Southeastern Geological Society
Field Trip Guidebook 44

Geomorphic Influence of Scarps in the Suwannee River Basin

May 7, 2005

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Field Trip Guidebook 44
Spring Field Trip
May 7, 2005

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Introduction/Acknowledgements

The purpose of the field trip is to discuss the influences that scarps have had on the residents of the Suwannee River Basin. These scarps influence both ground- and surface-water quality, as well as biology. They were important in the development of the area by Native Americans and European pioneers, and even today they have a significant influence on land use patterns and the local economy.

In 1981, the SEGS sponsored a field trip in the same general vicinity as this one. However, that trip focused on the dry segment of the Alapaha River and many karst features in Hamilton County. During that field trip, attendees were informed of the significance of the Cody Scarp on the Hydrogeology of North Central Florida (Ceryak, 1981). In 1996, a second SEGS field trip was conducted in the Suwannee River Basin. At that time we were informed of the significance of the Cody Scarp on the interactions of ground- and surface water (Davis, and Winkler, 1996). During this field trip, we will again discuss the Cody Scarp, but will also discuss how other, smaller scarps also influence the lives of local inhabitants.

This trip would not be possible without the assistance of many individuals. I want to acknowledge each of the speakers and contributors to this guidebook. They are in alphabetical order, are Ron Ceryak with the Suwannee River Water Management District (SRWMD), Brian Katz with the U.S. Geological Survey, Brian Kauffman with the SRWMD Joe King with the Florida Department of Environmental Protection, Harley Means with the Florida Geological Survey (FGS), Tom Mirti with the SRWMD, Tom Scott with the FGS, Sam Upchurch with SDII-Global Inc., and to Warren Zwanka with the SRWMD. In addition I would like to thank the management of the SRWMD for kindly allowing the SEGS to use their equipment and staff time, which were both necessary, and to the land owners who have allowed us access to their land. I would also like to acknowledge David Anderson and Paula Polson of the FGS for assistance with the figures.

Rick Copeland,
Tallahassee, FL
May 2005

Field Trip Overview

Friday, May 6

Activities will begin with a social hour at Camp Weed (Figure 1). The social hour will begin at 5:30 PM. At 7:00 each attendant will be treated to a sit down dinner.

After dinner, Rick Copeland (FGS) will give a brief introduction regarding the significance of scarps and how they affect the residents of the Suwannee River Basin. After the introduction, Tom Scott (Assistant State Geologist, FGS) will discuss the latest revisions to the State of Florida Geomorphic map. Ron Ceryak (SRWMD) will discuss the significance of the Cody Scarp on the hydrogeology of the area. Sam Upchurch (SDII Global Inc.) will then discuss aspects of the geomporhic evolution of the Cody Scarp. Tom Mirti (SRWMD) will discuss the water budget of a local swamp that is bordered by a “scarplet” (microscarp). Finally, Rick Copeland will discuss the significance of a “scarplet” in the western portion of the SRWMD.

Saturday, May 7

Beginning at 9:00 AM, participants will leave Camp Weed. From Camp Weed they will travel to Lake Louise, and then immediately to Lowe Lake. Both lakes are located in a topographically high area of the Alachua Karst Hills (formerly the Lake City Ridge). Joe King (Florida Department of Environmental Protection) will discuss the differences in chemistry and biology in the lakes above and below the Cody Scarp.

From Lowe Lake, participants will travel about 16 miles south to Little River Sink. This is a steep-sided collapse sink near the toe of the Cody Scarp. Attendees will be able to observe the Little River entering a swallet. Harley Means (Florida Geological Survey) will discuss the progress the FGS is having in mapping swallets around the state. Brian Katz (U.S. Geological Survey) will discuss aspects of ground- and surface-water interactions along the scarp, and the differences in water quality.

From Little River Sink, they will travel about 10 miles to Little River Spring. Brian Katz will continue his discussions regarding the interactions of ground- and surface-waters. Lunch will be provided at the spring.

After lunch, attendees will travel about 14 miles to Midway (Fire) Tower located east and south of Mayo in Lafayette County. The tower is located near the edge of a “scarplet” at the edge of the San Pedro in Mallory Swamp. Rick Copeland will compare and contrast various aspects of this “scarplet” to the Cody Scarp. Each attendee will have an opportunity to climb up the Midway Tower. The tower offers a panoramic view of the Mallory Swamp/San Pedro Bay, and one can compare the subtle differences between the landscapes above and below the scarplet.

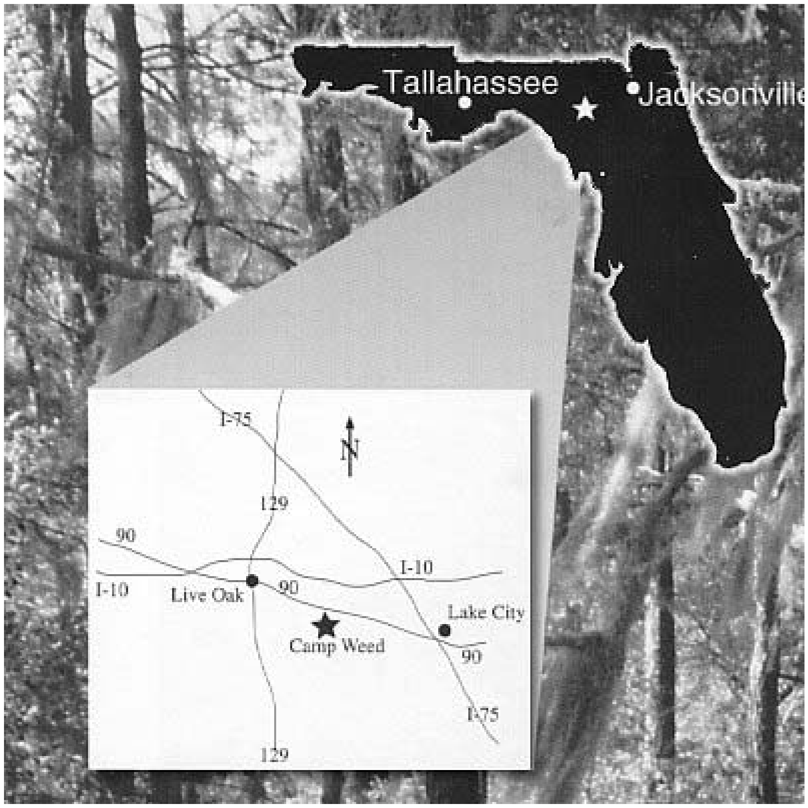

Figure 1. Camp Weed, Near Live Oak, Florida.
From the intersection of I-75 and I-10... go West on I-10 to exit 292 (old exit #41). Travel South on HWY 137 to US 90. Turn West and go approximately 5 miles. Then turn South on 75th Drive at the Camp Weed sign. Telephone (386) 364-5250.

From Midway Tower, the trip continues for about ten miles into the Mallory Swamp (the southeastern extension of the San Pedro Bay). Brian Kaufman (SRWMD) will give a presentation regarding land use management activities of the SRWMD in the swamp. Participants will then travel from the swamp about 14 miles back to the edge of the Bay, this time located at southern town limit sign for Mayo on State Road 51. Everyone will be able to check out the small scarp first hand.

From the Mayo everyone will travel about 15 miles to Troy Springs. In the spring run, attendees can see an abandoned Union ship from the Civil War. They will listen to a talk by Sam Upchurch (SDII-Global Inc.) regarding the Minimum Flows and Levels Development Program at the SRWMD, and will listen to Warren Zwanka (SRWMD) discuss efforts by the water management district to delineate the Troy Springs Springshed using ground-water potentiometry. After the two presentations, attendees can relax by exploring and swimming in Troy Springs. Everyone will return about 25 miles back to Camp Weed and arrive about 4:30 PM.

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An Overview of the Influences of Scarps on a Variety of Topics within the Suwannee River Basin of Florida

Rick Copeland, P.G.
Florida Geological Survey

Introduction

Scarps have had a profound influence in many different ways on the lives of the people residing in the Suwannee River Basin, as well as elsewhere in Florida. Scarps influenced where the Native Americans and the original European pioneers settled. For example, the location of scarps influenced where the settlers obtained their water, and the quality of the water they drank. In more recent time, scarps have directly and significantly affected land use patterns and thus the economy of the citizens of north central Florida.

Over the past several decades, the geomorphic and hydrogeologic aspects of the scarps have been investigated by many authors. For the most part, the emphasis has been on the Cody Scarp, the single most prominent scarp in the region. Doering (1960) was the first to mention the erosional feature. However, he did not give it a name. Puri and Vernon (1964, p. 11) named it the Cody Scarp and stated that the scarp, "…is the most persistent topographic break in the State. Its continuity is unbroken except by the valleys of major streams, but its definition is variable. In many places, it can be delineated with unequivocal sharpness; in others, it is shown only by a gradual reduction of the average elevations, and a general flattening of terrain as the lower elevations are reached." Ceryak (1981, p. 24) mentioned that, as a general rule, in Suwannee County, the crest of the scarp occurs between 100 and 110 feet (30 - 36 m) above mean sea level (msl). There is usually 25 - 30 feet (8 - 9 m) of relief along the scarp, but can be up to 85 feet (26 m) of relief within a distance of less than one mile (1.6 km). Note that in the Live Oak area, the crest of the scarp can be as high as 130 feet (40 m) above msl.

Lawrence and Upchurch (1976) mentioned that the scarp is actually the transition region lying between what was then known as the Northern Highlands and the Gulf Coastal Lowlands geomorphic regions. The two regions can now be thought of as the "Hills" and the "Plains." A brief discussion regarding the current geomorphic system taken from Scott (2005, in preparation) will be discussed shortly.

Figure 1 displays the transition region of the Cody Scarp in north-central Florida. Figure 2 is a photograph of the scarp located in Jefferson County where it is very pronounced. Figure 3 is a photograph of the Scarp in Suwannee County in the transition region where the scarp is not as well developed as in other parts of the state.

Ceryak (1981) discussed the significance of the scarp on the local hydrogeology of north-central Florida. He mentioned that the scarp is the boundary between a one-aquifer system on the toe-ward side, and either a two- or three- aquifer system on the head-ward side of the scarp.

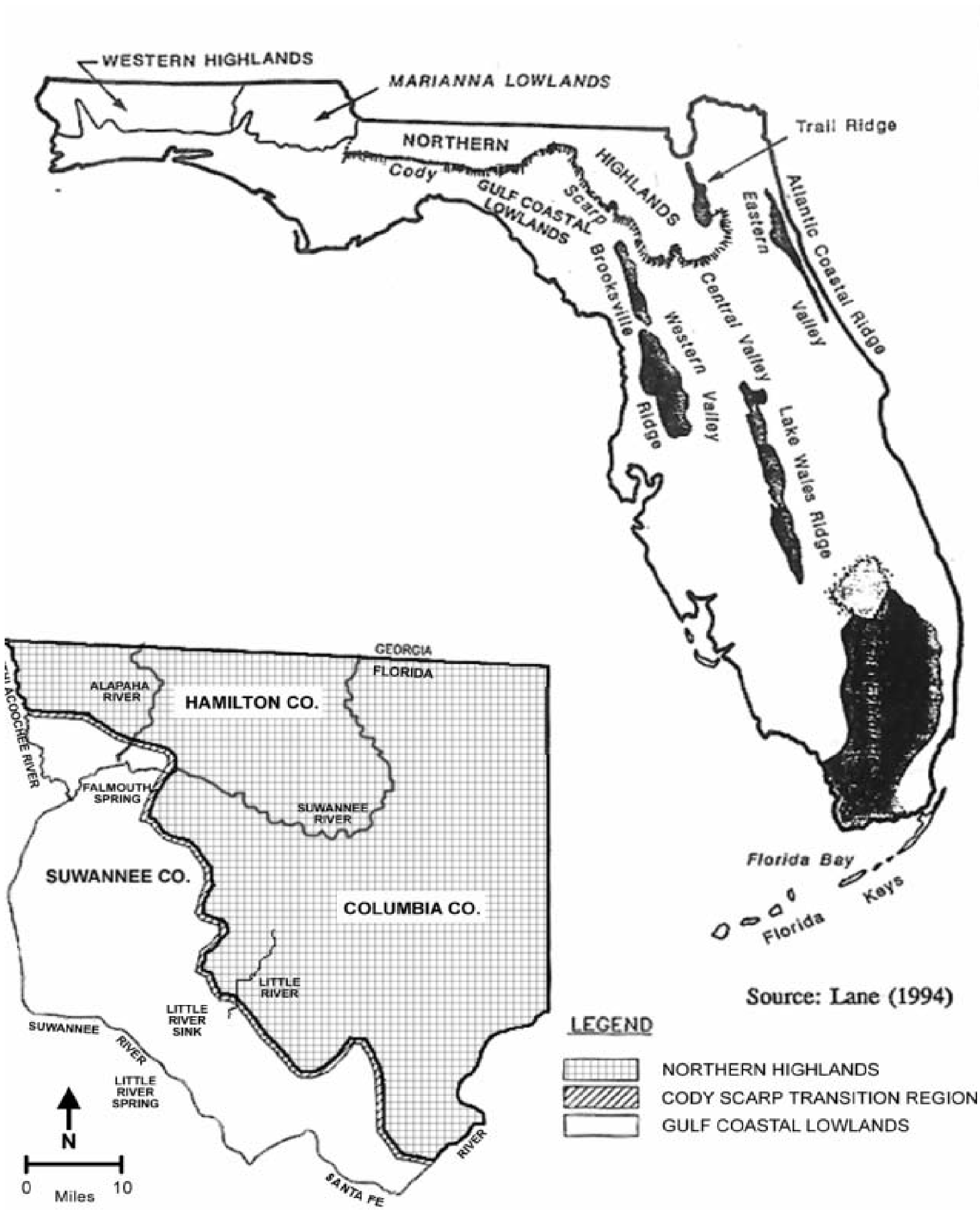

Figure 1. General Geomorphic Features Showing Cody Scarp Transition Region (Modified from Davis and Winkler, 1996).

Figure 2. Cody Scarp looking north in Jefferson County. Location is about one mile east of SR 59 on CR 259 and about five miles east of Cody in Jefferson County. The toe of the Scarp lies at 55 while the crest of the Scarp lies at about 180 feet above msl. The elevation of the photographer is approximately 70 feet above msl. (Photograph by R. Copeland of the Florida Geological Survey).

Figure 3. Cody Scarp looking east in Suwannee County. Location is 2.5 miles east of SR 49 on US 90. The toe of the Scarp lies at about 105 feet while the crest of the Scarp lies at about 130 feet above msl. The location of the photographer is near the toe. (Photograph by R. Copeland of the Florida Geological Survey).

Lawrence and Upchurch (1976) and Lawrence and Upchurch (1982) discussed how the scarp has a significant influence on the quality of groundwater. Davis and Winkler (1996) gave an excellent description of how groundwater and surfacewater interact with each other all along the scarp. They pointed out that almost all streams flowing over the scarp in north Florida actually disappear into swallets and flow underground through karst conduits in the exposed limestone bedrock. The streams later re-emerge in the form of river-rise springs located several miles down gradient of the swallets. This is evidenced by tannic waters similar in chemical composition to the parent river waters resurface.

Modified from Jackson (1997) the definition of a scarp is, "a relatively straight, cliff like face or slope of considerable linear extent, breaking the general continuity of the land by separating surfaces lying at different levels, as along … the margins of a plateau… " Jackson (1997) defined an erosional scarp is one produced by erosion

The geomorphology of north-central Florida is displayed in Figure 4. The two major geomorphic regions are: (1) the Karst Hills, including but not limited to the Northern and Southern Okeefenokee Basin, the Lake City Ridge, plus the Alachua Karst Hills, the Madison Hills and Tallahassee Hills (Scott, 2005, in preparation); and (2) the Karst Plains, including but not limited to the Chiefland and the Branford Karst Plains, the Woodville Karst Plain and the Perry Karst - San Pedro Bay.

San Pedro Bay and "Scarplet"

For the current discussion, there are two areas of concentration. The first lies within Hamilton, Suwannee, and Columbia Counties. Of interest for this trip are the Alachua Karst Hills and the Branford Karst Plain (Figure 4), plus the Cody Scarp Transition Zone (Figure 1). The second area lies to the west of the first and includes portions of Madison, Lafayette, Taylor and Dixie Counties. For this discussion, the two counties of particular interest are Lafayette and Taylor Counties, and the geomorphic regions contained in this area are: (1) the Perry Karst – San Pedro Bay, including the San Pedro Bay Subdivision, plus (2) the Branford and the Chiefland Karst Plains lying to the east and (3) the Woodville Karst Plain located to the west.

The San Pedro Bay (Figure 5) was probably named for an old abandoned Spanish mission (San Pedro), located in the area during the 1500s, and for the many cypress bays (bay heads) that are prominent in the region. Within the bay, a clay bed, generally up to five feet (1.5 m) thick, overlies the carbonate bedrock of the Ocala and Suwannee Limestones (Copeland, 1982). In addition, overlying the clay bed are Quaternary undifferentiated sands (Scott et al., 2001). The fine- to medium-grained sands are up to 50 feet (15 m) thick and they contain a water table aquifer (Copeland, 1982) that is part of the surficial aquifer system (SAS). Because the clay often contains the mineral fluorapatite, it is considered to be related to the Hawthorn Group (Olsen, 1972; and Scott, 2001). The clay bed (San Pedro Bay Clay (Copeland, 1982)) has reduced downward percolation of acidic water from an overlying surficial aquifer. This has resulted in fewer and less mature karst features, relative to either the Branford or the Woodville Karst

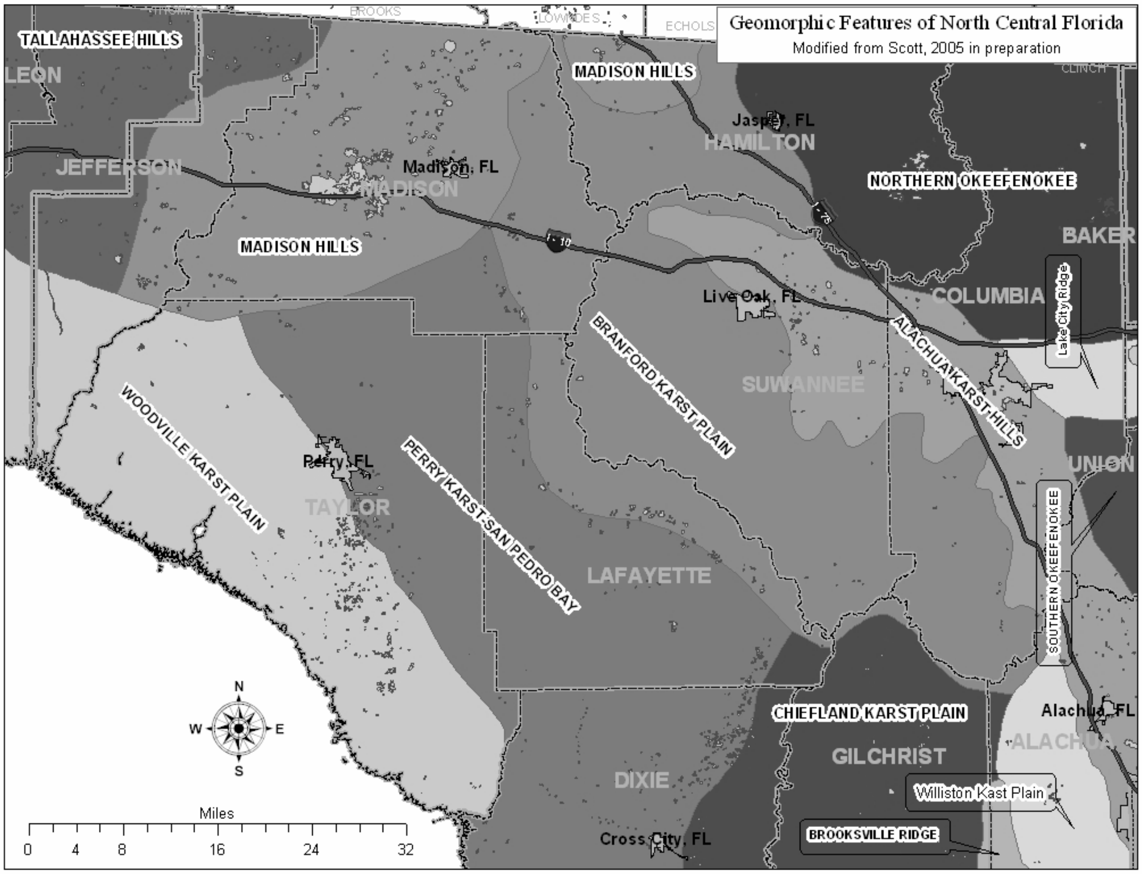

Figure 4. Geomorphic Features of North Central Florida (Modified from Scott, in preparation).

Plains. The region is a poorly drained. It has little relief and varies in elevation from between 45 and 100 feet (14 and 30 m) in elevation. In Lafayette County, locals refer to the southeastern portion of the bay as Mallory Swamp.

The origin of the clay bed is not entirely understood. Since it is believed to be related to the Hawthorn Group, is it simply an in situ remnant of the Hawthorn, or is it reworked Hawthorn material? One possible explanation is inverted topography (White, 1977). Knapp (1977) later elaborated on the theory with regards to the Brooksville Ridge (Figure 4). He postulated that the core of the Brooksville Ridge was incised into the surrounding plain. The clastic, Hawthorn Group sediments were possibly deposited in a tidal channel or marine lagoon. Since Miocene times, the Florida Platform was elevated relative to current sea level. Because of the insolubility of the clastic material, relative to the surrounding limestones, the clastic material did not erode as quickly. Over time, the low lying area receiving the material became a topographically high area. This model is also plausible for the San Pedro Bay.

The northern boundary of the San Pedro Bay is the Cody Scarp (Figure 5) lying in Madison County. However, along the remaining portion of the bay, its border is

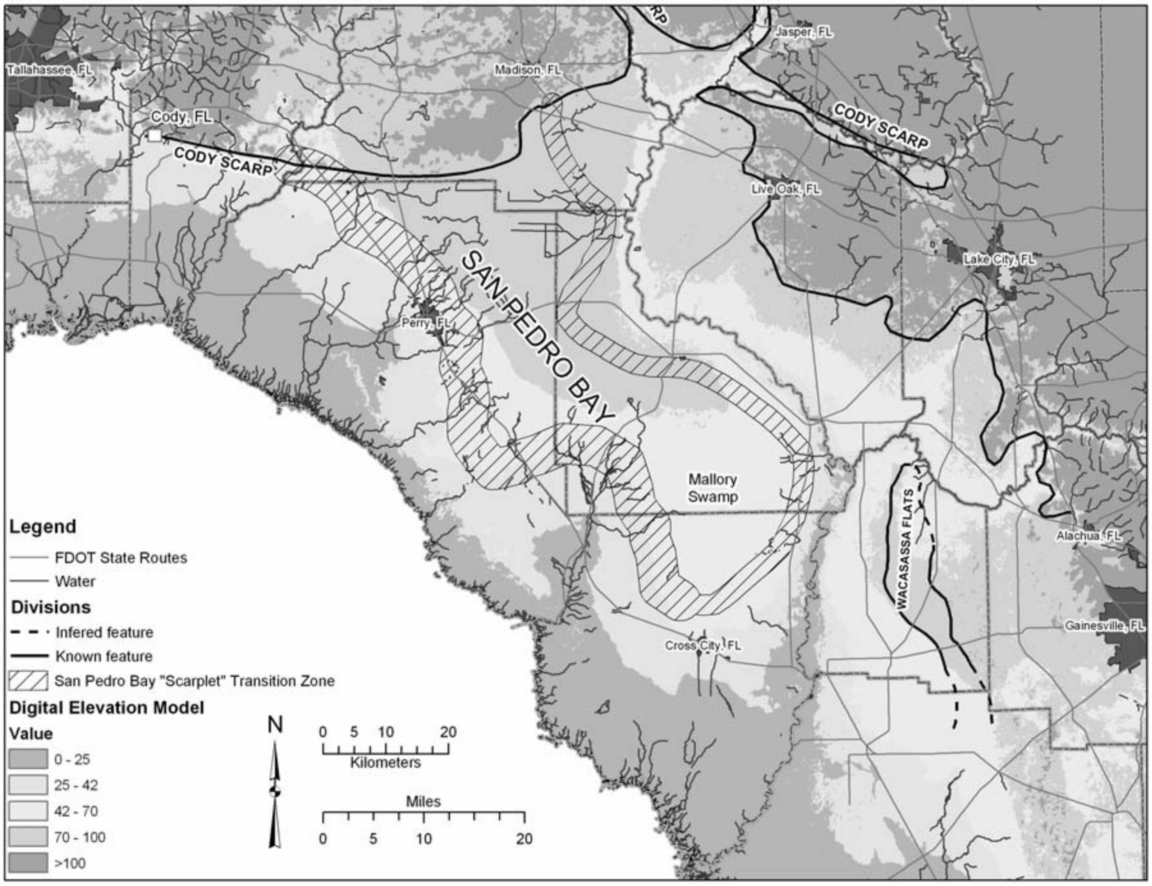

Figure 5. Topography and Selected Geomorphic Features of North Central Florida

represented by a small erosional feature which has been covered by Quaternary sands (Scott, 2001). Bates and Jackson (1987) defined a scarplet as, "a miniature scarp, ranging in height from several centimeters to 6 meters or more." Based on this definition, for this discussion, the erosional feature will be referred to as the San Pedro "Scarplet." Because of a low topographic gradient and because the sands cover the erosional feature, the term "scarplet" is in quotation marks. Think of the feature as being a "covered scarplet." Nevertheless, in places the "covered scarplet" or simply "scarplet" is observable in a transition zone.

In a discussion of marine terrace and shorelines of Florida, Healy (1975) mentioned that topographic breaks are common throughout Florida. He believed that many of the step-like topographic breaks in Florida represent terraces that correspond to former marine shorelines associated with the advances and retreats of the sea. He mentioned that in some parts of Florida the result of the erosional processes, that have occurred during and since the retreat of the last North American ice sheet, have obscured the remnants of these shoreline and marine features. In some places the shoreline and marine features are unrecognizable. Healy stated that the crest of the Wicomico Terrace stand is approximately 100 feet (30 m) above msl and the lower limit of the terrace stands at about 70 feet (21 m). A second terrace of interest is Healy's Penholoway Terrace. Although Healy did not map the Penholoway in Lafayette and Taylor Counties, he mentioned that the Penholoway Terrace forms a belt abutting the Wicomico. The

Penholoway shoreline crest stands at approximately 70 feet (21 m) and lower limit of the terrace is roughly 42 feet (13 m) above sea level (Figure 5).

At its higher elevations, the San Pedro "Scarplet", in northern Taylor and Lafayette Counties, lies anywhere from 70 to almost 100 feet (21 to 30 m) in elevation above the National Geodetic Vertical Datum (NGVD); approximately mean sea level. However, the elevation of the "scarplet" in the southern portion of the bay in places is less than 40 feet (12 m) above msl. This suggests that the San Pedro Bay covers both of Healy's Wicomico and the Penholoway sea level stands. A distinct break either never developed or subsequent erosional activities obliterated it.

Within the San Pedro Bay, rainfall percolates downward into the surficial sands to the clay bed that overlies the Floridan aquifer system (FAS). The clay bed restricts downward movement of groundwater to the FAS and acts as the base of the SAS composed of the surficial sands. As a result, the water table in the San Pedro Bay is very high. The water table of the SAS is usually less than three feet below land surface. Because of the high water table, neither the Native Americans nor the early European pioneers were able to use the bay for agricultural purposes. For centuries it remained virtually undeveloped. However, by the beginning of the 20th century, silviculture became, and remains to this day, the dominant land use within the bay.

In many places in both Lafayette and Taylor Counties the San Pedro "Scarplet" is almost imperceptible. However, in other places the crest is indirectly observable. For example all along the eastern portion of the "scarplet" in Lafayette County (Figure 5), many lakes and ponds exist within the "scarplet" in a transition region. The location of the lakes is related to the recharge to the FAS. Because the potentiometric surface of the SAS is higher than that of the underlying FAS, within the bay some groundwater percolates vertically downward through the clay, or breaches in the clay, to recharge the FAS. However, most groundwater, when it encounters the clay bed, moves laterally over it. When groundwater from the SAS reaches the edge of the clay, the lateral extent of the SAS, it again moves downward and recharges the FAS. All along the eastern edge of the "scarplet", recharge to the FAS is moderately high. The many lakes and ponds located in the transition zone were formed because of dissolution of the underlying carbonates by the acidic waters from the SAS. From the transition region toward the Suwannee River (the Lafayette - Suwannee County boundary), the water table of the FAS slopes to the Suwannee River.

In cross section A-A′ (Figure 6), from the center of San Pedro Bay to the Suwannee River to the northeast, the topographic gradient is about 10 feet per mile (about two m per km). Notice that for a short distance, the potentiometric gradient of the FAS increases along the eastern edge of the "scarplet" transition zone. In this transition region, the potentiometric gradient increases more rapidly than the topographic gradient before leveling off near the Suwannee River. The net effect of the two gradients is that the water table is greater than 20 feet (six m) below land surface in a narrow zone east of the transition zone in Lafayette County. This relatively "dry" zone corresponds to an agricultural belt. Most of the non-silviculture related economy of the county is generated from the land use activities occurring in this belt. Near the Suwannee River, the topography and the potentiometric surface of the FAS again approach each other in or near the flood plain of the Suwannee River.

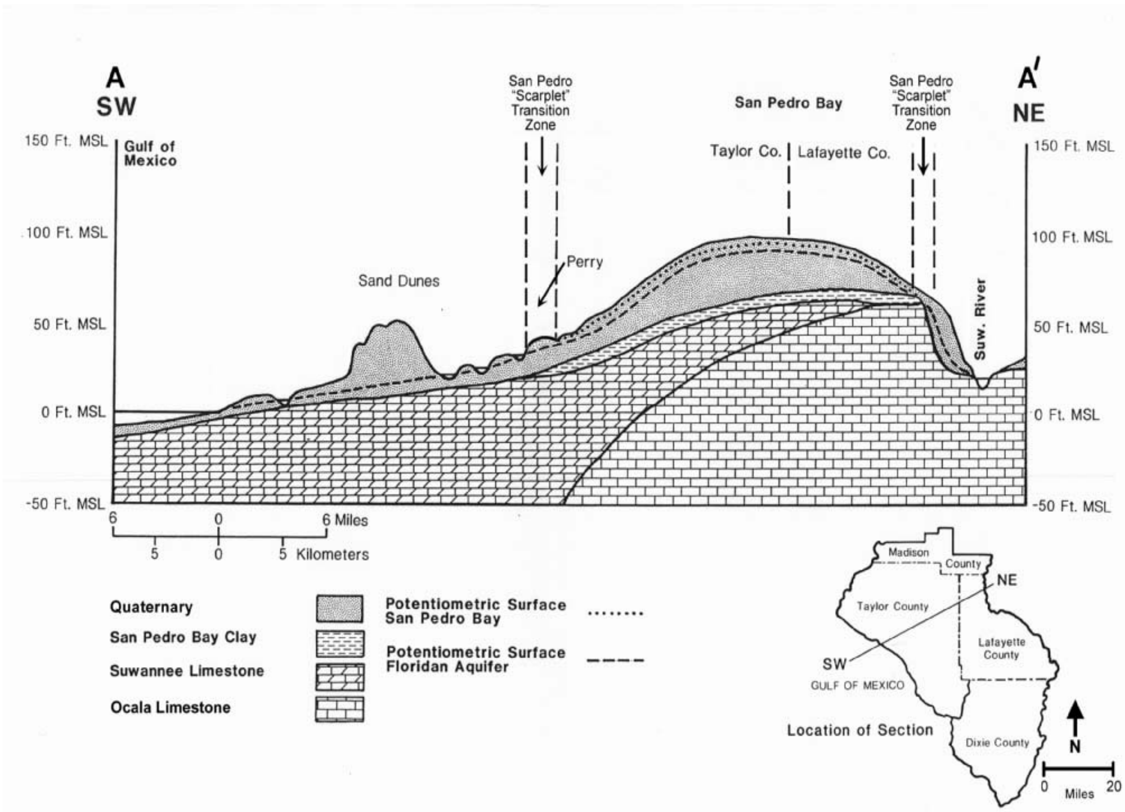

Figure 6. San Pedro Bay Cross Section.

Along much of the southern border and along portions of the western border of the bay, the San Pedro "Scarplet" is obscure. The reason is related to: (A) the topographic gradient and (B) the potentiometric surfaces of the SAS and the FAS. To better understand look at cross section A-A′ (Figure 6). Within the San Pedro Bay, the potentiometric surface of the SAS is the water table. The potentiometric surface of the FAS consistently lies between a few inches to over a foot below the water table of the SAS. Thus, the SAS recharges the FAS. Note that the SAS pinches out in the "scarplet" transition zone, along both the eastern and western sides of the San Pedro Bay. In the transition zone, the FAS changes form semi-confined conditions to water table conditions.

In the cross section (Figure 6) from the center of San Pedro Bay to the coast, the topographic gradient is only about three feet per mile (about one m per 1.6 km). Moving southwestward to the coast, the water table, except underneath paleo-sand dunes, is generally less than three feet below land surface and generally follows the land surface closely. Because there is no distinct break in either the topography or the water table, there is no indirect method to mark the presence of the "scarplet."

A notable exception is the town of Perry in Taylor County (Figure 6). The town is located in the "scarplet" transition zone. Figure 7 is a topographic map near Perry. Notice that several small streams, originating in the San Pedro Bay, drain to the west. As they flow over the edge of the San Pedro Bay Clay, they enter the transition zone. Here,

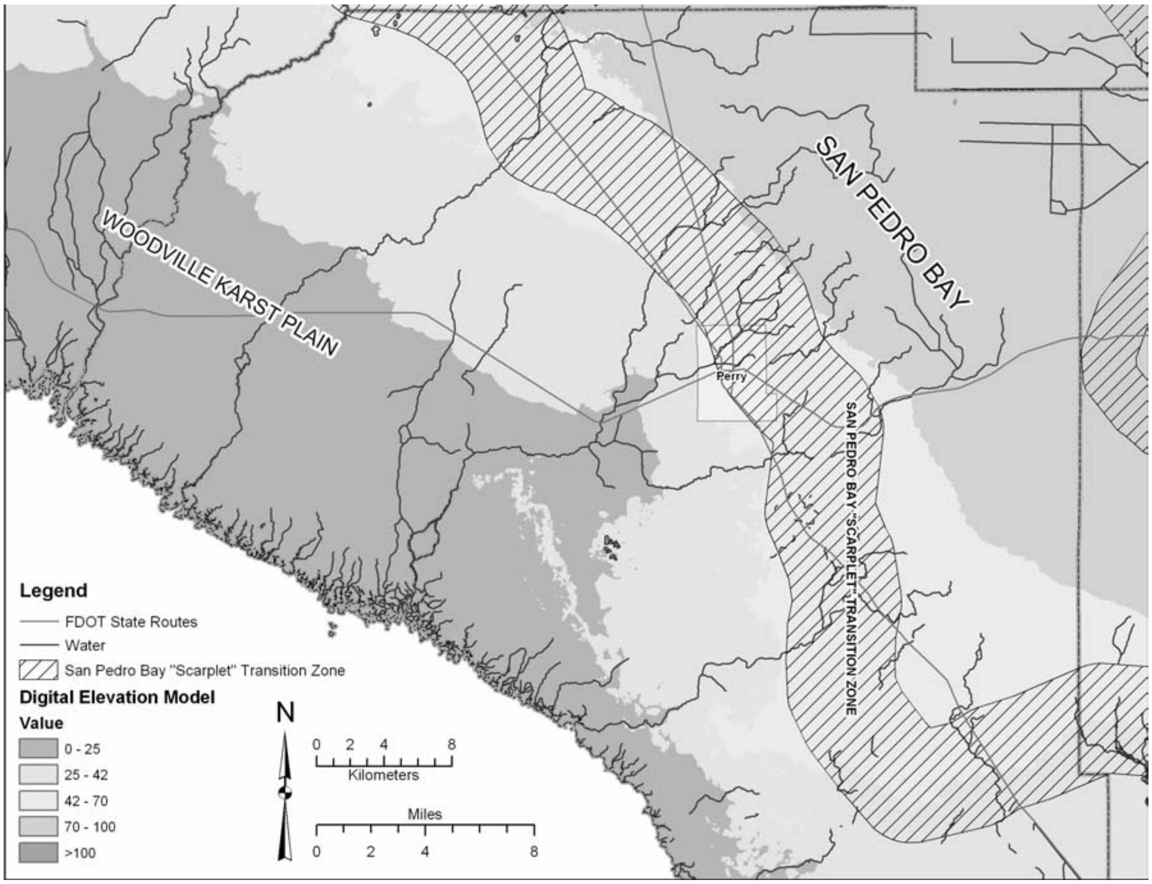

Figure 7. Topography of the Perry Area Showing the San Pedro "Scarplet" Erosional Feature.

some of the streams enter swallets, flow underground for up to a mile (about 1.6 km), and then re-emerge as river rise springs. The depth to the water table in the transition region is generally greater than three feet. This relatively "dry" zone, plus the presence of springs (separate from resurgences and which serve as a source of drinking water), are important factors as to why the town is located were it is.

Comparisons of the Cody Scarp and the San Pedro "Scarplet"

There are many similarities between the Cody Scarp and the San Pedro "Scarplet." The similarities and differences are displayed in Tables 1 and 2. Readers are encouraged to refer to these tables throughout these discussions.

Table 1

Cody Scarp Region
Comparisons among the Alachua Karst Hills,
the Scarp Transition Zone, and the Branford Karst Plains
(Hamilton, Suwannee, and Columbia Counties)

	Alachua Karst Hills **(Formerly part of the N. Highlands)**	**Cody Scarp Transition Zone**	**Branford Karst Plain** **(Formerly the part of the G.C. Lowlands)**
Major Geomorphic Regions	"Karst Hills" Ala. Hills, N & S Okeefen Basin, LC Ridge	Cody Scarp Transition Zone	"Karst Plain" Branford Karst Plain
Relative Elevation	High (Uplands)	Transition	Low (Lowlands)
Topography	Gen > 100 ft (NGVD)		Gen < 100 ft (NGVD)
Relief		25 - 30 ft	
Marine Terrace (Healy, 1975)		Wicomico (70-100 ft)	
Width		3 - 10 Miles	
Upper Stratum (No Undiff. Sed)	Hawthorn	Hawthorn	Ocala/Suwannee
Age of Surf Sed (No Undiff. Sed)	Miocene and younger	Mostly Miocene and Pliocene	Eocene and Oligocene
Surf. Lithology	Sands and clays	Sands and clays	Generally carbonates
Pot. Aquifers	SAS, IAS, FAS	FAS, IAS?	FAS
Generalized GeoHyd Cond	SAS (Uncon) IAS & FAS (Con)	Uppermost FAS (Semi-Con) IAS? (Semi-Con)	Uppermost FAS (Uncon to Semi-Con)
Recharge to FAS	Low to Mod	High to Disch (Toe)	Occasion. High to Disch
Water Type GWQ (Uppermost FAS)	Ca-Mg-Alk,	Ca-Mg-Alk ↑P, ↑F,	Ca-Mg-Alk, ↑NO3,
Major Lake Districts (Griffith et al., 1997)	Okefenokee Plains N.Pen. Karst Plains	Transition	N.Pen. Karst Plains
Lake Chem	↑Color, Mod P, Chlorophyll α ↓Alk, pH,	?	↑Alk, N, Chlorophhyll α Mod pH ↓Color, P
Biology	Not enough data	Not enough data	Not enough data
Relative amount of Human Development	Sparse to Mod	Intense to Mod (3 of 5 largest Towns)*	Sparse to Mod
Predominant Land Use	Forest/Ag	Urb/Surb/Ag	Forest/Ag

* **Jasper, White Springs, Live Oak**, Branford, and Lake City

Table 2

San Pedro "Scarplet" Region
Comparisons among the San Pedro Bay, the San Pedro Bay "Scarplet", the Branford (East) and Woodville (West) Karst Plains
(Madison, Lafayette, Taylor, and Dixie Counties)

	San Pedro Bay Subdivision	**San Pedro "Scarplet" Transition Zone**	**Branford Karst Plain (E) Woodville Karst Plain (W)**
Geomorphic Regions	San Pedro Bay	San Pedro "Scarplet" Transition Zone	Karst Plains Branford Karst Plain (E) Woodville Karst Plain W)
Relative Elevation	High (Uplands)	Transition	Low (Lowlands)
Topography	Gen > 40-80 ft (NGVD)		< 40-80 ft (NGVD)
Relief		< 5 ft	
Marine Terrace (Healy, 1975)		Penholoway (42-70 ft) and Wicomicco (70 - 100 ft)	
Width		Up to 4 miles	
Upper Stratum (No Undif. Sed)	Hawthorn	Hawthorn?	Ocala, Suwannee
Age of Surf. Sed.(No Undiff. Sed)	Miocene and younger	Miocene and Pliocene?	Mostly Eocene and Oligocene
Surf Lith.	Sands and Clays	Sands and Clays	Gen. Carbonates
Pot. Aquifers	SAS, FAS	FAS	FAS
Generalized GeoHyd Cond	SAS (Uncon) Uppermost FAS (Semi-Con)	Uppermost FAS (Semi-Con)	Uppermost FAS (Uncon toSemi-Con)
Recharge to FAS	Mod	Mod to High	Occasion High to Disch
Water Type GWQ (Uppermost FAS)	Ca-Mg-Alk ↑P, ↑F	Ca-Mg-Alk ↑P, ↑F	Ca-Mg-Alk ↑ NO3
Major Lake Districts (Griffith et al., 1997)	San Pedro Bay	San Pedro Bay	Northern Peninsula Karst Plains Big Bend Karst
Lake Chem	↓ Alk ↑P, F Mod Color, Chlor α	↑P, F Mod Color, Chlor α	↑Alk ↑ to ↓ N, Chlor α Mod pH ↑ Color, P
Biology	Not enough data	Not enough data	Not enough data
Relative Amount Of Human Development	Sparse	Mod (2 of 3 the three Largest Towns)*	Sparse to Mod
Predominant Land Use	Forest	Ag/Forest/ Urb/Surb	Ag/Forest

***Mayo, Perry**, and Cross City

Cody Scarp Region

Geomorphology and Hydrogeology

The Cody Scarp and transition zone separates the Karst Hills from the Karst Plains (Figures 1 and 4). The Karst Hills represent an upland area that is underlain by the Hawthorn Group. The Hawthorn often acts as a base to the SAS. It confines the FAS and occasionally contains an Intermediate Aquifer System (IAS). The Cody Scarp transition zone is generally three to ten mile wide. The Karst Plains are a lowland area with the underlying FAS generally under unconfined to semi-confined conditions.

As mentioned previously, in Hamilton, Suwannee, and Columbia Counties, the crest of the Cody Scarp generally lies at about 100 feet (30 m) and the toe at about 70 feet (21 m) above msl. However, in places both the crest and the toe can be greater than these elevations. The relief in the transition zone is generally approximately 25 to 30 feet (eight to nine m), but it can be as high as 85 feet (26 m) in some places. The upper undifferentiated sediments in the Karst Hills are composed of sands and clays of Miocene and younger age. A significant amount of these sediments are associated with the Hawthorn Group. The same can generally be said of the upper sediments in the transition zone. Except for very narrow erosional remnants of the Hawthorn Group lying within the Karst Plains (outliers), the uppermost sediments within the Karst Plains are limestones and dolostones. The two uppermost carbonate units are the Eocene Ocala Limestone and the Oligocene Suwannee Limestone.

Recharge and Ground-Water Chemistry

Recharge to the FAS within the Karst Hills above the Cody Scarp (Figure 1) is relatively low to moderate. Along the transition zone, recharge is relatively high. However, along the toe, discharge, in the form of springs, can occur. Throughout the Karst Plains recharge can be very high. Nevertheless, if the aquifer is full (e.g. during times of high water levels), recharge is low. Springs are located throughout the Karst Plains, indicating that this region can also be one of discharge.

Ground-water quality within the FAS throughout north Florida is of the calcium-magnesium-alkalinity type, indicating the water has been in contact with a carbonate aquifer for a relatively long period of time. However, in the transition zone, groundwater is also identified with a higher concentration of phosphorous and fluoride, signifying that fresh recharge water is traveling through the Hawthorn, which contains the mineral fluorapatite (rich in phosphorous and fluoride) (Upchurch and Lawrence, 1976). FAS water in the Karst Plains often contains high nitrate concentrations. The nitrates originate from fertilizers and animal wastes associated with agricultural activities in the Karst Plain regions of Lafayette and Suwannee Counties (Katz and Bohlke, 2000).

Lake Districts and Chemistry

Griffiths et al. (1997) mapped the Lake Districts of Florida. Their Okefenokee Plains (Figure 8) in eastern Hamilton and northern Columbia Counties corresponds to Scott's Northern Okefenokee Plains (Figure 4). Griffiths et al. referred to a region encompassing the Alachua Hills and the Branford Karst Plain as the Northern Peninsula Karst Plains (Figures 4 and 8). In terms of lake water chemistry, they indicated that the upland lakes had more color, and had moderate concentrations of phosphorous and chlorophyll α. It was also pointed out these lakes had relative low pH values and had relatively low concentrations of alkalinity. Conversely, lakes lying in their Northern Peninsula Karst Plains had relatively high concentrations of alkalinity, nitrogen, and chlorophyll α. They also had moderate pH and color levels, and low concentrations of phosphorous.

Human Development and Land Use Patterns

We do not have a thorough understanding as to where the Native Americans settled. However, a high water table probably prevented them from conducting many agricultural activities in the wetlands. The Cody Scarp transition zone, with its high relative depth to the water table and a number of springs along the toe of the scarp, was an attraction to both the native people and the early European settlers. This is recognized by a Native American settlement in what is now Tallahassee, and the relatively abundance of modern communities all along the transition zone (e.g. Gainesville, Live Oak, White Springs, Jasper, and Tallahassee).

San Pedro "Scarplet" Transition Region

Geomorphology and Hydrogeology

The following paragraphs will demonstrate that in many ways, the San Pedro "Scarplet" transition zone (Figure 5) is similar to the Cody Scarp transition zone. The "scarplet" transition zone separates a relatively small upland area (the San Pedro Bay) from the topographically lower Branford and Woodville Karst Plains. The San Pedro Bay is underlain by a thin clay bed that is either an erosional remnant of the Hawthorn or reworked Hawthorn Group material. The clay bed acts as a base to the SAS and it semi-confines the underlying FAS. However, it is to thin to contain the IAS. The San Pedro "Scarplet" transition zone is up to four miles wide. It separates the San Pedro Bay from the lower-lying Branford/Chiefland Plains to the east from the Woodville Karst Plains to the west. In the San Pedro Bay in the transition zone, the FAS is under semi-confined conditions. In the Karst Plains, the FAS is under unconfined to semi-confined conditions.

The topographic elevation of the "scarplet" transitions zone lies at approximately 40-70 feet above sea level in the south. However, toward the north, the elevations range between 70 and 100 feet above msl. The "scarplet" may coincide with Healy's (1975) Penholoway Terrace in the south and his Wicomico Terrace in the north. The upper sediments in both the San Pedro Bay and the "scarplet" transition zone are composed of

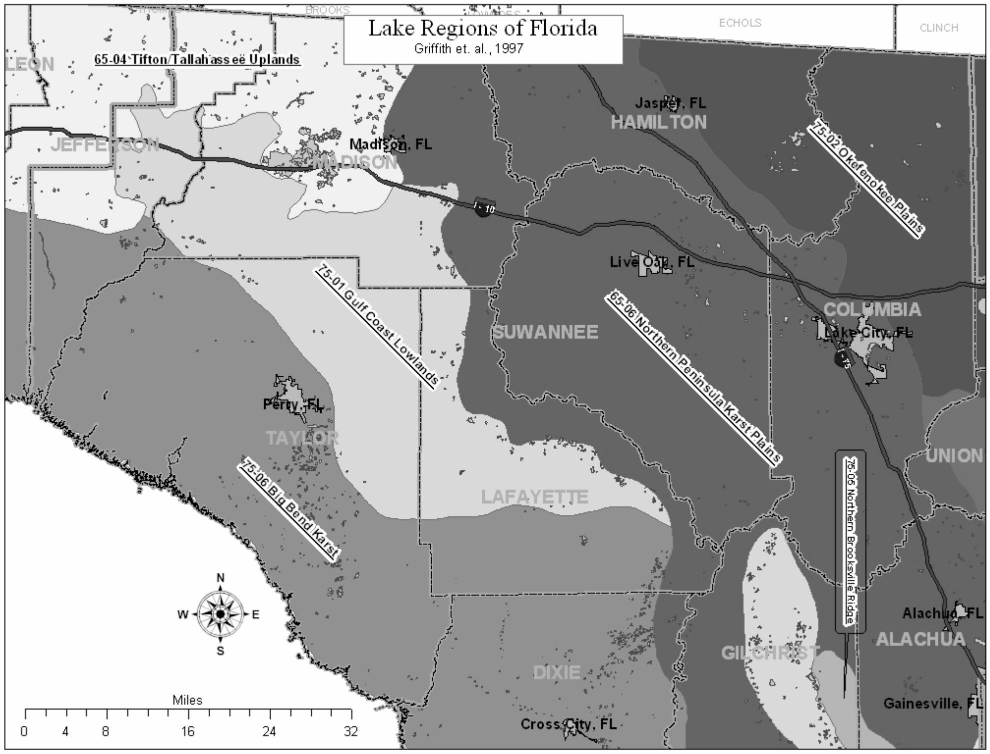

Figure 8. Lake Regions of North Central Florida (Modified from Griffith et al., 1997).

Miocene clays and younger sands. The upper sediments within the Branford/Chiefland and Woodville Karst Plains are carbonates of the Ocala and the Suwannee Limestones.

Recharge and Ground-Water Chemistry

In the San Pedro Bay (Figure 5), recharge to the FAS is low to moderate. Along the transition zone, recharge is moderate to high. Throughout the Karst Plains recharge can be very high. However, if the aquifer is full, recharge is low. The presence of springs indicates that this region is also one of discharge.

Ground-water quality within the FAS above, within, and below the transition zone is of the Calcium-Magnesium-Alkalinity type. However, above and within the transition zone, groundwater also has relatively high concentrations of phosphorous and fluoride. In the Branford Karst Plains of Lafayette County, FAS water contains high nitrate (NO_3 as N) concentrations. The nitrates originate from agricultural activities within the Plains (Copeland, 1982). It is important to note that throughout the Karst Plains in the SRWMD, if the protective clay layer is absent, the FAS is susceptible to contamination from man's land use activities.

Lake Districts and Chemistry

When referring to Lafayette and Taylor Counties, Griffiths et al. (1997) pointed out that, again three lake districts exist (Figure 8). They referred to the area located above and along the crest of the San Pedro "Scarplet" as the Gulf Coastal Lowlands, while lakes lying on the lowland side of the "scarplet" as being in either the Northern Peninsula Karst Plains or the Big Bend Karst. Relative to the Karst Plains, the water chemistry of the lakes in the San Pedro Bay and transition zone have more color, have moderately high concentrations of phosphorous and fluoride, and have moderately lower concentrations of chlorophyll α.

Human Development and Land Use Patterns

Regarding present day land uses, silviculture is the major economy in wetlands lying in both the upland (e.g. the San Pedro Bay) and lowland portions of the Karst Plains. Of the three largest communities, two (Mayo and Perry) are located in the "scarplet" transition zone. In the lowlands, if the water table is not extremely high, intense agriculturally-related land uses can occasionally be found (e.g. eastern Lafayette County). Unfortunately, because of the sandy soils, and because of the lack of confinement, the FAS is prone to ground-water contamination in areas where the fertilization of crops or animal concentrations are intense.

Other Examples of Erosional Features and Scarps in North-Central Florida

The Cody Scarp and the Sand Pedro "Scarplet" are not the only erosional scarp features in north-central Florida. One such feature is located east of Live Oak on SR 136 just west of Interstate 10 (Figure 9). The topography gains over 60 feet in elevation over about one quarter mile horizontally. The face meanders considerably and can easily be traced for several miles. It is possibly related to Healy's Sunderland Terrace (100-170 feet (30-52 m) above msl). Lying on the head-ward side of the feature is relatively flat upland area containing several shallow lakes. Lake Louise (Stop 1) is one of the lakes. Because part of the definition of a scarp is that it is a relatively straight and of considerable length, it is probably not justifiable to consider it a scarp. Nevertheless, it is an erosional feature separating an upland area from a lower standing topography and, in this manner it similar to a scarp.

Another erosional feature of interest is associated with the Waccasassa Flats in Gilchrist County (Figure 5). The Flats represent a wetland area underlain by Miocene clays that hold very shallow water table aquifer (SAS). The shallow aquifer overlies the FAS. On both the east and the west side of the Flats, there exists only a one aquifer system (the FAS). An erosional feature is present along the perimeter of the Flats and it is recognized by the many ponds that exist on both the east and west side of the Flats (Figure 5). Land use within the Flats is generally agriculture and silviculture, while land uses on both the east and west sides of the Flats are classified as rural residential (Col et al., 1997). As with the Cody Scarp and the San Pedro "Scarplet", the scarp or scarplet surrounding the Flats separate it from distinctly different geologic and geographic regions.

Figure 9. Erosional Feature (possibly Sunderland Terrace (Healy, 1975)). The photograph of the feature in the background is looking northeast on SR 136 about two miles east of US 129 in Live Oak. The elevation of the toe is about 105 feet, while the crest is over 160 feet above msl. The elevation of the photographer is about 120 feet above msl. The horizontal distance from the toe to the crest is about one-quarter of a mile. (Photograph by R. Copeland, Florida Geological Survey.)

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Revisions to the Geomorphology of Florida Focusing on the Eastern Panhandle and North-Central Florida

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INTRODUCTION

The physiography of Florida exhibits quite a bit of variation although it is subtle in comparison to North Carolina with its coastal plain and mountainous features. Many visitors to Florida see only the coastal lowlands and think of Florida as a very flat plain. Some areas of the State, such as the Everglades, are remarkable for being extremely flat with very little variation in elevation over vast areas. However, in the interior of the peninsula and in the panhandle, there are areas of rolling hills and valleys with local relief of nearly 200 feet (61 meters). These vistas stand in stark contrast to the flat profile often associated with the typical images of Florida.

The geomorphology is closely associated with how surface drainage develops, where and how quickly recharge to the aquifer systems occurs, and, in conjunction with the climate, what ecosystems dominate various areas. The geomorphology often dictates where development occurs and how susceptible an area is to karst processes.

The last state-wide geomorphic map published by the Florida Geological Survey (FGS) at a 1:2,000,000 scale was released in 1964 (White, Vernon and Puri, 1964). Brooks published a geomorphic map of the state at a scale of 1:500,000 in 1982. The new geomorphic map is a combination of an upgrade of the 1964 map and a reinterpretation of the state's physiography. Utilizing a combination of old-fashioned geological mapping techniques and modern, digital techniques, a new geomorphic map of Florida is being produced by the FGS. Initial mapping employed visual inspection of 1:24,000 scale topographic maps to identify physiographically similar areas then transferring those areas to a 1:750,000 scale map by hand. The resultant map was digitized. The digital outlines of the geomorphic features are being overlain on topography and aerial photography layers to aid in the resolution of boundary issues. Field checking of boundaries is occurring during travel for other FGS projects.

Presented in this paper is a revised interpretation of Florida's geomorphic framework. This interpretation relies on previous interpretations for the foundation. Among these previous investigations are Brooks (1981), Cooke and Mossom (1929), Cooke (1939, 1945) and White (1958, 1970). White, Vernon and Puri (1964) delineated the geomorphic subdivisions that most geologists working in the state utilize today. The geomorphology recognized in this publication follows this framework with some modification. Interpretations of the geomorphology of Alabama (Drahovzal, 1968) and Georgia (Clark and Zisa, 1976) were utilized in tying the regional geomorphology together and avoiding "state-line faults."

PREVIOUS INVESTIGATIONS

Kost (1887), the first State Geologist of Florida, in the initial report of the State Geological Survey, briefly discussed the physical geography of the state. In his discussion of the variability of the state's geography and geology, Kost stated " ... those who are disposed to rob our state of the element of variety in its physical geography and geological characteristics, had better finish their sayings before the geological survey of this state is published."

Shaler (1890) provided the first in-depth discussion of the topography of Florida. He believed the Florida peninsula to be an uplift which he likened to the "Cincinnati anticlinal". He recognized the variability of the terrain in Florida despite the fact that the relief is much subdued when compared to many other areas. Shaler recognized three distinct subdivisions of the interior of the peninsula: a northern undulating region, a central region of irregular topography and a southern flat region. He observed that as the elevation rose from the coastline "...careful observation shows a decided increase in the amount of the irregularities, until they attain their maximum relief in the uppermost portion of the country." The highly irregular features of the central ridge section of the peninsula, which are now identified as thick-cover sink holes, were thought by Shaler to be the result of the action of the Gulf Stream when the peninsula was submerged. He dismissed the idea that they were sink hole related.

Matson and Clapp (1909) discussed the topography and drainage of Florida and provided the first statewide topographic and geologic map of the state. They recognized the importance of dissolution of carbonate rocks and the formation of sink holes on the Floridian landscape.

Sellards (1912) studied the soils of Florida and their relationship to the underlying geology. He recognized that the presence or absence of carbonate rocks strongly influenced the resultant topography and utilized this in subdividing physiographic regions.

Matson and Sanford (1913) went in to more detail on the topography and geography of northern and central Florida and provided more insight into the southern Florida landscape. The first terrace map was included in this report.

Harper (1914) related the vegetation to the geography of northern Florida and outlined a detailed geomorphology of the northern portion of the state from the Alabama-Florida state line to the east coast. Harper supplied a map of the region depicting 20 "geographical (geomorphic and vegetational) divisions". He recognized the importance of observing the vegetation in the determination of the near-surface geologic conditions. Harper (1921) described the geography of the central Florida region and delimited 10 geographical (geomorphic) regions.

Cooke and Mossom (1929), in their Geology of Florida, briefly described the state's topography. They recognized that the St. Johns River and other coast-parallel lakes were the remnants of old lagoons.

Martens (1931) presented a discussion of Florida's beaches. He discussed the types of beaches, the conditions favorable for "extensive beach formation", and warned of the problems of development along the State's beaches.

Fenneman (1938), in a treatise on the physiography of the eastern United States, characterized Florida's geomorphology and its relationship to the surrounding states. He recognized the importance of the dissolution of carbonate sediments on the geomorphology and delineated two districts, the lime-sink district and the lakes district, based on the thickness of the overlying insoluble siliciclastic sediments. Fenneman also defined a series of terraces based upon elevation.

Cooke (1939) recognized five "natural" subdivisions of the state - the Coastal Lowlands, the Western Highlands, the Marianna Lowlands, the Tallahassee Hills, and the Central Highlands. He drew maps delineating the state's shape at various sea level stages corresponding to the development of the recognized, major terraces. Cooke (1945) utilized the same framework.

Stubbs (1940) contributed information on dissolution of carbonate rocks and how it modified the landscape of Florida. He outlined the processes involved and illustrated examples of sinkhole development.

Davis (1943) investigated the natural features of southern Florida and recognized 10 distinct physiographic features. This study focused on the vegetation and its relation to the physiographic features.

White (1958) discussed some of the physiographic features in central Florida. White named the major central Florida ridges and defined each in this text. These were the Lake Wales Ridge, Winter Haven Ridge, Lakeland Ridge, Brooksville Ridge, and the Orlando Ridge. He also provided insight into drainage patterns in this portion of the state.

The first thorough description of the geomorphic features of Florida was accomplished by White, Vernon and Puri (1964) in an apparently unpublished manuscript referenced in Puri and Vernon (1964). They recognized the three major physiographic zones - the northern or proximal zone, the central or mid-peninsular zone and the southern or distal zone. Within these zones they defined a large number of geomorphic features.

White (1970) utilized the same geomorphic framework depicted in Puri and Vernon (1964). White provided an in-depth discussion of the origin of the features and geomorphic processes involved.

Healey (1975) created a terrace and shoreline map of the state that delineated the features based solely on elevation. The text accompanying the map provides an excellent reference list for those wishing to review the literature on terraces.

Brooks (1981) produced a new physiographic map of Florida. He recognized few previously identified geomorphic features and named many new features.

Schmidt (1997) provides an excellent discussion of the State's geomorphology.

GEOLOGICAL SETTING

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 650 feet (200 meter) below sea level depth contour of the continental shelves. The axis of the platform extends north-northwest to south-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 450 miles (725 kilometers). From the Alabama-Florida line to the Atlantic coastline is approximately 370 miles (595 kilometers).

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, deposited and modified the later Tertiary, Quaternary and Holocene sediments. Fluvial processes, although more important in the panhandle, have helped sculpt the entire state, particularly during the low stands of sea level, eroding and redistributing the marine sediments.

The lay of the land in the State of Florida consists of east-west trending highlands and lowlands in the panhandle portion of the state and north-south trending geomorphic features extending along much of the length of the peninsula. Coastal lowlands occur between the highlands and the coastline wrapping around the entire state. The highest point in the state, 345 feet (105 meters) above mean sea level (msl) occurs in the Western Highlands near the Alabama-Florida state line in Walton County. There are several hilltops in the peninsular area that exceed 300 feet (91 meters) msl in elevation. The close relationship between the State's near-surface to surface lithostratigraphy and the geomorphology is quite evident when comparing the geologic map (Figure 1) (Scott et al., 2001) with the geomorphic map (Figure 2) (Scott, in preparation).

Karst processes have had a dramatic effect on Florida's 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 few feet (one meter) to more than 200 feet (61 meters), overlie the karstified carbonates. The overburden variability gives rise to a variety of karst features ranging from small depressions a few feet (one meter) in diameter to large depressions over 1,000 feet (305 meters) across (See Sinclair and Stewart, 1985, for discussion and a sinkhole distribution map).

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 (Figure 3).

GEOMORPHIC DISTRICTS

The Western Highlands, Marianna Lowlands, Northern Highlands and the Eastern Valley of White, Vernon and Puri (1964) and White (1970) are portions of larger physiographic features that extend across the state line into Alabama and Georgia. For this investigation, the district names from Alabama and Georgia are employed for the sake of consistency across state lines. The names include Southern Pine Hills, Dougherty Karst Plain, Tifton Upland, Okeefenokee Basin and the Barrier Island Sequence Districts (Figure 3). Other district names were selected by the author. The following discussion briefly describes the districts (see Figure 3). Not all of the individual geomorphic features mentioned in the text are labeled on Figure 2 due to size limitations.

Southern Pine Hills District

The Southern Pine Hills District extends from the western state boundary eastward to the Jackson-Washington-Bay County area. The district extends to the south to the coastline. The land surface of this district consists of rolling hills separated by streams that have dissected the once flat plain of the Citronelle "delta". Coastal features occur below elevations of less than 50 feet msl (15 meters). The two major geomorphic features recognized within the Southern Pine Hills District are the Western Highlands and the Gulf Coastal Lowlands (Figure 2). The highest elevation in Florida, 345 feet (105 meters) msl occurs within this district.

Dougherty Karst Plain District

The Dougherty Karst Plain District occupies a portion of the central panhandle covering most of Jackson County and part of Bay, Holmes and Washington Counties. The district can be subdivided into five distinct areas, the De Funiak -Bonifay Karst Hills, the

Figure 1 - Geologic Map of Florida

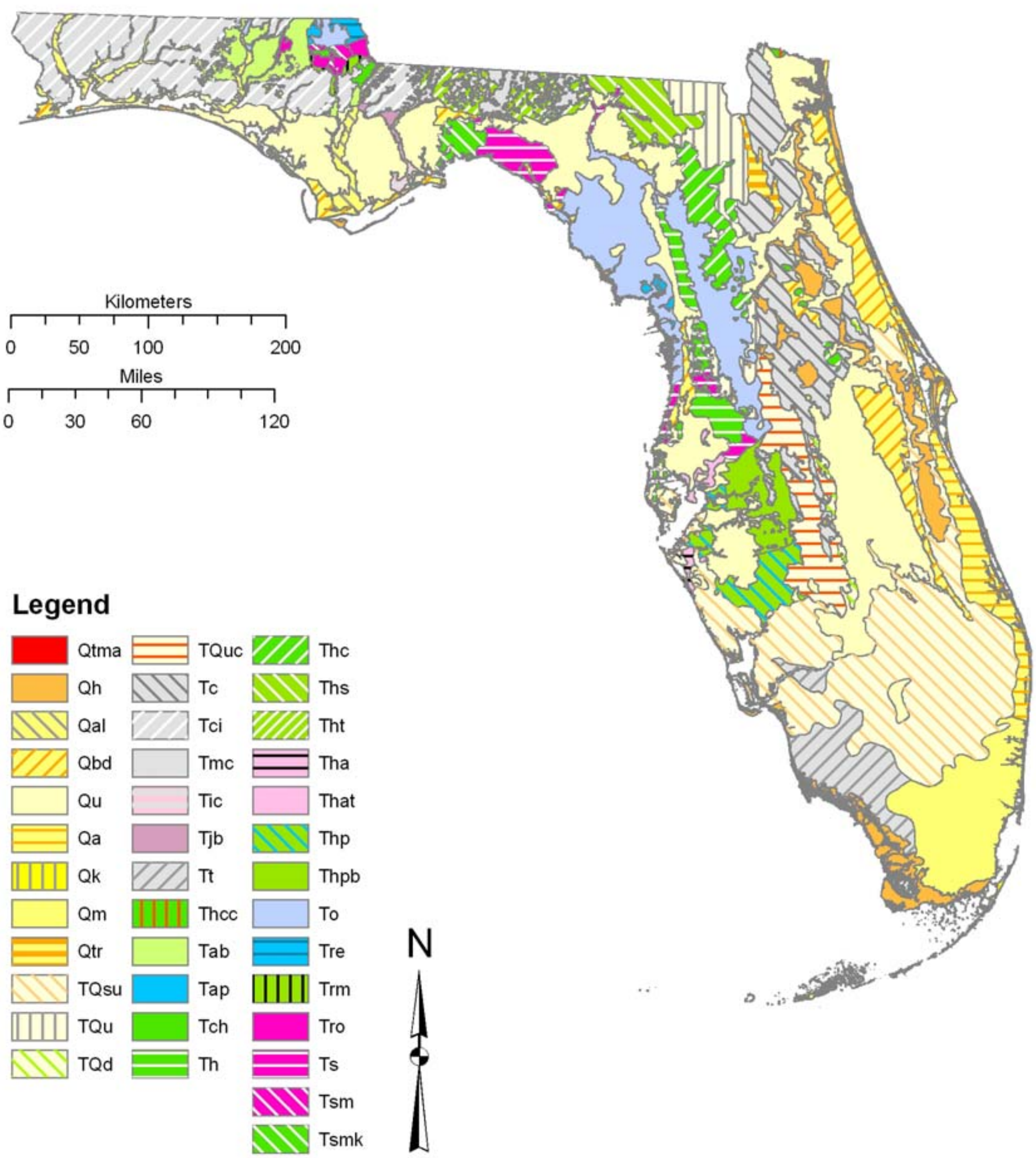


Figure 2 - Geomorphic Map of Florida

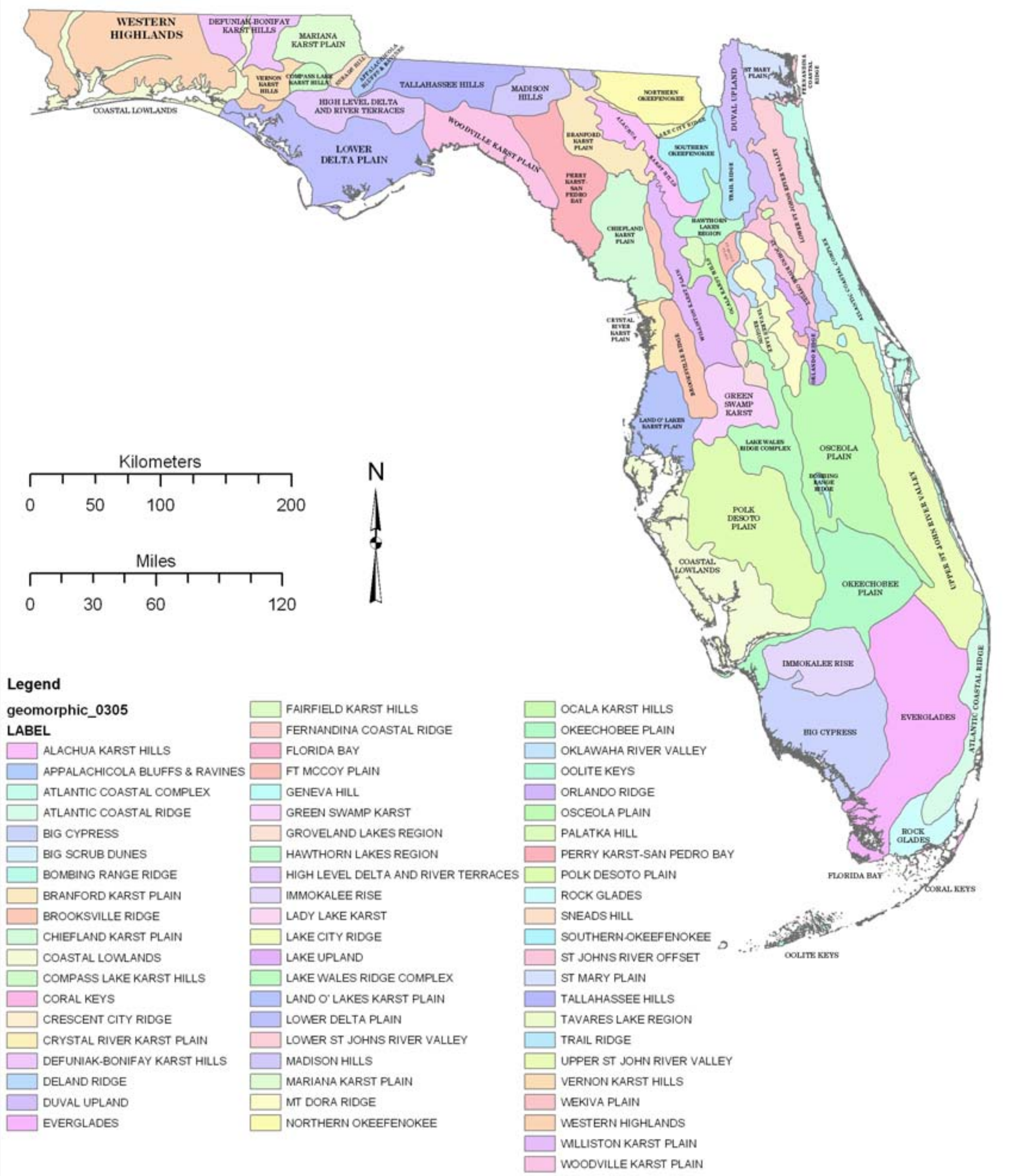
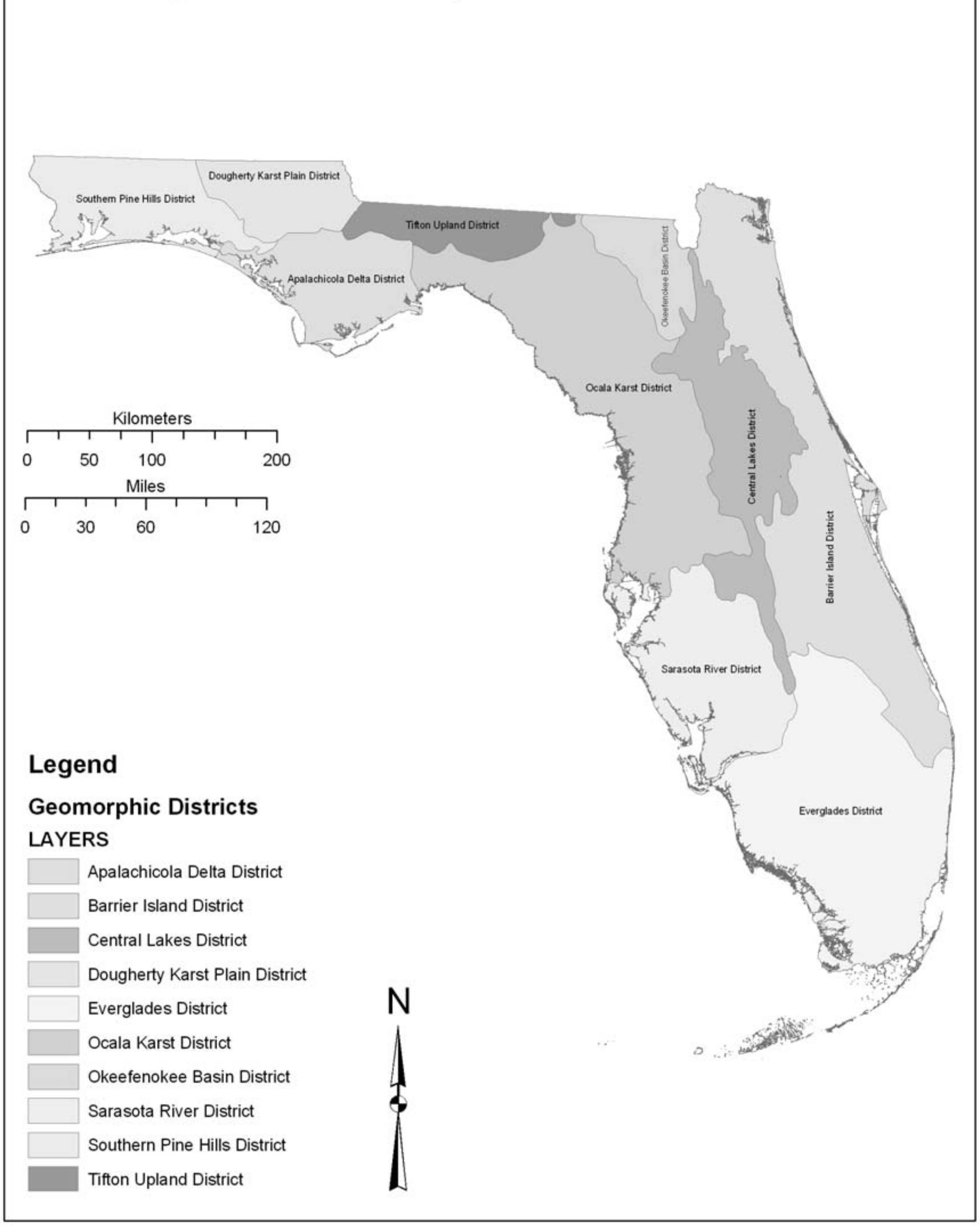


Figure 3 - Geomorphic Districts of Florida



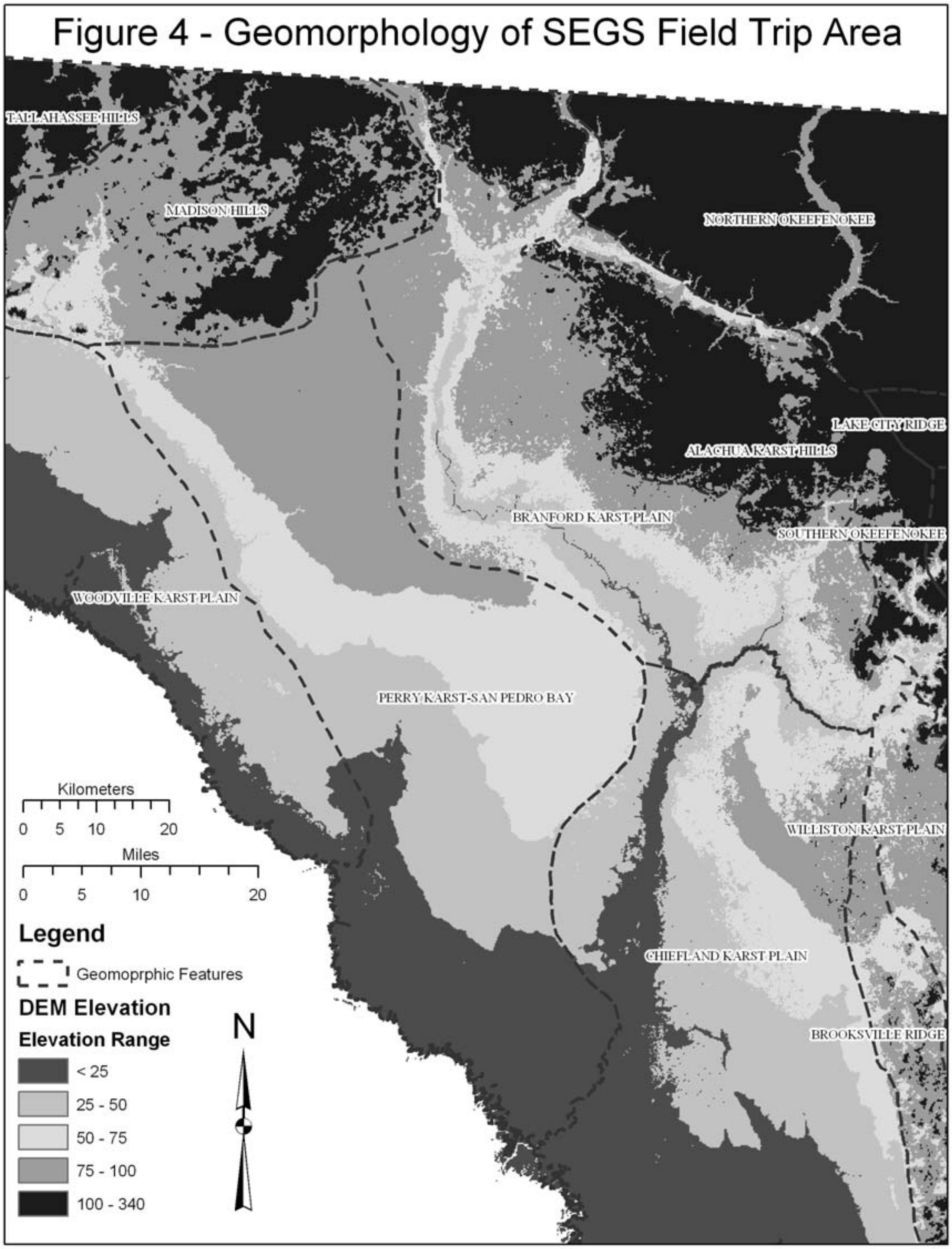


Figure 4 - Geomorphology of SEGS Field Trip Area
TALLAHASSEE HILLS
MADISON HILLS
NORTHERN OKEEFENOKEE
LAKE CITY RIDGE
ALACHUA KARST HILLS
BRANFORD KARST PLAIN
SOUTHERN OKEEFENOKEE
WOODVILLE KARST PLAIN
PERRY KARST-SAN PEDRO BAY
WILLISTON KARST PLAIN
CHIEFLAND KARST PLAIN
BROOKSVILLE RIDGE
Kilometers
0 5 10 20
Miles
0 5 10 20
Legend
Geomoprphic Features
DEM Elevation
Elevation Range
< 25
25 - 50
50 - 75
75 - 100
100 - 340
N

Marianna Karst Plain, the Vernon Karst Hills, Compass Lake Karst Hills and the Sneads Hills (Figure 2), based on the characteristics of the karstic landscape. Elevations range from less than 100 feet (31 meters) to more than 300 feet (91 meters) msl. The geology of the region controls the development of the karstic landscape. Structurally, the Chattahochee "anticline", a high on the Tertiary limestone, brings the soluble Eocene to Miocene carbonates near the surface. Younger siliciclastic sediments and a weathering residuum overlie the carbonates (Figure 1). Karst landscapes are most mature on the Marianna Karst Plain and less mature in the karst hills areas. Springs are common within the Dougherty Karst Plain District.

Apalachicola Delta District

The Apalachicola Delta District ranges from central Bay County east to the western third of Wakulla County where it merges with the western-most edge of the Ocala Karst District on the Woodville Karst Plain. To the west, the Apalachicola Delta District merges with the Southern Pine Hills. The district's northern limit is in Calhoun County where it borders on the Dougherty Karst Plain District. The southern terminus of the delta district includes the barrier island complex developed along the Gulf coast. The district is subdivided into an upper level delta plain and a lower delta plain (Figure 2) Sediments ranging from Miocene-Pliocene siliciclastic and carbonates to Quaternary-Holocene siliciclastics occur at the surface in the Apalachicola Delta District. The oldest unit is the Torreya Formation which is exposed in Wakulla County. Elevations in the Apalachicola Delta District range from more than 200 feet (61 meters) msl along the northern edge to sea level at the coast.

Tifton Upland District

The Tifton Upland District encompasses the area referred to as the Tallahassee Hills by White (1970). The uplands extend from the Apalachicola River eastward to central Hamilton County at the Alapaha River. Brooks (1981) stated that the Tifton Uplands were structurally controlled and restricted the district to the area underlain by the Gulf Trough. The Tifton Upland's topography is characterized by broad, undulating hills with a well developed dendritic drainage pattern. Elevations range from up to 300 feet (91 meters) msl on the hilltops to less than 100 feet (31 meters) msl in the major stream and river valleys and in the swamps of the eastern portion of the district. Elevations decrease toward the southern limit of the district. The Tifton Upland District merges with the northern portion of the Apalachicola Delta District at elevations around 200 feet (61 meters) msl along the western portion of the Cody Scarp. Where the uplands make the transition to the Ocala Karst District, the boundary is marked by the Cody Scarp at elevations around 100 feet (31 meters) msl down to approximately 50 feet (15 meters) msl, although there is some variation in scarp elevation. The uplands merge with the flat, swampy Okeefenokee Basin District in central Hamilton County. In general, the land surface elevations decline very gradually from west to east across the Tifton Upland. The District can be subdivided into three subdistricts or zones based on the character of the topography which is controlled by the underlying sediments. These are the Apalachicola Bluffs and Ravines, the Tallahassee Hills and the Madison Hills (Figure 2).

Okeefenokee Basin

The transition from the eastern Tifton Uplands and the Ocala Karst District to the Okeefenokee Basin is recognized based on topography and drainage. Isolated hills surrounded by poorly drained areas characterize the eastern-most Tifton Uplands (Madison Hills). The Lake City Ridge subdivides the district into northern and southern basins (Figure 2). In the northern Okeefenokee Basin, the hills are absent and the entire area is poorly drained and flat. Hills are common and the area is better drained in the Southern Okeefenokee Basin. Where the Okeefenokee Basin District makes the transition to the Ocala Karst District the land is better drained, has more numerous karst features and has more relief. It is bounded on the east by the toe of the Trail Ridge. Trail Ridge lies along the eastern boundary of the Okeefenokee Basin. White (1970) referred to this district as a portion of the Northern Highlands. Elevations vary within the district from approximately 100 feet (31 meters) to more than 190 feet (58 meters) msl. Where the Suwannee River occurs within the district, elevations along the river may be less than 50 feet (15 meters) msl. Miocene Hawthorn Group sediments to Plio-Pleistocene siliciclastics underlie the district. The Statenville and Coosawhatchie Formations, Hawthorn Group occur at or near the surface in the western portion of the district (Figure 1). Undifferentiated Plio-Pleistocene siliciclastics underlie the eastern portion of the district and form the Lake City Ridge.

Ocala Karst District

The Ocala Karst District encompasses a broad area from Wakulla County in the panhandle to Hillsborough and Pinellas Counties in west-central peninsular Florida. Carbonate sediments ranging from the Middle Eocene Avon Park Formation to the Oligocene-Miocene Tampa Member of the Arcadia Formation, Hawthorn Group and the St. Marks Formation lie near the land surface. Dissolution of these sediments has created distinct landforms that characterize the district, including numerous springs. The Ocala Karst District lies to the south of the Tifton Uplands, separated by the Cody Scarp. To the east of the Tifton Uplands, the Okeefenokee Basin lies to the north of the district. Throughout most of its eastern boundary, the Ocala Karst District merges with the Central Lake District with which it shares a karstic influence. The southern terminus of the district occurs where the impermeable Hawthorn Group sediments retard the development of karst features in the Sarasota River District and streams and rivers become more common.

Elevations within the district range from sea level along the coast to in excess of 300 feet (91 meters) msl on the Brooksville Ridge. The topography over much of the district is gently rolling with only minor relief. However, on the Brooksville Ridge, the terrain looks more like that of the Central Lake District and relief may exceed 200 feet (61 meters).

Sinclair and Stewart (1985) delineated zones of similar karst development in Florida based on the thickness and type of sediment cover and on the sinkhole types. The entire district is covered by a siliciclastic cover of varying thickness ranging from a few feet (one meter) of sand and clay to as much as 200 feet (61 meters) of sediment.

The Ocala Karst District is dominated by "solution sinkholes", shallow, broad bowl-shaped depressions producing a gently rolling topography. This type of dissolution occurs in areas where there is a thin, permeable, siliciclastic cover allowing downward percolating groundwater to dissolve the limestone surface. These sinkholes develop slowly. The area also exhibits collapse features developed from the collapse of cavern roofs. Springs, sinking and resurgent streams and numerous caves and caverns occur within the Ocala Karst District.

Areas of the Ocala Karst District where there is a thicker cover of permeable siliciclastic sediments are characterized by cover-subsidence sinks. These areas have few, shallow sinks formed by the downward movement of the siliciclastic cover to fill voids created by the dissolution of carbonate sediments. Cover subsidence sinkholes develop slowly in response to the dissolution.

Cover-collapse sinkholes form in those areas where the siliciclastics overlying the limestone are cohesive. Dissolution of the carbonate sediments forms voids into which the overlying sediments collapse. This type of sinkhole forms rather abruptly. Two excellent examples of this type of sinkhole are Devil's Millhopper in Alachua County and Brooks Sink in Bradford County.

The Ocala Karst District developed on the crest of the Ocala Platform, a high on the Tertiary limestone of the Florida Platform. The crest of the Ocala Platform occurs near the present day western coastline of the peninsula. To the north, south and east the thickness of sediments covering the carbonates increases. As sediment thickness increases, the type of sinkholes and their abundance changes grading from the solution sinks to the cover collapse sinks.

The maturity of karst development varies across the district. In those areas near the Tifton Uplands, Okeefenokee Basin and the Central Lakes District, the karst is younger, less mature and has more relief. Further away from these areas, in general toward the Gulf Coast, the karst is more mature and has less relief due to more extensive dissolution and erosion of the overlying siliciclastics.

A number of regional geomorphic areas are recognized within the Ocala Karst District based on elevation, abundance of karst features, drainage, and relief. These include the Woodville Karst Plain, Perry Karst-San Pedro Bay, Branford Karst Plain, Alachua Karst Hills, Chiefland Karst Plain, Williston Karst Plain, Fairfield Karst Hills, Ocala Karst Hills, Brooksville Ridge, Crystal River Karst Plain, Land 'O Lakes Karst Plain and the Green Swamp (Figure 2). White's (1970) Coastal Swamps form the coastline for much of the Ocala Karst District from Wakulla County to Pasco County.

Central Lake District

The Central Lake District occupies most of the Central Highlands of Cooke (1939) in peninsular Florida. As used in this report, the Central Lakes District is essentially the same as that outlined by Brooks (1981). The district extends from eastern Alachua County, southeastern Bradford County and southern Clay County to southernmost Highlands County. The Central Lake District lies east and south of the Ocala Karst District, east of the Sarasota River District, and west of the Barrier Island Sequence District. A thick (up to at least 200 feet [61 meters]) sequence of siliciclastic sediments of the Cypresshead Formation, undifferentiated sediments and siliciclastic and carbonate sediments of the Hawthorn Group overlie the Ocala Limestone in the district. Dissolution of the limestone and subsequent subsidence or collapse has created the characteristic sinkhole lakes and dry sinks that dominate the landscape.

The Central Lake District provides some of the most picturesque landscapes in the State with rolling hills interspersed with numerous closed depressions and circular lakes. Elevations in this district range from 50 to 60 feet (15 – 18 meters) msl in depressions and valleys to more than 300 feet (91 meters) msl on the highest hills. Sugarloaf Mountain, on the southwestern side of Lake Apopka, is one of the highest points in the peninsula with an elevation of 312 feet (95 meters) msl.

The influence of sea-level fluctuations on the development of the Central Lakes District is very evident from its coast-parallel orientation and the occurrence of relict beach ridges. In some areas, the distribution of karst lakes is controlled by the beach ridges. The district is bounded on the east by erosional scarps with toe elevations ranging from approximately 30 feet (9 meters) to 90 feet (27 meters) msl. Portions of the western boundary are marked by scarps with elevations ranging from 30 feet (9 meters) to 160 feet (49 meters) msl.

Aerial and satellite photographs and topographic maps provide an interesting view of the Lakes District. The distinctive circular to subcircular shape of the lakes can easily be seen showing individual sinkholes and coalescing sinks. As a result of the numerous sinkholes, the Central Lakes District is primarily internally drained through these karst features. Only one of the State's major rivers, the Okalawaha, flows any distance through the district. The largest lakes in the Central Lake District occur at the headwaters of the Okalawaha River in the Tavares Lake Region (White's Central Valley, 1970). Lake Apopka, the largest of the lakes lies at the southern terminus of the valley. The district includes the highlands designated as the Lakeland-Lake Wales Ridge Complex, the Orlando Ridge, Lake Upland, Big Scrub Dunes, Mt. Dora Ridge, Deland Ridge, Crescent City Ridge, and Trail Ridge (Figure 4). Low areas in the district include the St. Johns River Offset, Wekiva Plain, and the Hawthorne Lakes Region (Figure 2).

Barrier Island Sequence District

The Barrier Island Sequence District extends into Florida from Georgia. The district is characterized by beach ridges, dunes and paleo-lagoons. In Florida, the district extends from the Georgia-Florida state line southward to the vicinity of Lake Okeechobee. It lies to the east of the Okeefenokee Basin District, the Ocala Karst District, and the Central Lakes District. It lies north of the eastern portion of the Everglades District. The surficial and shallow subsurface sediments of the district were deposited during the Plio-Pleistocene and lie unconformably on sediments ranging from the Middle Eocene Avon Park Formation to the Oligocene-Miocene Hawthorn Group. Elevations range from sea level to more than 130 feet (40 meters) on the Bombing Range Ridge in the southern part of the district. The district includes the St. Mary's Plain, Lower and Upper St. Johns River Valley, Atlantic Coastal Complex, Osceola Plain, and the Okeechobee Plain (Figure 2).

Beach ridge plains occur in several areas of the Barrier Island Sequence District at elevations ranging from near sea level to more than 75 feet (23 meters) msl. These occur on portions of the Duval Upland, the Upper and Lower St. Johns Valley, the Osceola Plain and the Okeechobee Plain (Figure 2). Drainage patterns in these areas may be strongly controlled by the relict beach ridges forming, in some cases, a distinct trellis drainage pattern. The beach ridge swales are often swampy and control the development of lakes on portions of the Osceola Plain (see the Narcoossee, Narcoossee SE and Holopaw 7.5' quadrangles for excellent examples of this) and the Eastern Valley.

Dissolution of shell material in the widespread shelly Plio-Pleistocene sediments has created shallow karstic depressions over much of the district. This is particularly evident in Upper St. Johns River Valley and the southern portion of the district.

Sarasota River District

The Sarasota River District covers much of west-central peninsular Florida extending from Hillsborough and Pinellas Counties southward to the Caloosahatchee River in Lee and Glades Counties. The district is characterized by the occurrence of numerous rivers and streams which are more common than in any other geomorphic district in the State. The rivers in the Sarasota River District include the Alafia, Peace, Manatee, Braden, Myakka and Caloosahatchee Rivers and their tributaries. The Sarasota River District lies south of the Ocala Karst District, west of the Central Lakes District and north of the Everglades District.

Impermeable siliciclastic sediments of the Hawthorn Group underlie the Sarasota River District allowing the development of the numerous rivers and streams. The Ocala Karst District merges with the Sarasota River District where the Hawthorn Group sediments retard the development of karst features. The Sarasota River District to the Central Lake District transition occurs where the impermeable sediments of the Hawthorn Group either become more permeable due to a facies change or where the Hawthorn Group sediments are eroded and no longer retard the development of karst features. The separation of the Sarasota River District from the Everglades District occurs where the surface-water flow pattern shifts to a southerly, broad flow pattern.

The landscape of the Sarasota River District is relatively flat with limited relief. Elevations range from sea level along the coastline to more than 150 feet (46 meters) msl along the boundary with the Central Lake District. It includes the Coastal Lowlands and the Polk-DeSoto Plain (Figure 2).

Everglades District

The Everglades District covers the southern one-third of the Florida peninsula and includes the Florida Keys. The district extends from the Atlantic Coast to the Gulf Coast and incorporates Florida Bay. The northern boundary roughly follows the Caloosahatchee River Valley eastward from the Gulf Coast to the northern edge of Lake Okeechobee. The boundary then follows the northern shoreline of the lake then trends southeasterly into Palm Beach County toward the Atlantic Coast at Palm Beach. The Everglades District lies south of the Sarasota River District on the west and the Barrier Island Sequence District on the east. The boundaries are gradational in nature as can be easily recognized on satellite photographs. The district includes the Atlantic Coastal Ridge, Everglades, Rock Glades, the Big Cypress, the Coral Keys and the Oolite Keys (Figure 2).

Elevations within the Everglades District gradually decrease from north to south. The highest elevations generally occur along the northern boundary where elevations reach 30 to 35 feet (9 to 11 meters) msl. Much of the district lies at elevations below 20 feet (6 meters) msl. Plio-Pleistocene sediments, ranging from quartz sand to limestone, underlie the entire district. Dissolution of the limestone has resulted in the development of micro-karst. Dissolution of shell material in the widespread shelly Plio-Pleistocene sediments has created shallow karstic depressions over much of the district.

GEOMORPHOLOGY OF THE FIELD TRIP AREA

The area of geomorphic interest covered by the 2005 SEGS field trip includes three geomorphic districts: Tifton Upland District, the Okeefenokee Basin District and the Ocala

Karst District (Figure 3). The Ocala Karst District comprises most of the field trip region shown in Figure 4.

Tifton Upland

The Tifton Upland in this area consists of the Tallahassee Hills and the Madison Hills. The Tallahassee Hills extend from the Apalachicola Bluffs and Ravines in Gadsden and Liberty Counties on the west to eastern Jefferson County. Elevations of hill tops range to more than 300 feet (91 meters) msl. Well drained valleys have local relief often exceeding 150 feet (46 meters) msl. In general, the hill top elevations decrease from west to east and north to south. This area is generally well drained with swampy conditions existing in some of the lower elevations. The Tallahassee Hills are developed on the Hawthorn Group, Citronelle Formation and Miccosukee Formation siliciclastic sediments (Figure 1). Karst features are present within this zone where the carbonates of the St. Marks Formation and Suwannee Limestone occur near the surface.

The Madison Hills extend from the eastern end of the Tallahassee Hills in central Jefferson County eastward to eastern Madison County on the west side of the Withlacoochee River. A small area of northwestern Hamilton County is occupied by the Madison Hills. It is separated from the main body of this zone by the Withlacoochee River Valley. The elevation of the hills is generally lower than in the Tallahassee Hills with hill tops often below 200 feet (61 meters) msl. The valleys are broad, poorly drained and swampy. The Miccosukee Formation forms the higher areas while the Hawthorn Group sediments underlie the lower portions of the landscape (Figure 1). Karst features occur in the eastern part of the district where the Suwannee Limestone lies near the surface.

Okeefenokee Basin District

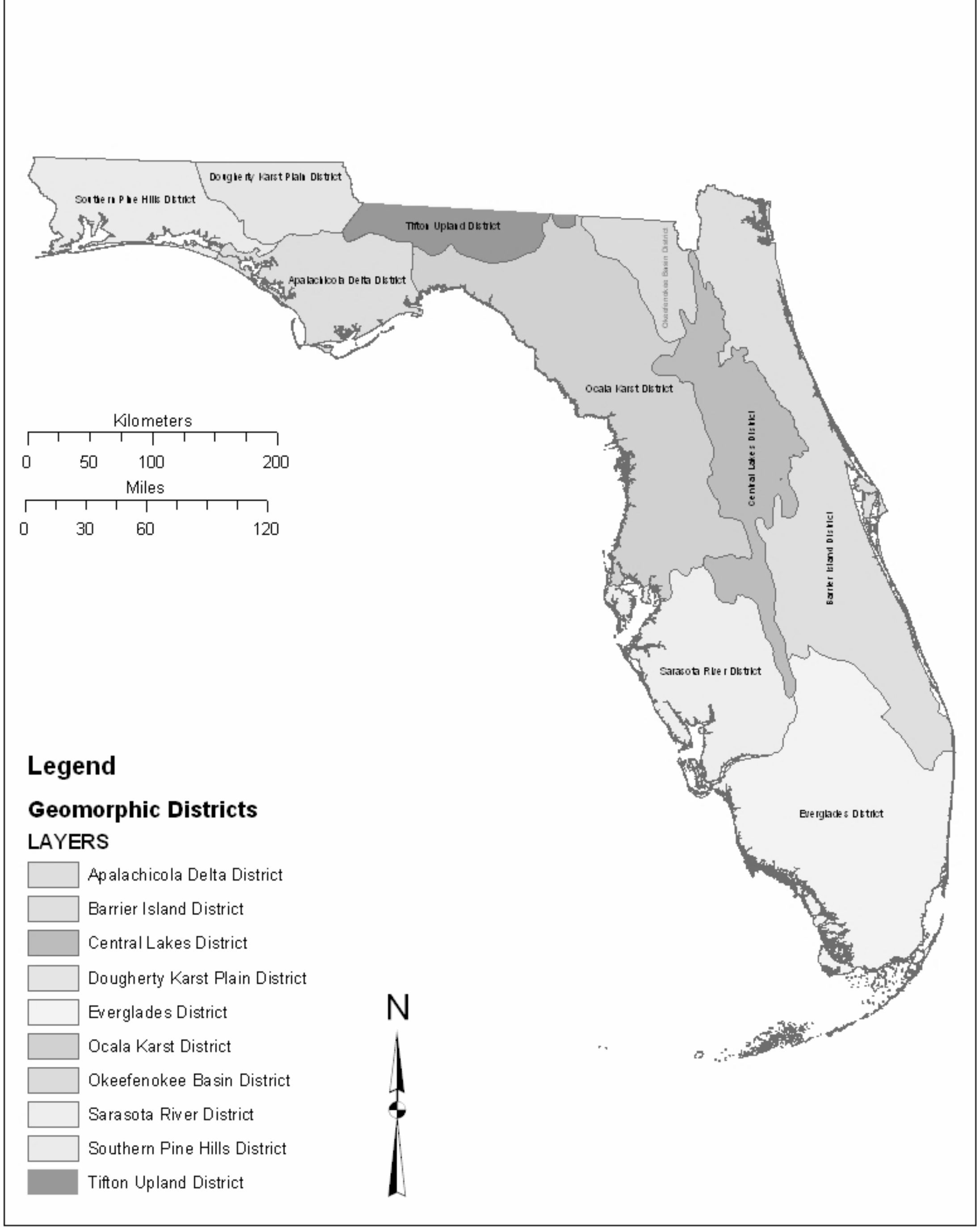
Portions of the Northern and Southern Okeefenokee Basin and the Lake City Ridge occur along the northeastern edge of the field trip area (Figure 4). As described above in the Okeefenokee Basin section, the Hawthorn Group is at or near the land surface. Phosphate is mined in the Northern Okeefenokee Basin in Hamilton County. The highest elevations in the district are on the Lake City Ridge.

The Northern Okeefenokee Basin lies to the north of the Lake City Ridge. The Okeefenokee Swamp occupies much of the northern portion of the Okeefenokee Basin from Georgia into Florida. The northern portion of the basin is very flat with few hills. Hills become more common towards the western and eastern boundaries of the area. Karst features are uncommon throughout most of the basin. Karst features occur primarily in the transition zone with the Ocala Karst District where the Hawthorn Group is thin and breached by sinkholes.

The Lake City Ridge separates the Okeefenokee Basin District into northern and southern segments. It appears to be a barrier island or spit and is truncated by, and therefore older than, Trail Ridge. It is composed of Plio-Pleistocene siliciclastic sediments. Sinkholes are present only on the western portion of the ridge in the transition zone with the Ocala Karst District.

The Southern Okeefenokee Basin lies to the south of the Lake City Ridge. Relief is more pronounced in the southern basin with well-drained, low hills with intervening swampy lowlands. The swampy nature of the low lying areas is due to the low permeability of the Hawthorn Group sediments. Karst features are present in the transition zones with the Ocala Karst District and the Central Lakes District.

Figure 3 - Geomorphic Districts of Florida



Ocala Karst District

The Ocala Karst District, in the field trip area, consists of portions of the Woodville Karst Plain, Perry Karst-San Pedro Bay, Branford Karst Plain, Alachua Karst Hills, Chiefland Karst Plain, Brooksville Ridge and the Williston Karst Plain (Figure 4). The karst plains and karst hills are delineated based on the amount of karstification and relief. The

Ocala Limestone, Suwannee Limestone and minor occurrences of St. Marks Formation underlie this part of the Ocala Karst District (Figure 1). Numerous springs, including many first magnitude springs, occur in this area (Scott, et al., 2004).

The Woodville Karst Plain extends from Wakulla and Leon Counties east and southward to the Steinhatchee River on the Taylor-Dixie County line. It lies south of the Tallahassee Hills and Madison Hills and west of the Perry Karst-San Pedro Bay. Elevations range from sea level to approximately 50 feet (15 meters) msl with very common karst features. There are many springs, disappearing streams and resurgent streams. A number of rivers and streams traverse the Woodville Karst Plain including the St. Marks, Aucilla, Wacissa, and Econfina Rivers. Relief is very low over the entire area and drainage is poor resulting in vast swamps. Sand dunes occur in various portions of the karst plain with dune crest elevations exceeding 50 feet (15 meters) msl.

The Perry Karst-San Pedro Bay complex extends from Madison County southward to the Gulf of Mexico in Dixie County. Elevations within this area range from less than 50 feet (15 meters) to in excess of 100 feet (31 meters) msl. The elevations in San Pedro Bay are generally higher than in the Perry Karst or the Branford Karst Plain (see Copeland, this volume, for discussion). Elevations decline to the south toward the Gulf Coast. The Perry Karst-San Pedro Bay is poorly to extremely poorly drained.

The Branford Karst Plain occurs from Madison and Hamilton Counties southward to the Santa Fe River on the Gilchrist County line. It occurs between the Perry Karst-San Pedro Bay zone on the west, south of the Madison Hills and west of the Alachua-Lake City Karst Hills. Elevations vary from less than 25 feet (8 meters) msl along the Suwannee River to more than 85 feet (26 meters) msl in the northern portion of the karst plain. Elevations generally decrease to the south. The Branford Karst Plain is well drained and there are numerous springs. The Upper Eocene Ocala Limestone underlies the southern portion of the Branford Karst Plain. The northern part of the karst plain is developed on the Lower Oligocene Suwannee Limestone (Figure 1). Varying thicknesses of siliciclastics overlie the carbonates throughout the area. Sand dunes developed in portions of this zone and can be recognized on the topographic maps.

The Alachua Karst Hills form the transition zone between the Ocala Karst District and the Okeefenokee Basin District in northern peninsular Florida. The karst hills extend from northern Suwannee County to central Alachua County. Elevations range from approximately 100 feet (31 meters) to in excess of 200 feet (61 meters) msl. The hills are well drained with swampy conditions occurring on some of the low lying areas. The karst hills formed in response to karstification of the uplands covered by Statenville and Coosawhatchie Formations, Hawthorn Group and undifferentiated Tertiary-Quaternary siliciclastics. Subsequent to the karstification, the clayey siliciclastic sediments eroded to form the topography seen at the present. These processes have caused the retreat of the uplands and created the karst plains west of the Alachua-Lake City Karst Hills. The southern portion of this area is underlain by Upper Eocene Ocala Limestone while the northern part is underlain by Lower Oligocene Suwannee Limestone (Figure 1). Few springs occur within the karst hills.

The Chiefland Karst Plain lies to the east of the southern portion of the Perry Karst-San Pedro Bay geomorphic feature, south of the Branford Karst Plain and west of the northern extension of the Brooksville Ridge. It occurs from northern Gilchrist County to southern Levy County. Included in the Chiefland Karst Plain are the more localized geomorphic features of the Bell Ridge and Waccasassa Flats. Elevations in this area range from sea level along the coast to more than 100 feet (31 meters) msl on the Bell Ridge. This karst plain is more poorly drained then the Branford Karst Plain to the north. The trend of the Waccasassa Flats is very poorly drained and forms the headwaters of the Waccasassa River. Many springs occur within the karst plain. The entire karst plain is underlain by Upper Eocene Ocala Limestone (Figure 1). Undifferentiated Quaternary siliciclastics overlie the limestone in varying thicknesses. The siliciclastics are thickest under the Waccasassa Flats. Dunes are often present on the karst plain.

The Williston Karst Plain extends from western Alachua County southward into southern Sumter County. It is bounded on the west by the Brooksville Ridge, on the east by the Alachua Karst Hills, the Fairfield Karst Hills, Ocala Karst Hills and the Green Swamp to the south. To the north it merges with the Branford Karst Plain and the Chiefland Karst Plain. Elevations generally range from 50 feet (15 meters) to 100 feet (31 meters) msl with a few outlier hills exceeding 150 feet (46 meters) msl. Much of the area is well drained. However, the southern portion becomes more poorly drained toward Tsala Apopka Lake and the Green Swamp. A number of springs occur within the karst plain. The Upper Eocene Ocala Limestone underlies the entire area (Figure 1). The outlier hills are composed of weathered Hawthorn Group sediments. A siliciclastic sediment cover overlies the older sediments throughout the karst plain and dune fields are common in this area.

The Brooksville Ridge, described by White (1970) as "the most massive of the ridges which rise above the general level of the Central Upland", stands out in stark contrast to the surrounding karst plains. It is subdivided into two sections, northern and southern, separated by the Withlacoochee River between Levy and Citrus Counties. The northern Brooksville Ridge begins in Gilchrist and Alachua Counties and terminates in Levy and Marion Counties. The southern section extends from Citrus County southward into Pasco County. The two sections of the ridge differ in elevation, length to width ratio and underlying geology. A portion of the northern part of the Brooksville Ridge falls within the area shown on Figure 4. Elevations in the northern, narrower portion of the Brooksville Ridge range from approximately 50 feet (15 meters) to greater than 150 feet (46 meters) msl. Elevations in some sinkholes are below 50 feet (15 meters) msl. This portion of the ridge has low, rolling karst hills interspersed with moderately shallow sinkholes. The Brooksville Ridge is well drained with wet conditions existing only in the low lying karst features. There are no springs found on the ridge. The Upper Eocene Ocala Limestone underlies the northern portion of the Brooksville Ridge. Weathered Miocene Hawthorn Group sediments lie on the Ocala Limestone with undifferentiated Quaternary siliciclastics mantling the ridge (Figure 1). Dunes are present on the flanks of the ridge.

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Significance of the Cody Scarp on the Hydrogeology of the Suwannee River Water Management District

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Two physiographic regions generally characterize the regional topography; the Northern Highlands and the Gulf Coastal Lowlands. The Highlands in the north and the east are characterized by land surface elevations that range from 100 feet above mean sea level (MSL) to 230 feet MSL. The Lowlands in the south and the west are characterized by land surface elevations that range from 0 MSL to 100 feet MSL.
The boundary between the Highlands and the Lowlands is the Cody Scarp, and it is the most persistent topographic break in the State of Florida. Relief along the Scarp can be as much as 80 feet. Every river or stream that originates in the Highlands, except the Suwannee River, disappears underground as it crosses this transition zone.

In the Highlands, the Floridan aquifer is confined on top and is under artesian conditions. Confined, artesian, carbonate intermediate aquifers exist above the Floridan within the Hawthorn Formation. There are surficial aquifers at land surface in portions of the Highlands. Perched ponds, lakes, swamps and streams are prevalent here and like the surficial aquifer they drain downward over the Cody Scarp into the Lowlands.

In the Lowlands, the Floridan is unconfined and is the only aquifer present. The Suwannee and Santa Fe Rivers are incised into the Floridan aquifer. Where surface-water features exist the water levels are usually coincident with the water table in the Floridan.

Geochemical and Geomorphic Evolution of a Karst Escarpment

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The Cody Scarp (Escarpment) is a classic example of a karst escarpment with numerous poljes, uvalas, sinkholes, sinking streams (swallets), springs, and other karst features along its length. The scarp is the topographic break between the Northern Highlands and Coastal Lowlands of Florida from Alachua County northwest to Leon County. The Northern Highlands are underlain by a thick sequence of siliclastic and carbonate sediments of the Miocene Hawthorn Group. Limestone and dolostone of Eocene Ocala Limestone and Oligocene Suwannee Limestone characterize the Coastal Lowlands. The scarp is a result of marine, fluvial, and karst-related headward erosion of the Hawthorn Group sediments of the Highlands and karstification of the Eocene/Oligocene limestones in the Lowlands.

The Cody Scarp is a topographic feature (Figure 1) with up to about 100 feet of relief. The scarp domain is characterized by large sinkholes, poljes, and uvalas because of the thickness of cover that remains between these large karst features. Plio-Pleistocene marine terrace deposits commonly form elevated ridges at the top of the scarp. The "peak" under the word "Scarp" in Figure 1 is an example of marine terrace accumulations at the top of the scarp.

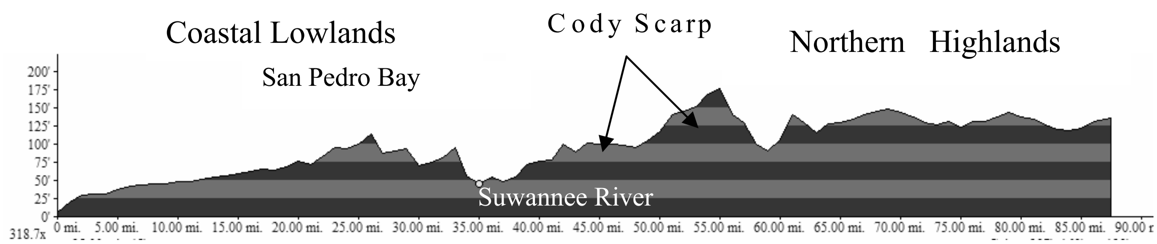
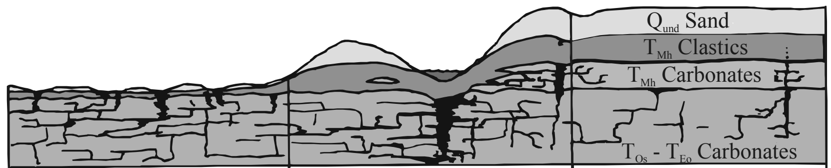


Figure 1 - Topographic profile from Taylor (Baker County) to Dekle Beach (Taylor County) on the Gulf. Northeast is to the right.

The presentation for this field trip discusses the evolution of the Cody Scarp, including ground- and surface-water geochemical processes, scarp-retreat mechanisms, and development of karst systems in the Floridan aquifer system. Figure 2 summarizes these processes.

Surface water and surficial aquifer ground water flowing off of the Northern Highlands is typically mildly acidic and often contains dissolved phosphate. Because of the siliciclastic component in the confining beds of the Hawthorn, there is little chemical buffering of this water as it moves toward the scarp. There is little recharge to the underlying Floridan aquifer and karst development in the Floridan is limited because of the confining properties of the Hawthorn Group. During this stage of scarp development, scarp retreat is largely by headward erosion in stream valleys (Figure 3).



GROUND-WATER DOMAINS	LOWLAND DOMAIN	SCARP DOMAIN	UPLAND DOMAIN
SATURATION STATES		**Zone of Colloidal Transport**	
Calcite	undersaturated	OVER SATURATED	saturated to sl. undersat.
Dolomite	undersaturated	undersaturated	undersat. to saturated
Quartz	undersaturated to saturated	OVER SATURATED	SUPERSATURATED
Hydroxylapatite	undersaturated	SUPERSATURATED	undersaturated
KARST DEVELOPMENT			
Vertical Conduits			
Horizontal Conduits			
Intrastratal Karst			
Solution Doline Development			
Collapse Sinks			
Uvala/Polje Development			
Paleokarst Reactivation			
RECHARGE PATTERNS	**DISPERSED RECHARGE**	**LOCAL, MAJOR RECH.**	**MINOR RECHARGE**

Figure 2 - Model for Cody Scarp retreat with summary of geologic processes in each geomorphic domain.

Upon reaching the vicinity of the Cody Scarp, the acidic, surficial water begins to contact carbonate rocks of the lower Hawthorn and underlying strata as a result of down cutting in stream valleys. Interstratal karst development is initiated within Hawthorn carbonate beds at this stage in scarp retreat. As the lower Hawthorn carbonates are dissolved away, residual sand and clay accumulate and sinkholes allow access of the acidic water to the underlying Floridan. Sinkholes are typically large because of the thick cover (Figure 3). Recharge to the underlying Floridan is focused at the scarp, where streams discharge into swallets and surface (and surficial aquifer) water recharges the Floridan. Sediments in transport in the streams are swept into the aquifer and landscape development changes from fluvial to karst. Relict stream valleys are common within the scarp domain, but they only function as surface water systems during extreme rainfall events. Karst development is geologically rapid and, because of the vertical component of ground-water flow, the conduits have a strong preference for vertical orientations (Figure 2). Contact with alkaline water and carbonate rocks in the lower Hawthorn and Floridan aquifer may result in precipitation of phosphate as carbonate hydroxylapatite (Florida’s “hard rock phosphate deposits”).

After the scarp has retreated from an area, the physiographic designation changes to the "Coastal Lowlands" because of lower topographic elevations and less relief. The Sinkholes that reflect the throats of the sinkholes and conduits that largely developed within the scarp domain pockmark the Lowlands. These features continue to be enlarged by locally recharging water and additional sinkholes develop. Sinkholes are small because of the thin cover, most of which has long before entered the Floridan aquifer system. Conduit development apparently develops a more horizontal component in the lowlands because of horizontal flow of ground water and dissolution of limestone near the water table.

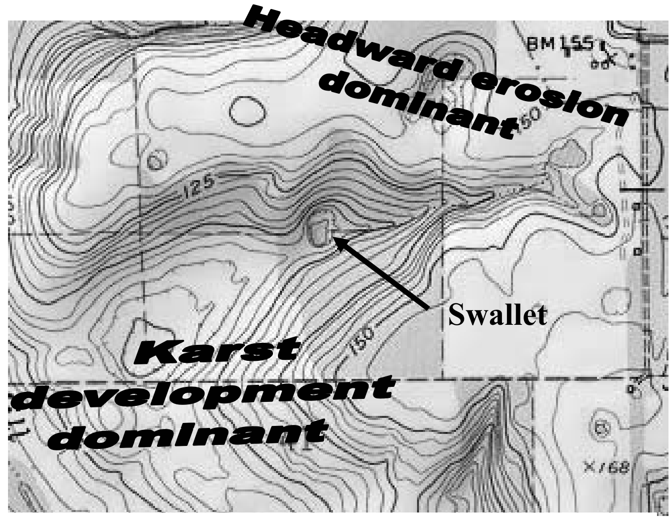


Figure 3 - Small valley north of Alachua (Alachua County) showing transition from headward erosion by stream to stream capture and karst development.

While the Cody Scarp is a named topographic feature that extends from Alachua County to Leon County, there are several other hydrogeologic features in the state that function hydrologically in a fashion similar to the Cody Scarp, but they do not have obvious topographic expression. One of these features will be observed on this field trip. The eastern edge of the San Pedro Bay, where there is a transition from a thin, clay-rich confining unit under the San Pedro Bay swamp to unconfined Floridan aquifer along the Suwannee River corridor. This transition area functions in many ways like a karst escarpment with headward erosion of stream valleys in a region where the Floridan is more-or-less confined, and sinking streams and karst in the lowland at the mouth end of the valleys. Other areas where similar scarps occur include the western margin of the Polk Uplands and the margins of the Green Swamp. Table 1 summarizes some of the properties of the Cody Scarp and other topographically distinct karst escarpments throughout the world, such as the Chester in Indiana, Highland Rim in Tennessee, and Pennyroyal in Kentucky. The table also summarizes apparent functions of areas where there is a transition from a fluvial domain (equivalent to a highland) to karst-dominated, lowland domains where there is no topographic expression.

In general, there is very little difference between the two types of transition to karst lowlands. The major difference is the thickness of the strata that form the aquitard between surficial and limestone aquifers in the "highlands" equivalent terrains. It is suggested that the scarps are similar in terms of hydrologic function and the low topographic relief scarps should be considered in the same light as the classic karst scarp.

This model presents several interesting questions for us to debate. These questions include:

Table 1
Some Properties of Karst Escarpments

Property	**Escarpments with Topographic Features**	**Escarpments that Function Hydrologically But Have Minimal Topographic Relief**
Topographic components		
Highlands	Present	Minor to absent
Escarpment	Present	Minor to absent
Lowlands	Present	Minor to absent
Surface drainage		
Highlands	Streams, swamps, lakes	Swamps, lakes, streams
Escarpment	Sinking streams, large lakes	Sinking streams, lakes
Lowlands	Internal drainage, few lakes or streams	Internal drainage, few lakes or streams
Surficial aquifer flow systems		
Highlands	Tothian flow, aquifer moderate to well developed	Tothian flow, aquifer poorly to moderately developed
Escarpment	Mostly absent[1]	Mostly absent[1]
Lowlands	Generally absent[1]	Generally absent[1]
Limestone aquifer flow system		
Highlands	Porosity development varies, flow often sluggish	Porosity development varies, flow often sluggish
Escarpment	Porosity well developed, flow very dynamic	Porosity well developed, flow very dynamic
Lowlands	Porosity well developed, flow very dynamic	Porosity well developed, flow very dynamic
Recharge to limestone aquifer		
Highlands	Limited and slow	Limited and slow
Escarpment	Rapid, includes runoff from highlands	Rapid, includes runoff from highlands
Lowlands	Rapid, localized by small catchments of sinkholes	Rapid, localized by small catchments of sinkholes
Karst development		
Highlands	Limited to interstratal karst within confining system	Limited to interstratal karst within confining system
Escarpment	Well developed, vertical conduits dominate	Well developed, vertical conduits dominate
Lowlands	Well developed, horizontal conduits highly developed	Well developed, horizontal conduits highly developed

[1] Limestone aquifer is normally the unconfined, water table aquifer.

- Are the low-relief, hydrologic transition areas karst escarpments in the same sense as the Cody Scarp? Should they be called karst escarpments, or some other term?

- Did the Northern Highlands once cover the entire field trip area? Perhaps the San Pedro clay is a remnant of the Hawthorn that was let down at the ancestral Cody Scarp and then modified by later marine and fluvial processes.

- Where does the siliciclastic sediment derived from fluvial processes and transported to the Floridan through swallets on the Cody Scarp and other transition areas go? Similarly, mass wastage continues to transport siliclastic sediments into the sinkholes of the lowlands. Where does it go?

- If, as suggested, there is a large volume of siliclastic sediment trapped in conduits of the Floridan, then many, if not most, fractures and caverns must not function for conduit flow. Are we over estimating the amount of functioning conduiting in the Floridan?

Lake Water Quality Above and Below the Crest of the Cody Scarp

Joe King
Florida Department of Environmental Protection

Abstract was not available at press time.

Swallets of Florida

Harley Means, P.G.
Florida Geological Survey

Swallets, or swallow holes, are sinkholes that are defined as "a place where water disappears underground in a limestone region" (Copeland, 2003). This term, swallet, is also synonymous with stream-to-sink as many of these features capture surface water streams as they flow from the highland regions of north Florida over the Cody Escarpment and disappear into the karst lowlands. Many of these features are known to exist in Florida but no inventory has ever been undertaken to document their numbers and distribution.

The Florida Geological Survey (FGS), with funding from the Florida Springs Initiative, is currently identifying and inventorying swallets. Swallet teams spend time looking over topographic maps and aerial photos to identify probable swallets then verifying the map data in the field. Data recorded on each verified swallet includes GPS location, size, depth, local geology and other pertinent information. Data recorded in the field are later transferred to a database. The goal of this project is to gather as much information about swallets as possible and produce a GIS coverage of their distribution. Metadata will be attached to the coverage and all files will be available to the public.

Swallets play an important role in aquifer recharge and are located in many of the state's spring basins. Since springs protection has become a priority in Florida, a comprehensive inventory of swallets is needed. Many swallets take untreated surface water from urbanized areas and may be directly affecting the water quality of springs like Ichetucknee and Wakulla – two of Florida's thirty-three first magnitude springs. Dye tracing studies have shown that swallets like Rose Sink, Dyal Sink and Black Sink are directly connected to the conduit systems that supply groundwater to Ichetucknee Springs (Butt and Murphy, 2003). Other swallets in the Wakulla Spring springshed have been linked by dye trace studies directly to the spring.

Currently there is insufficient data to quantify the impact on ground-water quality as a result of surface water input through swallets. As these features are identified and monitored our understanding of their importance in surface and ground-water systems will become better. One key component of swallets that remains unknown is how much water they actually take. Flow measurements should be made at different stages to determine what the capacity of some of the more substantial swallets is. Water quality of inflowing surface-water is also largely unknown. The first step, however, is to identify the major swallets in Florida.

Florida's population is burgeoning and storm-water runoff is becoming more of a problem as development tries to accommodate the influx. The standard method of storm-water containment is to construct ponds that hold the water and allow it to slowly percolate into the ground while contaminants settle to the bottom of the pond. A problem arises when storm water ponds are constructed in karst areas and sinkholes open in the ponds effectively creating swallets. Lake City has recently experienced this as well as many other regions of the state.

An example of how swallets may affect public policy recently unfolded in the Lake City area. Lake City, like most of Florida, is experiencing rapid growth and is considering an expansion of their designated urban development area. Lake City is situated near the Cody Escarpment in the Alachua Karst Hills region (Scott, in preparation) in an area with numerous swallets. The FGS was asked by the Florida Department of Community Affairs to prepare a map, based upon preliminary swallet location data, of the distribution and surface-water contribution areas to swallets. This map is now being used as a tool to help guide land-use decisions being made in areas where swallet surface-water basins exist in an effort to protect groundwater flowing to Ichetucknee Springs.

The FGS swallet mapping project will be completed by July 2006. The project will not identify all swallets in Florida but will provide the groundwork for an updatable GIS coverage of swallets. This coverage, which will be made available to the public, will be useful to land-use planners and other local and state entities in making decisions that may affect ground-water quality and ultimately spring-water quality. It will also provide the basis for further scientific study to determine what role these features play in regional surface-water and ground-water systems.

Porter Sink, Leon County, Florida. Swallet that drained Lake Jackson.

REFERENCES CITED

Butt, P. L. and Murphy, G.J., 2003, Dyal and Black Sinks Dye Trace Columbia County, Florida, May-September, 2003, Karst Environmental Services Report to the Florida Department of Environmental Protection, 47 pages.

Copeland, R, 2003, Florida Spring Classification System and Spring Glossary, Florida Geological Survey Special Publication Number 52, 18 pages.

Scott, T.M., in preparation, Geomorphic Map of Florida, Florida Geological Survey Map Series.

Changes in the Isotopic and Chemical Composition of Ground Water Resulting From a Recharge Pulse From a Sinking Stream

Brian Katz, P.G.
United States Geological Survey

The Little River, an ephemeral stream that drains a watershed of approximately 88 km^2 in northern Florida, disappears into a series of sinkholes along the Cody Scarp and flows directly into the carbonate Upper Floridan aquifer, the source of water supply in northern Florida. The changes in the geochemistry of ground water caused by a major recharge pulse from the sinking stream were investigated using chemical and isotopic tracers and mass-balance modeling techniques. Nine monitoring wells were installed open to the uppermost part of the aquifer in areas near the sinks where numerous subterranean karst solution features were identified using ground penetrating radar. During high-flow conditions in the Little River, the chemistry of water in some of the monitoring wells changed reflecting the mixing of river water with ground water. Rapid recharge of river water into some parts of the aquifer during high-flow conditions was indicated by enriched values of delta ^{18}O and delta deuterium (-1.67 to -3.17 per mil and -9.2 to -15.6 per mil, respectively), elevated concentrations of tannic acid, higher (more radiogenic) $^{87}Sr/^{86}Sr$ ratios, and lower concentrations of ^{222}Rn, silica, and alkalinity compared to low-flow conditions. The proportion of river water that mixed with ground water ranged from 0.10 to 0.67 based on binary mixing models using the tracers ^{18}O, deuterium, tannic acid, silica, ^{222}Rn, and $^{87}Sr/^{86}Sr$. On the basis of mass-balance modeling during steady-state flow conditions, the dominant processes controlling carbon cycling in ground water are the dissolution of calcite and dolomite in aquifer material, and aerobic degradation of organic matter.

Reference:

Katz, B.G., Catches, J.S., Bullen, T.D., and Michel, R.L., 1998. Changes in the isotopic and chemical composition of ground water resulting from a recharge pulse from a sinking stream. Journal of Hydrology, v. 211, pp. 178-207.

Hydrochemical Evidence for Mixing of River Water and Groundwater During High-Flow Conditions, Lower Suwannee River Basin, Florida, USA

Brian Katz, P.G.
United States Geological Survey

Karstic aquifers are highly susceptible to rapid infiltration of river water, particularly during periods of high flow. Following a period of sustained rainfall in the Suwannee River basin, Florida, USA, the stage of the Suwannee River rose from 3.0 to 5.88 m above mean sea level in April 1996 and discharge peaked at 360 m^3/s. During these high-flow conditions, water from the Suwannee River migrated directly into the karstic Upper Floridan aquifer, the main source of water supply for the area. Changes in the chemical composition of groundwater were quantified using naturally occurring geochemical tracers and mass-balance modeling techniques. Mixing of river water with groundwater was indicated by a decrease in the concentrations of calcium, silica, and ^{222}Rn; and by an increase in dissolved organic carbon (DOC), tannic acid, and chloride, compared to low-flow conditions in water from a nearby monitoring well, Wingate Sink, and Little River Springs. The proportion (fraction) of river water in groundwater ranged from 0.13 to 0.65 at Wingate Sink and from 0.5 to 0.99 at well W-17258, based on binary mixing models using various tracers. The effectiveness of a natural tracer in quantifying mixing of river water and groundwater was related to differences in tracer concentrations of the two end members and how conservatively the tracer reacted in the mixed water. Solutes with similar concentrations in the two end-member waters (Na, Mg, K, Cl, SO_4, SiO_2) were not as effective tracers for quantifying mixing of river water and groundwater as those with larger differences in end-member concentrations (Ca, tannic acid, DOC, ^{222}Rn, HCO_3).

Reference:

Crandall, C.A., Katz, B.G., and Hirten, J.J., 1999. Hydrochemical evidence for mixing of river water and groundwater during high-flow conditions, lower Suwannee River basin, Florida, USA. Hydrogeology Journal, v. 7, pp. 454-467.

WATER BUDGET OF MALLORY SWAMP

Tom Mirti
Suwannee River Water Management District

Mallory Swamp is located in southeastern Lafayette County, Florida. The Suwannee River Water Management District has owned the majority of the swamp since 2001, when it completed a full-rights purchase of 30,000 acres of land. At the time, the acreage had been devastated by a recent wildfire.

Most of the swamp lies within the Steinhatchee River Basin, although the eastern part of the swamp drains to the Suwannee River. Over the past 60 years, numerous drainage canals have been constructed for the purpose of dewatering low-lying areas and groundwater. As a result, the water budget of the swamp has been altered. A 1990 study showed that surfacewater runoff in the Steinhatchee River has increased by about 5 percent annually since 1950.

In reviewing historical potentiometric surface maps of the Floridan aquifer in the area, the overall effect of the drainage alterations appears to be that the groundwater table in the swamp has declined somewhat, and that the local groundwater divide may have shifted towards the south and west.

Restoring Mallory Swamp

Brian Kauffman, P.E.
Suwannee River Water Management District

Florida is home to many swamps, but few are as unique as Mallory. Mallory Swamp is known as a *pocosin*, a native-American word meaning "Swamp on the Hill."

Mallory straddles the divide and provides water to both the Suwannee and Steinhatchee Rivers. Since hilltop swamps receive most of their water directly from rainfall, they are very dynamic and experience extreme dry and wet cycles. These cycles create special wetland ecosystems that are very fire dependent and are home to many endangered plants and animals. Pocosins also serve as valuable groundwater recharge areas.

The 60,000-acre Mallory Swamp was formerly owned by Richard W. Sears, president of the Standard Lumber Company and co-founder of the famous Sears, Roebuck and Co. Since the "cut out and get out" days of the early 1900's the land has changed hands several times. But it wasn't until the 1980's that the swamp experienced its greatest changes.

Industrial landowners tried to convert the swamp to pine plantations by constructing a network of roads and canals that drastically altered the natural sheet flow of water. Prescribed fires that for generations had been used to mimic natural fires and enhance cattle grazing were no longer used. The consequences were dramatic. Local lakes surrounding the swamp began to dry up and fuel loads grew to devastating amounts. Reaching a crescendo in May 2001, a wildfire raged out of control for weeks, with smoke drifting as far as Tampa and other cities hundreds of miles away.

In April 2002 the Suwannee River Water Management District purchased nearly 30,000 acres of the swamp in an effort to help restore the natural resources. Water control structures are being installed to return the natural sheet flow.

Restoring Mallory Swamp will protect and enhance our water resources, reduce the risk of devastating wildfires, provide habitat for special plants and animals, and provide a unique recreational place for people to enjoy.

(KEY TERMS: Mallory Swamp, Pocosin, Swamp Restoration, Natural Community Restoration, Sheetflow, Wildfire, Groundwater Recharge)

Development of Minimum Levels and Flows in the

Suwannee River Water Management District

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Chapter 373.042 Florida Statutes requires each water management district to establish Minimum Flows and Levels (MFLs) in consideration of the provisions contained in Chapter 62-40.473 Florida Administrative Code. Specifically, the statutes require that Florida's water management districts structure each MFL for each candidate water body to provide protection for the following applicable water resource and human use values from "significant harm":

a. Recreation in and on the water;
b. Fish and wildlife habitats and the passage of fish;
c. Estuarine resources;
d. Transfer of detrital material;
e. Maintenance of freshwater storage and supply;
f. Aesthetic and scenic attributes;
g. Filtration and adsorption of nutrients and other pollutants;
h. Sediment loads;
i. Water quality; and
j. Navigation.

The Statutes further specify that MFLs be developed using "best available data." Thus, there are clear statutory directives as to which properties of a water body are to be protected and that the process of MFL development should not be limited by data needs beyond some minimum to be determined during the MFL development process.

As the characteristics and best available data pertaining to a water body under consideration for a MFL are reviewed, some of these statutory "values" may be more applicable or restrictive than others for the protection of the water body. In concept, if the MFL is developed to protect the most sensitive and limiting of these 10 values, the others will be protected as well. The determination of significant harm to the water resource and/or the ecology of the area are determined by the governing board of the water management district after consideration of many factors that result in the policy that determines "significant harm".

The Suwannee River Water Management District (District) has set the goal of completing adoption of minimum flows and levels (MFLs) for all qualified water bodies within the District by 2011. A team of scientists and engineers, including District staff and consultants from several firms has been assembled for MFL development under this aggressive schedule.

Water bodies to be protected include all major rivers, all first and many second magnitude springs, and a number of large lakes. Last year, the basis document for a MFL for Madison Blue Spring was developed by the consultants (Water Resource Associates, Janicki Environmental, and SDII Global Corporation). This MFL is currently under consideration by the District Board of Directors. The basis document for MFLs for the Lower Suwannee River is being finalized by District staff at the present time. The team is developing MFL basis documents for the Upper Santa Fe River, Waccasassa River, and Alapaha Rivers at the present time.

Delineation of the Troy Springs Basin Using Groundwater Levels

Warren Zwanka
Suwannee River Water Management District

In 2001, the Suwannee River Water Management District (District) was tasked with delineating the contribution area ("Springshed") for Troy Springs. Troy Springs is a first magnitude spring (>100 cfs average flow) that discharges from the Floridan aquifer system into the Suwannee River in Lafayette County, Florida. The discharge from the spring is sufficient to cause a drawdown in the regional potentiometric surface. Therefore, a groundwater levels network of 43 privately-owned wells and 26 District-drilled wells in Lafayette and Suwannee counties was established and the resultant potentiometric maps were used to delineate the contribution area. All wells were finished into the Floridan Aquifer System and vertical control of well measuring points was established to the 3rd order by a licensed surveyor. Ground water level measurements were recorded to 1/100th of a foot as elevation above mean sea level and collected in one day's time. The results of two groundwater levels measurement events on 5/15/2003 and 8/28/2003 indicate a significant portion of the contribution of flow from Troy Springs originates across the river in Suwannee County. In order to continuously monitor groundwater levels in the contribution basin, a network of three Lafayette County wells and three Suwannee County wells were fitted with continuous recorders.

(KEY TERMS: Springs, Springshed, Contribution Basin, Potentiometric surface, Troy Springs)

Field Trip Road Log
Saturday May 7, 2005
(See maps are in back cover of guidebook.)

Travel to Stop 1.

From the Camp Weed Entrance on 75th Dr., go 0.4 miles. north to the US-90. Turn left (northwest). Go 1.1 miles to the crest of the Cody Scarp. Proceed 0.5 miles to the toe of the scarp, which lies in Gum Slough. Continue to proceed northwest on US-90 an additional 3.2 miles to Lee Avenue (a total of 4.8 miles from 75th Dr.). Turn right on Lee Avenue and travel 0.2 miles and turn right (east) on SR-136. Travel east on SR-136 for 5.8 miles. Turn left and follow the road for about 0.45 miles to the Lake Louise boat ramp.

Stop 1 - Lake Louise boat ramp (Sec 14, T2S, R14E).

Lake Louise is situated at an elevation of about 143 feet above msl in the Alachua Karst Hills (Northern Highlands). Joe King of the Florida Department of Environmental Protection will discuss the biology and chemistry of lakes located in the Karst Hills and Karst Plains regions of north-central Florida.

Travel to Stop 2.

Follow the road about 0.45 miles back to SR-136. Turn right (west) on SR-136 and go 1.3 miles to the intersection of CR-417. Turn left (south) and follow CR-417 for 4.2 miles to US-90. Turn left (southeast) on US-90 and travel another 4.2 miles to Lowe Lake Rd. Turn right (south). Travel 0.5 miles to 4394 Lowe Lake Road. Turn left and follow driveway about 0.2 miles to Lowe Lake.

Stop 2 - Lowe Lake (Sec 17, T3S, R15E).

Lowe Lake is located at an elevation of about 145 feet above msl and above the crest of the Cody Scarp in the Alachua Karst Hills. Joe King will continue to discuss the biology and chemistry of lakes in the "Hills" and in the "Plains."

Travel to Stop 3.

Go back 0.2 miles to Lowe Lake Road. Turn left and follow road (see map) for 6.4 miles to SR-49 located in Sect. 34, T3S, R 14E. Turn left (south) and follow SR-49 6.8 miles to a lime rock road (200th). Turn right (west) and follow 200th for 2.1 miles to Little River Sink. By the time you get to Little River Sink, you will have traveled through the Cody Scarp Transition Zone.

Stop 3 - Little River Sink (Northeast corner of Sec 4, T5S, R14E).

Little River Sink is a swallet for the Little River. Brian Katz of the U.S. Geological Survey will begin a discussion of research related to the interaction of groundwater and surfacewater. Harley Means will discuss a swallet mapping study recently initiated by the Florida Geological Survey.

Travel to Stop 4.

Continue east on 200 to US-129. Turn left (south). Go 6.0 miles to road 240. Turn right on the paved road and follow it 1.9 miles to Little Springs Park.

Stop 4 - Little River Spring (Sec 1, T6S, R13E).

Little River Spring is possibly a river rise spring for the Little River. Brian Katz will continue his discussion of research related to the ground- and surface-water interactions in this portion of north-central Florida.

Travel to Stop 5.

Go back 1.9 miles on paved road to US-129. Turn right (south). Go 3.0 miles to US-27 in Branford. Turn right (west) and cross the US-27 into Lafayette County. Go 4.1 miles northwest to CR-405. Turn left (west) and continue 5.3 miles to Midway Fire Tower. The tower is located on the right.

Stop 5 - Midway Tower (Sec 6, T6S, R13E).

Midway Tower is located in the San Pedro “Scarplet” transition zone. Rick Copeland of the Florida Geological Survey will discuss the San Pedro Bay, the “scarplet” transition zone and the agricultural belt paralleling the Suwannee River in Lafayette County.

Travel to Stop 6.

From Midway Tower, turn right (west) onto CR-407 and go 1.3 miles to CR-360. At this intersection, turn left (south) and go 2.4 miles on CR-360 to Crapps Tower Road. Turn right (southeast) and go 5.8 miles to the intersection of Canal Road.

Stop 6 - Intersection of Crapps Tower and Canal Roads (Sec 1, T7S, R12E).

This intersection is located in the middle of Mallory Swamp. Brian Kauffman of the Suwannee River Water Management District will discuss the district’s Land Management Practices plan for the swamp.

Travel to Stop 7.

Turn around at intersection. Go back 5.8 miles to the intersection of Crapps Tower Road and CR-360. At this point Crapps Tower Road merges into CR-360. Go 6.0 miles to the intersection of CR-360 and S-51. Turn right (north) and follow SR-51 for 2.6 miles to the Mayo City Limits sign. Turn right on lime rock road and park.

Stop 7 - Intersection of SR-51 and Mayo City Limits Sign (Sec 13, T5S, R11E).

Rick Copeland will continue his discussion of the “scarplet” transition zone. The zone is very narrow at the city limit sign.

Travel to Stop 8.

Turn around. At SR-51 intersection turn right (north) and go 0.8 miles to stop light. Turn right (east) on to US-27. Go 12.5 miles to CR-425. Turn left (north). Go 1.1 miles to the entrance to Troy Spring Park. Turn right and go 0.6 miles to parking lot. Park your vehicle.

Stop 8 - Troy Spring (Sec 34, T5S, R13E).

Troy Spring is a beautiful spring. The remains of a Union ship from the Civil War are located in the spring run. Sam Upchurch of SDII-Global Inc. will discuss the Minimum Flows and Levels Development Project being conducted for the at the Suwannee River Water Management District. Warren Zwanka of the Suwannee River Water Management District will discuss how the district delineated the Troy Spring Basin Using Ground-Water Levels. After the discussions, attendees are invited to cool off by swimming in the spring. Refreshment will be available for everyone.

Travel back to Camp Weed.

From parking lot go 0.6 miles to CR-425. Turn left (south) and follow road 1.1 miles to US-27. Turn left (southeast) and follow US-27 for 4.9 miles to US-129. Turn right (north) and go 0.2 miles to SR-247. Turn right (northeast). Follow SR-247 for 5.0 miles. Turn left (north) on CR-49. Follow CR-49 21.3 miles to US-90. Turn right (southeast). Go approximately 3.7 miles to 75th Dr. Turn right (south) and go 0.4 miles to Camp Weed entrance. This is the end of the trip.