

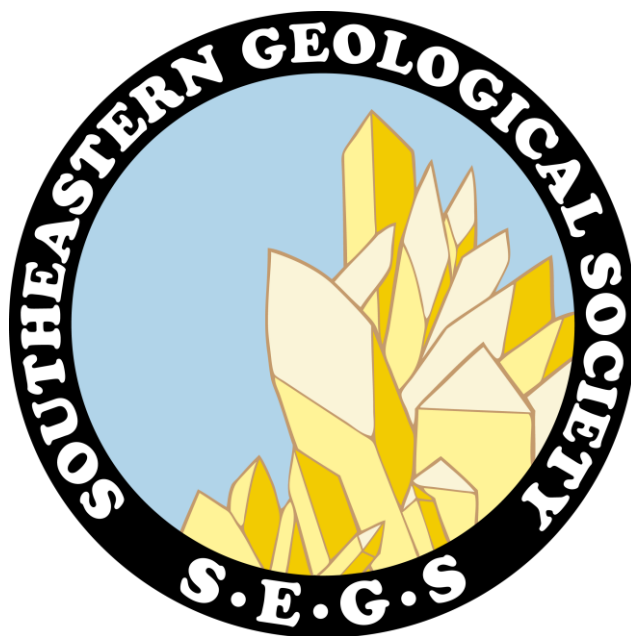


Geology of Citrus County, Florida



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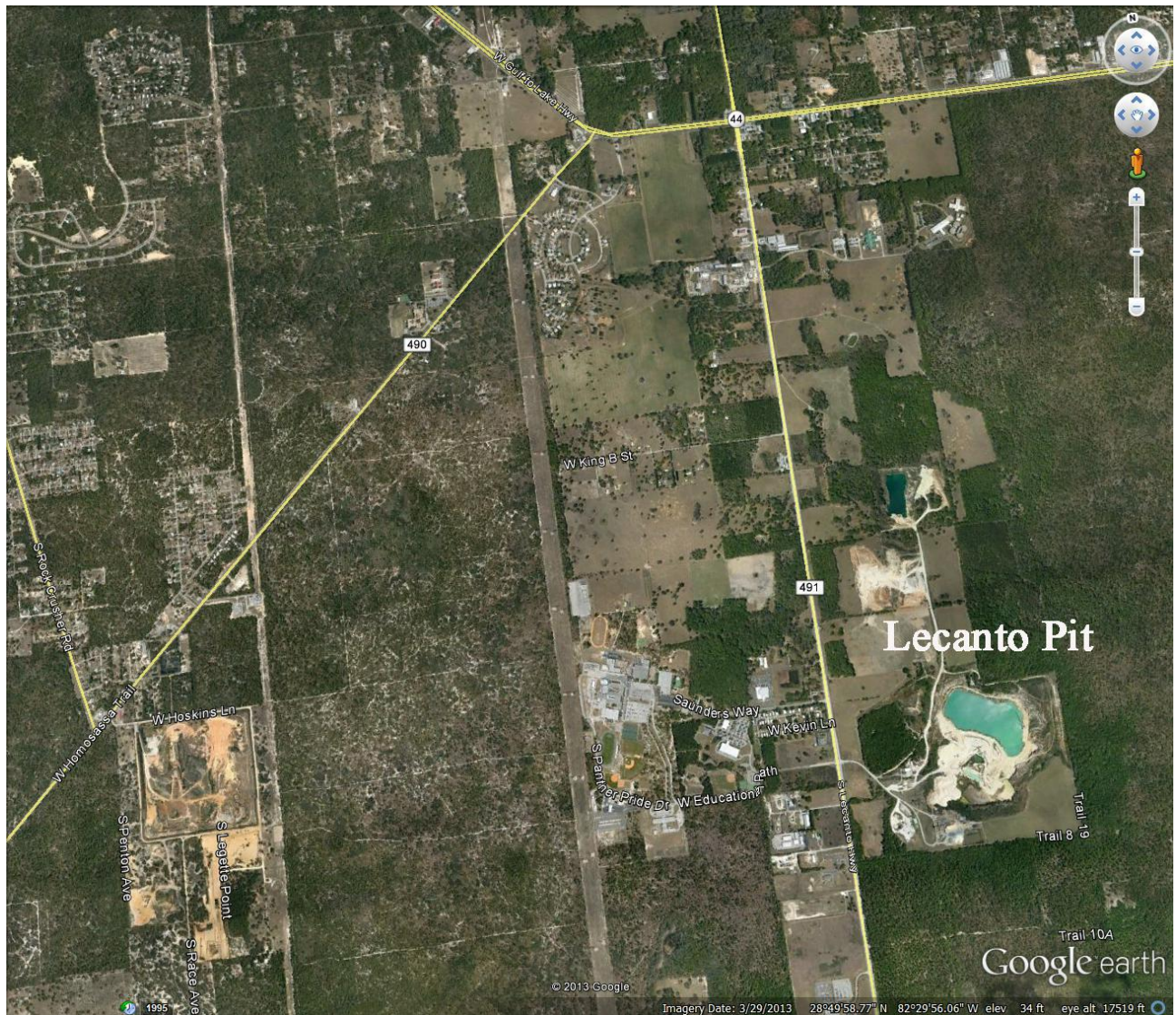
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Approximate mileages taken from Google Earth:

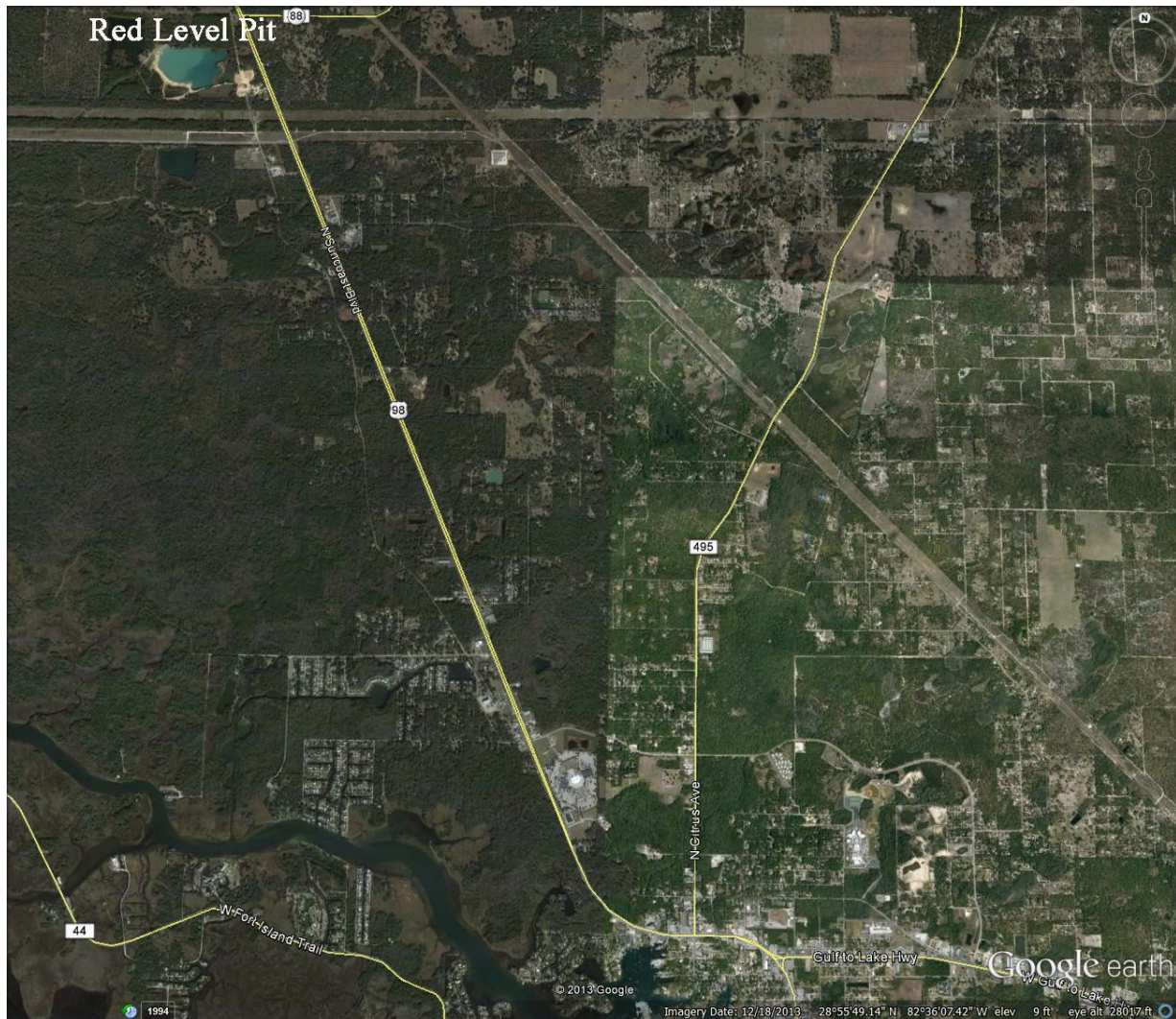
Stop 1 Crystal River Quarries Lecanto Pit: From the Holiday Inn Express on SR 44, drive approximately 6.2 miles SE to CR 491 – Lecanto Highway. Turn south (right). Proceed 2.2 miles to the Crystal River Quarries Lecanto Mine entrance on the east (left) side of the road. It is across the highway from a school complex. Follow the leaders into the pit and the parking area.



Stop 2 Crystal River Quarries Maylen Pit: Leave the Lecanto Mine, return to CR 491. Drive north 2.2 miles to SR 44. Turn northwest (left) on SR 44 and drive 1.3 miles to Maylen Road (on the right). Drive north 0.5 miles to the mine entrance on the right. Follow the leaders to the parking area.



Stop 3 Crystal River Quarries Red Level Pit: Leave the Maylen Mine and return to SR 44. Turn northwest (right) and drive 5.7 miles to US 19. Turn on right on US 19, drive 5.4 miles to the entrance to the Red Level Mine on the west (left) side of the road. Follow the leaders to the parking area.



GEOLOGIC OVERVIEW OF THE FLORIDA PLATFORM

By

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SDII Global Corporation

(Florida Geological Survey, retired)

INTRODUCTION

The Florida Platform is delimited by the 200 m (600 ft) isobath at the shelf break to the approximate location of the Paleozoic suture beneath southern Georgia and Alabama (figure 1). The Suwannee–Wiggins Suture (Thomas et al. 1989) is the proposed location where terranes with African affinities are welded to the North American Plate (Chowns and Williams 1983; McBride and Nelson 1988; Woods et al. 1991). The basement rocks of the Florida Platform are a fragment of the African Plate that remained attached to the North American Plate when rifting occurred in the Jurassic and range in age from late Precambrian-early Cambrian to mid-Jurassic (Barnett 1975). Excellent reviews of the geology of the basement are provided by Smith (1982), Arthur (1988), Smith and Lord (1997), and Heatherington and Mueller (1997). Barnett (1975) provided a structure contour map of the sub-Zuni surface. This surface equates to what is now recognized as pre-Middle Jurassic. Barnett's interpretation of the basement surface has it occurring as shallow as approximately 915 m (3000 ft) below mean sea level (msl) in central-northern peninsular Florida. The basement surface dips west and southwest toward the Gulf of Mexico basin, to the south into the South Florida basin, and to the east into the Atlantic basin. The basement surface reaches depths of more than 5180 m (17,000 ft) below msl in southern Florida (Barnett 1975).

The platform, deposited unconformably on top of the basement, is constructed of Middle Jurassic to Holocene evaporite, carbonate, and siliciclastic sediments deposited on a relatively stable, passive margin of the North American Plate. The age assignments for the Middle Jurassic to Holocene formations are, at times, tentative propositions due to limited, or lack of, paleontological evidence in some formations. The age determinations for some of the younger units, for example the Pliocene Tamiami Formation, are based on a vast amount of paleontological evidence. This, in part, is responsible for differing interpretations of when, where, and how much sediment was deposited across the platform (see and compare Salvador [1991b] and Randazzo [1997]).

STRUCTURE

The Florida Platform has been a relatively stable portion of the trailing edge of the North American Plate since the mid-Jurassic. Winston (1991) stated that the Mesozoic and Cenozoic structural movement on the Florida–Bahama Platform was entirely negative. Florida's arches, or structural highs, were not formed by uplift but as the result of subsiding more slowly than the flanking basins. However, faulting of the basement rocks created many of the structural features recognized on the pre–mid-Jurassic surface (Barnett 1975; Smith and Lord 1997). Faults

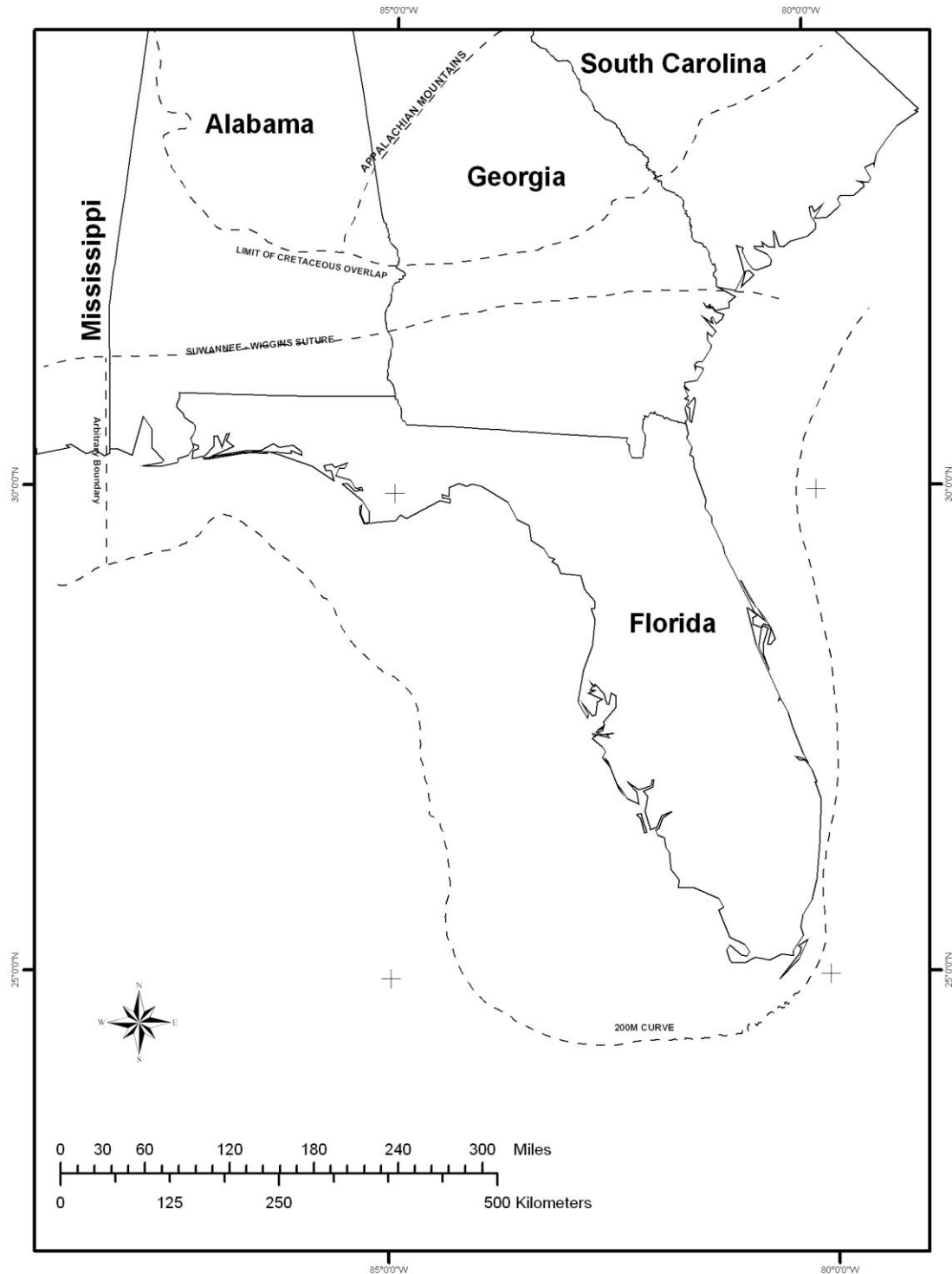


Figure 1 – Limits of the Florida Platform.

disrupting the Upper Jurassic sediments have been identified in northwestern Florida; some displacements exceed 305 m (1000 ft) (Lloyd 1989). Miller (1986) recognized a number of known or suspected Cenozoic faults that affect the Floridan Aquifer System. Duncan et al.

(1994) identified faulting in the Lower to Middle Eocene Oldsmar Formation. A number of hydrogeologic and geomorphic investigations have proposed the existence of faults (Wyrick 1960; Leve 1966; Lichtler et al. 1968; Pirkle 1970; White 1970). The faults in the Cenozoic section have very limited displacement, generally less than 30.5 m (100 ft) and are difficult to identify due to limited displacement, well control, few “marker” beds, erosional disconformities, and karstification.

Little has been said concerning folding of post–mid-Jurassic sediments on the Florida Platform. Missimer and Maliva (2004) believe that folding is more widespread on the Florida Platform than is presently recognized due to the limited amount of detailed subsurface data. They recognized folding with associated fracturing and faulting in the sediments of the Intermediate (Miocene–Pliocene sediments) and Floridan Aquifer systems (Eocene–Oligocene sediments) on the southern portion of the platform. They postulated that the interaction of the Caribbean and North American plates in the Late Miocene to Pliocene produced the folds, fractures, and faults.

The oldest features recognized as affecting deposition of post–mid-Jurassic sediments on the platform are expressed on the pre–mid-Jurassic surface (Arthur 1988). The Mesozoic structural features affecting deposition of sediments include a series of basins or embayments and arches (figure 2). Some of these features affected deposition into the mid-Cenozoic (for example, the South Florida basin; Scott 1988). Other features affected the deposition into the late Cenozoic (for example, the Apalachicola Embayment; Schmidt 1984). The Peninsular Arch affected deposition from the Jurassic through the Cretaceous and was intermittently positive during the Cenozoic (Miller 1986). The Cenozoic structural features affecting deposition are shown in figure 3.

One of the more interesting structural features of the Florida Platform is a southwest-to-northeast trending low that has affected deposition from the mid-Jurassic until at least the Middle Miocene. Some portions of the feature continued to affect deposition through the Pleistocene. This feature has an extended list of names that have been applied to all or parts of it. An excellent review of the names applied to the feature was presented by Schmidt (1984) and Huddleston (1993). However, Georgia Channel System is the name that has been applied to the entire sequence (Huddleston 1993) (figs. 2, 3).

The Georgia Channel System had its origin in the formation of the South Georgia Rift in the Triassic–Jurassic (?) (Huddleston 1993). From the Late Cretaceous through the Paleocene, this area was the boundary between carbonate deposition to the south and siliciclastic deposition to the north. By the Eocene, the Appalachian Mountains had been highly eroded leaving relatively low hills and significantly reduced siliciclastic sediment transport via streams and rivers. In the Eocene and Oligocene, as the result of a greatly reduced siliciclastic supply, carbonate deposition extended across the Georgia Channel System. The channel system was then infilled by predominantly siliciclastic sediments in the Late Oligocene to the Early Miocene in response to uplift in the Appalachians (Scott 1988). Gallen et al. (2013) postulated that a “post-orogenic” regional uplift of the Appalachians occurred in the Miocene based on geomorphic evidence. However, by the Early Miocene, a significant increase in the deposition of siliciclastic sediments was occurring in the lower Hawthorn Group of Florida and Georgia. This suggests that a rejuvenation of the southern Appalachians occurred prior to the Early Miocene providing a significantly increased supply of siliciclastic sediments.

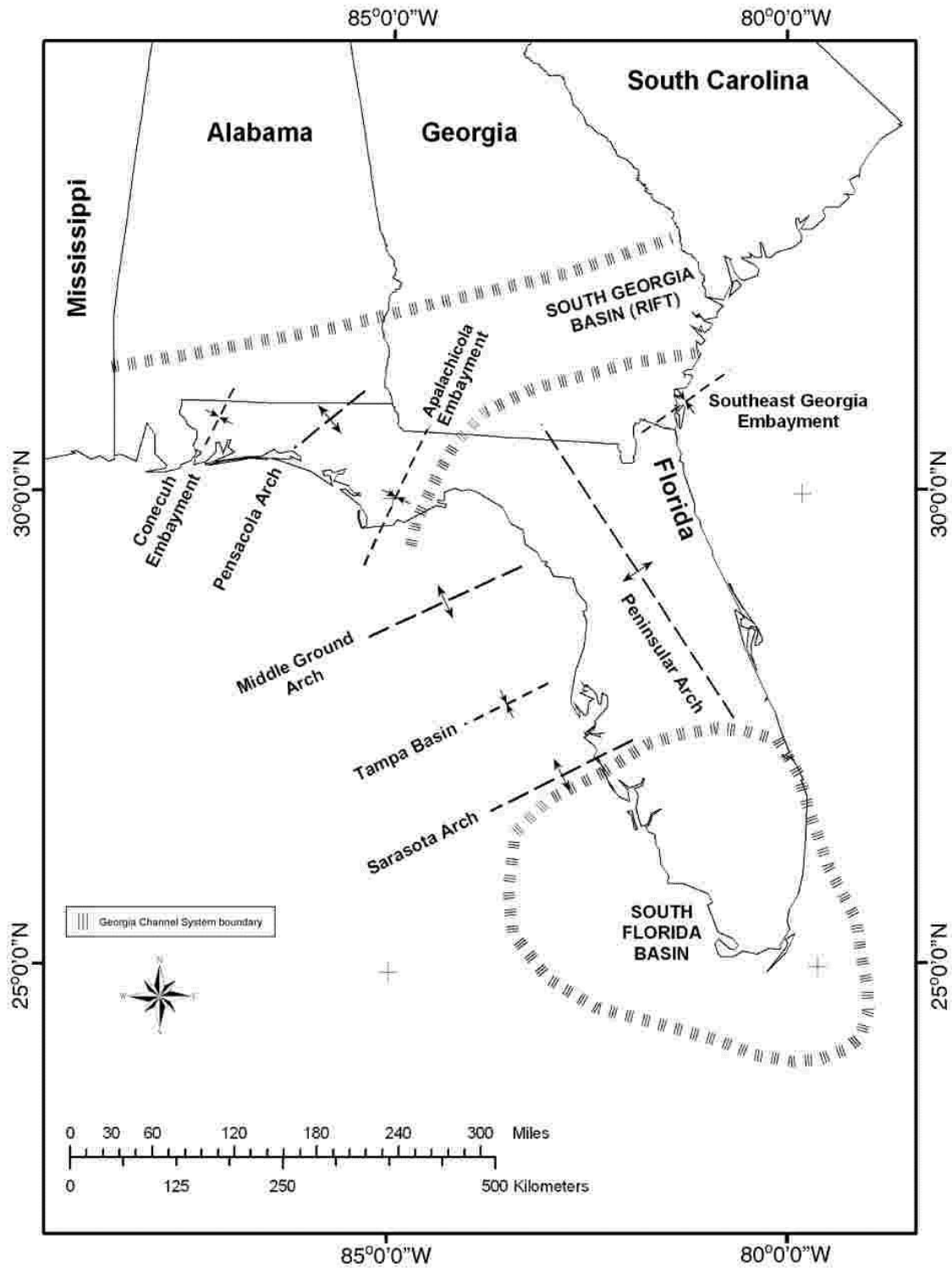


Figure 2 – Structures affecting the Mesozoic and early Cenozoic deposits (modified after Lloyd, 1997).

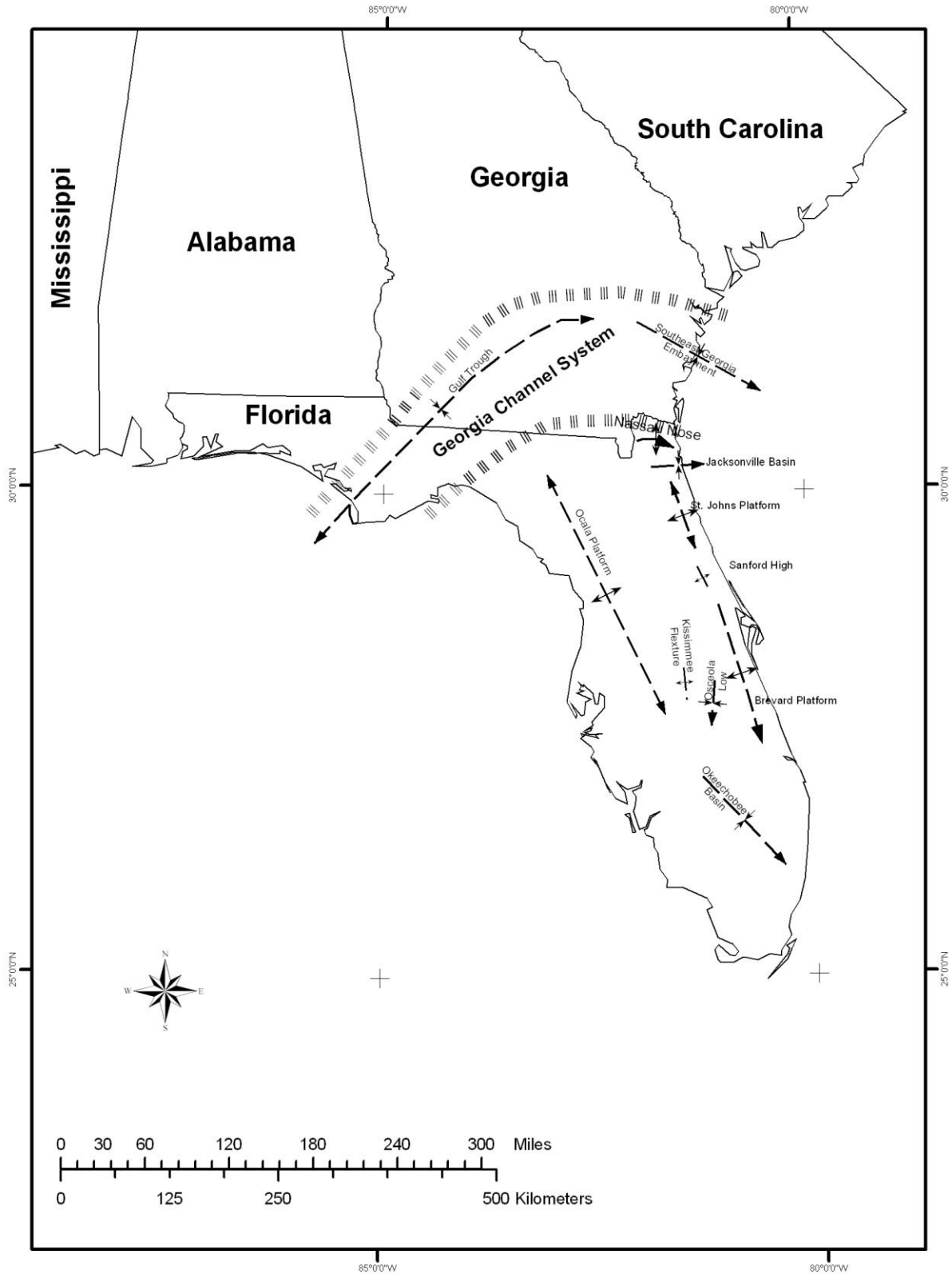


Figure 3 – Structures affecting the post-early Cenozoic deposits (modified after Scott, 1988).

DEPOSITIONAL ENVIRONMENTS

The initial depositional environments affecting the Florida Platform were restricted environments allowing for intense evaporation and the development of evaporites in limited areas. As the Gulf continued to expand and sea levels rose, siliciclastic and carbonate depositional environments began to cover more of the platform. Continued sea-level rise through the Cretaceous eventually covered the exposed land area in northern Florida. The Florida Platform sediments were deposited in a complex interplay of siliciclastic, carbonate, and evaporite facies as a result of sea-level fluctuations (Randazzo 1997). Siliciclastic deposition predominated on the northern part of the platform while carbonate and evaporite sediments formed to the south (Randazzo 1997).

In the early Cenozoic (Paleogene), the siliciclastic sediment supply was limited due to the highlands of the Appalachian trend having been reduced by erosion, and carbonate deposition expanded to cover the entire Florida Platform and beyond by the Oligocene. The carbonate platform, which began as a rimmed shelf in the Jurassic, evolved to a carbonate ramp sequence by the early Cenozoic (Randazzo 1997; Winston 1991). Subsequent to the maximum development of the carbonate platform, uplift occurred in the Appalachians providing a renewed supply of siliciclastic sediments (Scott 1988; Brewster-Wingard et al. 1997). This influx of siliciclastic sediments in the Neogene replaced most carbonate deposition on the Florida Platform by the mid-Pliocene. As sea level rose in the late Pleistocene, there was a decrease in siliciclastic sedimentation and carbonate deposition increased on the southern Florida Platform. The interplay of the carbonate and siliciclastic sediments with fluctuating sea level and changing climate created complex depositional environments (Scott 1988; Missimer 2002). The interaction of the carbonates and siliciclastics on the Florida Platform has been investigated and discussed by a number of authors (Warzeski et al. 1996; Cunningham et al. 1998; Guertin 1998; Guertin et al. 2000; Missimer et al. 2000; Missimer 2001, 2002; Cunningham et al. 2003).

STRATIGRAPHY

Stratigraphically, Florida is composed of pre-Mesozoic sedimentary, igneous and metamorphic rocks overlain by Mesozoic and Cenozoic sedimentary rocks. The Mesozoic sediments consist predominantly of siliciclastics except in central and southern Florida where carbonates predominate. In the Cenozoic, the Paleogene sediments are predominantly carbonates with some mixed carbonate-siliciclastic sediments. The Neogene and Quaternary sediments are predominantly siliciclastics (Braunstein et al, 1988).

The pre-Mesozoic rocks occur nearest to the land surface in northern peninsular Florida. These rocks dip deeper in the subsurface to the south under the exposed portion of the Florida Platform, to the east under the Atlantic Ocean and west into the Gulf of Mexico (Puri and Vernon, 1964). Consequently, the Mesozoic and Cenozoic sediments thicken in these areas exceeding 13,000 feet thick in southern Florida.

Pre-Mesozoic

The pre-Mesozoic (Proterozoic and Paleozoic) framework of the Florida basement is composed of igneous, sedimentary, and metamorphic rocks (figure 4). These rocks have been penetrated by oil exploration boreholes. A number of researchers have investigated the pre-Mesozoic rocks including Smith (1982), Chown and Williams (1983), Dallmeyer et al. (1987), Arthur (1988), and others. Refer to Smith and Lord (1997) for a summary of the research on the basement rocks. The granitic igneous rocks, which occur in east-central Florida, have been dated at approximately 530 million years old (early Paleozoic) (Dallmeyer et al. 1987; Smith and Lord

1997). Dallmeyer et al. (1987) recognized that these rocks, the Osceola Granite, were part of a complex that is also found in northwestern Africa. A metamorphic sequence, located on the southern flank of the Osceola Granite, indicates metamorphism was associated with the emplacement of the granite pluton.

Sedimentary rocks are found in two areas of the basement, a small area in the panhandle near the junction of Alabama, Florida, and Georgia, and in the northern peninsula north of a line connecting Tampa Bay in the southwest and a point between St. Augustine and Jacksonville in

PANHANDLE	N. FLORIDA	S. FLORIDA		SYSTEM	ERATHEM	AGE (Ma)
Unknown	Unknown	Unknown		Permian	Paleozoic	251.0
				Carboniferous		299.0
Devonian	359.2					
Silurian	416.0					
Ordovician	443.7					
Unnamed Sediments	Unnamed Sediments	Cambrian	488.3			
Unknown		Unnamed Metamorphic Complex	Unnamed Granitic Complex			
Unnamed Sediments						
Unnamed Volcanic and Plutonic Complex	Unnamed Volcanic and Plutonic Complex			Precambrian	Proterozoic	542.0

Figure 4 - Paleozoic stratigraphic columns (modified after Braunstein et al, 1988).

the northeast (Jones 1997; Smith and Lord 1997). With the exception of sediments encountered in a few wells, the sandstone, siltstone, and shale are usually sparsely fossiliferous. Ages derived from the fossil assemblages range from Early Ordovician to Middle Devonian (Jones 1997). Opdyke et al. (1987) recognized a pre-Mesozoic shale in northern Florida that exhibited low-grade metamorphism.

Mesozoic

Mesozoic sediments on the Florida Platform were deposited in response to the separation of plates beginning in the Triassic. Subsequent to the breakup of the plates, marine sedimentation began and remained the dominant depositional type for much of the geologic history of the Platform.

Triassic

Triassic rifting associated with the breakup of Pangea and the formation of the Atlantic Ocean created the South Georgia basin (Rift) (figure 2). Triassic red beds, the Newark Group, and Eagle Mills Formation (Braunstein et al. 1988) (figure 5), filled the rift system. Basalt and diabase (tholeiites), with an average age of 192 million years (Arthur 1988), have been encountered in a number of boreholes. These rocks were emplaced or occurred as flows in response to the continued separation of the plates (Arthur 1988).

PANHANDLE		N. FLORIDA		S. FLORIDA			SYSTEM	ERATHM	AGE (Ma)
Selma Group		Pine Key Formation	Lawson Formation	Lawson Formation	Rebecca Shoals Dolomite		Cretaceous		65.5
Eutaw Formation			Pine Key Formation			Orlando Sound Dolomite			
Tuscaloosa Group			Atkinson Formation						
Unnamed Sediments		Unnamed Sediments		Marquesas Supergroup	Naples Bay Group		Mesozoic		145.5
					Big Cypress Group				
					Ocean Reef Group	Suniland Fm.			
					Glades Group				
					Pumpkin Bay formation				
					Bone Island formation				
Unnamed Sediments	Sligo-Hosston Formation	Cotton Valley Formation			Ft. Pierce Formation	Wood River Formation	Jurassic		199.6
Cotton Valley Formation									
Haynesville Formation									
Smackover Formation									
Norphlet SS									
Louann Salt / Werner Anhydrite									
Diabase		Diabase					Triassic		251.0
Eagle Mills Formation		Newark Group							

Figure 5 – Mesozoic stratigraphic columns (modified after Braunstein et al, 1988).

Jurassic

The Gulf of Mexico basin began to form in the Late Triassic as rifting began to separate the lithospheric plates (Salvador 1991a). The first post-rifting sediments deposited on the Florida Platform were upper Middle Jurassic evaporites in the Apalachicola Embayment and the

Conecuh Embayment (figure 2). These were deposited in very limited portions of the northwestern Florida Platform (Salvador 1991b; Randazzo 1997). Deltaic to shallow-marine siliciclastics, carbonates, and evaporites were deposited on the northwestern Florida Platform during the Late Jurassic (Salvador 1991b). These sediments contain important petroleum-producing horizons, including the Norphlet Sandstone and the Smackover Formation (carbonates) (Braunstein et al. 1988) (figure 5) that were discovered between 1970 and 1986 (Lloyd 1997). In southern Florida, Upper Jurassic siliciclastics were followed by carbonates and evaporites deposited on an unnamed Upper Triassic to Upper Jurassic volcanic complex (Braunstein et al. 1988). These sediments occur below important petroleum producing horizons in the South Florida basin (Applegate et al. 1981). Throughout the mid-Jurassic to the beginning of the Cretaceous, sea levels rose, progressively reducing the exposed portion of the Florida Platform (Salvador 1991b; Randazzo 1997). The thickness of post-mid-Jurassic to Cretaceous sediments in northwestern Florida Platform exceeds 1000 m (3500 ft) (Randazzo 1997). In the southern part of the platform, the thickness may exceed 915 m (3000 ft) (Winston 1987).

Cretaceous

By the beginning of the Cretaceous, a limited portion of the northern Florida Peninsula remained above sea level (McFarlan and Menes 1991). As sea level rose through the Early Cretaceous, more of the platform was submerged (McFarlan and Menes 1991; Randazzo 1997). Deposition in the northwestern Florida Platform was dominated by marine and non-marine siliciclastics. Carbonates and evaporites covered the southern portion of the platform (McFarlan and Menes 1991; Winston 1987, 1991). During the Lower Cretaceous, carbonates and evaporites of the Ocean Reef Group, Sunniland Formation (figure 5) and associated units were deposited. The Sunniland sediments became the reservoir rocks for Florida's first oil discovery (1943) (Lloyd 1997). The thickness of the Lower Cretaceous sediments reaches more than 1830 m (6000 ft) on the northwestern and 2740 m (9000 feet) on the southern portions of the platform (Randazzo 1997).

In the early portion of the Late Cretaceous, sediments in the northern portion of the Florida Platform continued to be dominated by siliciclastics, while carbonates were being deposited in southern Florida (Sohl et al. 1991; Winston 1991). By the mid-Late Cretaceous, carbonates, including chalk, with limited siliciclastics were deposited over the entire Florida Platform (Sohl et al. 1991). The Upper Cretaceous sediments are more than 915 m (3000 feet) thick in northwestern and southern Florida (Randazzo 1997).

At the end of the Cretaceous, a large bolide (meteorite, asteroid, or comet) collided with Earth in the Gulf of Mexico–Caribbean region (Hildebrand et al. 1991). The bolide impacted at an oblique angle, spreading ejecta to the north and west (Schultz 1996). It is thought that 100 to 300-m (330 to nearly 1000 ft) high tsunamis (Bourgeois et al. 1988; Matsui et al. 1999) spread across the Gulf of Mexico (Kring 2000). Discussions with a number of geologists investigating the Chicxulub impact suggest that the Florida Platform should have been influenced by the event (Chicxulub planning meeting–Group on Mesozoic–Cenozoic stratigraphy and the Cretaceous–Tertiary (KT) boundary, Puerto Vallarta, Mexico, 1993). However, no evidence of the impact or tsunamis has been discovered on the Florida Platform to date. The lack of cores across the KT boundary, the limited number and wide distribution of wells penetrating the KT boundary, and the general poor quality of the cuttings from the wells hinder the search for evidence.

Cenozoic

Carbonate sedimentation dominated during the Paleogene and into the earliest Neogene on much of the Florida Platform. A significant change in sedimentation occurred in the early Neogene. Siliciclastic sediments began to replace carbonates as the dominant sediment.

Paleogene

Carbonate–evaporite deposition dominated much of the Florida Platform during the Paleocene (Miller 1986). The carbonate–evaporite sediments graded to the northwest into shallow marine fine-grained siliciclastic sediments across the Georgia Channel System. The main carbonate-producing area was interpreted to be rimmed by a reef system creating the restricted environment necessary for evaporite deposition (Winston 1991). The Paleocene sediments cover the entire Florida Platform and have a maximum thickness of more than 670 m (2200 ft). The thick anhydrite beds in the Cedar Keys Formation (figure 6) form the regionally extensive lower confining bed of the Floridan Aquifer System (Miller 1986, 1997).

The evaporite content of the Lower to Middle Eocene sediments declined in response to sea-level rise and resulted in the development of a more open, carbonate-ramp depositional system on the platform. Evaporites occur primarily as pore fill (Miller 1986). The carbonate sediments grade into siliciclastic sediments in the Georgia Channel System (Miller 1986). The Lower to Middle Eocene sediments cover the entire platform, ranging to maximum thickness of more than 945 m (3100 ft). Middle Eocene carbonates (Avon Park Formation) are the oldest sediments exposed on the platform (Scott et al. 2001). These sediments crop out on the crest of the Ocala Platform (figure 3). The Lower to Middle Eocene limestone and dolostone, in part, form the lower portion of the Floridan Aquifer System while, in some areas, these sediments are part of the lower confining bed of the aquifer system (Miller 1986, 1997).

Carbonate deposition covered virtually the entire Florida Platform in the Late Eocene. Carbonates were deposited to the north of the Georgia Channel System nearly to the Fall Line (limit of Cretaceous overlap), beyond the limits of the Florida Platform (figure 1). The carbonate ramp was well developed and evaporites have not been found in the limestone or dolostone. The carbonates grade into siliciclastics on the northwestern most part of the platform. Upper Eocene carbonates range in thickness to more than 213 m (700 ft) but, due to erosion, are absent in several areas of the platform (Miller 1986; Scott 1992, 2001). In a large area on the southern part of the platform, the Upper Eocene sediments are absent, probably due to erosion by currents similar to episodes identified in the Oligocene to Pliocene in this region (Guertin et al. 2000). On the areas of the platform where the Oligocene carbonates are absent, the Upper Eocene carbonates form the upper Floridan Aquifer System (Miller 1986, 1997).

Lower Oligocene carbonate deposition occurred as far updip as did the Upper Eocene deposition. The carbonates grade into siliciclastics on the northwestern most part of the platform. Very minor amounts of siliciclastics are incorporated in these carbonates. However, beds of fine quartz sand occur in the Lower Oligocene of southern Florida (Missimer 2002). Whether or not the carbonate deposition covered the platform is open to conjecture. The Lower Oligocene sediments range in thickness to more than 213m (700 ft) but are absent over large portions of the platform (Miller 1986; Scott 1992, 2001). These sediments are missing due to nondeposition or erosion, or both, in a large area on the eastern flank of the Ocala Platform in an area referred to as the paleo-Orange Island (Bryan 1991). Where the Lower Oligocene sediments are present, they form the upper portion of the Floridan Aquifer System (Miller 1986, 1997).

Chert (silicified limestone) occurs primarily in the upper portion of the Middle Eocene carbonates through the Lower Oligocene carbonates. The chert formed as the result of the weathering of the overlying clay-rich Miocene sediments that covered the platform (Scott 1988). Weathering of the clays releases large amounts of silica into the groundwater and, in the appropriate geochemical environment, replaces limestone. Groundwater beneath the present-day erosional scarp near Lake City in northern Florida is supersaturated with respect to Opal-CT and slightly saturated with respect to quartz due to weathering of the clays (S. B. Upchurch, personal communication 2005). Fossils including foraminifera and corals are often preserved in the chert.

Sea-level lowering in the Late Oligocene restricted deposition to portions of southern and northwestern Florida (Missimer 2002). Although absent over much of the platform, these

PANHANDLE			N. FLORIDA		S. FLORIDA			SERIES	SYSTEM	ERATHM	AGE (Ma)
Undifferentiated Holocene - Pleistocene Sediments			Undifferentiated Holocene - Pleistocene Sediments		Undifferentiated Sediments			Holocene	Quaternary		0.01
					Anastasia Formation	Miami Limestone	Key Largo Limestone	Pleistocene			
					Fort Thompson Formation			Pliocene			
					Bermont Beds						
Citronelle Formation	Intracoastal Formation	Miccosukee Formation	Cypresshead Formation	Nashua Formation	Caloosahatchee Formation			Pliocene	Neogene	Cenozoic	1.8
Jackson Bluff Formation		Tamiami Formation									
Pensacola Clay	Choctawhatchee Formation		Coosawhatchie & Statesville Formations		Hawthorn Group	Bone Valley Member	Hawthorn Group	Miocene			23.0
	Intracoastal Formation	Shoal River Formation									
	Bruce Creek Limestone	Oak Grove Sands	Peace River Formation								
	Chipola Formation										
Chattahoochee Formation		Penney Farms Formation		Arcadia Formation					Oligocene	Paleogene	
Chickasawhay Formation		Suwannee Limestone		Tampa Member	Nocatee Member						
Vicksburg Group				Suwannee Limestone							
Ocala Limestone		Ocala Limestone		Ocala Limestone			Eocene	55.8			
Claiborne Group		Avon Park Formation		Avon Park Formation							
Wilcox Group		Oldsmar Formation		Oldsmar Formation			Paleocene		65.5		
		Cedar Keys Formation		Cedar Keys Formation		Rebecca Shoals Dolomite					

Figure 6 – Cenozoic stratigraphic columns (modified after Braunstein et al, 1988).

sediments may exceed 135 m (440 ft) in thickness (Braunstein et al. 1988). The stratigraphic section in southern Florida may represent the most complete Upper Oligocene section in the southeastern United States (Brewster-Wingard et al. 1997). In very limited areas, the Upper Oligocene carbonates may form the top of the Floridan Aquifer System (Miller 1986, 1997).

Cross sections showing the distribution of the Paleogene sediments are shown in figure 7. A generalized geologic map of Florida is shown in figure 8. The Paleogene lithostratigraphic units occurring in the surface and shallow subsurface of the panhandle, northern, and southern portions of Florida are shown in figure 9.

Neogene–Quaternary

Significant depositional changes occurred in the latest Paleogene–earliest Neogene. Several factors were responsible for the changes including epeirogeny in the Appalachians that took a highly eroded and reduced mountain range and uplifted it (Stuckey 1965; Schlee et al. 1988). The rejuvenated mountain range again became a source of sediment due to increased erosion, and the siliciclastic sediments were transported by streams and rivers; marine currents transported the sediment southward onto the Florida Platform. Sea level rose through the Middle Miocene, began significantly fluctuating until the end of the Pleistocene, and rose in the Holocene to present sea level.

Initially, in the Early Miocene, the siliciclastics were deposited interbedded and mixed with carbonates in northern Florida while carbonates continued to dominate in southern Florida (Scott 1988). By the Middle Miocene, with continued sea-level rise, siliciclastics replaced carbonate deposition (Scott 1988; Missimer 2002). Carbonate deposition continued only in the southernmost portions of the platform, and siliciclastic sediments continued to be transported further south and, ultimately, dominated the deposition system on most of the Florida Platform by the early Pliocene. Carbonates continued to be produced but on a much more limited scale and in the late Neogene, carbonate most often occurred as matrix. Siliciclastic sediments prograded onto the southernmost portion of the platform in the Pliocene, forming the foundation for the northern half of the Florida Keys (Cunningham et al. 1998). In the Quaternary, siliciclastics dominated over much of the platform. However, in the late Quaternary, with a reduction in siliciclastic supply, carbonate deposition began to occur over portions of the southernmost peninsula.

Sediments deposited in the Miocene covered the entire platform; however, subsequent erosion and redeposition created the distributional pattern seen today (Scott et al. 2001). The initial distribution of Pliocene sediments is not known but can reasonably be inferred to have been more extensive than the present occurrence (Scott et al. 2001).

Unusual depositional environments are recorded on the Florida Platform in the late Cenozoic (Neogene) as the result of sea-level fluctuations and marine upwelling bottom waters. Major phosphorite and palygorskite deposits formed as the result of these conditions (Weaver and Beck 1977; Riggs 1979; Scott 1988; Compton 1997). The age of the phosphorites indicate that the phosphogenic environment occurred in the Early and Middle Miocene (Compton 1997). The peri-marine environments in which the palygorskite deposits formed also occurred during the Miocene in northwestern Florida (Weaver and Beck 1977). Palygorskite also formed in alkaline lakes in the western-central part of the peninsula in association with sea-level fluctuations (Upchurch et al. 1982). Associated with the alkaline lake deposits are some very interesting opaline chart deposits.

In the late Neogene and into the Quaternary, climate and depositional conditions allowed the development of extremely fossiliferous molluscan-bearing lithologic units. Some of the formations defined within the late Neogene and early Quaternary contain some of the most diverse faunas in the world. How these units formed has been a source of discussion (Allmon 1992; Scott and Allmon 1992). Due to the abundance and diversity of the molluscan fossils, paleontologists have been drawn to study these sediments for more than a century (Scott 1997). As sea level rose in the Pleistocene, sediments were deposited over that portion of the platform that is below 18.3–30.5 m (60–100 ft) above sea level. The Pleistocene sea level rose no higher than this level (Colquhoun et al. 1968). The rising sea level in the late Pleistocene and increased carbonate production on the southern portion of the platform allowed for the development of Miami Limestone (figure 6), a broad carbonate bank and oolite shoal complex, and Key Largo Limestone, the paleo-reef tract of Florida Keys. The Neogene–Quaternary sediments range in thickness from 0 to more than 914 m (3000 ft) (Miller 1986). During the last glacial stage of the Pleistocene, sea level dropped approximately 122 m (400 ft) exposing vast portions of the Florida Platform that are presently beneath marine waters of the Gulf and Atlantic Ocean. Stream and river channels that can be seen on bathymetric maps provide evidence for erosion during sea-level lowstands.

Holocene sea level rose from approximately 18 m (60 ft) depth to the present level, and 8000 to 6000 years BP-archeological sites are found offshore in the Florida Big Bend (Faught and Donoghue 1997). Davis (1997) stated that the 3000 years BP-sea level was not significantly lower than the present sea level. Davis believes that much of the present-day coastline formed during the last 3000 years as the result of the relatively stable sea-level conditions. The Florida Everglades formed during this general time frame through the deposition of mangrove peat and freshwater calcitic mud covering a broad expanse of Miami Limestone.

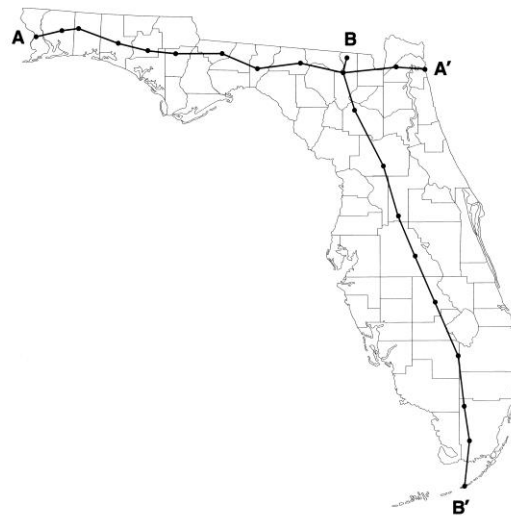


Figure 7A – Cross section locations.

Quaternary

Holocene

Qh Holocene sediments

Pleistocene/Holocene

Qal Alluvium
Qbd Beach ridge and dune
Qu Undifferentiated sediments

Pleistocene

Qa Anastasia Formation
Qk Key Largo Limestone
Qm Miami Limestone
Qtr Trail Ridge sands

Tertiary/Quaternary

Pliocene/Pleistocene

TQsu Shelly sediments of Plio-Pleistocene age
TQu Undifferentiated sediments
TQd Dunes
TQuC Reworked Cypresshead sediments

Tertiary

Pliocene

Tc Cypresshead Formation
Tci Citronelle Formation
Tmc Miccosukee Formation
Tic Intracoastal Formation
Tt Tamiami Formation
Tjb Jackson Bluff Formation

Miocene/Pliocene

Thcc Hawthorn Group, Coosawatchie Formation, Charlton Member
Thp Hawthorn Group, Peace River Formation
Thpb Hawthorn Group, Peace River Formation, Bone Valley Member

Miocene

Trm Residuum on Miocene sediments
Tab Alum Bluff Group
Th Hawthorn Group
Thc Hawthorn Group, Coosawatchie Formation
Ths Hawthorn Group, Statenville Formation
Tht Hawthorn Group, Torreya Formation
Tch Chatahoochee Formation
Tsmk St. Marks Formation

Oligocene/Miocene

Tha Hawthorn Group, Arcadia Formation
That Hawthorn Group, Arcadia Formation, Tampa Member

Oligocene

Tro Residuum on Oligocene sediments
Ts Suwannee Limestone
Tsm Suwannee Limestone - Marianna Limestone undifferentiated

Eocene

Tre Residuum on Eocene sediments
To Ocala Limestone
Tap Avon Park Formation

Figure 7B – legend for cross sections and geologic map.

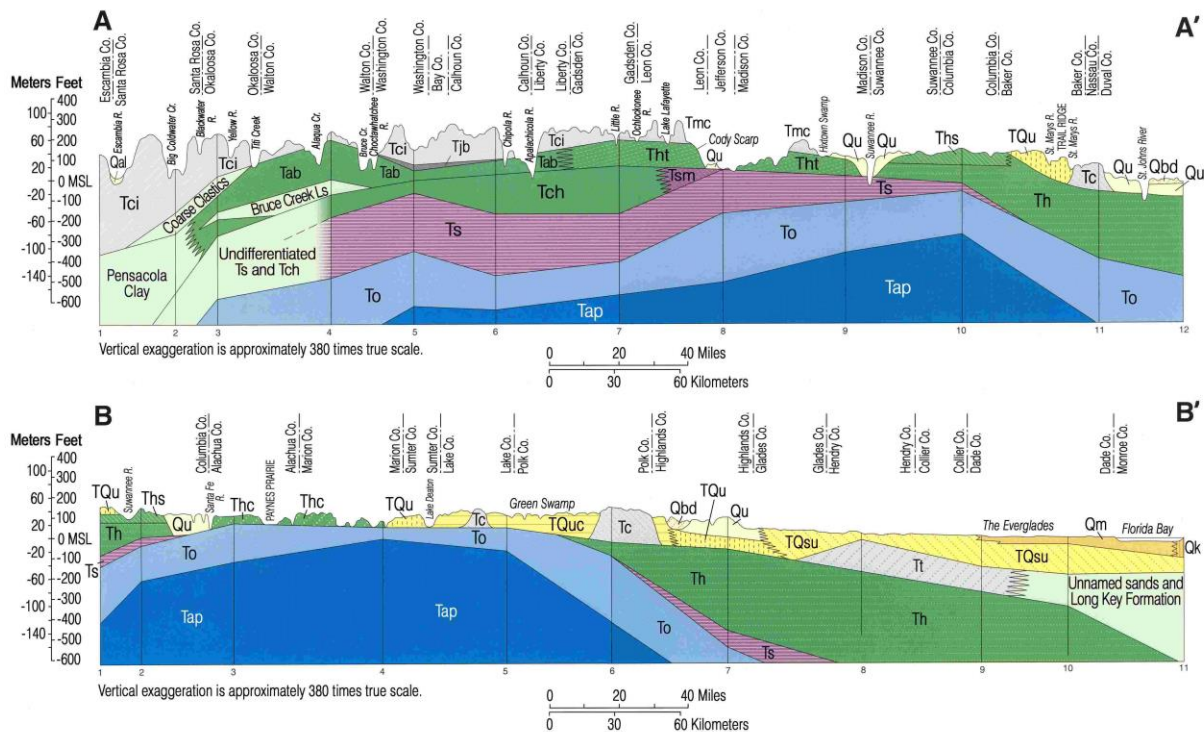
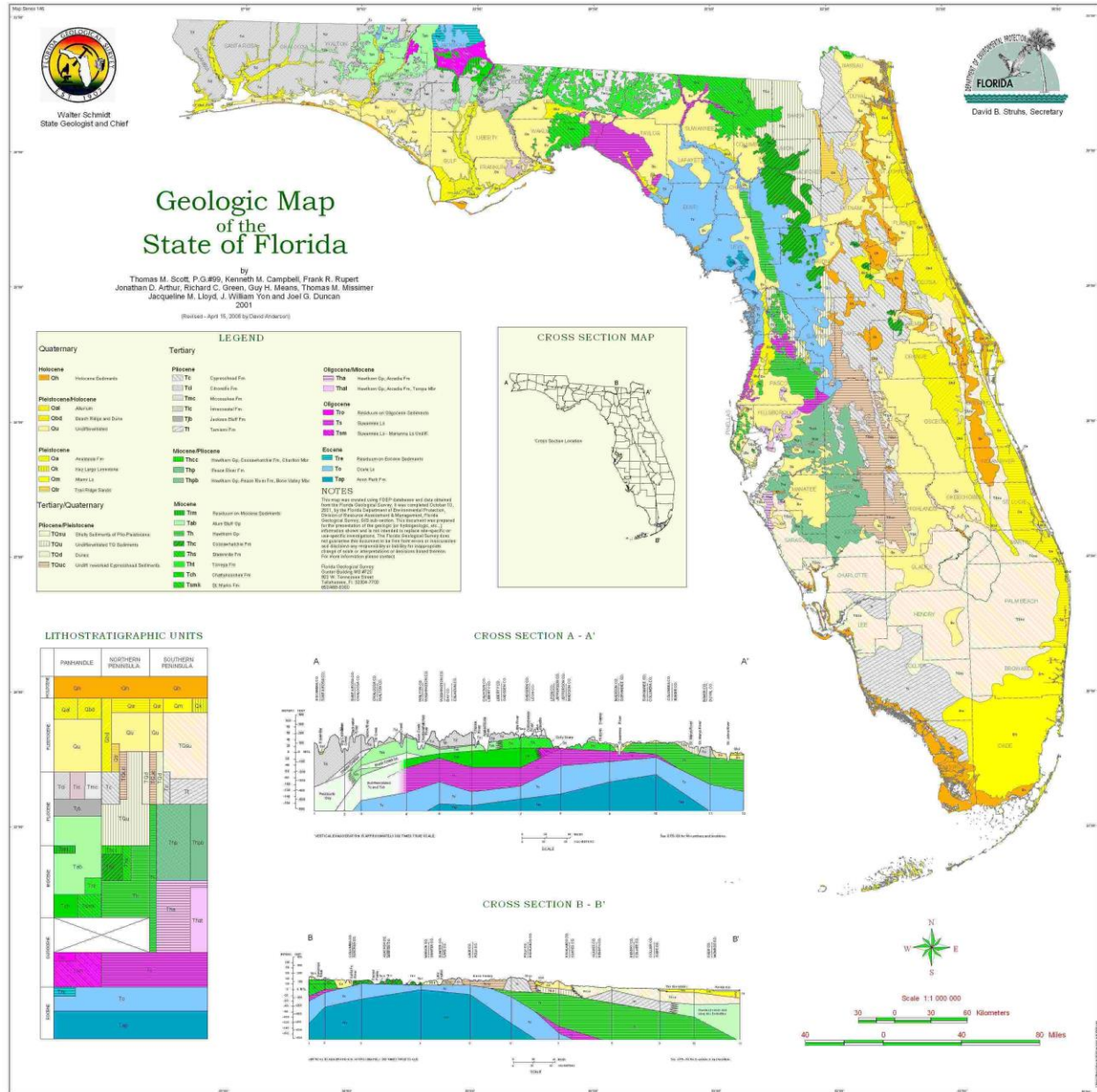


Figure 7C – Cross sections showing the shallow subsurface and surface distribution of Paleogene, Neogene and Quaternary lithostratigraphic units (Scott et al., 2001).



HYDROGEOLOGY

The Cenozoic sediments of Florida form a series of aquifer systems, which provide more than 90% of the drinking water for the state (Berndt et al. 1998). The aquifer systems are the Floridan, intermediate, and surficial (Southeastern Geological Society [SEGS] 1986; see Miller 1986 and Arthur et al. 2008 for overviews) (Figure 10).

The Floridan Aquifer System (FAS) is composed of Paleogene carbonates with highly variable permeability. This aquifer system, which is widespread in the southeastern United States, is one of the most productive aquifers in the world (Miller 1986; Berndt et al. 1998). Budd and Vacher (2004) characterize the Floridan as a multi-porosity aquifer: a fractured, porous aquifer where confined, and a karstic, fractured, porous aquifer where unconfined. The FAS occurs over the entire platform. The base of the FAS occurs in the lower Paleogene rocks where evaporites restrict the permeability (Miller 1986; SEGS 1986). The top occurs where the carbonates are overlain by impermeable sediments of the Intermediate Aquifer System or by surface sands.

The intermediate aquifer system (IAS) (referred to by the SEGS [1986] as the intermediate aquifer system/confining unit) is composed of permeable and impermeable sediments deposited during the Neogene. The siliciclastics flooding onto the Florida Platform during the Miocene and Pliocene contained an abundance of clay. Deposition of the clayey sediments on the Paleogene carbonates created an impermeable sequence of confining beds (Miller 1986, 1997). Permeable carbonate and siliciclastic sediments are, in some areas, interbedded with the impermeable units creating regionally limited water-producing zones (Miller 1986, 1997). The base of the IAS occurs at the top of the regionally extensive, permeable carbonates of the FAS (SEGS 1986). The top of the IAS is placed at the top of the laterally extensive and vertically persistent lower permeability beds (SEGS 1986). The IAS is absent over much of the Ocala Platform.

The surficial aquifer system (SAS) is composed of late Pliocene through the Pleistocene–Holocene, permeable siliciclastic and carbonate sediments with some zones of more clayey, less-permeable sediments (Berndt et al. 1998). In two areas of the state, the SAS is particularly important since the FAS does not contain potable water. In these areas, the westernmost panhandle and southeastern peninsula, the SAS is the primary source of drinking water. In the western panhandle, the SAS is a thick sequence (up to 152 m [500 ft]) of siliciclastic sediments (Sand and Gravel Aquifer). In the southeastern peninsula, the SAS is made of very permeable, interbedded carbonates and siliciclastics, which underlie some of the largest metropolitan areas in Florida (Biscayne Aquifer). The base of the SAS occurs at the top of the laterally extensive and vertically persistent lower-permeability beds (SEGS 1986). The SAS is generally absent on the Ocala Platform.

GEOMORPHOLOGY

The Florida Platform extends southward from the continental United States separating the Gulf of Mexico from the Atlantic Ocean. The exposed portion of the platform, the Florida Peninsula, constitutes approximately one-half of the Florida Platform measured between the 200-m (600 ft) depth contour of the continental shelves. The axis of the platform extends northwest to southeast approximately along the present-day west coast of the peninsula. The Florida Peninsula, from the St. Mary's River to Key West, measures nearly 725 km (450 mi). From the Alabama–Florida line to the Atlantic coastline is approximately 595 km (370 mi).

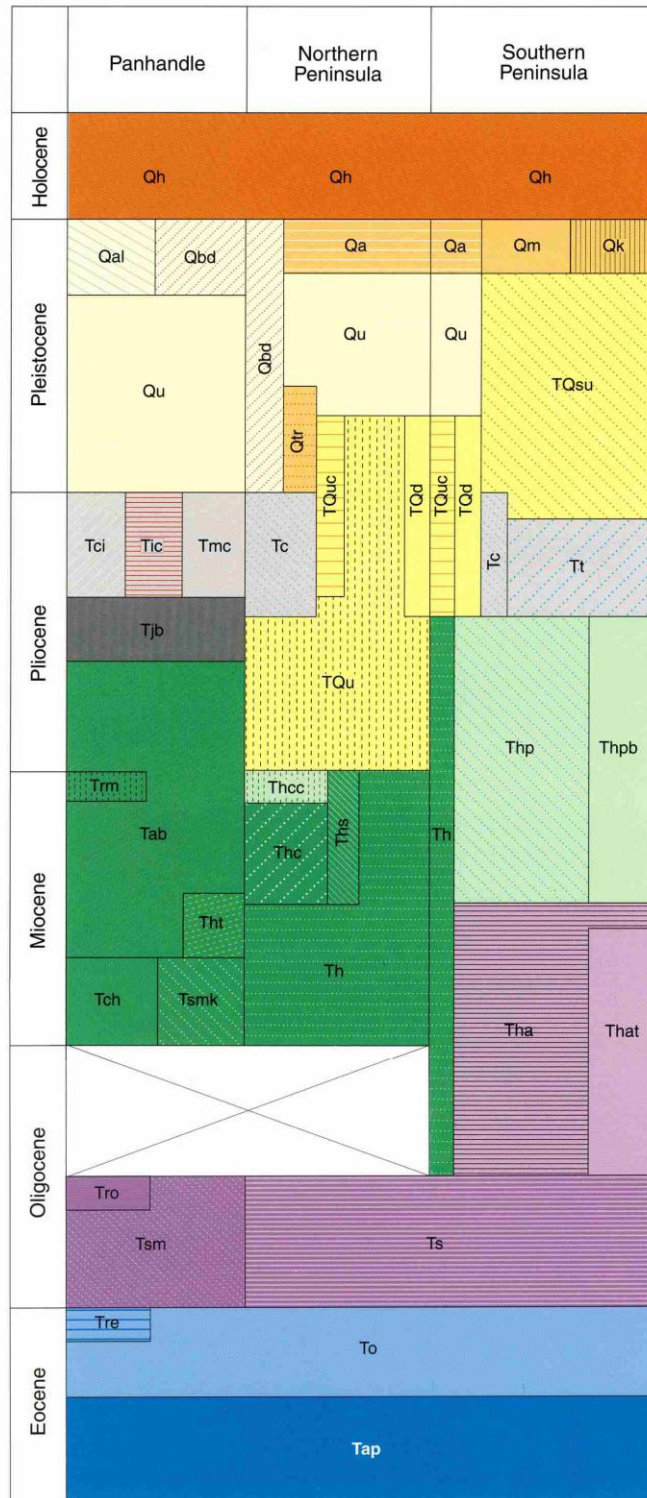


Figure 9 – Paleogene to Quaternary stratigraphic chart of Florida showing the lithostratigraphic units occurring in the shallow subsurface and at the surface (Scott et al., 2001).

SYSTEM	SERIES	PANHANDLE FLORIDA		NORTHERN FLORIDA		SOUTHERN FLORIDA	
		FORMATION	HYDROSTRATIGRAPHIC UNIT	FORMATION	HYDROSTRATIGRAPHIC UNIT	FORMATION	HYDROSTRATIGRAPHIC UNIT
QUATERNARY	HOLOCENE	Undifferentiated sediments	sand and gravel aquifer	Undifferentiated sediments Anastasia Formation	surficial aquifer system	Undifferentiated sediments Miami Limestone Key Largo Limestone Anastasia Formation	surficial aquifer system
	PLEISTOCENE						
TERTIARY	PLIOCENE	Citronelle Formation Miccosukee Formation Jackson Bluff Formation Intracoastal Formation Alum Bluff Group Coarse Clastics	intermediate aquifer system or intermediate confining unit	Undifferentiated sediments Miccosukee Formation Cypresshead Formation	intermediate aquifer system or intermediate confining unit	Undifferentiated sediments Tamiami Formation Long Key Formation Hawthorn Group	intermediate aquifer system or intermediate confining unit
		Coarse Clastics Alum Bluff Group Pensacola Clay Intracoastal Formation Hawthorn Group Chipola Formation Bruce Creek Limestone St. Marks Formation Chattahoochee Formation					
	MIOCENE	Bucatanua Clay Chickasawhay Limestone Marianna Limestone Suwannee Limestone	Floridan aquifer system	Hawthorn Group	Floridan aquifer system	Hawthorn Group	Floridan aquifer system
	OLIGOCENE	Ocala Limestone Avon Park Formation Lisbon Formation Tallahatta Formation Claiborne Group Undiff.	undifferentiated aquifer systems and confining units	Suwannee Limestone	undifferentiated aquifer systems and confining units	Suwannee Limestone	undifferentiated aquifer systems and confining units
	EOCENE	Wilcox Group Midway Group					
	PALEOCENE	Undifferentiated					
CRETACEOUS AND OLDER							

Figure 10 – Hydrostratigraphic nomenclature chart (modified from SEGS, 1986).

Florida lies entirely within the Coastal Plain Physiographic Province as defined by Fenneman (1938) and is the only state in the United States that falls completely within the Coastal Plain. Much of the surface of Florida shows the influence of the marine processes that transported and deposited the later Tertiary, Quaternary, and Holocene sediments. Fluvial processes, although more important in the panhandle, have helped sculpt the entire state, particularly during the lowstands of sea level, redistributing the marine sediments.

Karst processes have had a dramatic effect on the Florida landscape due to the near-surface occurrence of soluble carbonate rocks. Middle Eocene to Pleistocene carbonate sediments are affected by karstification over large areas of the state. Siliciclastic sediments, ranging in thickness from a 1 m (3 ft) to more than 61 m (200 ft), overlie the karstified carbonates.

More than 700 springs are recognized in Florida with the major springs occurring within the karstic areas of the state (Scott et al. 2004). The vast majority of the springs are located in the Ocala Karst District, the Central Lake District, and the Dougherty Karst Plain District (Scott unpublished).

The general geomorphology of the Florida consists of east–west trending highlands in the northern and western portions of the state and north–south trending highlands extending approximately two-thirds the length of the peninsula. Coastal lowlands occur between the highlands and the coastline that wraps around the entire state. The highest point in the state, 105 m (345 ft) above sea level, occurs in the Western Highlands near the Alabama–Florida state line

in Walton County. There are several hilltops in the Central Highlands that exceed 91 m (300 ft) msl in elevation. Florida has the distinction of having the lowest high point of any state in the United States.

White et al. (1964) and White (1958, 1970) delineated the geomorphic subdivisions that most geologists working in the state recognize (see Schmidt 1997 for a review). Scott is creating a new geomorphic map of the state (unpublished).

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Karst Features in Citrus County, Florida

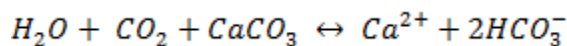
By

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SDII Global Corporation

Introduction

As noted by Scott et al. (this volume), Citrus County is located within the Ocala Karst District. Karst is a Serbo-Croatian term for a dry landscape created by the dissolution of limestone and similar strata. While Florida is not dry, many areas of the Ocala Karst District are internally drained. In that sense, Florida karst, too, is an area with little surface water. The term karst is applied to a series of landforms developed by the dissolution of carbonate rocks and, in many cases, re-precipitation of carbonate minerals as secondary cements and void fillings.

The process of karst development can be described by the following equation, which uses dissolution of calcite in limestone as an example.



Water and carbon dioxide combine in the atmosphere and soils to form carbonic acid (H_2CO_3), which dissociates to H^+ and HCO_3^- . It is the hydrogen that causes dissolution.

Dissolution drives the equation to the right, with rock (calcite) being dissolved and dissolved calcium and bicarbonate being added to the water. If the equation is at chemical equilibrium, it is fully saturated with respect to calcite and neither dissolution nor precipitation can occur. If, however, the equation goes to the left, the calcite precipitates and water and carbon dioxide are released. The mineral precipitation process is caused by removal of water or carbon dioxide from the solution.

Karst Erosional Features

Karst erosional features are common throughout Citrus County, and many will be observed in the Lecanto and Maylen quarries. Dolomite is substantially less soluble than calcite, so karst features are rare in the dolostones of the Avon Park Formation. If the Red Level Quarry were to be drained, you might see textural and structural evidence of dolomitization and development of cements within the dolomite sediment, but little or no true karst.

Sinkholes, Uvalas, and Poljes

On a large scale, the features commonly associated with karst abound in Citrus County. Perhaps the most notorious karst features are sinkholes, or dolines. Sinkholes (Figure 1) range from simple, nearly conical depressions to complex shapes caused by coalescence of multiple sinkholes into one depression. The latter, coalescent sinkholes are known as uvalas in karst terminology (White, 1988; Ford and Williams, 1989). The arrow in Figure 1 illustrates an hour-glass-shaped uvala near the center of the map. If the coalescent sinkhole complex becomes filled

with lacustrine or wetland sediments so that it has a flat floor, it is known as a polje. Lake Tsala Apopka, which is located on the eastern county line, is an example of a polje.

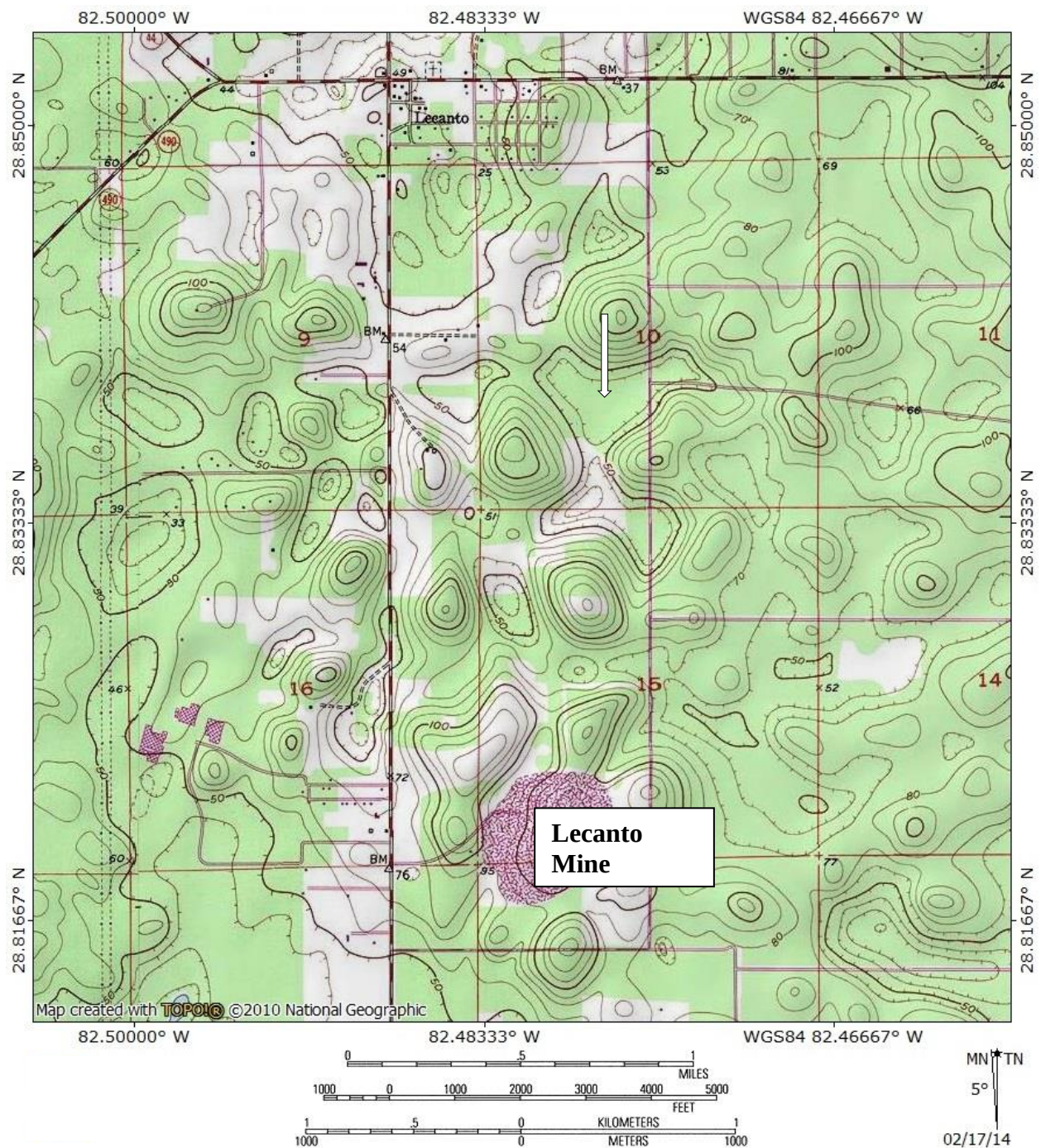


Figure 1 – Topographic map of the Lecanto area of Citrus County. Note the well-developed closed depressions (sinkholes) and conical hills.

Conical Hills

Between the sinkholes there are well-developed conical hills (Figure 1). In the Lecanto area, these are remnants of the upland portions of the Brooksville Ridge. Conical hills are a common landform in tropical karst areas (White, 1988; Ford and Williams, 1989). Well-developed conical hills are uncommon in the karst terrains of Florida, but they are very well developed in the Lecanto area.

Other karst erosional features you will see in the quarries include openings caused by dissolution of rock that range in size from vugs to caverns, epikarst, in-filled sinkholes, fractures, and pinnacles.

Vugs and Caverns

Vugs and caverns are common in the Lecanto and Maylen quarries (Figures 2 and 3). They may, or may not be filled with sediment or cave decorations (flowstone, stalactites, and stalagmites). Figure 2 illustrates a cavern that has been open at the Maylen Quarry for many years. If water actively flows through a cavern, the turbulent flow often causes fluted and scalloped surfaces on the cavern walls (Figure 3). Curl (1974) developed a way to estimate the flow velocity based on scallop measurements in caves.



Figure 2 – A small cavern on the west wall of the Maylen Quarry (photograph by S. Upchurch).



Figure 3 – Interior of a cavern exposed in the 1990s in the Lecanto Quarry. Note the fluting and scalloping of the cave walls (photograph by S. Upchurch).

Epikarst

Epikarst is a term applied by karst scientists to the upper-most horizon of a limestone or dolostone stratum that has been subjected to weathering. The epikarst horizon includes a number of artifacts of dissolution and, where precipitation and water-table fluctuations are seasonal, reprecipitation of calcium carbonate. Some artifacts of epikarst development include development of highly permeable rubble zones, voids at the water table, variability in the amount of dissolution and/or precipitation and recrystallization of the carbonate materials, variability in

the thickness of the weathered zone, variability of the elevation of the upper surface of the carbonate rock, including pinnacles, depressions; and mixing of the underlying carbonate material with the sediments that overlie the epikarst if it is covered (Klimchouk, 2004).

Figure 4 shows an excellent example of epikarst development. This quarry face was cut into the Lower Oligocene Suwannee Limestone at the Vulcan Mine, northwest of Brooksville, in Hernando County. Here, the epikarst consists of two horizons: an upper rubbly and soft zone and a lower, relatively soft zone with caverns and somewhat enhanced porosity. Note that there are two elevations with small voids developed in a more-or-less planar configuration. These formed by dissolution of the limestone at two different positions of the water table.

The pore space in the rubble zone and in the cavern is filled by greenish clay derived from the overlying Hawthorn Group sediments. The fact that these clay-rich sediments are green suggests that the clay entered the cavern and porosity of the rubble zone during Hawthorn time or shortly thereafter. If they were being introduced today, the colors would be reddish owing to oxidation of the ferrous iron in the smectite clay. Some of the reddish tint in the upper rubble zone is caused by infiltration of ferric hydroxide and weathered clay into the pore space of the rubble in more recent times. Epikarst is moderate- to well-developed in both the Maylen and Lecanto quarries. Look for rubble zones near the top of the rock.

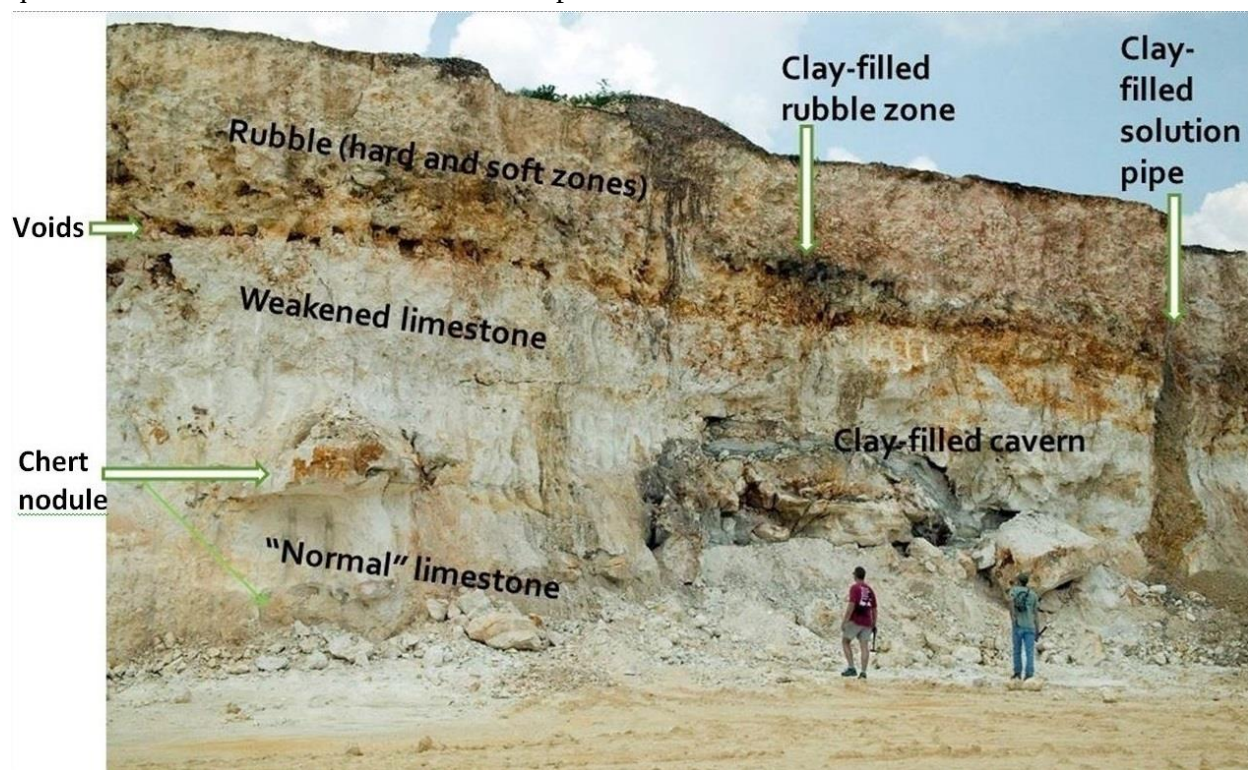


Figure 4 – Example of epikarst features exposed in the Vulcan Mine, near Brooksville, Hernando County (photograph by T. Scott).

In-Filled Sinkholes

In-filled sinkholes are common sights at both the Maylen and Lecanto quarries (Figure 5). Look for depressions in the upper rock surface and the presence of rubble and clayey sand with reddish coloration. It is common to see large blocks of limestone that have fallen into the depression in

the limestone, and clayey and sandy sediments and soils derived from the Hawthorn Group residuum and Pleistocene dune/marine terrace sand fill the depressions.

Pinnacles and Cutters

The upper surface of epikarstic carbonate rock is commonly sculpted by running water and differential dissolution. The features, known as karren, developed on the upper surface vary in geometry and orientation (White, 1988; Ford and Williams, 1989) depending on how infiltrating water flows over, and into, the underlying rock. In Florida, most forms of karren are rare or absent because the limestones have high porosity and water infiltrates into the rock rather than



Figure 5 – Infilled sinkhole on the west wall of the Maylen Quarry (photograph by S. Upchurch).

flowing across the upper surface.

One form of karren, pinnacles and cutters, is widespread, however. This is because they are formed by water infiltrating into the limestone and differentially dissolving away portions of the rock. Pinnacles are the positive features that remain after the limestone has been dissolved away. The adjacent, low areas are known as cutters. Pinnacles are well documented throughout the Ocala Karst District. They are best observed in quarries, but they are commonly encountered when drilling, as well. Pinnacles as high as 40 to 50 feet are known.

The pinnacles shown in Figure 6 have been emphasized by the quarrying process. They are well lithified and quarrying has excavated the softer limestone adjacent to them. Not all pinnacles are so well cemented, but they commonly do exhibit different hardness and penetration resistance than the intervening limestone and siliciclastic fill.



Figure 6 – Pinnacles in the Ocala Limestone on the east wall of the Maylen Quarry (photograph by S. Upchurch),

Fractures

While fractures are not true karst features, they play an important role in karst development. Fractures in Florida are joints and cracks in the rock caused by minor tectonic and earth-tide stresses. Since they are cracks, water can differentially flow through them and cause dissolution of the adjacent rock, which is a karst process. Figure 7 is an example of fractures in the Ocala Limestone at the Lecanto Quarry that have been enlarged by dissolution. Note that the fractures are essentially straight up and down, a common vertical orientation for joints and fractures. Spatially, Florida fractures occur in sets with northeast-southwest and northwest-southeast axial orientations. An often less well developed, north-south set is commonly observed, as well. There was a prominent fracture that extended through the Lecanto Quarry in an almost north-south orientation prior to today's extensive quarrying. Wood and Stewart (1985) used this fracture to study the geophysical properties of fracture traces in Florida. Their study area was located on the Crystal River Quarries, Inc. property just south of the quarry and centered on the



Figure 7 – Fractures spaced about a meter apart from the Lecanto Quarry (photograph by S. Upchurch).

fracture as it was exposed in the quarry. The fracturing shown in Figure 7 was part of that large fracture trace.

Springs

Finally, springs are an important karst feature in Citrus County. Several first magnitude (mean discharge > 100 cubic feet per second) and many smaller springs are located within Citrus County. The first magnitude springs include the spring group complex located in and near Kings Bay (Jones and Upchurch, 1994) and Chassahowitzka, and Homosassa springs south of the community of Crystal River (Jones et al., 1977).

The springs themselves are former sinkholes connected to springsheds that originally developed when sea level was lower. Today, these springs drain most of Citrus County. Recharge to the springsheds is through the closed depressions in the interior of the county and from the Withlacoochee River along the county line to the east.

Karst Depositional Features

The Lecanto and Maylen quarries are locally famous for calcite crystals, which are represented in museum mineral collections worldwide. In recent years, quarrying has moved into strata where calcite crystals are uncommon, and collecting has been poor, but in the 1970s and 80s, collecting was spectacular. On our field trip, you will have the opportunity to see thin crusts of calcite crystals and, perhaps, some flow stone. Coarse crystals are also present, so keep your eyes open!

There are at least two mechanisms that cause the chemical reaction discussed above to move to the left. You will see examples of the products of each of these two processes (carbon dioxide degassing and water evaporation) on the trip.



Figure 8 - Calcite specimen from west-central Florida showing well-crystallized, limpid crystals (from the collection of T. Scott).

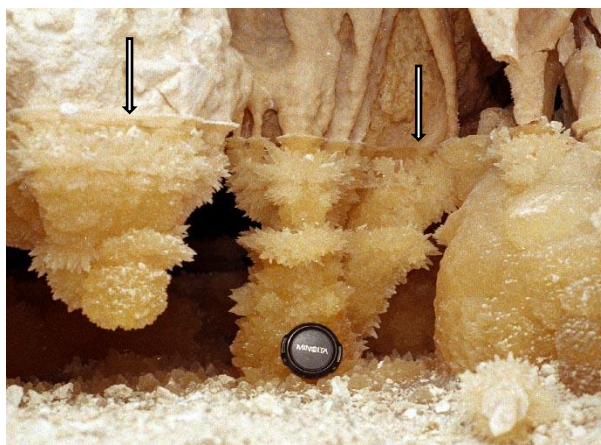


Figure 9 - Calcite crystals formed at the water table in limestone, west-central Florida (photograph by T. Scott).

If calcium-bicarbonate-rich water enters a (1) cavern or the vadose (unsaturated) zone or (2) a spring (Starks, 1986), where pressures are being released, carbon dioxide gas may escape and cause precipitation of clear, well crystallized calcite (Figure 8). This process is slow and provides time for crystallization of the clear, well-formed crystals. Figure 9 shows the effects of

carbon dioxide degassing at the water table. Note that above the position of an ancient water table (arrows, Figure 9), the calcite is in the form of flowstone draperies. Below the old water-table position, well-formed crystals have developed. The flowstone draperies formed by water evaporation, which happens quickly and does not allow for the development of well-formed crystals. Normally, during evaporation, the calcite crystals are bundles of fiber-shaped crystals or equant grains of calcite. Below the water table, crystals formed because degassing of carbon dioxide from the water caused calcite precipitation.

Summary

There are few locations in Florida where one can observe the results of dolomitization and karstification.

In the Red Level Mine you will see dolostone dredged from the Middle Eocene Avon Park Formation. Look for massive dolostone, sucrosic dolostone, moldic dolostone, and rare nodules of silt-sized dolomite cemented by calcite. Some of the latter have crude calcite crystal shapes. Plant fossils will be very evident as black to dark gray inclusions within the dolomite.

At the Maylen Pit you will see epikarst, pinnacles, caves, and in-filled sinkholes. Calcite crystals and flowstone are also present.

At the Lecanto Mine you will see the same, plus Avon Park dolostone and the more massive lower Ocala Limestone. Look for crusts and weathering surfaces exposed in rocks from the epikarst.

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Surficial Geology of Citrus County, Florida

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GEOLOGY

The Crystal River Quarries, Inc. mines, which are located in Citrus County, Florida, produce limestone and dolostone mined from the Middle Eocene Avon Park Formation (Red Level mine) and the Upper Eocene Ocala Limestone (Maylen and Lecanto mines) (Figure 1). Occasional remnants of the Lower Oligocene Suwannee Limestone occur in the Maylen and Lecanto mines. The Suwannee Limestone is overlain by undifferentiated sediments consisting of weathered remnants of the Miocene Hawthorn Group and younger sediments, including dune sands.

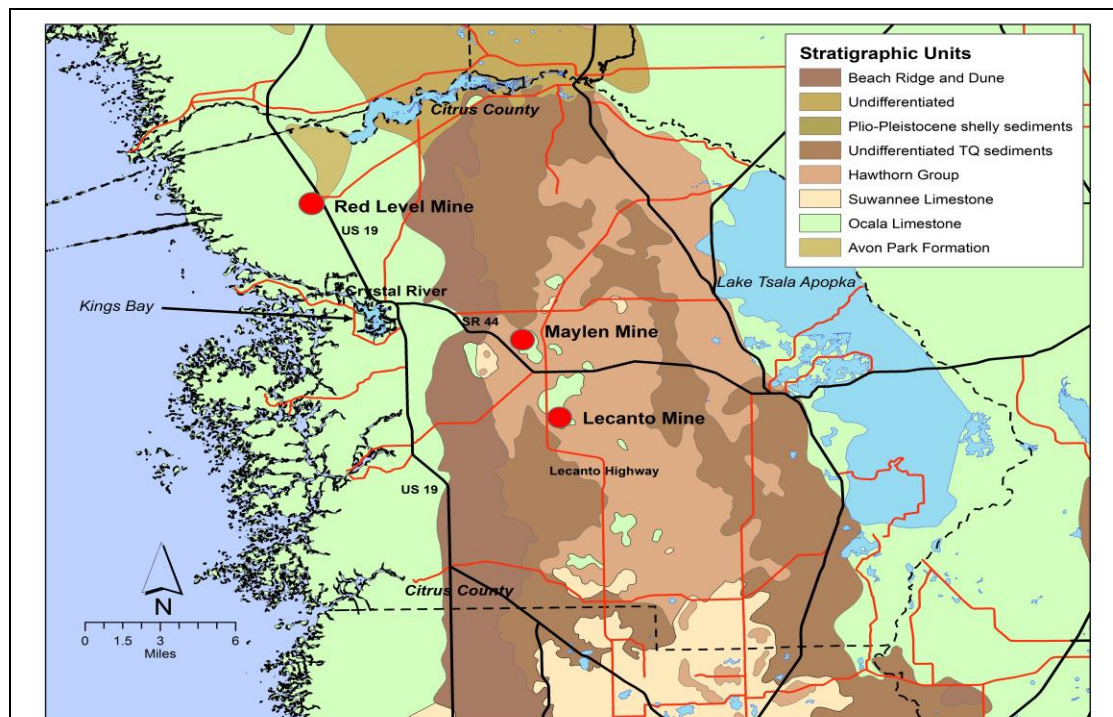


Figure 1 – Locations of the Red Level, Maylen, and Lecanto quarries, Citrus County, Florida.



Figure 2 – Views of the Red Level Quarry in northern Citrus County (see Figure 1).
Photographs by S. Upchurch

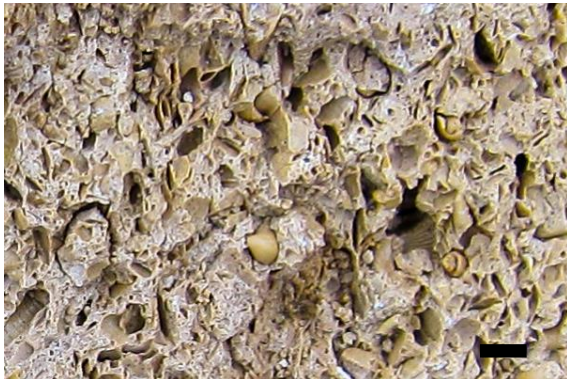


Figure 3 – Vuggy, moldic dolostone, Red Level Mine. Scale is 1 cm. Photograph by S. Upchurch.



Figure 4 – Fine-grained, sucrosic dolostone with abundant, carbonized plant fossils, Red Level Mine. Scale is 1 cm. Photograph by S. Upchurch.

Middle Eocene - Avon Park Formation

The Middle Eocene Avon Park Formation was originally described by Applin and Applin (1944). In their description they identify a distinctive microfaunal unit that underlies the Ocala limestone and proposed the name Avon Park limestone. They also described and named the Lake City limestone which the Avon Park limestone rests directly on (Applin and Applin, 1944). Since the original description of these units was based on fossil assemblages and on limited well coverage, Miller (1986) proposed abandoning the Lake City limestone terminology and incorporating all of the cream to brown pelletal limestone and interbedded brown to cream dolomite of middle Eocene age in peninsular Florida and southern Georgia into the Avon Park Formation. Miller also proposed a reference section for the Avon Park Formation as being the interval between 221 and 1,190 feet below land surface in the Coastal Petroleum Company Number 1 Ragland well (FGS W# 1537).

The Avon Park Formation consists of cream to tan colored soft to well indurated, pelletal and micritic limestone and dolostone (Miller, 1986). In Citrus and Levy counties Vernon (1951) recognized three general lithologic types within the Avon Park Formation including: 1) a cream to brown, highly fossiliferous, moldic limestone that weathers to white and purple tinted hues; 2) a cream to brown, pasty and fragmental peat-flecked and seamed fossiliferous limestone; and 3) tan to brown, thin-bedded and laminated, very finely crystalline marine dolomite.

The Avon Park Formation is underlain by the Lower Eocene Oldsmar Formation and is overlain by the Upper Eocene Ocala Limestone. In cores and cuttings it is sometimes difficult to distinguish between the overlying and underlying units and the distinctive fossil fauna becomes an important diagnostic tool. Although the fossil fauna is not an accepted method for recognizing lithostratigraphic units, the Avon Park Formation does contain a number of index fossils that aid in its identification. The cone-shaped foraminifer *Cushmania americana* (Cushman, 1919) and the small echinoid *Neolaganum dalli* (Twitchell, 1915) are found only in the Avon Park Formation (Figure 5). Other fossils found in the Avon Park Formation include carbonized plants (fossil sea grass and leaves), echinoids, mollusks, foraminifera, ostracods and algae.

The environment of deposition for the Avon Park Formation has been interpreted to be a mix of nearshore, supratidal to shallow subtidal marine environments. The presence of terrestrial leaf fossils suggests that the Avon Park Formation was deposited in close proximity to a shoreline and may represent a time when sea levels were low enough for land to be exposed on the Florida Platform for the first time in the Paleogene. In the lower part of the Avon Park Formation gypsum becomes an accessory mineral and is evidence for deposition in a tidal flat or another restricted marine environment conducive to the deposition of evaporite minerals. This may have also facilitated the deposition of dolomite which is commonly found in the Avon Park Formation.

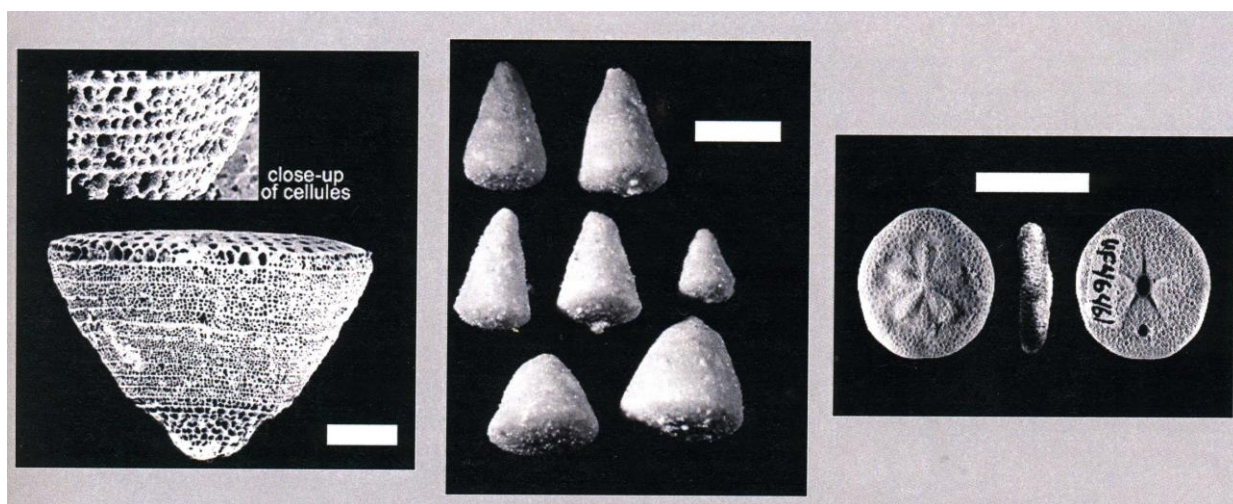


Figure 5 – *Cushmania americana* and *Neolaganum dalli* from the Avon Park Formation. Courtesy of FLMNH.

Upper Eocene - Ocala Limestone

Dall and Harris (1892) referred to the limestones exposed near Ocala, Marion County, in central peninsular Florida as the Ocala Limestone. Puri (1953, 1957) elevated the Ocala Limestone to group status recognizing its component formations on the basis of foraminiferal faunas (biozones). Scott (1991) reduced the Ocala Group to formational status in accordance with the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983).

The Ocala Limestone (Figure 6) consists of nearly pure limestones (Figure 7) and occasional dolostones. It can be subdivided into lower and upper facies on the basis of lithology. The lower facies (Figure 8) is composed of a white to cream-colored, fine to medium grained, poorly to moderately indurated, very fossiliferous limestone (grainstone and packstone).

	
Figure 6 – Exposure of the Ocala Limestone in the Maylen Mine. Note the karst features. Photograph by S. Upchurch.	Figure 7 – Massive, hard Ocala Limestone with vuggy porosity partly filled with flowstone at the Lecanto Quarry. Scale is 10 cm. Photograph by S. Upchurch.

The lower facies may not be present throughout the areal extent of the Ocala Limestone and may be partially to completely dolomitized in some regions (Miller, 1986). The upper facies is a white, poorly to well indurated, poorly sorted, very fossiliferous limestone (grainstone, packstone and wackestone). Silicified limestone is common in the upper facies (Figure 9).

	
Figure 8 – Lower facies of the Ocala Limestone exposed in the Lecanto Quarry. Photograph by S. Upchurch.	Figure 9 – Chert nodule consisting of Ocala Limestone that has been replaced by microcrystalline quartz in the Maylen Quarry. Photograph by S. Upchurch.

Fossils present in the Ocala Limestone include abundant large and smaller foraminifers, echinoids, bryozoans and mollusks. The large foraminifera *Lepidocyclina* sp. is abundant in the upper facies and extremely limited in the lower facies. The presence of these large foraminifers in the upper facies is quite distinctive.

The Ocala Limestone is at or near the surface within the Ocala Karst District in the west-central to northwestern peninsula and within the Dougherty Plain District in the north-central panhandle (Figure 10; Scott et al., 2005, in preparation). In these areas, the Ocala Limestone exhibits extensive karstification. These karst features often have tens of feet (meters) of relief, dramatically influencing the topography of the Ocala Karst District and the Dougherty Plain District (Scott, in preparation). Numerous disappearing streams and springs occur within these areas.

The permeable, highly transmissive carbonates of the upper Ocala Limestone form an important part of the FAS in north and central. It is one of the most permeable rock units in the FAS in these areas (Miller, 1986).

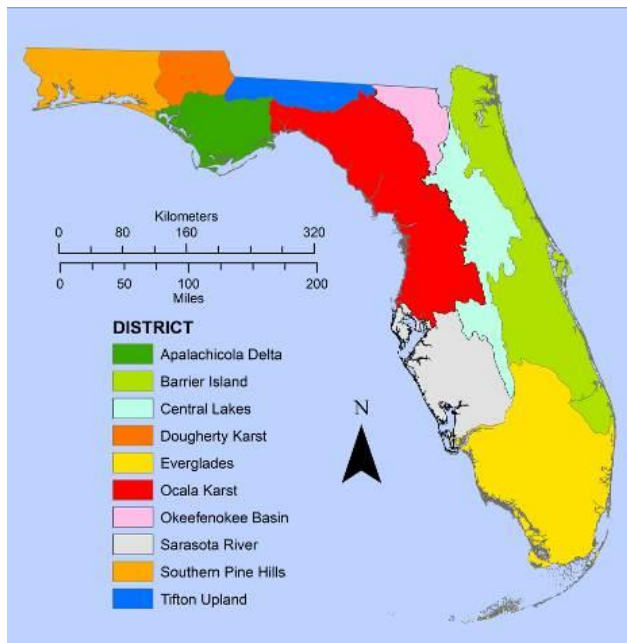


Figure 10 – Geomorphic districts in Florida (Scott, 2005; Scott et al., in preparation)

Lower Oligocene - Suwannee Limestone

Lower Oligocene carbonates crop out on the northwestern, northeastern and southwestern flanks of the Ocala Platform. The Suwannee Limestone is absent from the eastern side of the Ocala Platform due to erosion, nondeposition or both, an area referred to as Orange Island (Bryan, 1991).

The Suwannee Limestone, originally named by Cooke and Mansfield (1936), consists of a white to cream, poorly to well indurated, fossiliferous, vuggy to moldic limestone (grainstone and packstone). The dolomitized parts of the Suwannee Limestone are gray, tan, light brown to moderate brown, moderately to well indurated, finely to coarsely crystalline, dolostone with limited occurrences of fossiliferous (molds and casts) beds. Silicified limestone is common in Suwannee Limestone. Fossils present in the Suwannee Limestone include mollusks, foraminifers, corals and echinoids. Chert is very common in the Suwannee Limestone.

The Suwannee Limestone is at or near the surface within the Ocala Karst District (Figure 10) in the west-central to northwestern peninsula and within the Dougherty Plain District in the north-central panhandle (Scott, 2005; Scott et al., in preparation). In these areas, the Suwannee Limestone exhibits extensive karstification. These karst features often have tens of feet (meters) of relief, dramatically influencing the topography of the Ocala Karst District and the Dougherty

Plain District (Scott, in preparation). Numerous disappearing streams and springs occur within these areas.

The permeable, highly transmissive carbonates of the Suwannee Limestone form an important part of the FAS. It is one of the most permeable rock units in the FAS (Miller, 1986).

Miocene and Younger – Undifferentiated Sediments

These sediments consists of reddish brown to orangish, variably sandy clay and clayey sand with inclusions of variably fossiliferous, silicified limestone and silicified nodules. In part, these sediments are a residuum of Hawthorn Group sediments that once blanketed this area. Younger sediments include gray to tan unconsolidated fine to medium-grained dune sands.

KARST FEATURES

Karst features are very common in the Maylen and Lecanto mines. Numerous caves and cavities can be seen throughout the quarries (Figures 6, 7, 8, 11 and 12). See Upchurch, this volume for a discussion of the karst features you will observe in the quarries.



Figure 11 – Karst features Maylen Quarry (photograph by T. Scott).



Figure 12 – Cave in Lecanto Quarry (photograph by T. Scott).

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