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The Southeastern Coastal Plain: An Overview

Lee J. Florea
Western Kentucky University, lflorea@bsu.edu

H. L. Vacher

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The Coastal Plain

THE COASTAL PLAIN of the eastern and southeastern USA is composed of fairly young Cenozoic sediments that dip gently off the continent into the Atlantic Ocean and Gulf of Mexico. They form a low-relief fringe around the edge of the continent from New York through Texas, and southward into Mexico. It covers the eroded edges of the much older rocks of the Appalachian Mountains and extends northward into the wide lowland of the Mississippi River, known as the Mississippi Embayment. Most of the Coastal Plain material is poorly consolidated clay, silt, and sand; but in the southeast it includes limestone, and in Florida this is the dominant rock type. As a result, Florida is one of the most important karst and cave regions of North America. Because of the high primary porosity and hydraulic conductivity of the limestone, the caves and karst have formed through a combination of conduit and diffuse groundwater flow that is rare elsewhere in the country. There is no western equivalent of the Coastal Plain, because the young western Coast Ranges drop steeply into the Pacific.

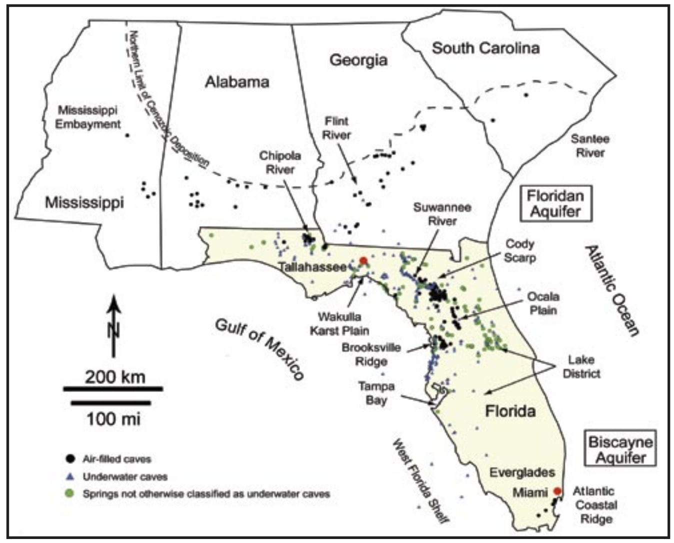

Figure 6.2: Location of springs and caves in the southeastern U.S. (data in part from the Florida Cave Survey, Moore (2006), and the Florida Geological Survey).

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The deep, cool water of Silver Springs, clear as air, flows in immense volumes out of limestone basins and caverns in the midst of a subtropical forest. Seen through the glass-bottomed boats, with the rocks, under-water vegetation, and fish of many varieties swimming below as if suspended in mid-air, the basins and caverns are unsurpassed in beauty. – Marion County, Florida, Chamber of Commerce tourism booklet from the 1920s.

These eloquent words convey the mystique that still surrounds the karst of the southeastern Coastal Plain (Fig. 6.1). Florida enjoys the highest density of large springs in North America (Scott et al., 2004);

Figure 6.1: View looking out of the main vent at Ginnie Springs, near High Springs in north-central Florida. This portal to the underwater world drops 18 m into a cavern called the Ballroom. The cave system beyond is gated. A subsidiary of Coca-Cola (CCDA Waters) bottles this spring water for regional distribution. Photo by Jill Heinerth (*www.IntoThePlannet.com*).

Silver Springs is just one of the 33 first-magnitude springs (mean flow greater than 100 cfs (2.8 m^3/s), and there are hundreds of smaller springs (Fig. 6.2; see Meinzer, 1927, and Scott et al., 2004). They are supplied by spectacular underwater caves that are internationally recognized in the cave-diving community. Less well known are the many air-filled caves of the region (see Florea, 2006; Moore, 2006; Lane 1986). Though generally smaller than their aquatic counterparts, their beauty can rival the world's best show caves. This overview describes the character of caves and karst in the Cenozoic limestones of the Southeast and contrasts them with caves and karst of older limestones elsewhere in the USA.

Hydrogeologic and Historical Background

Springs and caves of Florida occupy part of a great belt of karst that spans five states (Florida, Mississippi, Alabama, Georgia, and South Carolina) in Cenozoic limestones that range in age from mid-Eocene to late Pleistocene – about 42 million to 100,000 years old (Fig. 6.3). They cluster in regions where the limestones are exposed either directly at the surface (Fig. 6.4) or semiconfined by younger less soluble rocks.

The Floridan aquifer consists of middle Eocene and Oligocene limestones that extend from the northern outcrop in Mississippi, Alabama, Georgia, and South Carolina, to offshore of the Florida Keys in the south. These limestones overlie late Cretaceous and early Tertiary anhydrite and limestone that form the lower confining units for groundwater flow (Miller, 1986). Overlying the Floridan aquifer are younger strata that include the Miocene Hawthorn Group throughout Florida (Scott, 1988), the Pliocene limy sands of the Tamiami Formation in south Florida (Fish and Stewart, 1991), and the mostly Pleistocene limestones of the Biscayne aquifer in southeastern Florida (Cunningham et al., 2006; Parker et al., 1955; Scott et al., 2001). The Floridan aquifer is estimated to contain more than 19,000 km^3 of water and is one of the largest and most productive freshwater aquifers in the world (Miller, 1986).

The first thorough study of this aquifer was done in 1935 by V.T. Stringfield (1935) of the U.S. Geological Survey (USGS). From 1941 to his retirement in 1972, Stringfield was Eastern Region Division Chief of the USGS. Toward the end of his career and even after he retired, Stringfield produced a remarkable succession of publications, many with his colleague Harry LeGrand. Of particular interest was an outpouring

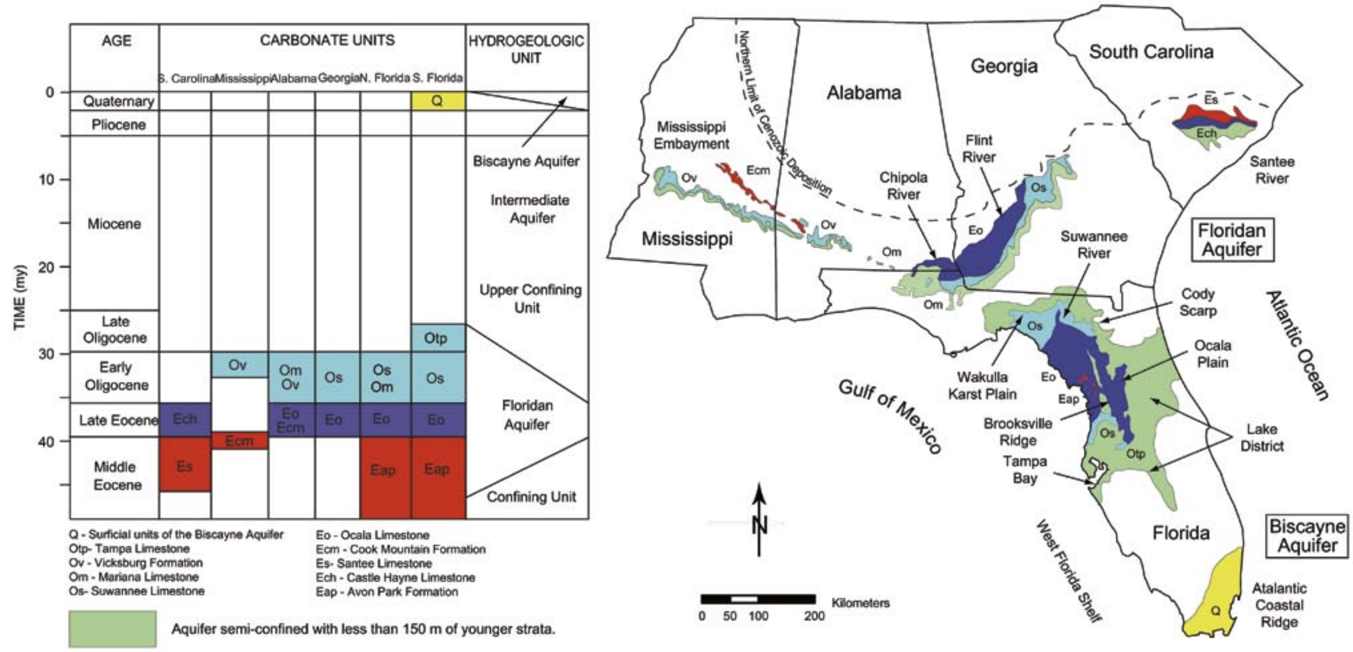

Figure 6.3. Generalized outcrop of the Eocene and Oligocene limestones that comprise the Floridan aquifer in west-central and north-central Florida (data in part from Scott et al., 2001).

of papers on what they called karst hydrology (e.g., Stringfield and LeGrand, 1966, 1969a, 1969b, 1971; LeGrand and Stringfield, 1973). These papers stressed the role of geologic setting and history in the development of limestone permeability and the interactions between karst and coastal groundwater. One product of this effort was an edited volume, *Important Karst Regions in the Northern Hemisphere* (Herak and Stringfield, 1972). Yet, despite this monumental effort, his work has been largely overlooked by mainstream publications in karst hydrology, as are most references to Florida karst.

Why has the broader karst community largely ignored Florida karst? A possible reason was that Stringfield and LeGrand were not cavers, nor evidently did they interact with Florida cavers or cave divers. They were unable to report about the many air-filled caves that are now known. Moreover, they did not have information about the water-filled caves now available from cave divers. Thus their papers lacked first-hand knowledge about caves. We suspect, however, that the major factor was that the southeastern USA is so dissimilar to "normal" karst such as the Mammoth Cave region of Kentucky (Chapter 3).

Figure 6.4: Ocala Caverns, between the cities of Ocala and Belleview in central Florida. This cave was a tourist site in the 1950s and 1960s before the construction of nearby Interstate 75. Boats carried visitors through the cave over the crystal-clear waters of the Floridan aquifer. Such caves are common in the southeastern US where the limestones of the Floridan aquifer are exposed at the surface. Photo by Sean Roberts.

Eogenetic Karst

Solution features in the Cenozoic limestones of the southeastern USA can be classified as ***eogenetic karst***. This term has been applied to karst by Vacher and Mylroie (2002) to draw a parallel with the early porosity stages in limestones as defined by Choquette and Pray (1970). According to this scheme, eogenetic processes are those that take place before the primary depositional porosity is reduced by deep burial. Those that follow are called ***telogenetic***. The most significant contrast between eogenetic karst and the more common telogenetic karst is the magnitude and relative significance of the different types of porosity and permeability in the limestone matrix. Porosity in the Floridan aquifer, for example, may be up to 30-40% (Budd and Vacher, 2004). In contrast, at Mammoth Cave the limestone porosity averages 2-3% (Worthington et al., 2000). In addition, the limestone matrix is about 100,000 times as permeable in Florida as at Mammoth Cave (Budd and Vacher, 2004).

Cenozoic limestones and eogenetic karst are not randomly distributed around the world. They occur in the same general region where carbonate sediments are accumulating today, such as on low-latitude (tropical to subtropical) carbonate platforms like the Bahamas (Mylroie and Carew, 1995), Florida (Florea, 2006), and the Yucatan (Smart et al., 2006). Another locale includes isolated, small carbonate islands (Vacher 1997) such as Bermuda (Mylroie et al., 1995), the Cayman Islands (Jones, 1992), and Barbados (Jones and Banner, 2003). Indeed, according to the original usage of Choquette and Pray (1970), the eogenetic zone is a *net depositional realm* and the telogenetic zone is a *net erosional realm*.

The climatic characteristics of eogenetic karst reflect low latitudes and proximity to warm marine water. They typically include a rainfall regimen dominated by frequent thunderstorms and infrequent tropical cyclones (hurricanes). As a result, the amount and character of rainfall is typically seasonal, with convective thunderstorms during the summer and tropical cyclones during the late summer and early fall.

Because the bedrock of the Floridan aquifer is so sponge-like, the common, convective-style rain events during the rainy season do not appear as independent peaks in water-level records in wells or in the discharge at many of the springs (Florea and Vacher, 2007). Rather, the spring hydrographs show smooth, seasonal or longer-period cycles (Florea and Vacher. 2006). The slow response and smooth shape of spring hydrographs in Florida attest to the massive volume of accessible storage in eogenetic limestones.

Infrequent, large, and widespread storms, such as hurricanes, do produce identifiable peaks in water-level and spring-discharge data, because the torrential discharge is shunted through the largest conduits. Observations of water level show that these infrequent events appear to be the principal contributor to changes of storage within the Floridan aquifer (Florea and Vacher, 2007). In general, in eogenetic karst it cannot be assumed that rainy season summer thunderstorms equate to a recharge season.

During infrequent and widespread storms, recharge to the Floridan aquifer occurs simultaneously in caves and in the limestone matrix over large distances (Florea and Vacher, 2007). Thus, in eogenetic karst, it is not appropriate to assume that water flows through the limestone via a system of integrated conduits in otherwise uninvolved, low-permeability rock. Rather, eogenetic karst contains a permeable rock matrix. Although some caves in this permeable rock are connected and form conduits, many others are now choked with sediment so that they are discontinuous, while still others may have formed as isolated chambers (Florea, 2006). The distinction between isolated caves and conduits is relevant because the pattern of sinking streams and springs typical of epigenic telogenetic karst heavily colors the prevailing view of caves in karst hydrology.

Recent trends

Rapid urbanization has taken place in the southeastern USA since the time of Stringfield, particularly in Florida, and there has been a great increase in groundwater consumption. Currently more than 90% of the 17 million Florida residents rely on the Floridan and Biscayne aquifers for domestic use, industry, and irrigation (Scott et al., 2004). Yet most Florida hydrogeologists, both past and present, have had little direct exposure to caves. Many rely upon indirect observations such as landscape geomorphology such as sinkholes (e.g., Tihansky, 1999; Sinclair et al., 1985), geophysical surveys (e.g., Beck and Wilson, 1988; Stewart and Wood, 1991), and geochemical data from springs and wells (Katz, 2004; Upchurch, 2002; Martin and Dean, 2001; Back and Hanshaw, 1970).

Karst wields a powerful socio-economic influence in Florida. For example, state parks protect 17 major springs, and national forests and wildlife refuges manage dozens more. More than a million visitors spend a total of $65 million per year at the parks that protect Florida's four largest springs (Bonn and Bell, 2003). Spring water is also an economic resource; major bottling companies, such as Nestlé, Dannon, and Coca-Cola, market Florida spring water around the nation.

Water-quality data from Florida springs reveals a problematic trend. For example, chemical data from Chassahowitzka Springs, published by the Florida Geological Survey, is representative of aquifer health during the past three decades. Specific conductivity has risen 500%, sulfates 520%, chlorides more than 1000%, and total nitrogen 170% since the 1970s (Scott et al., 2004). Furthermore, nitrate levels in many Florida springs exceed EPA health standards. These are a measure of anthropogenic pollution such as fertilizers. Increased nitrate in springs reduces species biodiversity and is a primary cause of algal blooms.

Conditions in Florida springs have become ominous enough that the Florida Department of Environmental Protection, with support of the Governor and the Florida legislature, founded the Florida Springs Initiative and Task Force in September 1999, and in 2001 allocated $2.5 million to fund research. Much of this has been spent delineating recharge areas for major springs and identifying sources of pollution (Scott and Means, 2003).

Caves are an integral part of the Spring Task Force investigation and are more than curiosities with significance only to cave explorers. The late William Wilson, who spent innumerable hours studying the air-filled and submerged caves of Florida, put into perspective the sheer volume of Florida caves. Using well-cavity data of Lichtler et al. (1968) for Orange County, central Florida, Wilson (1988) made a rough estimate that the upper part of the Floridan aquifer contains 2.9×10^6 m^3/km^2 of cave, or, in terms of cylindrical passages with diameter equal to the average cavity height (3.3 m), some 550 km of passage per square kilometer.

A series of conferences followed the funding of the Task Force. In March 2002, the Karst Waters Institute hosted "Hydrology and Geology of Post-Paleozoic Karst Aquifers." In November of the same year the Task Force hosted "Blueprints for the management and protection of Florida Springs;" and in 2003 it sponsored "Natural Gems – Troubled Waters" in association with the National Cave and Karst Management Symposium, and "Significance of Caves in Watershed Management and Protection." These conferences have provided a springboard for karst research, both direct and indirect, throughout the southeast. The next sections of this chapter highlight some of that research.

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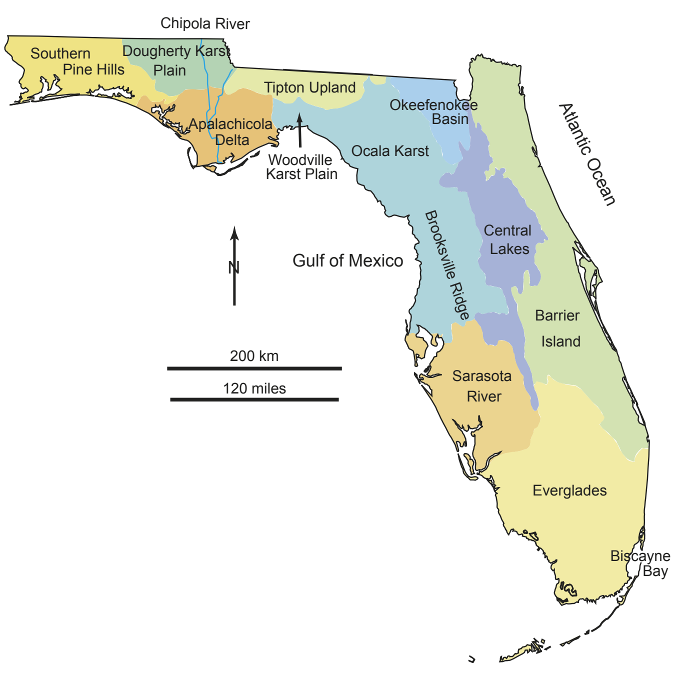

Figure 6.5: Geomorphic districts in Florida (from Scott, 2004).

The Florida Panhandle

Tom Scott

THE FLORIDA PANHANDLE consists of the long, narrow western part of the state. It and the adjacent parts of Alabama and Georgia contain extensive karst. In the highest elevations the limestone is overlain by thick low-permeability, relatively insoluble clastic sediments, but in the karst areas these sediments are mostly absent, and only a thin veneer of sand and clay overlies the limestone. Two karst regions are discussed here – the Ocala Karst District and the Dougherty Karst Plain and associated uplands (Fig. 6.5; see Scott, 2004).

Geologic Framework

Strata with the greatest influence on karst of the Florida panhandle are described briefly below, from oldest to youngest (Figs. 6.6–6.7; see Scott, et al., 2001). Their distribution is influenced by regional geologic structures (Puri and Vernon, 1964; Miller, 1986; Scott, 1988 and 1991; see Fig. 6.8).

The Upper Eocene ***Ocala Limestone*** consists of nearly pure, very fossil-rich limestone and sparse dolomite. The Lower Oligocene ***Suwannee Limestone*** consists of a white to cream, poorly to well indurated (consolidated), fossil-rich, vuggy, granular limestone. Silicified limestone is also common. The Lower Oligocene ***Marianna Limestone*** is a soft, chalky, fine-grained limestone, with many fossil foraminifera. The Lower Oligocene ***Bridgeboro Limestone*** is a white to cream to light gray, coral-algal, fine-grained limestone of limited areal extent.

The Lower Miocene ***Chattahoochee Formation*** is predominantly a yellow-gray, poorly to moderately indurated, fine-grained, typically fossil-rich, silty to finely sandy dolomite. The Lower Miocene ***St. Marks Formation*** is a white to yellowish gray, poorly to moderately indurated, sandy, fossiliferous limestone. Mollusk molds and casts are abundant in many places.

The Miocene ***Hawthorn Group*** in Florida is composed of a number of different formations and members (Scott, 1988) but mainly consists of poorly indurated sand and clay with some phosphate present.

The Pliocene ***Citronelle Formation*** consists of gray to orange, commonly mottled, unconsolidated to poorly consolidated, very fine to very coarse, poorly sorted, clean to clay-rich sands. It contains significant amounts of clay, silt and gravel. It grades laterally into the ***Miccosukee Formation*** of the eastern Florida panhandle. The Pliocene Miccosukee is composed of grayish orange-to-red, mottled, poorly to moderately consolidated, interbedded clay, sand, and gravel of varied coarseness and admixtures. It occurs in the Tallahassee Hills from central Gadsden County to eastern Madison County, and commonly caps hills.

The undifferentiated residuum mapped in parts of the area typically consists of reddish

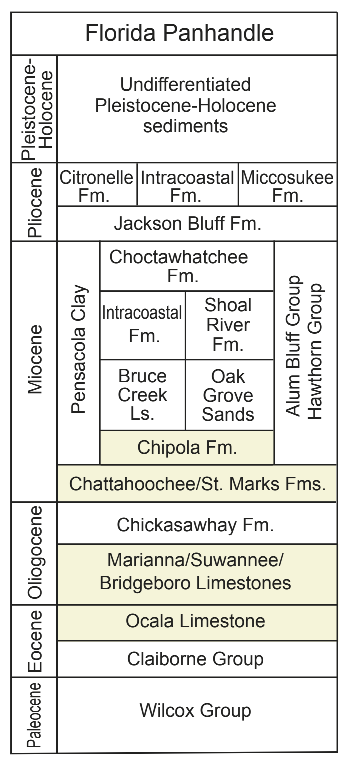

Figure 6.6: Eocene to Holocene stratigraphic column of the Florida Panhandle (Florida Geological Survey). Yellow identifies carbonate units that host caves and karst.