ground-water use, with an estimated 200 million gallons per day being withdrawn. Pumpage is primarily for irrigation in most of those counties in central Florida where 20 to 100 million gallons per day are withdrawn (**fig. 66**). The large withdrawals (50 to 100 million gallons per day) in Taylor County in the easternmost part of panhandle Florida are primarily for industrial use (pulp and paper production).

Substantial volumes of fresh ground water are withdrawn in several coastal counties in northeastern Florida and coastal Georgia (**fig. 66**). During 1980, public supply and industrial pumpage accounted for about 160 million gallons per day in the Duval-Nassau County, Fla., area (Jacksonville and Fernandina Beach); about 100 million gallons per day in Glynn County, Ga., (Brunswick); and about 75 million gallons per day in both Wayne County (Jesup) and Chatham County (Savannah), Ga. In Georgia, the greatest withdrawals for agricultural purposes, primarily irrigation, during 1980 were in a 15-county area known as the Dougherty Plain in southwestern Georgia, where a total of about 210 million gallons per day was withdrawn.

Uncontrolled flowing wells in many counties in central and southern Florida are a commonly overlooked but important source of discharge from the Floridan aquifer system. Where hydraulic heads are high, some of these wells discharge at land surface; others discharge into shallow zones in the Floridan or overlying aquifers through deteriorated well casings or open boreholes. In 1978, there were as many as 15,000 uncontrolled flowing wells in Florida that discharged an estimated 790 million gallons per day—almost one-third as much as was pumped from the aquifer system during 1980. Many of these wells were subsequently located and plugged under an ongoing program conducted by State and local governmental agencies.

INJECTION WELLS

Parts of the Lower Floridan aquifer that contain saltwater are locally used as receiving zones for industrial and municipal wastes disposed of through injection wells in Florida. The location of injection-well sites in Florida that were operating as of January 1988 is shown in **figure 67**. About 208 million gallons per day of wastes are injected into these wells; about 97 percent of this volume is municipal waste. Some of the wells, such as those in Polk County, Fla., are used to inject wastes into permeable rocks below the Floridan aquifer system because the entire Floridan contains freshwater in Polk County. The majority of injection wells, however, are completed in the deeper parts of the Floridan that contain saltwater.

In central Florida, particularly in the Orlando area (Orange County), drainage wells have been used since the early 1900's to dispose of storm runoff into the Upper Floridan aquifer (**fig. 67**). Public water-supply wells in the Orlando area, accordingly, are drilled into the Lower Floridan aquifer, which is separated from the Upper Floridan aquifer by a confining unit. There is no evidence to date that the drainage wells have contaminated the Lower Floridan aquifer to any great extent, even though they provide an estimated 30 to 50 million gallons per day of recharge to the system.

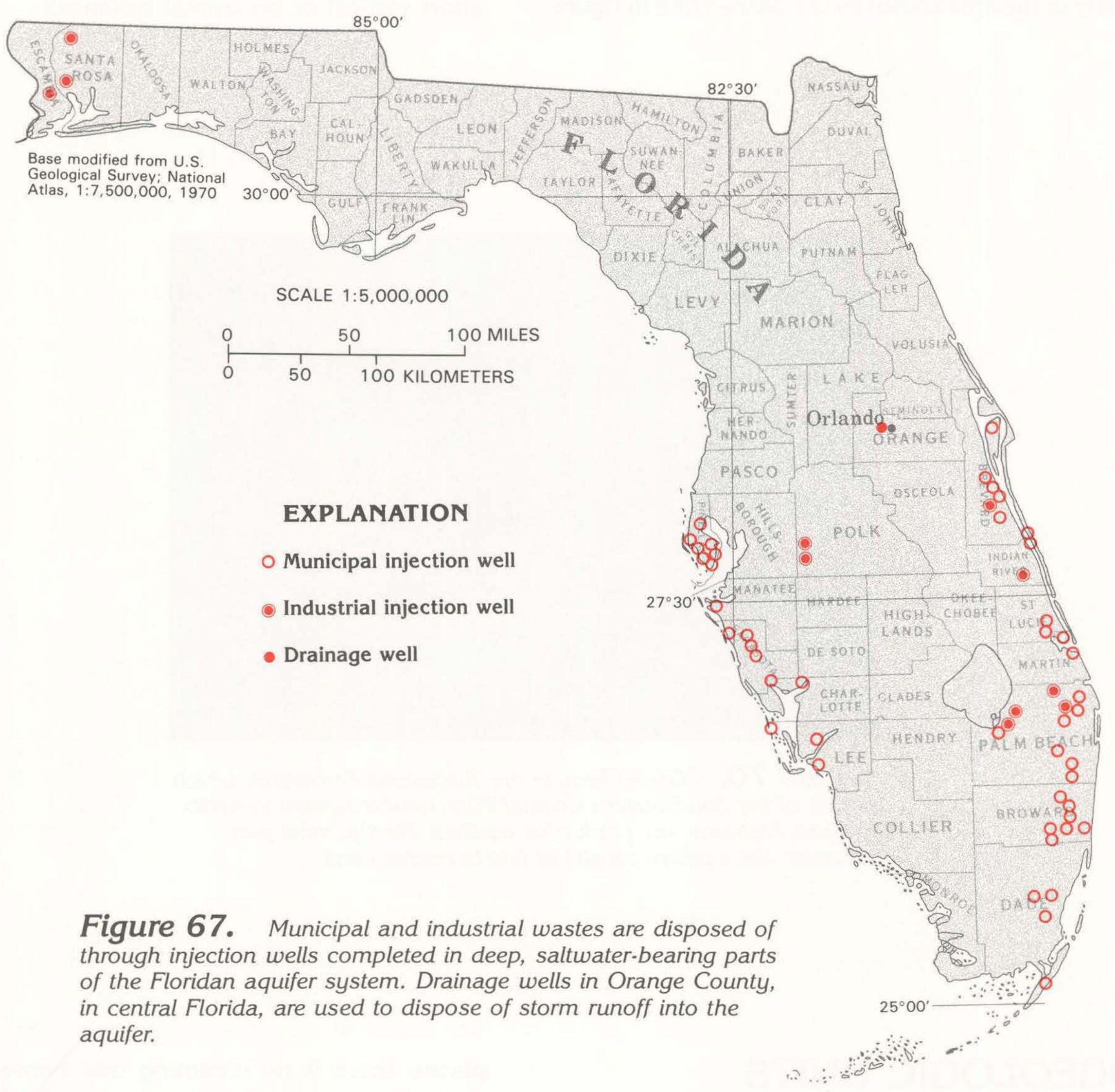
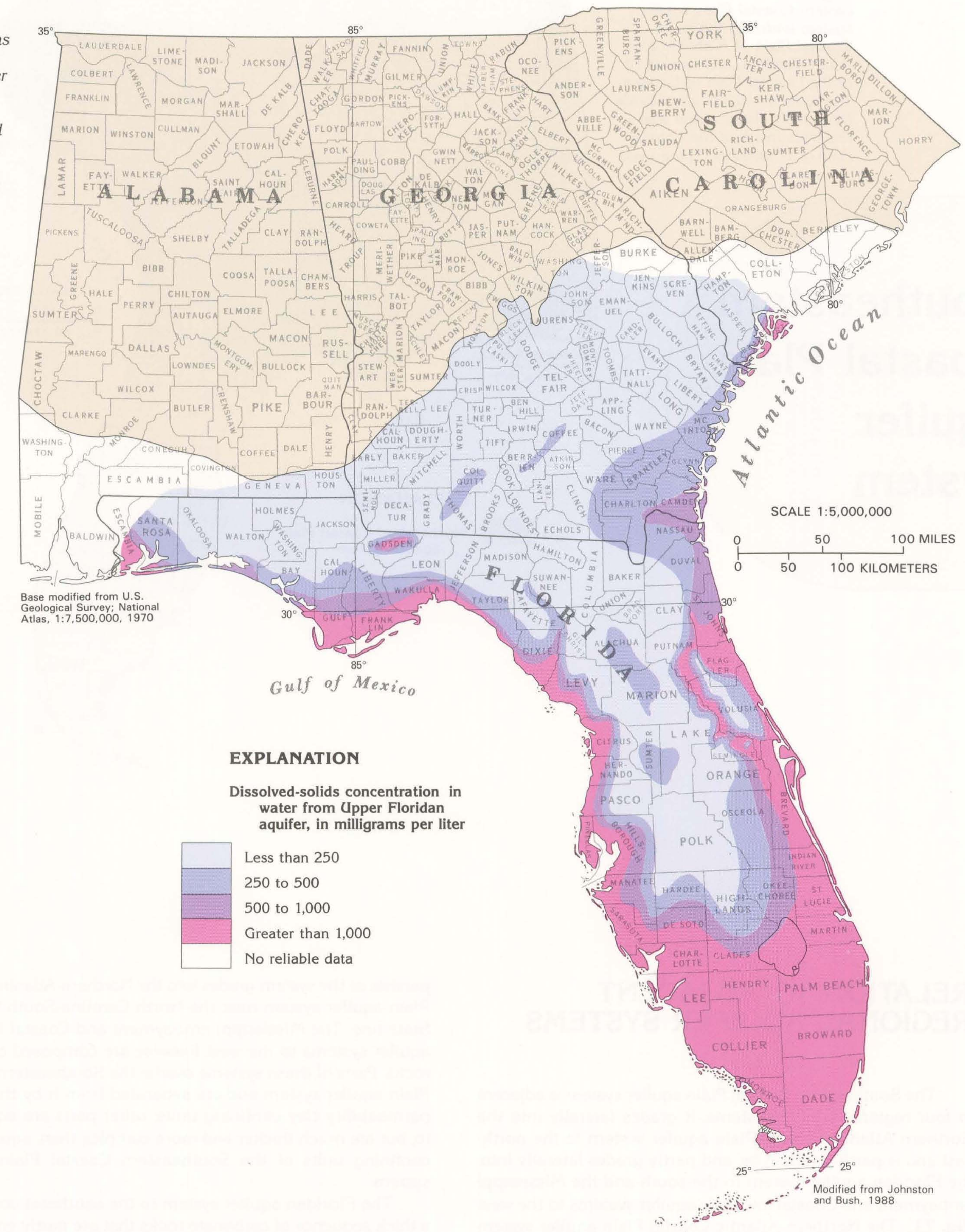


Figure 67. *Municipal and industrial wastes are disposed of through injection wells completed in deep, saltwater-bearing parts of the Floridan aquifer system. Drainage wells in Orange County, in central Florida, are used to dispose of storm runoff into the aquifer.*

Figure 68. *Concentrations of dissolved solids in water from the Upper Floridan aquifer increase coastward, primarily because of mixing with saltwater. In outcrop areas and where the upper confining unit is thin, flow is vigorous and dissolved-solids concentrations are generally less than 250 milligrams per liter.*



GROUND-WATER QUALITY

Dissolved-solids concentrations (the sum of all cations and anions in solution) of water in the Floridan aquifer system are related to: (1) the ground-water flow system, and (2) the proximity to saltwater. In places where the aquifer system is unconfined or thinly confined, ground-water flow is vigorous. Large volumes of water move quickly in and out of the aquifer system, and dissolved-solids concentrations are minimal. Water that travels down longer flowpaths, and, thus, dissolves more limestone and possibly sulfate minerals, such as gypsum, has greater dissolved-solids concentrations. Dissolved-solids concentrations in the Upper Floridan aquifer are shown in **figure 68**. Near the east and west coasts of Florida, and locally in eastern South Carolina and adjacent areas of coastal Georgia, large dissolved-solids concentrations are due to the mixing of fresh ground water with deeper saltwater that migrates into the aquifer from the ocean. In western panhandle Florida and in the southern one-third of that State, large concentrations of dissolved solids result from the ground water mixing with residual saltwater that a sluggish flow system has left unflushed from the aquifer. The band of large dissolved-solids concentrations along the St. Johns River in east-central Florida likewise reflects unflushed, residual saltwater.

The most common cations in water from the Upper Floridan aquifer are calcium, magnesium, and sodium; the most common anions are bicarbonate, chloride, and sulfate. All of these ions are present either in the minerals of the aquifer or in unflushed saltwater within the aquifer. In general, water in the Lower Floridan aquifer is chemically similar to that of the Upper Floridan aquifer, except for dissolved-solids concentrations. There are more dissolved solids in the water in the Lower Floridan aquifer because this water has followed longer flowpaths and, accordingly, has had more time to dissolve aquifer minerals.