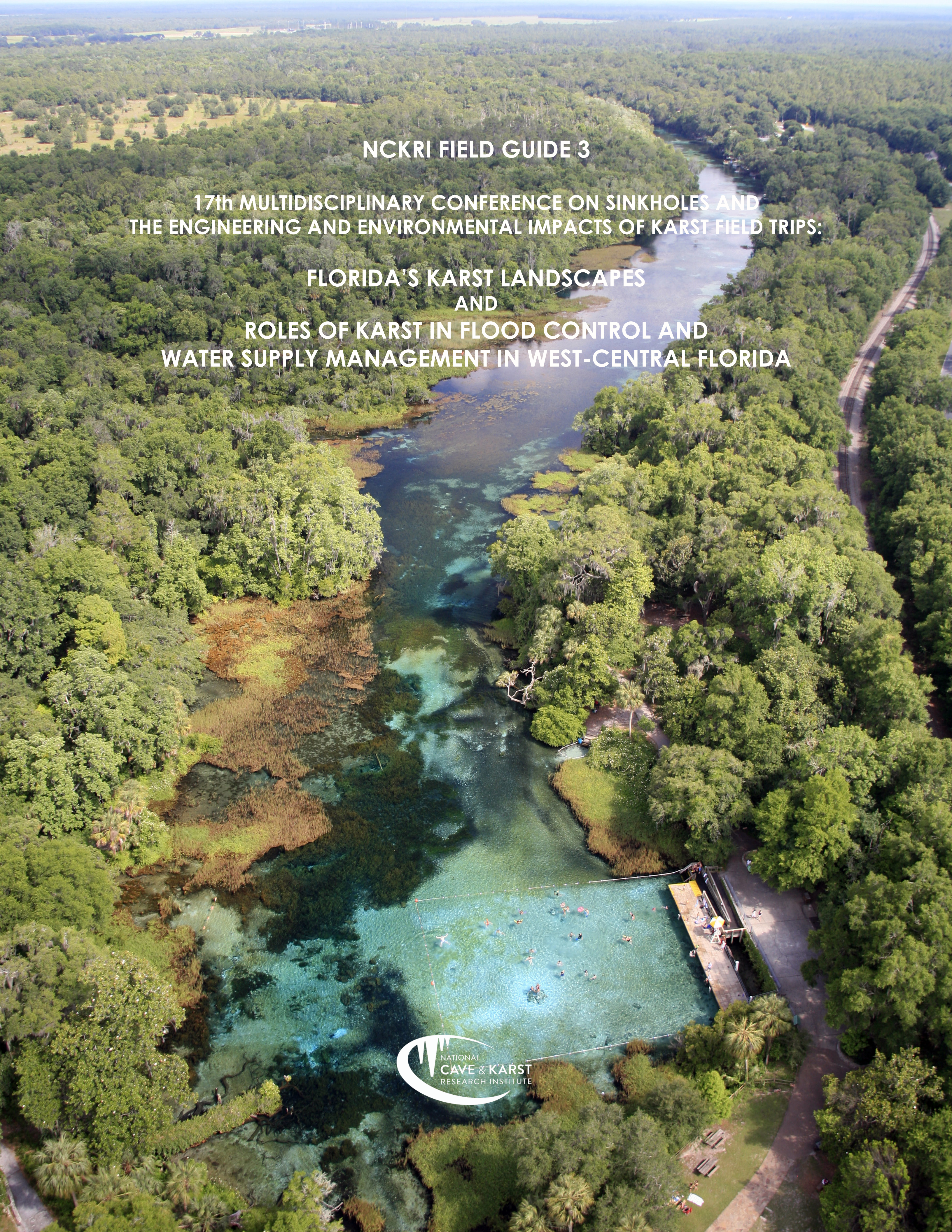

NCKRI FIELD GUIDE 3

17th MULTIDISCIPLINARY CONFERENCE ON SINKHOLES AND THE ENGINEERING AND ENVIRONMENTAL IMPACTS OF KARST FIELD TRIPS:

FLORIDA'S KARST LANDSCAPES AND ROLES OF KARST IN FLOOD CONTROL AND WATER SUPPLY MANAGEMENT IN WEST-CENTRAL FLORIDA

NATIONAL CAVE & KARST RESEARCH INSTITUTE

National Cave and Karst Research Institute
Field Guide 3

Florida's Karst Landscapes

and

Roles of Karst in Flood Control and Water Supply Management in West-central Florida

Published and distributed by:

National Cave and Karst Research Institute

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400-1 Cascades Avenue
Carlsbad, NM 88220 USA

www.nckri.org

Citation information:
Veni, George (editor). 2023. 17th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst Field Trips: Florida's Karst Landscapes and Roles of Karst in Flood Control and Water Supply Management in West-Central Florida. National Cave and Karst Research Institute Field Guide 3, Carlsbad, New Mexico.

Front cover photo: Rainbow Springs is one of the world's highest discharge springs and the source of the Rainbow River, Rainbow Springs State Park, Marion County, Florida. Photograph courtesy of Guy "Harley" Means.

Back cover photo: Sand-filled swallet in the Peck Sink Preserve, Hernando County, Florida. Photo courtesy of Jason LaRoche.

ISBN: 978-0-9795422-9-9

NCKRI Organization and Mission

NCKRI was created by the US Congress in 1998 in partnership with the State of New Mexico and the City of Carlsbad. NCKRI is administered by the New Mexico Institute of Mining and Technology (aka New Mexico Tech or NMT).

NCKRI's enabling legislation, the National Cave and Karst Research Institute Act of 1998, 16 USC, §4310, identifies NCKRI's mission as to:

1) further the science of speleology;
2) centralize and standardize speleological information;
3) foster interdisciplinary cooperation in cave and karst research programs;
4) promote public education;
5) promote national and international cooperation in protecting the environment for the benefit of cave and karst landforms; and
6) promote and develop environmentally sound and sustainable resource management practices.

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NCKRI uses this report series to publish informative guides to caves and karst areas, often in association with conferences. The reports are produced on a schedule whose frequency is determined by the timing of the conferences or other factors. This series is not limited to any topic or field of research, except that they involve caves and/or karst. Anyone using these guides is responsible for obtaining legal access to the properties described. Some properties, especially privately owned, are only accessible to conference field trips and for research under special conditions and are not open to the general public. All reports in this series are open access and may be used with citation. To minimize environmental impact, few or no copies are printed. They may be downloaded at no cost from the NCKRI website at www.nckri.org.

Table of Contents

Florida's Karst Landscapes

Roles of Karst in Flood Control and Water Supply Management in West-Central Florida

List of Figures: Florida's Karst Landscapes

List of Tables: Florida's Karst Landscapes

List of Figures: Roles of Karst in Flood Control and Water Supply Management in West-Central Florida

Florida's Karst Landscapes

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Introduction

This guide is a summary and road log for a one-day field trip to some of the areas with the densest sinkhole distributions in Florida. We will see examples of broad expanses characterized by sinkholes, uvalas, and poljes in a covered karst setting. Additionally, we will see abandoned mines and quarries that exploited Miocene to Pliocene hard-rock phosphate deposits that formed within ancient sinkholes. Stops include an unusually deep, collapse sinkhole, a quarry famous for its solution pipes and fossils, and one of Florida's and the nation's largest karst-spring groups.

Along the way, the trip leaders will discuss the regional karst geomorphology, karst landforms, and the human impact of this karst, especially sinkhole development in active karst plains and ridges.

The digital version of this field guide on the NCKRI website includes hyperlinks to some locations, organizations, publications (see the references), and other items of interest.

Recent Advances in Florida Karst

Florida's Geomorphology Atlas

The geomorphology of Florida is relatively subtle in comparison to many other states. Florida has over 2,000 km (more than 1,200 miles) of coastline, modern and ancient coastal features, and numerous karst features. The Florida Geological Survey (FGS) recently published online Special Publication 59, the "Florida Geomorphology Atlas" (Williams, Scott, and Upchurch, 2022) which includes a web page and interactive maps. The maps characterize and classify areas of topographically distinctive landforms. These are typically regions with genetically related landforms which include ridges, valleys, plains, marine terraces, sinkholes, and other karst landforms in Florida.

This atlas is the first comprehensive delineation of Florida's geomorphic districts and provinces within districts based on landform patterns and origins based on modern technology. As such, many of the districts and provinces are defined because of karst-landform development.

One of the goals of this guidebook is to introduce participants to this new geomorphological classification system and demonstrate the importance of sinkholes and other karst landforms in Florida's karst landscape. In this atlas, the larger, regionally classified geomorphic features are termed districts, which are then subdivided into provinces. Districts have topographic features that are genetically related. Provinces are areas within a district that have spatially related landforms with a common set of origins. Important data for the classification of districts and provinces include near-surface geology that impacts local and regional landforms, as well as the effects of coastal, fluvial, and karst processes on these landforms.

Geomorphically, Florida is divided into 10 districts and 71 provinces (Figure 1). This Florida's Karst Landscapes field trip will be primarily in the Ocala Karst District with a few features in the Lakes District that will be discussed during the trip. Brief descriptions of these districts and the provinces the trip will cross are provided in this guidebook. In-depth discussions

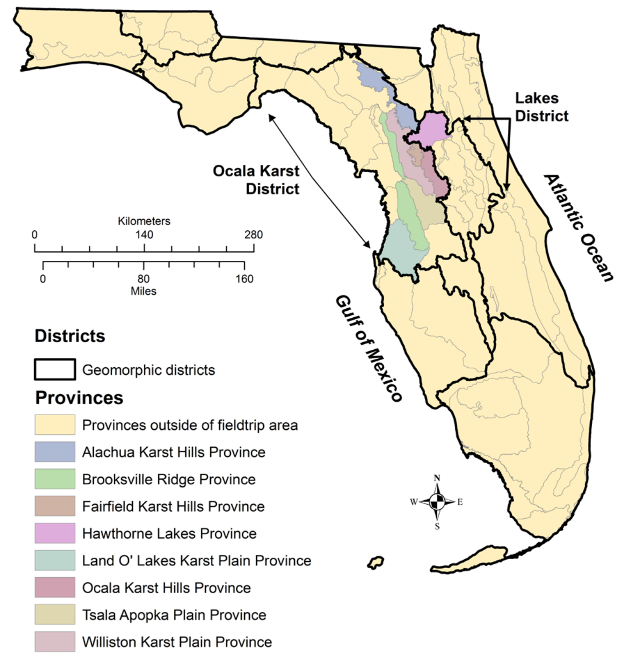

Figure 1. *Florida's geomorphology districts and provinces showing the location of the Ocala Karst and Lakes districts and the provinces through which the field trip passes (modified from Williams et al., 2022).*

of Florida's geomorphic districts and provinces are provided in Williams, Scott, and Upchurch (2022).

Karst Systems of Florida

In 2019, Upchurch et al. published "Karst Systems of Florida" which deals with Florida's eogenetic karst and the interactions of the karst landforms with the siliciclastic cover sediments. Because of the cover sediments, many of the details of Florida's karst landforms differ from telogenetic karst in the mid-continent US and Europe. The landforms discussed in this field trip guide are explained in depth in Upchurch et al. (2019).

Geomorphology of West-Central Florida Karst: Geomorphic Districts and Provinces Encountered on this Field Trip

This field trip passes through some of the most heavily karstified areas in Florida. These areas are part of the Ocala Karst District. The Ocala Karst District was subdivided into 17 provinces by Williams et al. (2022). These include the seven provinces we will visit in this field trip. We will see and discuss, from south to north in the order encountered, the Land O'Lakes Karst Plain, Brooksville Ridge, Tsala Apopka Plain, Ocala Karst Hills, Fairfield Karst Hills, Hawthorne Lakes, Alachua Karst Hills, and Williston Karst Plain provinces (Figure 2). The Hawthorne Lakes Province is the westernmost province of the Lakes District and is the only province that we will discuss on the trip that is not part of the Ocala Karst District

Ocala Karst District

The Ocala Karst District includes plains, ridges, hills, and topography dominated by karst landforms. The district represents most of the largest expanse of eogenetic karst in the United States and one of the largest areas of geologically young karst worldwide. Karst-related landforms include abundant sinkholes; uvalas; poljes; swallets; arches; land bridges; springs, including more first-magnitude springs than any other state; karst windows; and vadose and phreatic caves, including many that support cave-diving activities. The district is a major recharge area of the Floridan aquifer system, one of the most productive carbonate aquifers in the world.

Alachua Karst Hills Province

The Alachua Karst Hills Province is a hilly, karst escarpment within the Ocala Karst District (Figure 2). The toe of the escarpment roughly follows the western boundary of the province, and the top of the escarpment is the approximate eastern boundary of the province (Williams et al., 2022). The province is characterized by numerous sinkholes, uvalas, and poljes created by the dissolution of the underlying limestones. Streams mostly drain to the abundant swallets in the province.

Brooksville Ridge Province

The Brooksville Ridge Province is a relatively high, north-northwest to south-southeast trending ridge (Figure 2). The province is divided into two ridge segments by the Dunnellon Gap (White, 1970), which is partially occupied by the Withlacoochee River. The province varies in elevation and relief with highest elevations and greatest relief in the southern half of the province. The predominant landforms in the province are large sinkholes, creating hilly topography. Dunes are present in many parts of the province, especially on the western and, to a lesser extent, eastern flanks of the province.

Fairfield Karst Hills Province

The Fairfield Karst Hills Province is a region of sandy, clayey hills that have relatively higher topographic relief compared to adjacent provinces (Figure 2). Short streams that either terminate in swallets and other depressions or exit the province have developed because of the reduced permeability of the siliciclastic

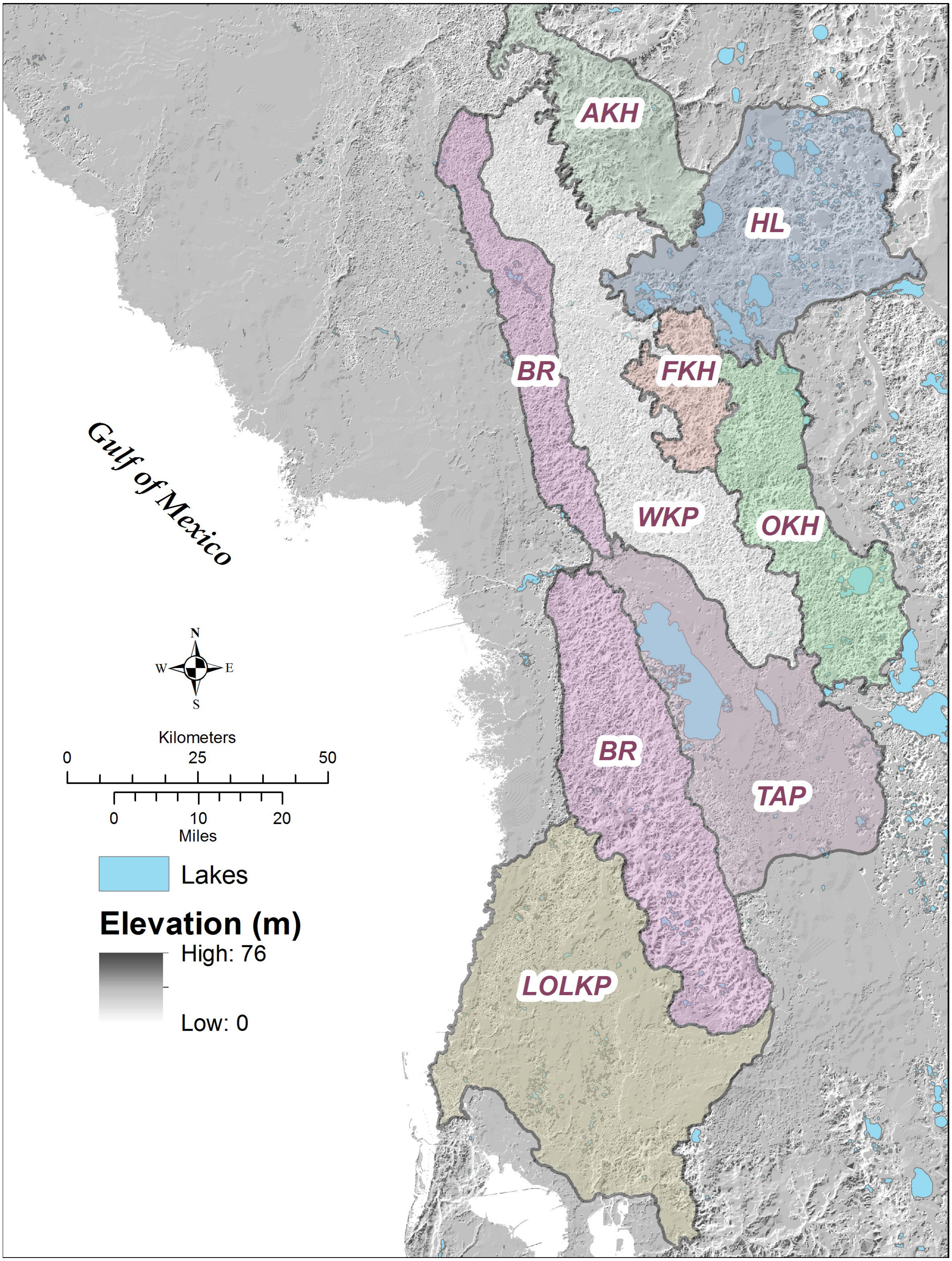

Figure 2. *Geomorphic provinces and topography that will be crossed in this field trip. Province key: LOLKP = Land O'Lakes Karst Plain, BR = Brooksville Ridge, TAP = Tsala Apopka Plain, OKH = Ocala Karst Hills, FKH = Fairfield Karst Hills, HL = Hawthorne Lakes, AKH = Alachua Karst Hills, WKP = Williston Karst Plain.*

sediments that constitute the hills within the province.

Land O'Lakes Karst Plain Province
The Land O'Lakes Karst Plain Province is a coastal karst plain that is separated from the other karst plains crossed during this field trip by the Brooksville Ridge Province (Figure 2). Dry sinkholes and shallow, karst wetland depressions dot the landscape. A notable characteristic of the province is the abundance of coastal springs. The province also contains abundant sand dunes, particularly within several kilometers (a few miles) of the Gulf of Mexico coast.

Ocala Karst Hills Province
The Ocala Karst Hills Province (Figure 2) has mixed terrain with areas of low, karst depressions and rolling hills with less than 8 m (25 feet) of relief and areas of higher karst hills with over 15 m (50 feet) of relief. The karst landforms include individual sinkholes and sinkhole lakes, uvalas, and poljes. Caves and swallets are common in the northern two-thirds of the province.

Tsala Apopka Plain Province
The Tsala Apopka Plain Province is a moderately flat, inland karst plain (Figure 2) that is crossed from south to north by the Withlacoochee River. The northern half of the province is characterized by a complex chain of lakes and wetland systems that are collectively known as Tsala Apopka Lake. The lake is adjacent to and connected by canals to the Withlacoochee River. Lake Panasoffkee also drains to the river in the northern part of the province. The southern half of the province is characterized by low sandy hills and better surface water drainage. Sinkholes, sinkholes lakes, and poljes occur throughout the province.

Williston Karst Plain Province
The Williston Karst Plain Province (Figure 2) is an inland karst plain with mostly internal drainage. Many sinkholes, caves, swallets, and karst windows are present. Springs abound near the northern and southwestern margins of the province.

Lakes District
The Lakes District has been subdivided into 13 provinces (Figure 1). Of these, we will cross the southwestern part of the Hawthorne Lakes Province as we drive to the first field trip stop. The Lakes District occupies much of central peninsular Florida. It is a geomorphically complex district with numerous, north-to-south trending ridges separated by valleys and large lakes. Provinces in the Lakes District demonstrate significant karst landform development. The district also includes an important segment of the St. Johns River valley and the headwaters of the Peace and Ocklawaha rivers.

Hawthorne Lakes Province
The Hawthorne Lakes Province (Figure 2) includes many large karst lakes and "wet prairies" or wetlands. Some of the lakes in the region have developed outflow streams. Many of the lakes in the northern part of the province have well-developed steephead ravines. Important karst features include Paynes Prairie, a large polje, and Orange Lake, a complex sinkhole lake that is filling with sediment to form a polje.

Geologic Framework of the West-Central Florida Karst

Florida's geologic framework in west-central Florida creates a unique template for the formation of extensive eogenetic karst. The structure of the land areas of the Florida Platform (Figure 3) is primarily responsible for the surface and shallow subsurface occurrence of Eocene, Oligocene, and Miocene carbonate sediments in west-central Florida. The carbonates are overlain by predominantly siliciclastic Miocene and younger sediments. The development of karst within this stratigraphic sequence created the interesting karst features we will see and discuss on the field trip. In addition, the karstic carbonates form the upper portion of the Floridan aquifer system, one of the most productive aquifers in the world.

Structure
The primary geologic structure affecting the distribution of karst in west-central Florida is the Ocala Platform (Figure 3). The platform is the result of down warping in the Gulf of Mexico Basin and along the trailing edge of the North American Plate (Upchurch et al., 2019). The part of the Florida Platform identified as the Ocala Platform was more stable and remained as a higher part of the Florida Platform. This gives it the appearance of an uplift (Ocala Uplift of older usage). Miocene and younger sediments were deposited across the Ocala Platform and subsequently removed by erosion and karstification (Scott, 1988; Upchurch et al., 2019). The area of the field trip lies on the flank of the platform just east of the crest.

Stratigraphy
The surficial and near surface stratigraphy of west-central Florida ranges from middle Eocene to Pleistocene and Holocene (Table 1). Carbonates comprise the Eocene and Oligocene section while predominantly siliciclastic sediments with some

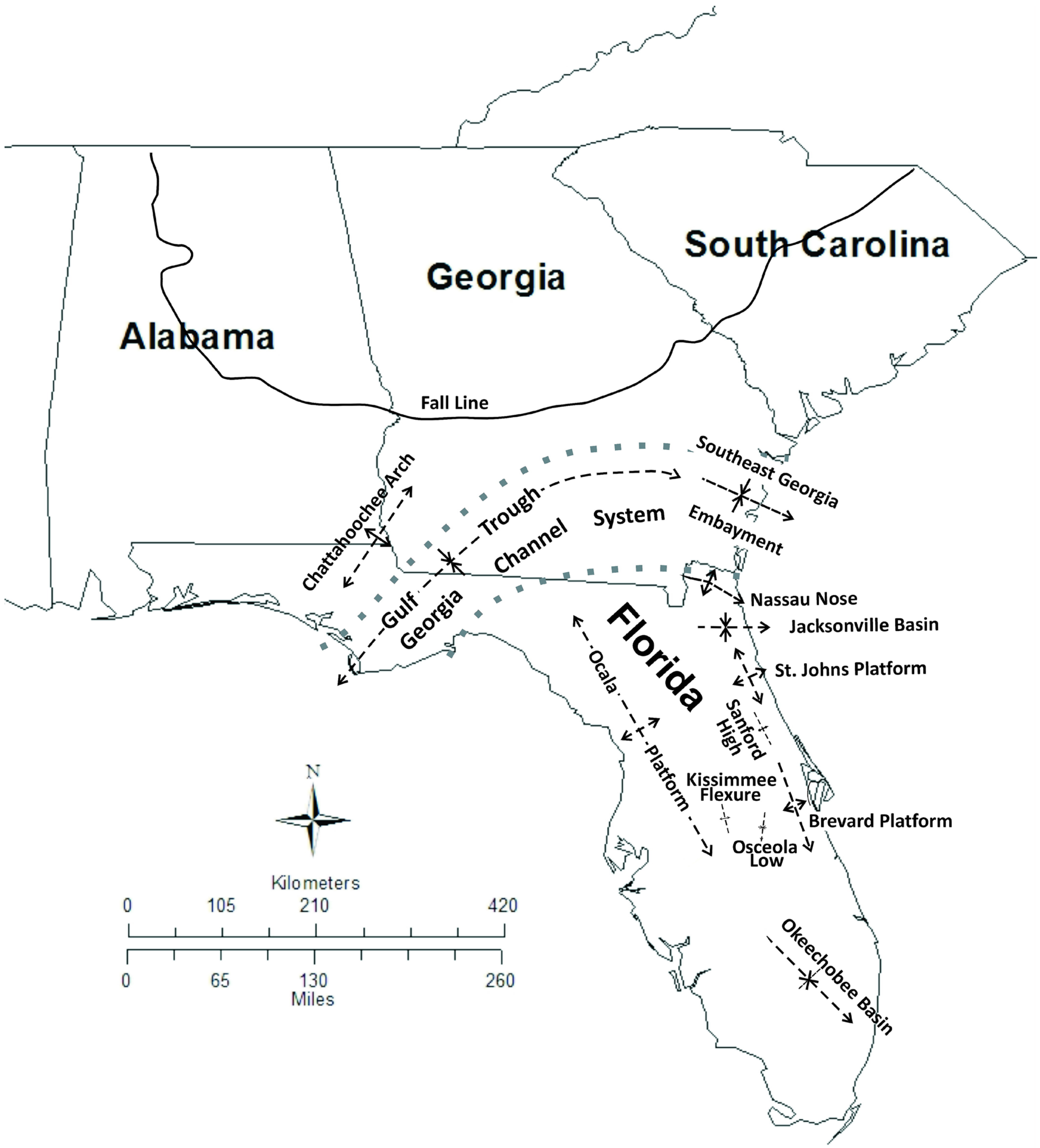

Figure 3. *Structural framework of the land areas of the Florida Platform. The karst addressed in this guide is developed on the flanks of the Ocala Platform in west-central Florida (from Upchurch et al., 2019).*

lower Miocene carbonates make up the Miocene and younger section within the field trip area. For a thorough discussion of Florida's near surface and surface geology, see Scott et al. (2001), Scott (2001), and Florida Geological Survey STATEMAP map products. Figure 4 shows stratigraphic units mapped in the vicinity of the field trip route in west-central Florida. For brevity, the formations and members of the Oligocene-Pliocene Hawthorn Group (Table 1; Figure 4) are discussed at the group level rather than at the formation level. Only strata of middle Eocene and younger age crop out in Florida. The lower Eocene and Paleocene strata shown in Table 1 are of little importance in terms of karst landform development.

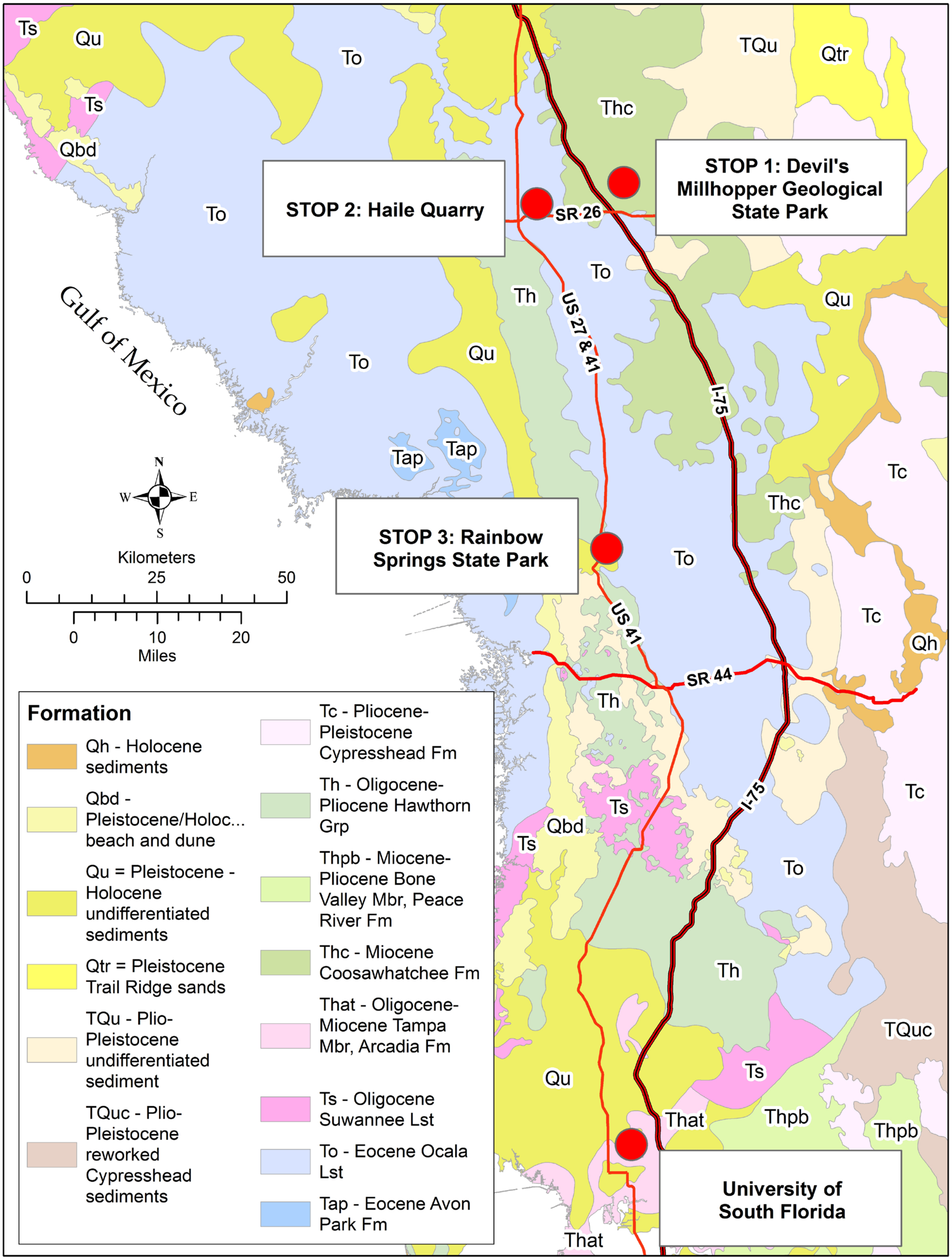

Figure 4. *Geologic map showing the near-surface strata in the vicinity of the field trip route (modified from Scott et al., 2001).*

Table 1. *Cenozoic stratigraphy of peninsular Florida. Stratigraphic units are modified from Braunstein et al. (1988) and ages are from Walker et al. (2018).*

N. FLORIDA	S. FLORIDA	SERIES	SYSTEM	ERATHEM	AGE (Ma)
Undifferentiated Holocene - Pleistocene Sediments	Undifferentiated Sediments	Holocene	Quaternary	Cenozoic	0.01
Undifferentiated Holocene - Pleistocene Sediments	Anastasia Formation; Miami Limestone; Key Largo Limestone	Pleistocene	Quaternary	Cenozoic	
	Fort Thompson Formation	Pleistocene	Quaternary	Cenozoic	
	Bermont Beds	Pleistocene	Quaternary	Cenozoic	
Cypresshead Formation; Nashua Formation	Caloosahatchee Formation	Pleistocene	Quaternary	Cenozoic	2.6
Cypresshead Formation	Tamiami Formation	Pliocene	Neogene	Cenozoic	
	Bone Valley Member (Peace River Formation); Long Key Formation; Stock Island Formation (Hawthorn Group)	Pliocene	Neogene	Cenozoic	5.3
Charlton Member; Coosawhatchie & Statenville Formations (Hawthorn Group)	Bone Valley Member; Peace River Formation (Hawthorn Group)	Miocene	Neogene	Cenozoic	
Marks Head Formation (Hawthorn Group)	Peace River Formation (Hawthorn Group)	Miocene	Neogene	Cenozoic	
Penney Farms Formation (Hawthorn Group)	Tampa Member; Arcadia Formation (Hawthorn Group)	Miocene	Neogene	Cenozoic	23.0
Suwannee Limestone	Nocatee Member; Arcadia Formation (Hawthorn Group)	Oligocene	Paleogene	Cenozoic	
Suwannee Limestone	Suwannee Limestone	Oligocene	Paleogene	Cenozoic	33.9
Ocala Limestone	Ocala Limestone	Eocene	Paleogene	Cenozoic	
Avon Park Formation	Avon Park Formation	Eocene	Paleogene	Cenozoic	
Oldsmar Formation	Oldsmar Formation	Eocene	Paleogene	Cenozoic	55.8
Cedar Keys Formation	Cedar Keys Formation; Rebecca Shoals Dolomite	Paleocene	Paleogene	Cenozoic	65.5

Eocene Avon Park Formation and Ocala Limestone

The middle Eocene Avon Park Formation (Table 1; Tap, Figure 4) occurs at or near land surface on the crest of the Ocala Platform to the west of the field trip area. In west-central Florida, the Avon Park Formation is a poorly to well indurated dolostone and is not involved in karst development.

The upper Eocene Ocala Limestone (To, Figure 4) overlies the Avon Park Formation except where the Ocala Limestone has been removed by erosion in limited areas. It is a poorly to moderately indurated, fossiliferous limestone. It dips and thickens to the east and south from the crest of the Ocala Platform. Dissolution of the limestone has created a highly karstic terrain.

Oligocene Suwannee Limestone

The lower Oligocene Suwannee Limestone (Ts, Figure 4; Table 1) overlies the Ocala Limestone in the southern part of west-central Florida. It has been removed by erosion in much of west-central Florida. It is a poorly to moderately well indurated, fossiliferous limestone. It dips and thickens to the south. Dissolution of the Suwannee Limestone has created a highly karstic terrain.

Oligocene to Pliocene Hawthorn Group

The upper Oligocene to lower Pliocene Hawthorn Group (Th, Thc, Thpb, and That on Figure 4; Table 1) occurs scattered around west-central Florida. The Hawthorn Group is upper Oligocene to lower Pliocene in the southernmost part of this area. In most of west-central Florida, the Hawthorn Group is lower to middle Miocene. The group consists of carbonates and siliciclastics. The carbonates are both limestone and dolostone, variably indurated, clayey, sandy and phosphatic. Carbonates are abundant in the lower Hawthorn Group and decrease in abundance up-section. The carbonates are predominantly dolostone in central and northern Florida while limestone dominates in southern Florida. Quartz sand, quartz silt, and clay increase up-section and they are usually unconsolidated to poorly consolidated and phosphatic. The Tampa Member (That, Figure 4) is a limestone at the base of the Arcadia Formation (Hawthorn Group). It is involved in karstification only in the southernmost part of west-central Florida. Table 1 and Figure 4 list some Hawthorn Group formations and members (see Scott (1988) for a thorough discussion of the Hawthorn Group, its component formations and members, and its extent on the Florida Platform).

Pliocene to Holocene Cover Sediments

The Pliocene-Pleistocene Cypresshead Formation (Tc, Figure 4; Table 1) overlies the Hawthorn Group in parts of west-central Florida. The Cypresshead Formation is composed entirely of siliciclastics, predominantly quartz sand and clay minerals. It consists of unconsolidated to poorly consolidated, fine to very coarse grained, clean to clayey sands, some of which are cross bedded. Discoid quartz pebbles and mica are also often present. Clay beds are generally thin and discontinuous. The Cypresshead Formation was more widespread, but its areal extent was reduced by erosion, reworking, and penetration by widespread karst depressions.

The Pliocene-Pleistocene units (TQuc, TQu, Qu, Qbd, Qtr on Figure 4; Table 1) are not formal lithostratigraphic units. The units were identified in order to map different parts of Florida's nearly ubiquitous quartz sand cover to better describe Florida's geologic framework. The Holocene sediments (Qh) were mapped based on the occurrence in floodplains and estuaries and are also not formal lithostratigraphic units.

The Pliocene-Pleistocene reworked Cypresshead sediments (TQuc, Figure 4; Table 1) overlies the Hawthorn Group and older formations where the Hawthorn Group is missing. It is the result of reworking and redeposition of Cypresshead Formation sediments. Lithologically, it is nearly indistinguishable from Cypresshead Formation sediments. It occurs filling paleo-valleys and on the flanks of ridges composed of the Cypresshead Formation. The topography on these sediments is much subdued compared to the Cypresshead Formation.

The Pliocene-Pleistocene undifferentiated sediments (TQu, Figure 4; Table 1) overlie a variety of older units depending upon the location. It consists of unconsolidated to poorly consolidated, fine to coarse grained, quartz sand, sandy clay, and clay. This unit is recognized based on the occurrence of a sand sequence generally above about 30 m (100 feet) mean sea level (MSL).

Pleistocene Trail Ridge sands (Qtr, Figure 4; Table 1) overlie the Cypresshead Formation. This unit consists of unconsolidated, fine to medium grained quartz sand. Some parts of the deposit contain significant concentrations of heavy minerals. The geomorphic feature, Trail Ridge, is composed of these sediments.

Pleistocene-Holocene undifferentiated sediments (Qu, Figure 4) overlie a number of different formations depending on the location. These sediments consist of unconsolidated to poorly consolidated, generally fine to medium grained quartz sand, silt, and clay. Organic matter is often present. The Pleistocene-Holocene undifferentiated sediments occur below 30 m (100 feet) MSL.

Pleistocene-Holocene beach ridge and dune sediments (Qbd, Figure 4) overlie different units depending on the location. These sediments are typically unconsolidated, fine to medium grained. They were mapped based on a surface morphology indicative of beach ridges and dunes.

Holocene sediments (Qh, Figure 4) occur in river and stream valleys in the areas shown in Figure 4. These sediments consist of wide-ranging mixtures of quartz sand, silt, clay, carbonate, and organic matter.

Hydrostratigraphy

The hydrostratigraphic framework in the field trip area consists of the Floridan aquifer system, the intermediate confining unit, and the surficial aquifer system (Table 2; Southeastern Geological Society, 1986). For an in-depth discussion of Florida's hydrostratigraphic framework, see Upchurch et al. (2019).

Floridan Aquifer System

The upper part of the Floridan aquifer system in the field trip area consists of the Ocala Limestone, the Suwannee Limestone, and the Tampa Member of the Arcadia Formation (Hawthorn Group). In much of west-central Florida, the Suwannee Limestone and the Tampa Member are absent due to erosion, karstification and, possibly, nondeposition. In this area, the Ocala Limestone comprises the uppermost unit of the Floridan aquifer system. In much of the southern part of west-central Florida, the Suwannee Limestone is the

Table 2. *Hydrostratigraphic framework of Florida (from Fowler and Albritton, 2022).*

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

uppermost Floridan aquifer system unit. In southernmost west-central Florida, the Tampa Member is the uppermost Floridan aquifer system unit. The epigenetic karst features of the field trip area are developed near the top of the Floridan aquifer system, in the limestones of the Ocala Limestone, Suwannee Limestone, and Tampa Member.

Intermediate Confining Unit

The intermediate confining unit occurs in the impermeable to very low permeability sediments of the Hawthorn Group. The intermediate confining unit is absent in much of west-central Florida where karst landforms are most abundant. The intermediate confining unit serves as an upper, semiconfining unit for the Floridan aquifer system. Where karst penetrations and other breaches of the intermediate confining unit occur, recharge to the underlying Floridan aquifer system is higher. Where residual clays and sand that remain from erosion of the sediments of the intermediate confining unit/Hawthorn Group are present, they constitute important cover components during sinkhole development.

Surficial Aquifer System

The surficial aquifer system occurs in the quartz sand-rich cover materials that overlie older stratigraphic units. In areas where the intermediate confining unit is absent, the surficial aquifer system lies on the Floridan aquifer system. In these areas, quartz sands of the surficial aquifer system overlie the Floridan aquifer system carbonates. However, the surficial aquifer system is poorly developed in the field trip area. In some cases, the potentiometric surface of the Floridan aquifer system is above the top of the carbonates and occurs in the overlying cover materials. In this case, the surficial aquifer system does not exist by definition (Southeastern Geological Society, 1986). Where the surficial aquifer system is relatively thick, biogenic CO_2 increases the acidity of meteoric water and contributes to karst development in the underlying limestones (Upchurch et al., 2019).

Karst Landform Development in West-Central Florida

The processes and sequences of landform development in the field trip area are complicated. The dominant processes that have sculpted the landscape are:

1. Miocene to Pleistocene sea-level fluctuations that resulted in deposition of marine-terrace sands and coastal landforms during high sea stands and erosion of strata during low sea stands, and
2. pervasive development of karst landforms by dissolution of limestones in Eocene to Miocene strata.

The Brooksville Ridge, Ocala Karst Hills, Fairfield

Karst Hills, and Alachua Karst Hills provinces are a result of karst escarpment retreats. The Alachua Karst Hills Province is an escarpment formed by fluviokarst erosion. The toes and lower flanks of these scarps have been modified by marine and coastal processes.

Conditions That Have Affected the Karst

The karst landforms in the field trip area are similar in many ways to the karst landforms elsewhere in the US. However, three factors complicate the story:

1. the karst is eogenetic,
2. deposition, diagenesis, and karst development are multiphasic because of Miocene to Holocene sea-level variations, and
3. the carbonates are mostly covered by siliciclastic cover sediments that are subject to soil creep and other forms of mass wastage.

Eogenetic Karst

The Eocene to Miocene limestones that host the karst have never been buried more than 100 m (328 feet) and diagenetic recrystallization and cementation have been limited. As a result, primary porosity is present and subject to pervasive dissolution in most of the limestones. This has resulted in void development independent of secondary porosity, such as along fractures. Many of these voids have become interconnected resulting in anastomosing or maze cave patterns. Secondary porosity is also widespread, especially along fractures. These fractures commonly enhance dissolution, so many caves follow a reticulated pattern with northwest-to-southeast and northeast-to-southwest orientations.

High matrix and fracture surface areas combined with abundant rainfall and recharge to the limestone aquifer have resulted in extensive areas characterized by epigenetic karst landforms. Sinkholes are the most obvious, but caves and springs abound. Given high groundwater levels in the Floridan aquifer system in many areas, sinkhole lakes are widespread, and many caves are phreatic.

Limestone Dissolution and Diagenesis

Eocene to Miocene limestones have variable levels of cementation and compaction. Well-cemented limestones are uncommon, and many limestone deposits are so poorly cemented that they and can be mined with backhoes. Dolostone deposits are present, but they are seldom involved with karstification (Upchurch et al., 2019).

Owing to the high grain and fracture surface areas, meteoric water quickly equilibrates with the calcite in the limestone, so shallow karst near the water table is developing in many areas. Karst at the freshwater/saltwater interface has also been documented (Herbert and Upchurch, 2016; Upchurch, 2017). With the many sea-level excursions in the last few million years, epigenetic and, possibly, hypogenetic karst horizons have been created throughout much of the shallow limestone (Upchurch et al., 2019).

Covered Karst

The Pliocene through Pleistocene, glacioeustatic sea-level excursions resulted in marine terrace, quartz-sand sheets that drape over the Miocene and older strata. This sand is mostly fine to medium grained and loose to cemented by ferric hydroxides and organics. Where the sand is not cemented it tends to creep down slopes. The result is rounding of slopes and in-filling of karst basins. Sinkhole lakes fill with sand and organics to form wetlands, and sinkholes become shallower with gently sloping sides. Many ancient sinkholes are buried and, in the absence of land-surface depressions, not perceptible without subsurface testing.

Sinkhole Triggers

The field trip area is largely rural. Where urbanization has occurred, there appears to be an increase in modern sinkhole development. It is often impossible to identify the cause of a sinkhole collapse, but there are cases that suggest causation. These include:

1. groundwater withdrawals, especially where there are cyclic changes in the effective stress on the overlying sandy cover (Upchurch et al., 2013, 2019; Scott, 2017b),
2. sudden loading by extreme rainfall events (Upchurch, 2016; Scott, 2017a), and
3. alterations in surface water drainage, especially stormwater drainage systems (Upchurch et al., 2019).

Age of Florida's Karst

There is generally no way that we can directly date when an existing sinkhole formed. We can, however, date the fossils they contain, which tells us when an animal or plant lived, fell, or was washed into a sinkhole.

The Alachua Karst Hills Province is the site of the oldest known sinkhole in Florida. When I-75 was being constructed near Gainesville, Oligocene vertebrate fossils were found in an ancient sinkhole (Morgan and Hulbert, 2007). The fossils are of land mammals that lived in late early Oligocene time (about 30 million years ago). They included over 40 species such as land tortoises, bats, horses, and peccaries. The bats suggest that the sinkhole was associated with a vadose-zone cave and the abundance of terrestrial animals trapped in or washed into in the sinkhole suggests that it may have been associated with a stream-to-sink drainage system. The sinkhole was clearly well developed when the fossils accumulated, which suggests that the sinkhole/cave system had been forming for millennia before the animal remains arrived.

Clearly, sinkhole development has been episodic, largely because of sea-level position and the amount of denudation that had occurred during episodes of lower sea levels. Sinkhole development by rock and cover collapse and suffosion continues today. Cover-subsidence sinkholes are also forming, but they are most evident south of our field trip route.

Landforms

Karst Landform Depressions

This field trip focuses on sinkholes as components of the Florida karst landscape. Virtually all the karst landforms are mantled by Pliocene-Pleistocene marine terrace sands and residual clays derived from the Oligocene-Pliocene Hawthorn Group. The sand mantle consists of fine-grained, quartz sand, which results in low angles of repose. As a result, the sand is susceptible to stream and sheet-flow erosion and creep over time. Therefore, the karst hills are typically rounded and depressions shallow. Where this sand lies directly on limestone, sinkholes are likely caused by simple suffosion.

Uvalas are common in all the provinces we will visit. They commonly occur in the vicinity of fracture intersections where dissolution of the doubly porous limestone was enhanced. Florida poljes are large, coalesced, flat-bottomed sinkholes and uvalas that have been filled with lacustrine and/or paludal sediments. With Florida's relatively high water tables, the poljes usually include wetlands that are both lakes and marshes with emergent grasses and sedges. In Florida, such grasslands are termed wet prairies or prairies. In the subsurface, both uvalas and poljes have limestone pinnacles, and their limestone rims range from steep to gentle, irregular slopes. In many areas, sinkholes extend below either the water table of the localized, perched surficial aquifer or the Floridan aquifer system where it is unconfined.

Areas between the depressions and many depressions have remnants of the clayey and sandy Oligocene-Pliocene Hawthorn Group or its residua. Where this relatively cohesive material is present, the sinkholes that form are likely caused by rock- or cover-collapse.

Epikarst and Karren

The upper surface of the limestone varies in complexity. In some areas, elevation is relatively constant over distances of 30 to 60 m (100 to 200 feet) suggesting lack of epikarst or karren development or planation by subsequent marine erosion. However, most areas have epikarst. The epikarst horizon is characterized by breccia or disaggregated, dissolution residua that range from sand to clay sizes. Often, the pore space within the epikarst is filled with sand and/or clay that was either introduced by reworking as a later marine transgression occurred or by suffosion. The epikarst is often more permeable than surrounding materials, so drilling fluid circulation is commonly lost.

Because of the cover over the karst land surface, most karren structures are only observed in quarries and the rare roadcut. Most notable are the solution pipes and pinnacles that are common at the cover/limestone interface. The solution pipes range from less than 1-3 m (3-10 feet) in diameter. They have common depths that are inferred to be water table positions. They are usually filled with clayey to sandy residual sediments. The pinnacles are common throughout west-central Florida. They range from about a half to over 15 m in height (2 to 50 feet). Based on observations in quarries, the cutters between pinnacles often follow fractures. For a more complete discussion of Florida's karst landforms, see Upchurch et al. (2019).

Karst Escarpments

The area covered by this field trip guide includes several karst escarpments that formed because of variable combinations of karst, fluvial, and coastal erosional and depositional processes. These escarpments range from fluviokarst areas that span from a lowland upward to an upland with active stream systems to ridges that no longer have an associated upland, so scarp retreat is by sinkhole formation alone.

<u>The Cody Escarpment</u>

Much of our understanding of these escarpments and the processes that formed them comes from many decades of research (see Upchurch et al. (2019) for references) on the escarpment known as the Cody Escarpment, primarily in the Alachua Karst Hills Province. The Cody Escarpment is a complex of landforms in Florida that requires discussion because it is cited frequently in the descriptions of the districts and provinces of northern Florida. The Cody Escarpment is well developed in three of Florida's geomorphic provinces: from southeast to northwest, the Alachua Karst Hills, which we will visit on this field trip, Madison Hills, and Tallahassee Hills provinces (Figure 5). This field

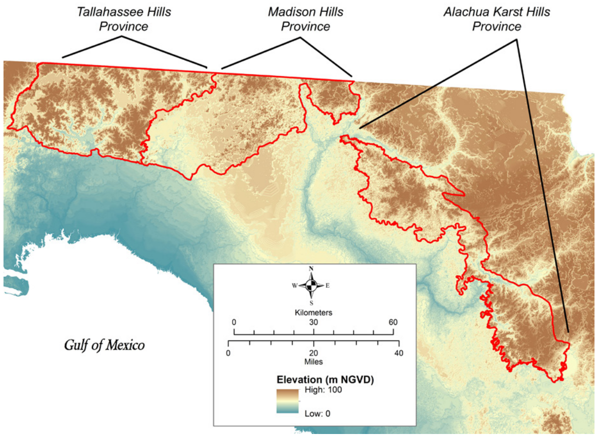

Figure 5. *Most of the highly dissected terrain in the Alachua Karst Hills, Madison Hills, and Tallahassee Hills provinces consists of the karst escarpment known as the Cody Escarpment.*

trip guide crosses the Cody Escarpment between Stop 1, the Devil's Millhopper, and Stop 2, Haile Quarry.

The Cody Escarpment was originally named by Puri and Vernon (1964). They described it as "… the most persistent topographic break in the State" (p. 11). They described the location of the toe of the escarpment, which has been modified by coastal processes, as extending from near the Apalachicola River in the Florida Panhandle eastward along the southern boundaries of the Tallahassee Hills and Madison Hills provinces (Tifton Upland District) and the western boundary of the Alachua Karst Hills Province of the Ocala Karst District (Figure 5) to the southeast. Puri and Vernon then extended the escarpment east to the southern boundary of the Trail Ridge Province (Barrier Island Sequence District) and northward along the toe of the eastern facing slope of the Trail Ridge Province to the Georgia state line. Today, the eastward end of the toe is thought to terminate at the southeastern extent of the Alachua Karst Hills Province (Upchurch, 2014; Figure 5).

White (1970) did not refer to the Cody Escarpment by name, but he noted a "bounding scarp" (p. 155-156) and expanded upon Puri and Vernon's (1964) description of the extent and polygenetic origins of the escarpment. He stated that the escarpment from the southern end of the Alachua Karst Hills Province, as defined in Williams et al. (2022), westward to the western part of the Madison Hills Province had been influenced more by stream erosion and limestone dissolution than the reach westward from the southwestern Madison Hills Province (the Tallahassee Hills Province; Figure 5) where marine erosion is an important defining characteristic. The Cody Escarpment is a polygenetic escarpment characterized by the complex interactions of fluvial, karst, and marine erosional processes over millennia.

The toe of the Cody Escarpment is a result of the temporal and spatial interplay between coastal marine erosion and fluvial and karst erosional (fluviokarst) processes (Upchurch et al., 2019). The toe has a distinct increase in elevation from the adjacent lowlands to the area within the escarpment. There is also a change from abundant, small sinkholes in the lowlands to large sinkholes and increased relief within the escarpment area. In many areas, the fluviokarst landforms at the toe of the Cody Escarpment have been truncated and/or reoriented by later marine coastal erosion and depositional processes. The top of the escarpment is less distinct but defined by a reduction in land slope and the number and size of sinkholes, where present.

The Cody Escarpment includes an area that extends from the toe of the escarpment upward into a complex system of streams and karst landforms (Figure 5). It varies from as little as 1 or 2 km to over 16 km (0.5 to 10 miles) in width. The toe is much easier to recognize than the top of the escarpment because it has been truncated by marine erosion in some locations.

The top of the Cody Escarpment is the location where sinkholes and other karst landforms either cease to dominate the landscape or change in abundance and size because of the influences of processes other than escarpment erosion and retreat. Streams flow from the uplands above the top of the escarpment into the escarpment area where, with few exceptions, they encounter swallets and in-stream siphons and disappear underground to later emerge in adjacent lowland provinces. Lakes, many of which sporadically drain due to sinkholes, are common in the escarpment area.

The Cody Escarpment was not identified as a geomorphic province by Williams et al. (2022) because it constitutes a region that is sometimes a narrow boundary, but other times affects landforms within provinces (Figure 2). Changes in the relative importance of coastal, fluvial, and karst processes, which affect geomorphology at the province scale, also shift along the Cody Escarpment. Landforms within regions of the escarpment have also been interrupted by large stream valleys with characteristic sets of landforms, most notably groundwater resurgences as springs and a dominance of fluvial landforms. The origin, hydrology, and groundwater chemistry of the Cody Escarpment have been described by Upchurch et al. (2019).

Other Karst Escarpments

The Oligocene-Pliocene Hawthorn Group once covered the Ocala Platform (Scott, 1988) in the field trip area. Through a combination of karst, fluvial, and marine erosion, the Hawthorn Group sediments and underlying Oligocene Suwannee Limestone and Eocene Ocala Limestone have been partly to completely removed from this area. The results are vast karst plains where the Oligocene and Eocene limestones are thinly covered by marine terrace sediments and a series of karst hills that consist of intact and residual Hawthorn Group sediments, often with onlapping coastal Pliocene-Pleistocene dunes. The karst hills (Brooksville Ridge, Ocala Karst Hills, Fairfield Karst Hills, and Alachua Karst Hills provinces) represent erosional, karst escarpments. Each will be discussed in the road log, but for now consider the basic layout of a karst escarpment.

Figure 6 is a hypothetical cross section in the Alachua Karst Hills Province as drawn by Upchurch (2002). As we will see at our first stop and then on our drive westward, this escarpment is dominated by large sinkholes and fluviokarst drainage. The cross section illustrates the topography, groundwater quality, karst-conduit development pattern, and relative recharge in the uplands, escarpment, and lowlands.

While forming, each of the karst-ridges and hill provinces once had an upland (Upland Domain, Figure 6) that was underlain by a surficial sand mantle (Q_{und}) and the Miocene Hawthorn Group. The upper Hawthorn Group (T_{Mh}) is predominantly siliciclastic, and the lower part is interbedded siliciclastic and carbonate. The Hawthorn Group is an efficient aquitard so recharge to the underlying Floridan aquifer system (Oligocene Suwannee Limestone [T_{Os}] and Eocene Ocala Limestone [T_{Eo}]) is limited and stream networks form and flow to the escarpment (Scarp Domain). There is only minor development of conduits in the Hawthorn Group under the upland as a result of fracturing, and groundwater residence times in the underlying limestone aquifer are high, resulting in water that is chemically saturated with respect to calcite. Minor interstratal karst conduits develop in the Hawthorn Group sediments near the adjacent karst escarpment. The Alachua Karst Hills Province has a well-developed upland and is a fluviokarst domain.

There is evidence that the Brooksville Ridge and other karst hills provinces once had uplands, but they no longer exist. As a result, these hill areas are predominantly karst with modification by coastal processes at their toes. LiDAR data suggest remnant surface-water drainage on the crests of the karst hills and ridges. Some drainage patterns remain on the crest of the southern part of the Brooksville Ridge.

The hills in the Scarp Domain (Figure 6) are characterized by a thick cover of intact and residual Hawthorn Group sediments. Because of the thick cover, sinkholes are large and deep. Many are uvalas

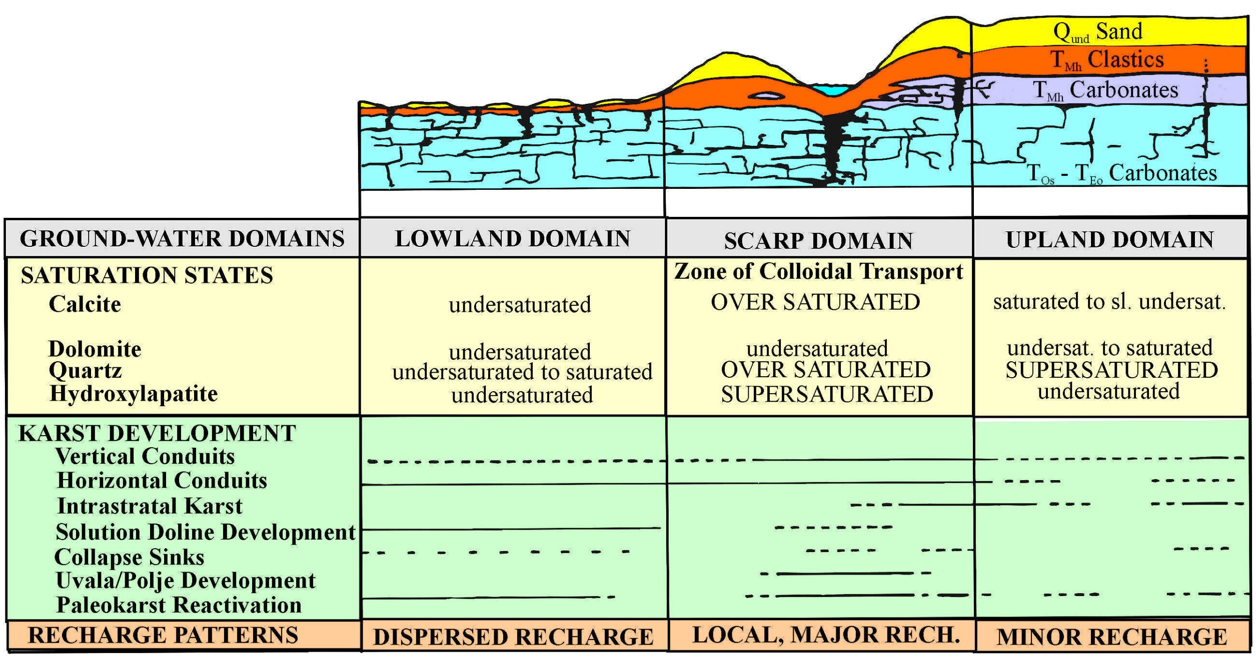

Figure 6. *Generalized cross section through the Cody Escarpment in the Alachua Karst Hills Province; not to scale (from Upchurch et al., 2019).*

or poljes with wetlands. This domain is an area of enhanced recharge to the Floridan aquifer system because of the dominant, internal drainage patterns and, where there are streams developed in the Upland, swallets. Groundwater contains colloidal sediment precipitates, and it is equilibrated with calcite and other minerals. It is, however, chemically aggressive when it first encounters limestone so conduit development is rapid. Note that the groundwater in the Alachua Karst Hills Province is supersaturated with respect to carbonate-rich hydroxlapatite, the dominant phosphate mineral in Florida's hard-rock phosphate deposits. This phenomenon is responsible for the hard-rock phosphate deposits we will discuss on this trip. In the Scarp Domain, vertical conduiting along and between fractures develops. As the scarp retreats, conduiting becomes more horizontal as groundwater flow systems integrate into regional flow networks.

In the Lowland Domain (Figure 6), the sand mantle is thin and the Hawthorn Group siliciclastics are largely gone. What remains is a discontinuous, thin, clayey and sandy, residual soil. Here, the Floridan aquifer system is unconfined. Because of the thin cover, there are many sinkholes, but they are small and shallow. Karst conduiting is largely horizontal and consists of well-developed cave networks. Karst windows are present in the lowlands and the groundwater discharges to streams via springs. This shallow groundwater remains chemically undersaturated with respect to calcite because of rapid recharge in this internally drained network.

Hard-Rock Phosphate

A major key to understanding the origin and retreat of the karst escarpments is the presence of hard-rock phosphate deposits in ancient sinkholes. Florida's hard-rock phosphate deposits are unusual karst features that once fueled a thriving mining industry.

The most important sources of phosphate in Florida are the phosphate-bearing sediments found throughout the Hawthorn Group. Two apatite group minerals predominate in the phosphatic sediments: carbonate-rich fluorapatite ($Ca_5(PO_4,CO_3)3(F,O)$, or "francolite") and carbonate-rich hydroxylapatite ($Ca_5(PO_4,CO_3)_3(OH,O)$), or "dahlite") (Upchurch, 1992). Weathering of both minerals introduces dissolved phosphate into slightly acidic ground and surface waters.

Carbonate-fluorapatite is the primary phosphate mineral in the Hawthorn Group. It was precipitated from the Miocene sea throughout the Ocala Platform, including its crest. Based on the amount of hard-rock phosphate remaining on the flanks of the Ocala Platform, there must have been a huge amount of phosphate originally deposited on the Platform crest. Weathering and erosion of the phosphatic Hawthorn Group sediments from the Ocala Platform (Scott, 1988) dissolved the carbonate-fluorapatite and released carbonic and phosphoric acids to surface and shallow groundwaters.

The phosphate mineral that precipitated in the hard-rock phosphate deposits from the phosphate-rich waters was carbonate-hydroxylapatite. This mineral formed when the phosphate-rich water became slightly alkaline as it met Floridan aquifer system water in the sinkholes. The phosphoric and carbonic acids were neutralized, and carbonate-hydroxylapatite precipitated as platelets, clay-sized particles, and limestone replacements (Figure 7) were formed. Therefore, the hard-rock phosphate in sinkholes is both evidence of removal of Hawthorn Group sediments from the upland areas on the Ocala Platform and deposition in karst depressions in the escarpments and karst plains. The carbonate-hydroxylapatite is unusually pure and was in high demand. As a fertilizer that required crushing but no other beneficiation, the deposits were valuable, and small mines were present throughout the northern part of the field trip area.

Early hard-rock phosphate mining in Florida was categorized by the type of deposit being excavated (Matson, 1915). The earliest commercial deposits were found in relict sinkholes with mineral replacements of the limestone in sidewalls and pinnacles (Figure 8) and direct deposits as plates and clay-sized colloidal sediments (Figure 7) mixed with sand, chert, and clay. Vertebrate land-mammal fossils were abundant in these deposits (Morgan and Hulbert, Jr., 2007). Because the deposits were limestone replacements and crusts, they were termed hard-rock phosphate as opposed to river pebble and land pebble deposits which were mined elsewhere in the state.

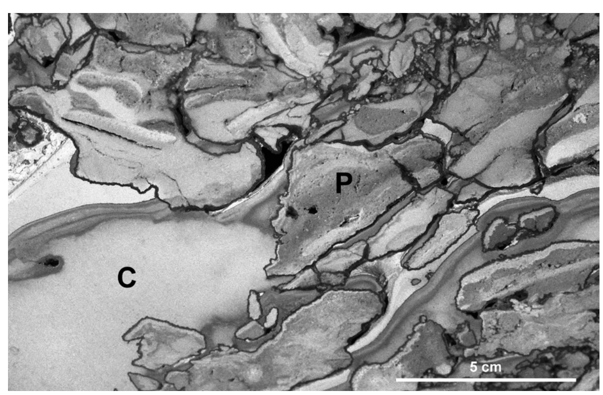

Figure 7. *Slab of hard-rock phosphate from near Hernando, Citrus County, Florida. Note plates (P) and clay-sized accumulations (C). Photo courtesy of Sam Upchurch.*

Figure 8. *Pinnacles of Ocala Limestone exposed in a hard-rock phosphate mine north of Ocala in 1910. Photo from Florida Memory Project Image GE051 by P. Jumeau.*

Field Trip Overview

Field Trip Route

The field trip begins at the main entrance of the University of South Florida (USF), the site of the 2023 Sinkhole Conference. We will drive north to just past Gainesville on I-75 (Figure 9).

The first stop is at the Devil's Millhopper Geological State Park where we will have an opportunity to inspect an unusually deep, rock-collapse sinkhole. Steps extend to the bottom and along the way you will be able to see rock exposures, seep springs, and lush foliage resulting from the high humidity and warm microclimate of the sink.

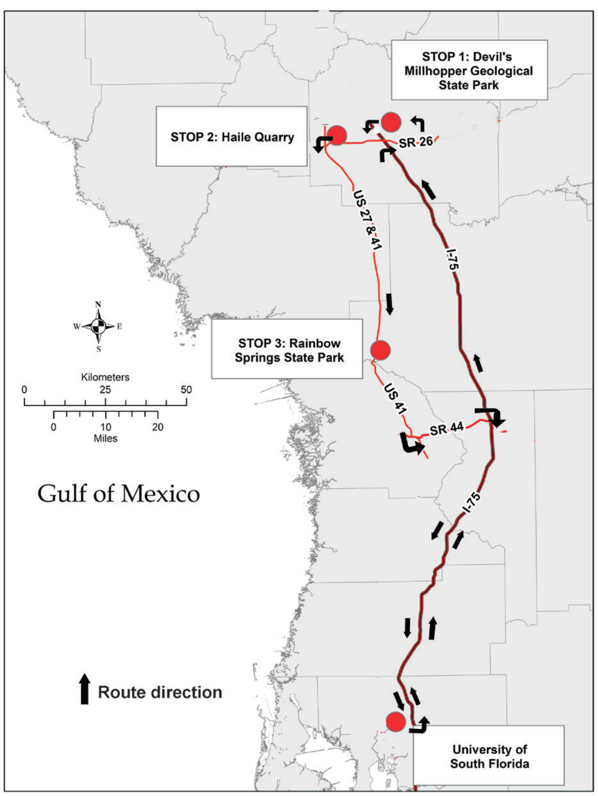

Figure 9. *Field trip route. Arrows indicate direction of the trip.*

We then proceed west across the fluviokarst escarpment of the Alachua Karst Hills and then onto an extensive karst plain to the Haile Quarry (Figure 10). The Haile Quarry is renowned for its karst features and paleontological resources. Most obvious in the quarry are numerous solution pipes or channels, but sand and clay-filled sinkholes, sediment-filled caves, and a sinkhole filled with phosphatic sediment are also present. We will have a box lunch while at the quarry.

Next, we continue our journey west to US 27 and US 41 where we will turn south. Views of the karst plain are spectacular. As we near our last stop, Rainbow Springs State Park, the karst plain becomes hilly, and we will see evidence of a mid-19th to mid-20th century mining industry where hard-rock phosphate was extracted from ancient sinkholes.

At Rainbow Springs we will pass by a hard-rock phosphate mine and tour one of the largest spring

Figure 10. *Track hoe mucks out solution channels and removes limestone pinnacles at the Haile Quarry, Newberry, Florida. Photo courtesy of Tom Scott.*

groups in Florida. There will be time to stroll trails that pass through the riparian swamp with sand boils and other small springs and the ruins of a historic, road-side attraction.

The tour then continues south through the heart of the former hard-rock mining district. We will turn east in Inverness and drive along the shore of Tsala Apopka Lake, a large, scarp-toe lake comprised of multiple, coalescing sinkholes and small coastal dunes. This route rejoins I-75 where we will turn south and return to the University of South Florida.

Organization of Stops and Drive-By Discussions

There are three stops on the field trip. These sites are described in detail in separate sections below. We will also travel over several karst terrains and large landforms that merit discussion. These "drive-by discussions" are presented in the road log and will be discussed *en route* by the field trip leaders.

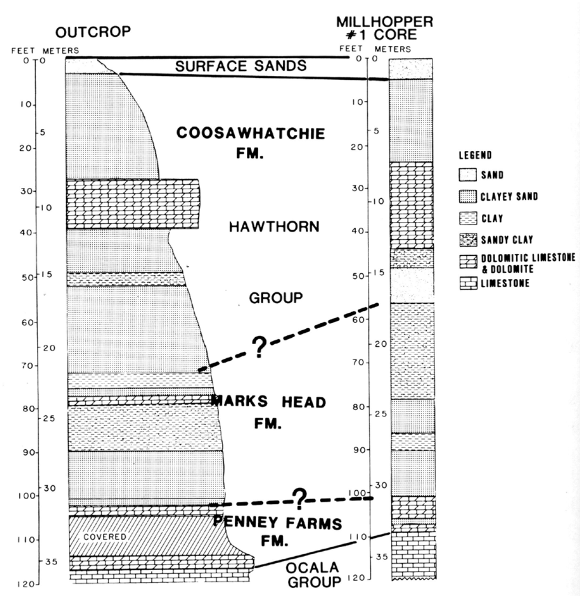

Figure 11. *Comparison of the stratigraphic section in the Devil's Millhopper to a nearby core (from Scott, 1986).*

Stop 1: The Devil's Millhopper Geological State Park

Devil's Millhopper is a large, impressive rock-collapse sinkhole located in northwestern Gainesville, west-central Alachua County, Florida. The State of Florida incorporated the sinkhole and the surrounding area in the Devil's Millhopper Geological State Park. The Florida Geological Survey designated Devil's Millhopper a "Florida State Geologic Site" in 1998. Access to the sinkhole is limited to the designated trails and a boardwalk to the bottom. The sinkhole can be viewed from a trail that circles the feature.

The Millhopper exposes sediments of the upper Eocene Ocala Limestone and the lower to middle Miocene Hawthorn Group (Figure 11). The Ocala Limestone may be visible at the base of the sinkhole, depending on water level and sediment fill. The Devil's Millhopper has long been considered an important exposure of the lower to middle Miocene Hawthorn Group due to the thickness of the section exposed. The Hawthorn Group phosphatic sands, clays, and dolostones are approximately 34 m (112 feet) thick with about 1 m of undifferentiated sands comprising the surface layer. In 1980, the Florida Geological Survey drilled a core on the north side of the sinkhole (W-14641, Devil's Millhopper #1). Figure 11 compares the exposure with the core (Scott, 1986). Hawthorn Group sediments are exposed along the boardwalk leading to an observation deck near the bottom of the sink. The sinkhole formed when sediments overlying the Ocala Limestone collapsed into cavities dissolved in the limestone by groundwater. Though covered with lush vegetation, Devil's Millhopper is one of the best natural exposures of the Hawthorn Group in Florida. This sinkhole occurs within the Alachua Karst Hills Province, Ocala Karst District. The elevation at the lip of the Millhopper is approximately 53 m (176 feet) MSL and the bottom of the sinkhole is approximately 18 m (60 feet) MSL.

Throughout much of the state, the Hawthorn Group sediments function as low permeability aquitards (intermediate confining unit) and, in some areas, as water-bearing aquifers (intermediate aquifer system). These sediments are also extensively mined for phosphate in northern and central Florida.

Stop 2: Haile Quarry

Limestone Products LLC's Haile Quarry (Figure 12) is a historic mining complex that began as a hard-rock phosphate mine in the late 1800s and, today, is one of the larger limestone mines in the area. Over the years, the quarry has become famous for its karst features and many important invertebrate fossils from the Eocene Ocala Limestone and vertebrate fossils from the Miocene to Pleistocene karst features.

The quarry lies within the Williston Karst Plain Province, a relatively flat plain that is dotted with thousands of sinkhole depressions. Most are relatively small because of the thin cover. However, there are large uvalas that have formed where intense dissolution of the limestone has been enhanced, often at fracture intersections.

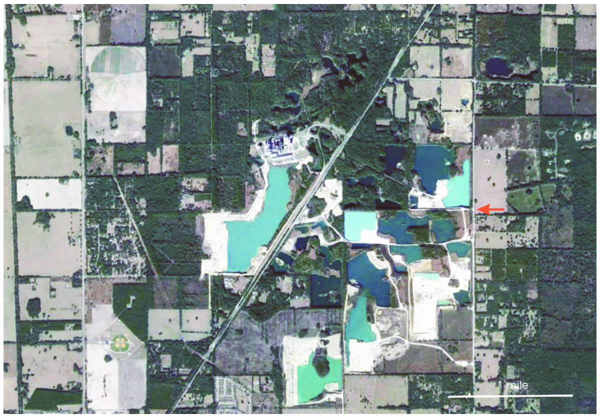

Figure 12. *Aerial photograph of the Haile Quarry showing the area visited on this trip (red arrow). Modified from Google Earth imagery.*

The Limestone

The quarry operation excavates the upper Eocene Ocala Limestone; a nearly pure, biogenic carbonate that was deposited in a shallow marine environment nearly 35 million years ago. Non-carbonate minerals (quartz, chert, and clay) typically constitute less than 1 to 2 percent of the rock volume. The limestone facies typically range from wackestones to grainstones containing skeletal and non-skeletal allochems. The total thickness of the Ocala Limestone in the Newberry area is roughly 27 m (89 feet). However, Limestone Products mines only to a depth of 21 m (70 feet) below ground level by first removing overburden to expose the top of the unit. Overburden consists of 1 to 2 m (3 to 7 feet) of vegetation, dirt, and clay. Then, once sand, dirt, and clay-filled solution features are removed, 5 to 6 m of limestone are excavated to just above the water table with large backhoes. Another 12 to 14 m (40 to 46 feet) of rock are then mined from below the water table using a combination of blasting and draglines and dumped in piles for processing as aggregate (Portell and Hulbert, Jr., 2014).

Solution Pipes

The well-developed solution pipes (Figure 13a, 13b) are the first karst features that one sees when entering the quarry. These solution pipes are common in the Ocala Limestone throughout the area. Their diameters are relatively uniform, and they have a common depth, which was apparently the water table of the unconfined Floridan aquifer system. Examination of the pipes where the residual sediment/soil fill has been removed indicates that they commonly have a thin, reddish, inner rind of well cemented, micritized limestone. In thin section, this rind has remnants of partly micritized foraminifera and other microfossils, micritic cement, and clay inclusions. The rind is likely a result of wetting and drying of the limestone. In the model of retreat of a karst escarpment (Figure 6), the first conduiting to develop is for vertical flow of meteoric water. In the Ocala Limestone, these vertical conduits are commonly solution pipes. The Haile Quarry site was once within the karst-escarpment domain like we just traversed, and these solution pipes are most likely a result of the onset of recharge to the Floridan aquifer system within the escarpment.

Caves

Small, sediment-filled caves (Figure 14) are found throughout the quarry. Note in Figure 14 that there are two layers of sediment, a sandy clay at the base and clayey sand at the top. This stratification has been observed in several examples in the Williston Karst Plain and appears to correlate with the sequence of erosion of cover sediments in a retreating karst escarpment (Figure 6). As the Hawthorn Group

Figure 13a. *Examples of the solution pipes (chimney sinks). As a result of exposure during quarry operations, the reddish soil that once filled them has washed away. Photo by Sam Upchurch from Upchurch et al. (2019).*

Figure 13b. *Oblique view of the solution pipes filled with soil. Note the apparent alignments of the pipes and their relative uniformity in diameter. Photo courtesy of Tom Scott.*

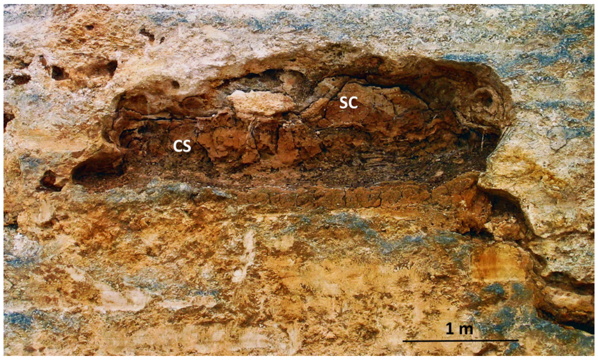

Figure 14. Cave filled with clayey sand (SC) and sandy clay (CS) derived from erosion in the Cody Escarpment. Photo by Sam Upchurch from Upchurch et al. (2019).

sediments are eroded away, clay-rich sediments would be expected to enter the cave system. Deposition after the escarpment has developed is likely sandier because of slope erosion on the karst hills.

Hard-Rock Phosphate Deposits at the Haile Quarry

The Haile Quarry complex began in the late 1800s as a hard-rock phosphate mine. Little remains of the hard-rock phosphate industry other than a few overgrown pits. Exposures of hard-rock deposits are rare anywhere in north or central Florida. There is a deposit (Figure 15) exposed in the Haile Quarry that reveals that they were in ancient sinkholes and that movement of siliciclastic sediments into the sinks was dynamic, as if by a stream. This deposit consists of dipping quartz sand and clayey sand. Many of the erosion resistant beds (Figure 15) are phosphatic. Slickensides are visible on at least one bed. This suggests that the phosphatization was contemporaneous with sedimentation in the ancient sinkhole and that slumping, and subsidence accompanied sediment deposition.

Figure 15. A sediment-filled sinkhole with hard-rock phosphate beds and plates. Photo courtesy of Sam Upchurch.

Fossils

Numerous marine invertebrate fossils have been collected from the Eocene Ocala Limestone excavated at Limestone Products. Many thousand specimens now reside in the [Florida Museum of Natural History](). These invertebrates include skeletal remains of the phyla Foraminiferida (single-celled protists), Cnidaria (corals), Bryozoa (moss animals), Mollusca (snails, clams, and cephalopods), Annelida (worms), Arthropoda (crabs, shrimps, barnacles, and ostracodes), and Echinodermata (sea urchins, sea biscuits, sand dollars, and sea stars).

Typically, Ocala Limestone invertebrates whose skeletons originally consisted of aragonite are preserved as casts or external molds. Most corals and mollusks are preserved in this manner. Known coral genera include colonial species such as *Astrocoenia*, *Caulastrea*, *Cyathoseris*, and *Alveopora*, along with holdfasts of undescribed species of sea fan (Order Alcyonacea). Solitary forms include the genus *Turbinolia*. Common moldic mollusks comprise the bivalve genera *Crassatella*, *Plicatula*, *Lithophaga*, and *Botula* and the gastropod genera *Xenophora*, *Eovasum*, a new genus of the family Strombidae, *Laevella*, *Cypraedia*, *Seraphs*, *Voluticella*, *Caricella*, and an undescribed *Platyoptera*. One nautiloid cephalopod (genus *Aturia*) is found, rarely. Invertebrates whose skeletons were originally calcite typically preserve as body fossils. These include the super abundant single-celled foraminifera (genera *Nummulites* and *Lepidocyclina*), bryozoans, oysters, and scallops (genera *Hyotissa* and *Amusium*, respectively), crabs (genera *Ocalina*, *Calappilia*, and *Lophoranina*), and echinoderms (genera *Oligopygus*, *Neolaganum*, *Weisbordella*, *Fibularia*, and *Phyllacanthus*). Occasionally, *Eupatagus* (proposed state fossil) and *Amblypygus* are encountered (Portell and Hulbert, Jr., 2014). Ichnofossils are found in the Ocala Limestone at Limestone Products. The most common being a supposed sponge trace fossil (ichnogenus *Lithoplasion*).

Non-Ocala Limestone invertebrate fossils are also found at the quarry. Sometimes, lower Oligocene Suwannee Limestone residual boulders containing silicified sea biscuits (*Rhyncholampas gouldii*) are encountered in un-excavated areas of the quarry. Additionally, late Pleistocene freshwater snails (i.e., genera *Planorbella*, *Physella*, and several members of the family Hydrobiidae) are collected from an exposed sinkhole we shall visit (see Figure 15).

Rare vertebrate fossils have also been collected from the Eocene Ocala Limestone excavated at Limestone Products and include marine fish (shark genus *Otdous* and mouth parts of rays and bony fishes), ancient sea cows, primitive whales (genus *Zygorhiza*), and crocodiles.

However, as mentioned above, numerous sediment-filled karst features exposed in the quarry have produced hundreds of fossil vertebrates ever since hard-rock phosphate mining began here. Most of these fossil vertebrate-producing karst features (in order of abundance) are latest Pleistocene (10 to 25 thousand years old), followed by late Miocene (8 million years old), and then early Pleistocene (1 to 2.5 million years old). The latest Pleistocene karst features are in-filled with mostly rust-colored sand and contain numerous mammals (i.e., rodents, deer, llamas, bison, horses, and mammoths), reptiles, amphibians, and birds. The late Miocene karst features often contain sand and phosphatic gravel with a mixture of both terrestrial and marine vertebrates (i.e., fish, crocodiles, turtles, horses, rhinos, tapirs, and birds).

Lastly, the early Pleistocene karst features are typically in-filled with layers of sand and clay with abundant freshwater fish species (i.e., catfish and bowfin), amphibians (i.e., frogs), reptiles (alligators and turtles), and oftentimes beautifully preserved, mammal remains of tapir, peccary, ground sloth, bear, and saber-toothed cats (genera *Tapirus*, *Platygonus*, *Eremotherium*, and *Megalonyx*, *Arctodus*, and *Smilodon*, respectively) (Portell and Hulbert, Jr., 2014).

Stop 3: Rainbow Springs State Park

The Rainbow Springs Group (Figure 16 a,b) is one of largest spring complexes in Florida in terms of discharge. There are 11 named springs (Jones et al., 1996) with an average combined discharge from 1965 to 1974 of 21.6 m^3/s (763 cfs; Scott et al., 2004). The springs discharge to the Rainbow River (Figure 16b), a spring run that empties into the Withlacoochee River 9.2 km (5.7 miles) south.

History

The spring group has a long and interesting history. Archaeological evidence indicates the presence of indigenous peoples beginning thousands of years ago. The first settlement by Europeans was in the 1850s. The long defunct phosphate mining and community of Juliette came next. Both activities relied upon the Rainbow River and, later, a railroad for shipment of goods. The springs were a retreat for locals. At that time the springs and spring run were known as Blue Springs and Blue Run, respectively.

With the advent of tourism along the major north-south highways (e.g., US 41), the springs were purchased and developed as a tourist attraction. To avoid confusion with the many other Blue Springs in Florida, the springs and attraction were renamed Rainbow Springs. There was a hotel, zoo, gardens, and overhead tramway (Hollis, 2006). With the remains of the mines in the area, there was plenty of rock to construct features at the attraction. One of these features that remains is an 18-m (59 feet) high waterfall (Figure 17a). Unlike other springs that offered glass-bottom boats, Rainbow Springs had boats with seats and portholes below the water line (Figure 17b). With the advent of the interstate highway system, the attraction closed its doors for lack of tourists.

The State of Florida bought the property in 1980 and opened it as Rainbow Springs State Park with camping and water-recreation facilities. Remains of the zoo and the waterfalls have been preserved and are worth the short hike along the east side of the headspring bowl. There is a short trail at water level that features spring boils and riparian forest.

What to See at the Springs

There will be time to walk the nature trail through the riparian swamp just to the left (east) of the Gift Shop (Figure 18). This beautiful walk can be wet, but it includes scenes photographed by Florida's iconic Clyde Butcher and has several small sand boils (Figure 19).

Geology and Extent of the Springshed

It is thought that the shallow, Floridan aquifer system groundwater within the Ocala Limestone is forced to the land surface against the less permeable, dolomitic Avon Park Formation (Faulkner, 1973). The springshed (Figure 20) includes much of the Williston Karst Plain Province. It abuts the Silver Springs springshed at an indistinct boundary to the east. Very little of the discharge comes from the adjacent Brooksville Ridge Province to the west. The springshed delineation is consistent with Faulkner's (1973) explanation for the location of the springs. The springshed is largely rural and agricultural.

Chemical Fingerprinting of the Springs in the Spring Group

As part of their investigation of the sources of nitrate in the springs, Jones et al. (1996) chemically fingerprinted water from five sets (groups) of 11 springs and matched water-quality patterns to water quality from monitoring wells in the springshed. They were able to identify six areas (domains, Figure 21) from which the spring discharge derived.

Domains I and II (Figure 22) did not have a matching spring (Figure 21). The groundwater from Domain I discharges to Silver Springs to the east (Figure 20). The water from Domain II was not detected in a spring, either because of incomplete sampling or dilution and dispersion. Domain VI is water under the eastern margin of the Brooksville Ridge. Domain VI water could not be matched to a spring, but small seeps on the path to the dock and swimming areas (Figure 18) may be derived from the domain.

Figure 16a. The headspring area at Rainbow Springs State Park. Photo courtesy of Sam Upchurch.

The remaining domains could be matched with one or more of the 11 springs. Water discharging from the headsprings is from Domains IV and V. Water discharging from Domain III and the southern Domain IV (Figure 22) occurs in springs in the river and an arm of the river that extends to the east, not the headspring area.

Environmental Issues

Like most of Florida's springs, Rainbow Springs is threatened with excess nitrate loading, from agricultural activities and septic systems, and loss of discharge volume. Some of the measures taken to mitigate these issues include public awareness, establishment of minimum flows and levels (MFLs), and target concentrations and total maximum daily load (TMDL) management.

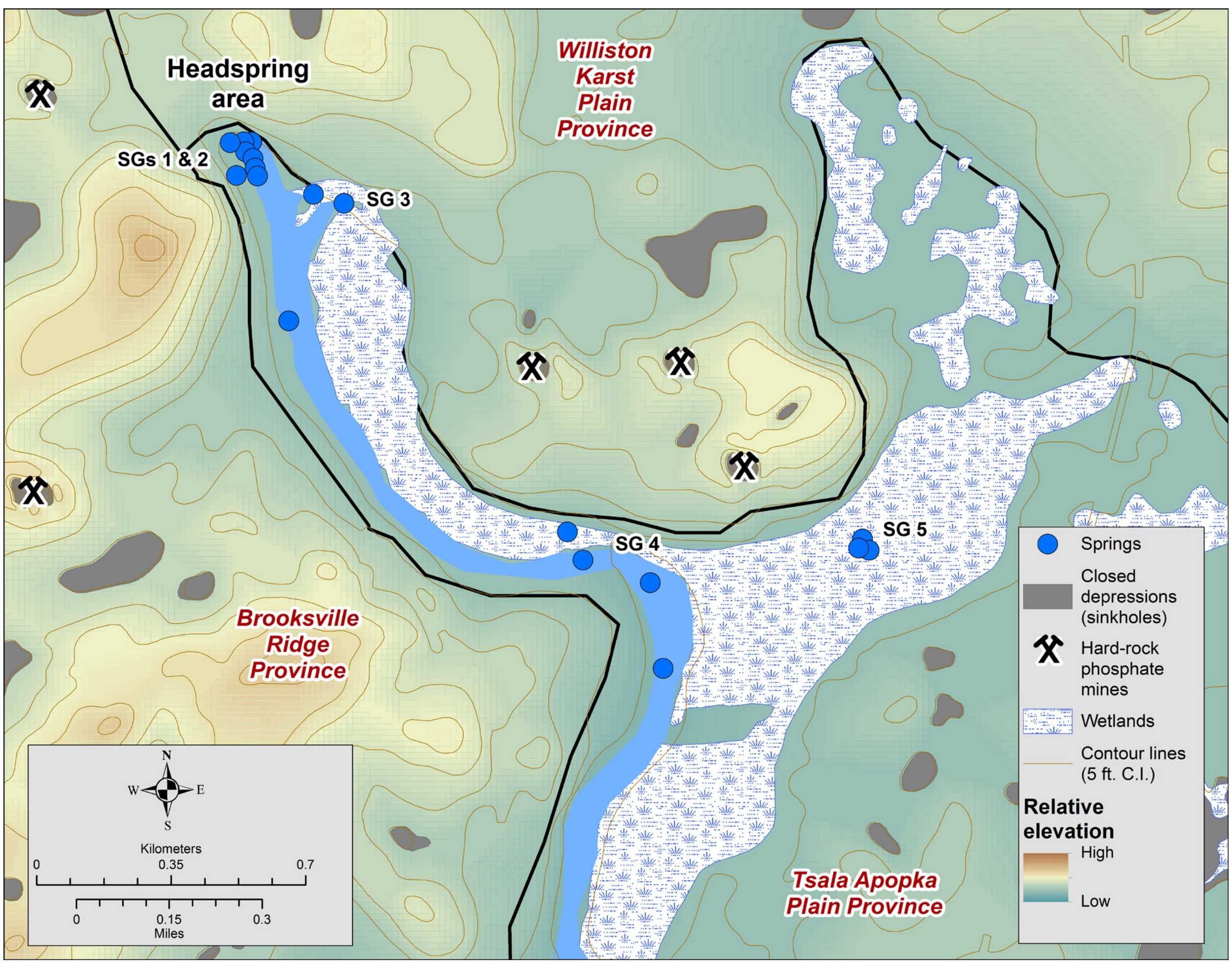

Figure 16b. The springs of the Rainbow Springs Group and Rainbow River.

Figure 17a. *The waterfall at Rainbow Springs was constructed as part of the privately owned attraction. Photo courtesy of Sam Upchurch.*

Figure 17b. *Postcard image showing the underwater-viewing boats at Rainbow Springs. Courtesy of the Sam Upchurch postcard collection.*

Public Awareness

As a first magnitude springs group in a Florida state park, several important measures have been taken to protect the springs. One measure is to increase public awareness, through the use of signage (Figure 23), as to the consequences of activities that might impair the springs. Marion County, within which the springs fall, and the [Florida Department of Environmental Protection]() have placed signage on major roads at locations where springshed delineation has suggested vulnerability to contamination or loss of discharge may occur.

Spring Discharge

Many of Florida's springs suffer from declining discharge because of drought and climate change and consumptive use of groundwater. Figure 24 illustrates the discharge of the spring group as measured at a downstream bridge on the spring run. Discharge is

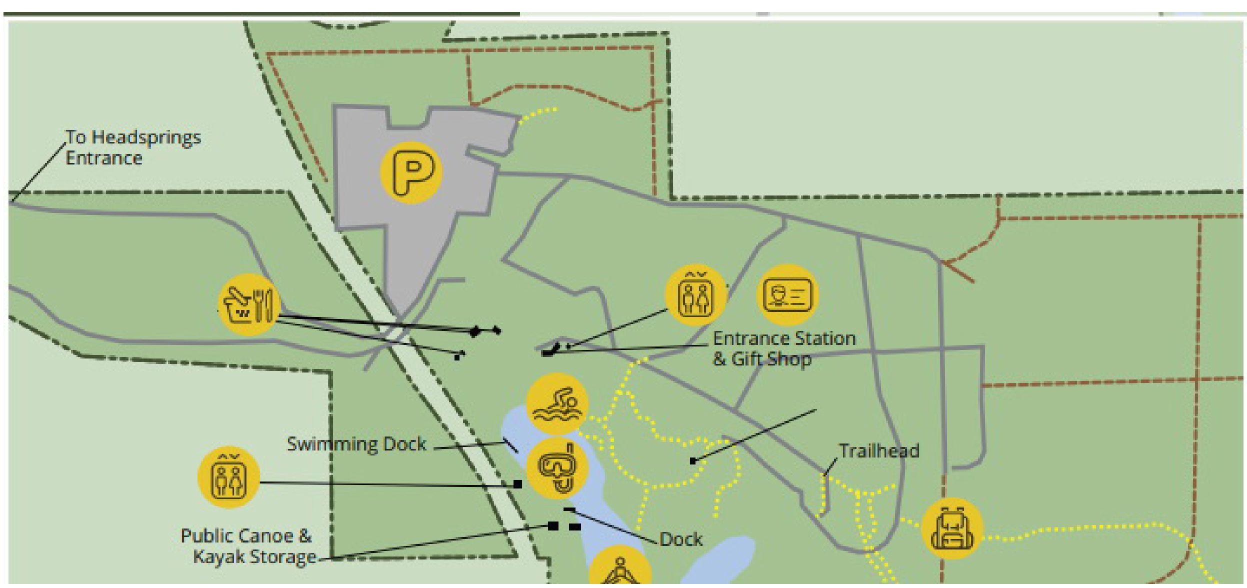

Figure 18. *Map showing the headspring area and nature trails (from the Florida State Park Rainbow Springs brochure, Florida Department of Environmental Protection, Division of Recreation and Parks).*

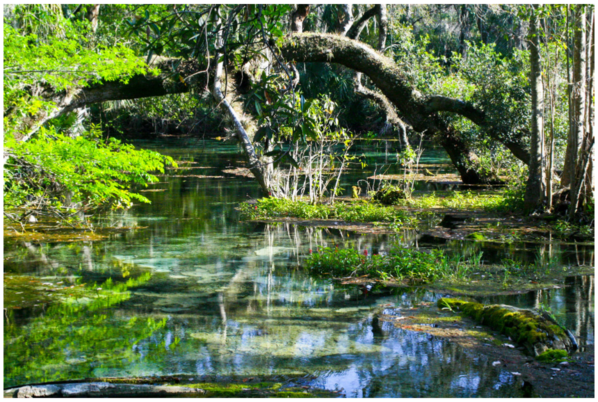

Figure 19. *View along the spring-side nature trail and its sand boils. Photo courtesy of Sam Upchurch.*

cyclic and clearly sensitive to year-to-year rainfall and water use. In comparison with many other Florida springs, discharge from the Rainbow Springs Group seems able to rebound after episodes of multi-year drought. Even so, the Southwest Florida Water Management District (SWFWMD) is setting minimum flows and levels (MFLs) for spring discharge. MFLs are regulatory measures to assist in controlling

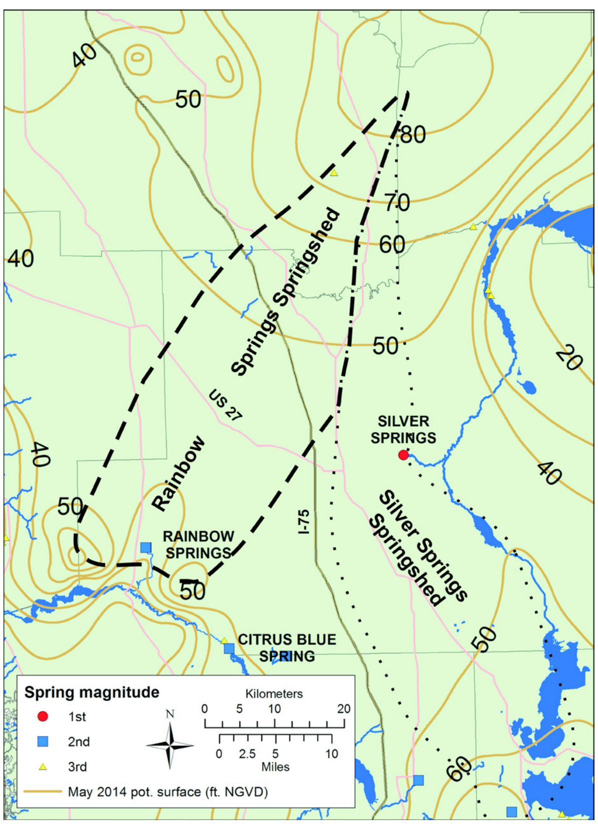

Figure 20. *The Rainbow Springs springshed as delineated by flow-net analysis from the May (dry season) 2014 Floridan aquifer system potentiometric surface map (data from the Southwest Florida Water Management District; map from Alfieri and Upchurch, 2018).*

excessive ground- and surface-water pumpage. The MFL statutes (Ch. 373, Florida Statutes) define significant harm in terms of water levels or discharge amounts that impair such factors as water supply, ecological and biological conditions, and recreation.

Nitrates

Almost all of Florida's springs are suffering from excess nitrate (NO_3^-) in discharging waters. Most, not all, springs are well below the Federal and State Maximum Contaminant Level (MCL) of 10 mg/L, as N, however, the nutrient is causing serious, unwanted algal growth and other problems in our springs (Florida Springs Task Force, 2000).

Rainbow Springs is threatened by this nitrate contamination. As shown on Figure 24, the nitrate plus nitrite (NO_2^-) concentrations have been increasing at a rate of 0.07 mg/L per year and unwanted algal growth is becoming evident. To combat this rise in the nitrate concentrations and loads, the Florida Department of Environmental Protection is establishing target concentrations, a Basin Management Action Plan (BMAP), and total maximum daily loads (TMDLs). Several of these measures are best applied to surface water, so implementation to control groundwater quality within the springsheds will be a challenge.

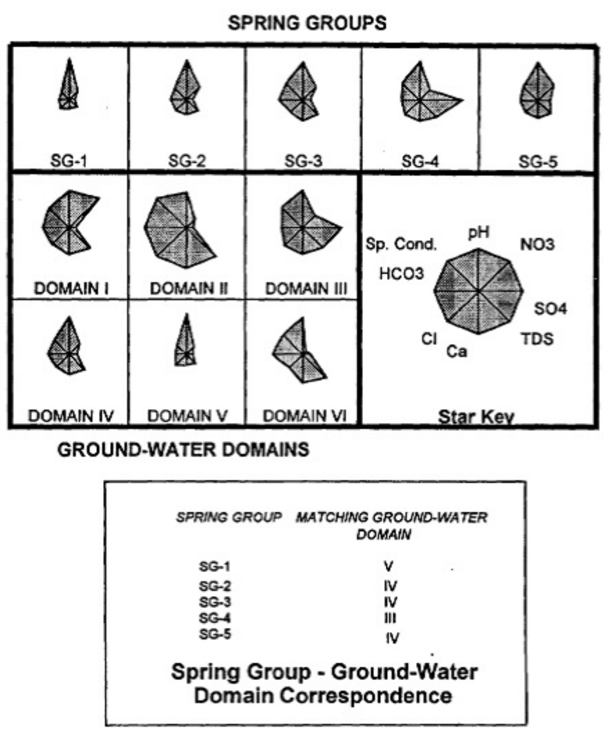

Figure 21. *Chemical fingerprints, as star diagrams, of five sets of springs and six areas (domains) from which the water was recharged (from Jones et al., 1996, Figure 41).*

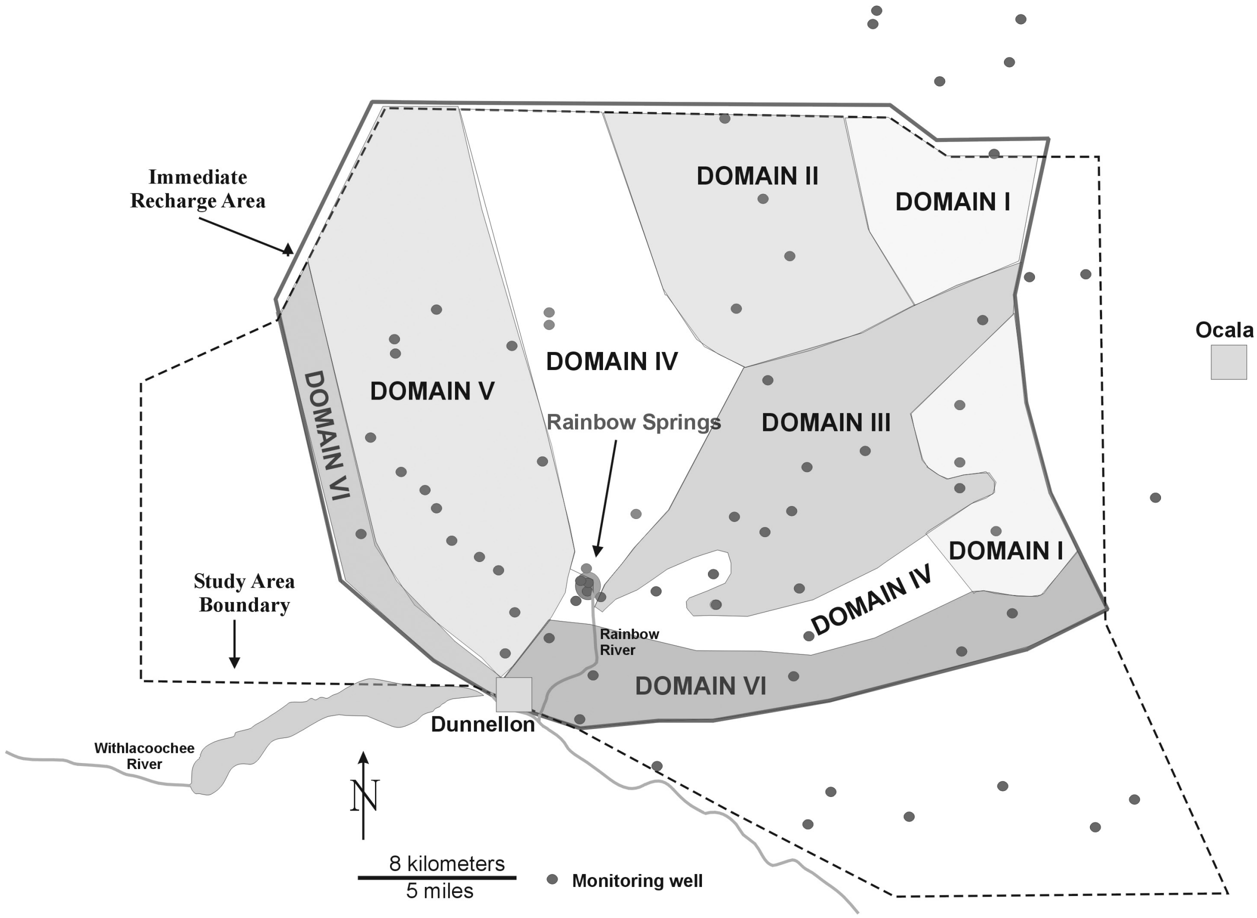

Figure 22. *The geochemical domains from which water originates in springs of the Rainbow Springs Group (from Jones et al., 1996, Figure 42).*

Figure 23. *Sign placed by Marion County to acquaint the public of their effects on Rainbow Springs. Photo courtesy of Sam Upchurch.*

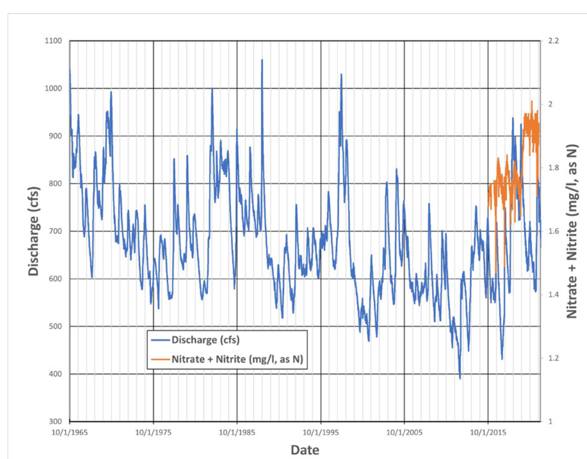

Figure 24. *Daily discharge and nitrate + nitrite concentrations in water from Rainbow Springs.*

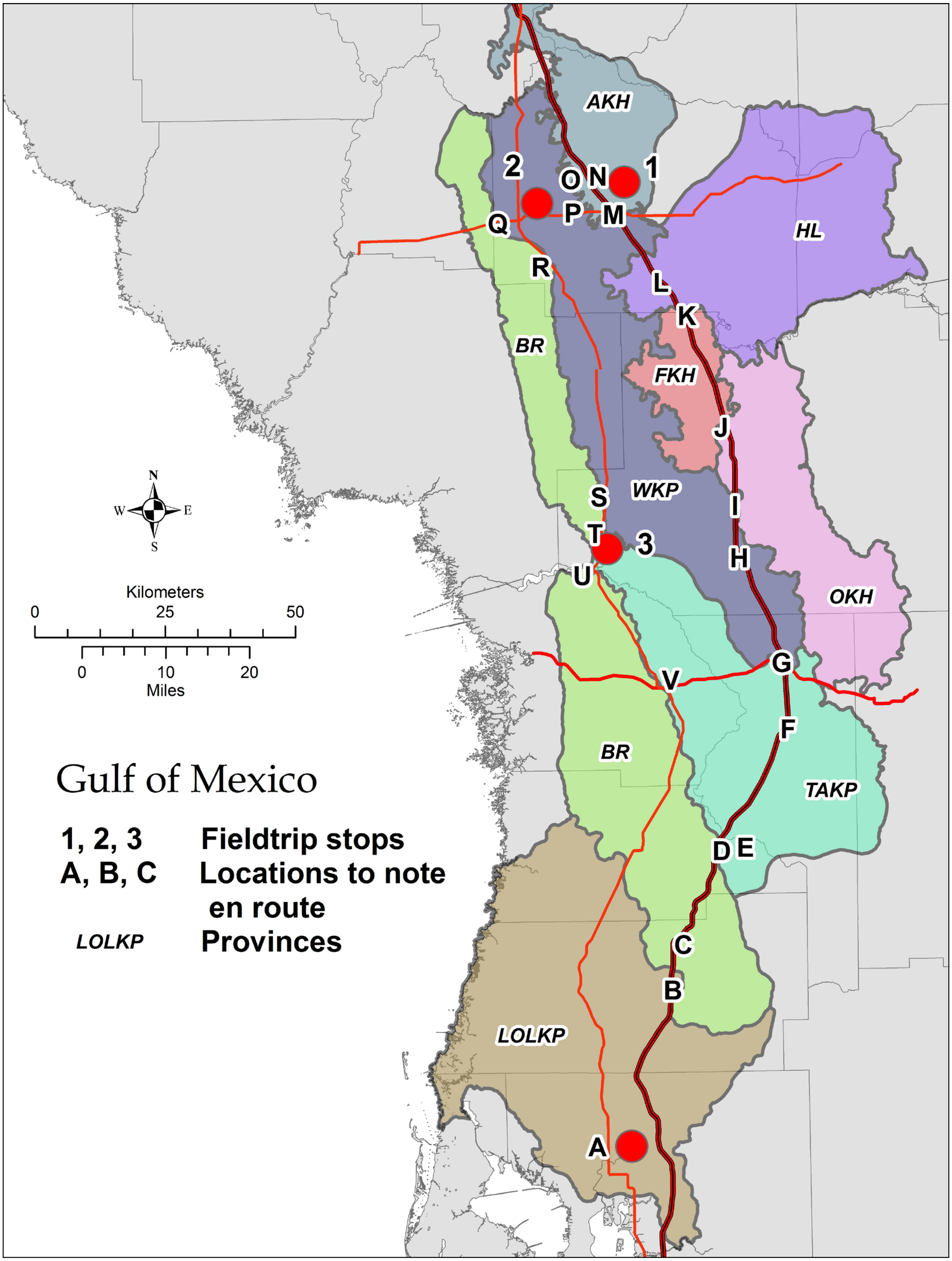

Figure 25. *Field trip route map with approximate locations of stops and notable locations to view en route. See Figure 2 for geomorphic province name abbreviations.*

Road Log

The road log provides directions for navigating the field trip, including locations of importance along the way. Figure 25 presents the general locations of the stops (indicated by numerals) and locations to view (indicated by letters) while driving. While NCKRI uses the International System of Units (the metric system) in its research and reports, road log distances below are given in miles since those are the units used on highway distance markers and in most US vehicles.

Total Miles	Miles since last landmark	Route directions and landmarks
0.0	0.0	Exit the main entrance of the University of South Florida (4202 E. Fowler Avenue, Tampa, Florida) and turn left (east) on Fowler Avenue. **Land O'Lakes Karst Plain Province:** The University of South Florida (USF; A, Figure 25) is located within the Land O'Lakes Karst Plain Province. Sinkholes are common in the area but are mostly obscured by urban development. Where they remain, they are often utilized as stormwater basins. In the 1950s, the university was developed on the remains of a World War II Army Air Corps training field. At that time, the karst topography was visibly widespread (Figure 26) and new sinkholes frequently developed on and near the property. Just west of the university, Fowler Avenue crossed a shallow, large sinkhole and was prone to flooding during extreme rainfall events. For example, following Hurricane Donna in 1960, Fowler Avenue and many depressions on campus were flooded, which resulted in a need for extensive drainage engineering prior to site development. At the time, local newspapers even called the new university "Sinkhole University." Many of the campus buildings have required deep foundations with extensive grouting because of the karst. For the next 30 miles on I-75, we will be passing through the Land O'Lakes Karst Plain (Figure 25). Urbanization and development along the interstate make observation of the many sinkholes difficult. The area crossed by I-75 is characterized by shallow Oligocene-Miocene Tampa Member limestone, Oligocene Suwannee Limestone, and, farther north, Eocene Ocala Limestone. These limestones are riddled with karst conduits and fractures (joints). Cover consists of clayey, sandy, Hawthorn Group and residual Hawthorn Group sediments overlain by Pliocene-Pleistocene marine terrace sands.
3.6	3.6	Pass under the overpass and bear right (north) on to the ramp for I-75 north to Ocala.
5.3	1.7	The interstate splits here to avoid a deep sinkhole which is obscured by trees in the median. During interstate construction, small sinkholes were grouted and/or filled. Large sinkholes were bypassed.
29.7	24.4	**Brooksville Ridge Province** (B, Figure 25): Here, the interstate begins to rise as we climb the southwestern flank of the Brooksville Ridge. The ridge originates a few kilometers to the southeast of this point and extends north-northwest for approximately 182 km (113 miles). The topographic relief on the ridge is a result of sinkhole development in an area of thick cover, including remnants and residua from the largely siliciclastic, Miocene Hawthorn Group. The ridge has coastal scarps and dune- and beach-sand deposits at its toe. It is thought that the ridge formed by karst escarpment retreat on both its eastern flank (facing a large sound or embayment) and western flank (facing a shallow shelf and the Gulf of Mexico). The Oligocene Suwannee Limestone underlies the Hawthorn Group sediments and residua in the southern parts of the ridge. The Eocene Ocala Limestone underlies the Suwannee Limestone in the southern part of the ridge and the Hawthorn Group sediments to the north. As we cross the Brooksville Ridge, you will see abundant large sinkholes, uvalas, and, rarely, poljes. Sandy, Pliocene-Pleistocene marine terrace sands are draped over the Eocene to Miocene strata. These sands are typically loose and subject to creep erosion by runoff. As a result, karst depressions have relatively thick, sandy, and clayey fill. Clay may result in perched and ephemeral lakes and wetlands. If the depressions intersect the Floridan aquifer system, perennial lakes result. The hills between the karst features are typically rounded by this sand mantle, resulting in gently rolling hills and valleys. Isolated, cone-shaped hills are common in some areas. In the subsurface, the limestones are commonly pinnacled, often with relief of 15 m (50 ft) or more. Vadose caves are locally accessible (Florea, 2008, 2009) in some areas (most cave entrances in Florida are found on private property and are not accessible to the general public without permission by the property owner). Except for local seeps, there are no springs in the Brooksville Ridge Province. Because of the closed depressions, the ridge is a significant recharge area. This water enters the Floridan aquifer system and flows to the adjacent karst plains to the west where large springs abound.

Total Miles	Miles since last landmark	Route directions and landmarks
30.4	0.7	**Moody Lake Uvala and Vicinity** (C, Figure 25): Moody Lake (Figure 27) is one of three sinkhole lakes that occupy a large uvala elongated from northwest to southeast. This is a common orientation of uvalas and alignments of sinkholes throughout peninsular Florida. It reflects regional fracture orientations in the underlying limestone. Local relief in the vicinity of the uvala is as much as 38 m (125 feet). Because of the intense development of large sinkholes, the closed depression (gray area on the map) is only about 1.5 m (5 feet) above lake level. Relief in the Moody Lake uvala is over 30 m (100 feet), however. The intervening hill areas are isolated because of coalescence of the sinkholes. The area includes some of the best developed covered-karst landforms in Florida. Clay Hill (Figure 27) is a remnant of the highlands that once existed in the area. At 92 m (301 feet) MSL, Clay Hill is the highest point in the Brooksville Ridge Province and one of the highest in peninsular Florida. The remnant high areas often include isolated, cone-shaped hills and many of the larger sinkholes, which tap the Floridan aquifer system to form lakes, are isolated and "star-shaped" (e.g., Jessamine Lake, Figure 27). Because of rapid sand movement, karst depressions tend to fill quickly (geologically speaking). Steep-sided depressions are considered geologically young, perhaps only a few hundred years old. Depressions with gentle slopes may date back to the Pliocene.
40.0	9.6	**Tsala Apopka Plain Province** (D, Figure 25): We have descended from the Brooksville Ridge Province onto the Tsala Apopka Plain Province (Figure 28) which we will encounter again near the end of this field trip. Large karst lakes at the toes of karst escarpments are common in Florida. Upchurch et al. (2019) termed these karst landforms "scarp-toe lakes." We will discuss these lakes in more detail on the return leg of this trip when we view Lake Tsala Apopka (V, Figure 25).
40.8	0.8	**Withlacoochee River and Silver Lake** (E, Figure 25): On the right (east) as we cross the Withlacoochee River, you will see Silver Lake (Figure 28). Silver Lake is a former, in-stream phosphate mine. There are several such mines that were operational in the river during the late 19th and early 20th centuries. The phosphate was dredged from isolated deposits in relict sinkholes in the river and from detrital, phosphatic sediments.
55.1	14.3	**Lake Panasoffkee (Florida Veterans Memorial Bridge)** (F, Figure 25): The swamp on both sides of I-75 is an arm of Lake Panasoffkee that has been filled with calcitic marl precipitates. The lake is largely spring fed and calcitic sediments are rapidly accumulating.
61.9	6.8	I-75 exit for SR 44. We continue on I-75 and near the end of our field trip we will rejoin I-75 at this exit.
62.8	0.9	**Williston Karst Plain Province** (G. Figure 25): The Williston Karst Plain is a prominent region characterized by numerous, shallow sinkholes developed in the thinly covered Eocene Ocala Limestone.
76.2	13.4	**Marjorie Harris Carr Cross Florida Greenway Park** (H, Figure 25): Construction began on the Cross Florida Barge Canal in the 1930s. Construction on the canal ceased in 1971 and it was deauthorized in 1991 because of environmental opposition. Marjorie Carr was a leader in this opposition. Only about 25% of the canal was completed, but the property had been purchased. In 1991 the land was dedicated as a state trail and greenway that is 177 km (110 miles) long and covers 280 km^2 (70,000 acres). Preliminary geological investigation by the US Geological Survey (Faulkner, 1973) provided a wealth of subsurface information regarding karst in the area. Faulkner's work suggested that area springs and groundwater flow patterns would be disrupted by the canal—ammunition for Ms. Carr and her colleagues. Faulkner's work also explained the presence of Rainbow Springs, our third stop.
84.6	8.4	**Ocala Karst Hills Province** (I, Figure 25): The interstate crosses into the Ocala Karst Hills Province here. There is a slight increase in relief as the thickness of cover increases. The Ocala Karst Hills were formed largely by sinkhole development. There is an indistinct, coastally eroded toe to the hills. LiDAR images of the province suggest that there were once stream systems that drained to the east, away from our location. However, there is insufficient data to conclude that fluvial erosion of an upland area contributed significantly to scarp retreat.
93.3	8.7	**Fairfield Karst Hills Province** (J, Figure 25): The interstate enters the Fairfield Karst Hills Province, a series of erosional outliers that remain from the retreat of the western Ocala Karst Hills escarpment. The hills are somewhat higher than are present in the Ocala Karst Hills Province nearby. There are short streams with swallets near the base of the Fairfield Karst Hills.
106.8	13.5	**Hawthorne Lakes Province** (K, Figure 25): The Hawthorne Lakes Province lies within the Lakes District. As the name suggests, the province is characterized by large sinkhole lakes. Topography is relatively flat.

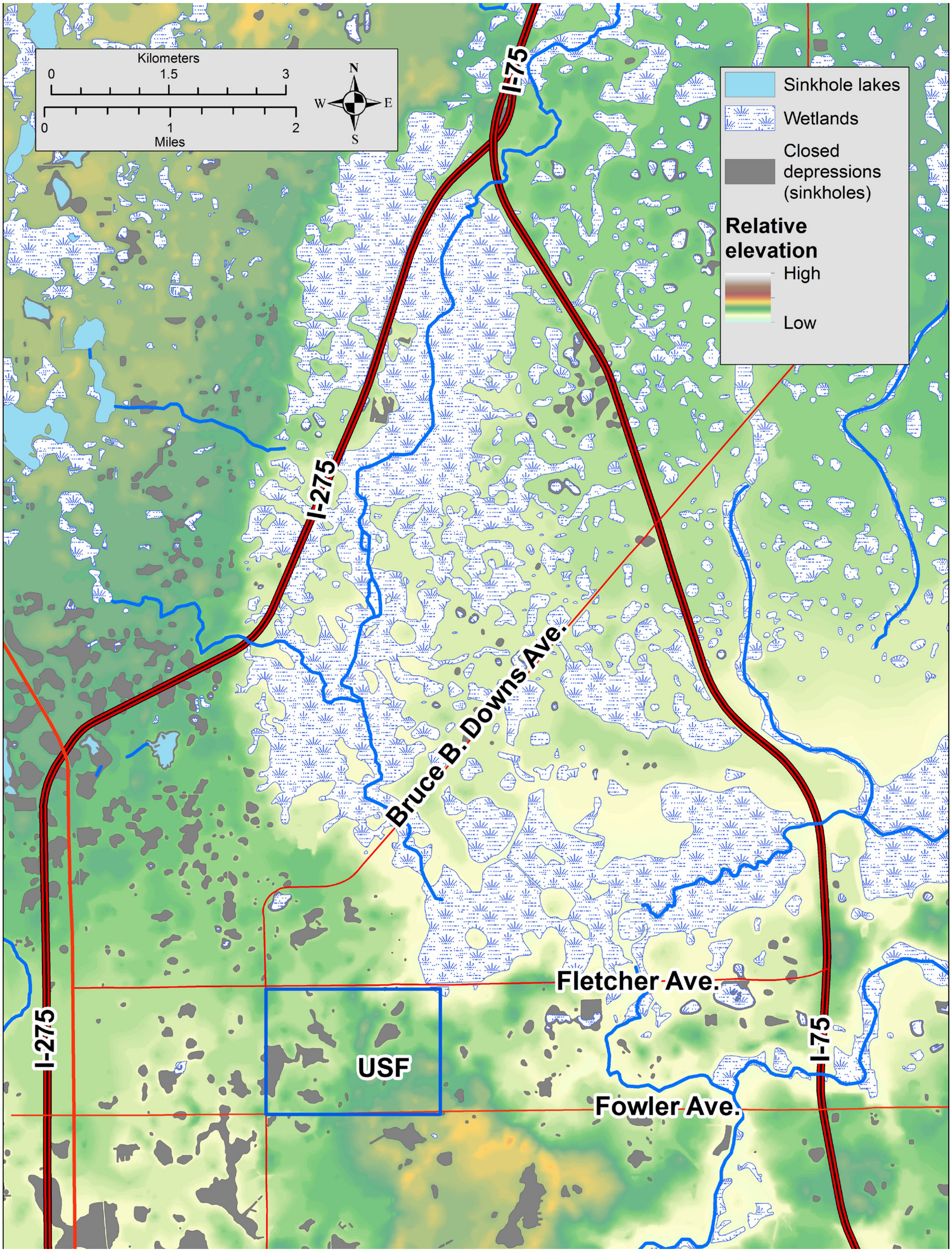

Figure 26. *Example of the topography in the Land O'Lakes Karst Plain Province from the University of South Florida campus to the junction of I-75 and I-275. Gray shapes are dry, closed depressions (sinkholes). The wetlands are Hillsborough River floodplain swamps that are highly irregular in shape because of karst depressions.*

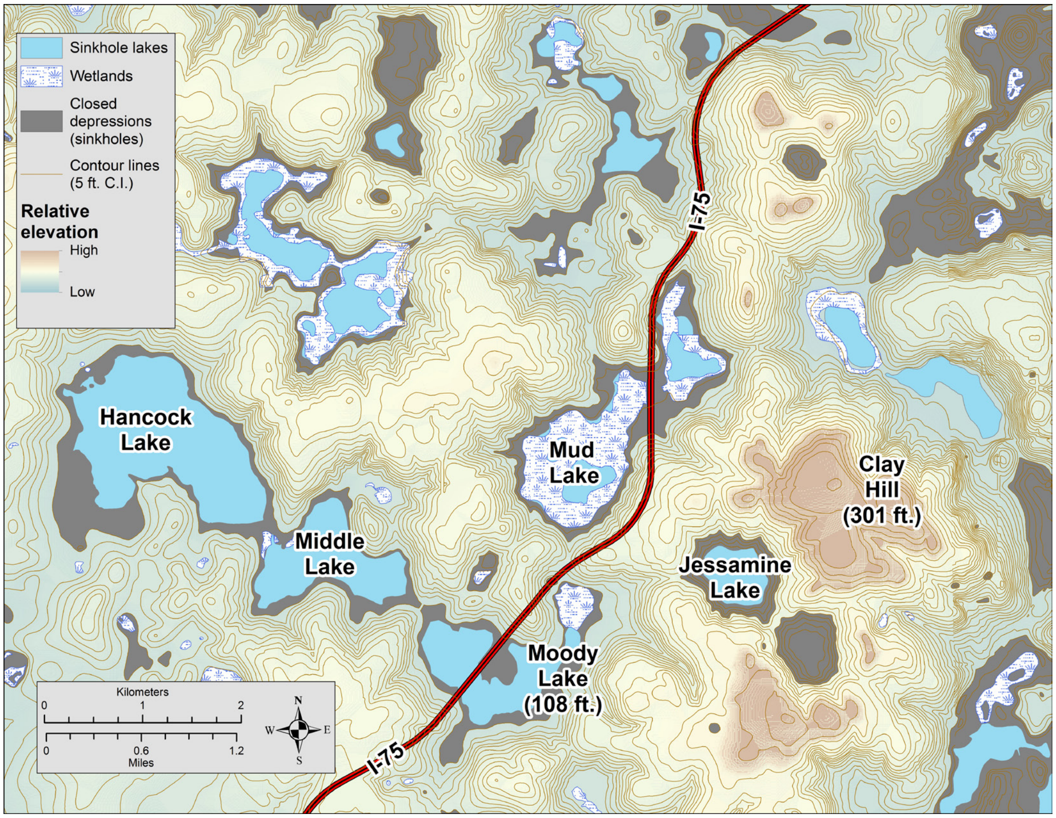

Figure 27. *The crest of the Brooksville Ridge Province on I-75 at Moody Lake. Clay Hill is the highest point in the province.*

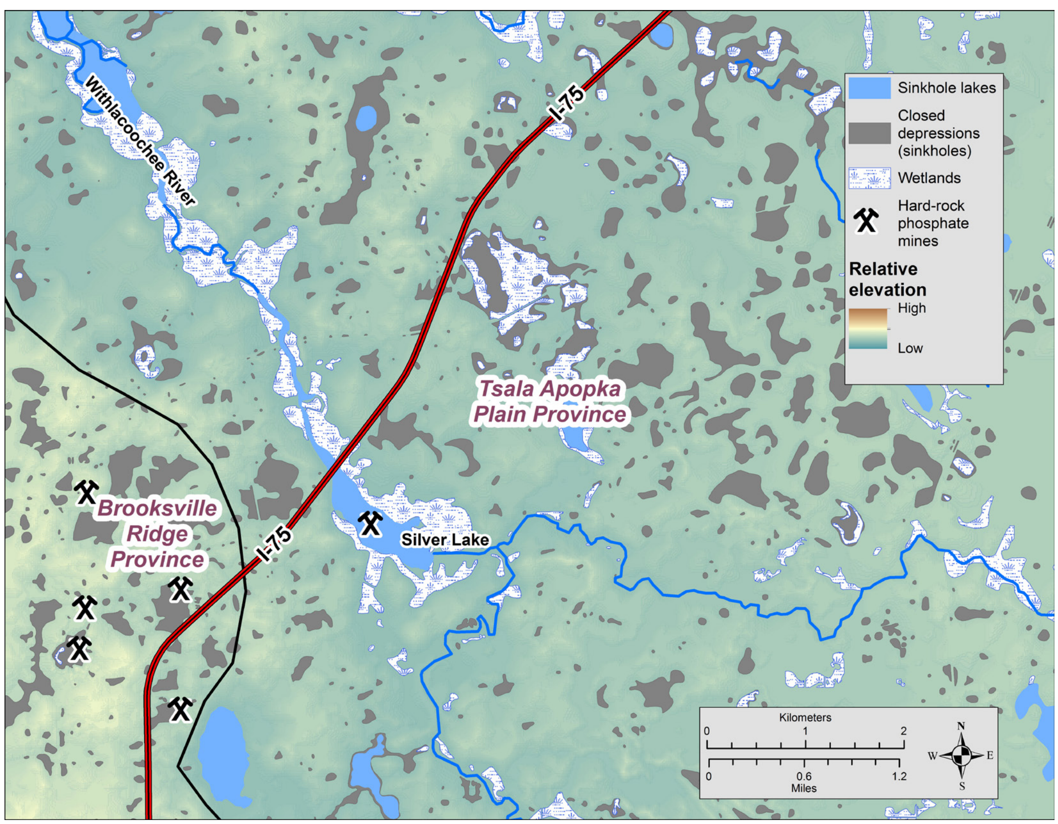

Figure 28. *The transition from the Brooksville Ridge Province to the Tsala Apopka Plain Province. Note the numerous hard-rock phosphate mines on the eastern flank of the Brooksville Ridge.*

Total Miles	Miles since last landmark	Route directions and landmarks
107.8	1.0	**Paynes Prairie State Park**: If you turn right on CR 234 (Exit 374) you will reach Paynes Prairie Preserve State Park which has several nature trails, a tower from which one can view Paynes Prairie, and an interpretive center. There are small herds of wild horses and bison roaming the prairie. The route to the park is well marked.
113.1	5.3	**Paynes Prairie Polje** (L, Figure 25): The interstate crosses Paynes Prairie, Florida's best-known polje (Figure 29). Jensen (1987) was first to term these Florida lacustrine and paludal sediment-filled, karst basins poljes. Test borings around the rims of these poljes reveal that the upper limestone surface often has a steep bluff, like the Dinaric karst, but the sand mantle normally masks such features (Upchurch, unpublished data). Florida's polje floors range from dry or seasonally dry to perennially wet. The term prairie or wet prairie is commonly used in Florida to refer to large marshes with emergent grasses and sedges. The term is applied to poljes and broad, shallow, drainage marshes such as the Kissimmee [River] Prairie north of Lake Okeechobee. The prairie receives drainage from the nearby upland areas. It drains to the Floridan aquifer system through the Alachua Sink (Figure 29). It has one or more small, open-water areas and scattered areas of normally dry land. It is one of a series of sinkhole lakes and poljes (Figure 29) that lie at the toe of the southeastern margin of the Alachua Karst Hills Province of the Ocala Karst District and occupy the western part of the Hawthorne Lakes Province of the Lakes District (Williams et al., 2022). The 85-km^2 (21,000-acre) Paynes Prairie is an important historic feature in Florida. It was inhabited by Native Americans for thousands of years. When settled by Europeans, the Spanish government arranged land grants in the area. It became an early, important agriculture area. The great explorer and botanist William Bartram (1891) visited the prairie in 1874. He called it the Alachua Savannah and described the inhabitants and environment in the area. The area was, at that time, largely a grassland. In 1871, the Alachua Sink became plugged, and the prairie flooded, forming Alachua Lake. For 20 years the lake was plied by steamboats. The Alachua Sink opened, and the lake drained in 1891. Since then, efforts have been made to keep the sinkhole/swallet open. Even so, during periods of extreme precipitation local flooding occurs.
115.4	2.3	**Williston Karst Plain Province** (M, Figure 25): As we cross Paynes Prairie, the southern boundary of the Williston Karst Plain Province is evident as a steep (for Florida) hill straight ahead.
117.1	1.7	**Hogtown Creek** (N, Figure 25): At this point the interstate quickly crosses Hogtown Creek. Figure 29 also shows the Hogtown Creek drainage system, which is typical of the stream-to-sink drainages of the Alachua Karst Hills Province and results in attribution of the escarpment to fluviokarst processes. The creek heads in an upland (Figure 29) to the east and northeast of the Alachua Karst Hills Province. It flows southwest through Gainesville where it begins to cut its way through the clay-rich Hawthorn Group until it encounters carbonate rocks. There, a series of small swallets interrupts normal flow. During episodes of seasonal high flow, the infiltration capacity of the swallets is exceeded and flow continues to a scarp-toe polje (Hogtown Prairie) and then to Lake Kanapaha (Figure 29) in the Williston Karst Plain where recharge to the Floridan aquifer system and evapotranspiration disperse the water. **Alachua Karst Hills Province:** Shortly after crossing Hogtown Creek, the interstate enters the Alachua Karst Hills Province (Figure 25). The Alachua Karst Hills, an extensively studied, fluviokarst escarpment, is part of the Cody Escarpment that includes three physiographic provinces (Williams et al., 2022; Figure 5). The scarp is a series of karst hills that have been variously modified by marine and fluvial erosion. See Upchurch et al. (2019) and Williams et al. (2022) for discussions of the escarpment and references.
121.3	4.2	Bear right on Exit 390 ramp for SR 222.
121.8	0.5	Turn right (east) on SR 222 (NW 39th Avenue).
125.1	3.3	Turn left (north) on NW 43rd Street.
126.1	1.0	Turn left (west) on SR 232 (NW 53rd Avenue).
126.4	0.3	Turn right (north) to Devils Millhopper Geological State Park (1; Figure 2), proceed to parking area. **STOP 1: Devil's Millhopper Geological State Park** (Figure 30): The Devil's Millhopper Geological State Park was the first of several such areas set aside for their unique and important geology. The Millhopper is a rock-collapse sinkhole that penetrates the entire local section of the

Total Miles	Miles since last landmark	Route directions and landmarks
		Hawthorn Group (see stop description) and terminates in the Ocala Limestone. You will be able to catch glimpses of exposures and small seeps from the boardwalk. The sink is the easternmost karst landform of the karst escarpment that constitutes the Alachua Karst Hills Province. This area is part of the Cody Escarpment, a large karst escarpment that extends through three physiographic provinces from just south of Gainesville to west of the Tallahassee area. Depending upon location, the escarpment shows evidence of marine erosion, especially near its toe, fluvial erosion, and extensive karst development. Because it is a narrow, near vertical shaft, a humid, warm microclimate has developed. The resulting, lush vegetation is notable.
126.6	0.2	Return to NW 53rd Avenue (Millhopper Road) and turn right (west). As we travel west, we are crossing from near the top of the escarpment toward its toe. Note the development of a hilly landscape with abundant sinkhole depressions.
130.8	4.2	**San Felasco State Preserve** (N; Figure 25): The parking area is to the left and the trailhead is to the right. The San Felasco State Preserve (Figure 30) is accessed by trails. It is notable as an example of the development of a polje and disarticulated, dendritic drainage system. Like Hogtown Creek, streams cross the upper regions of the Cody Escarpment and enter the Sanchez Prairie polje where at least two mapped swallets convey water to the underlying Floridan aquifer system. **Disarticulated Drainage Networks:** Figure 30 also shows several textbook examples of stream-to-sink drainages. Based on the topography, these stream systems were once a part of a larger single, dendritic stream network (White, 1970). As the karst escarpment has retreated from west

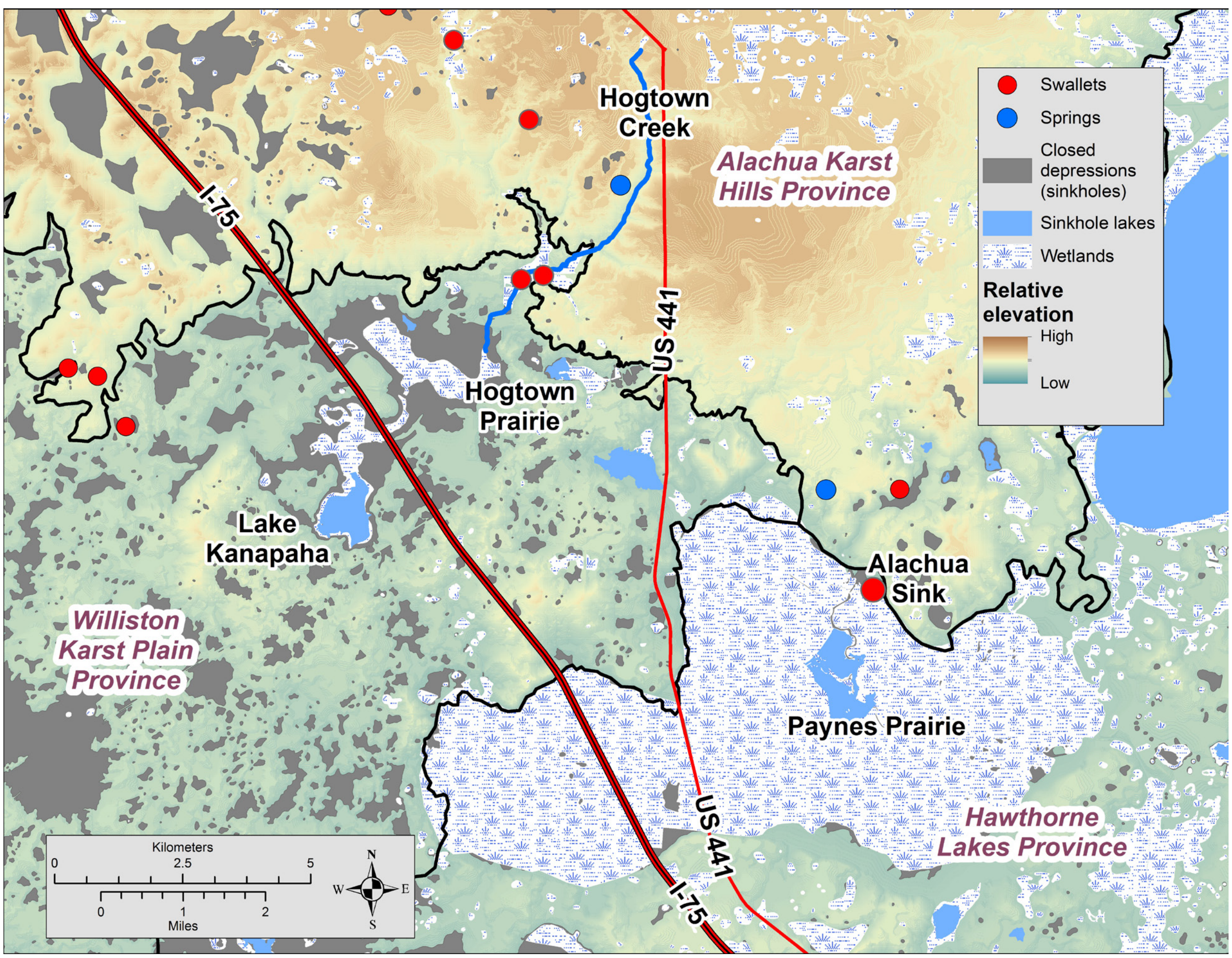

Figure 29. The Paynes Prairie polje and Hogtown Creek stream-to-swallet drainage system.

Total Miles	Miles since last landmark	Route directions and landmarks
		to east, swallets have developed and captured flow, breaking the larger drainage system into several smaller systems. Upchurch et al. (2019) explain this process in detail.
131.8	1.0	**Williston Karst Plain Province** (O; Figure 25): As we traveled west from the Devil's Millhopper, we have crossed the Cody Escarpment in the Alachua Karst Hills Province. As we neared the toe of the escarpment, the hills, which consist of residual and remnant Hawthorn Group sediments, have become lower and sinkholes have become smaller and shallower. We will cross the Williston Karst Plain Province (Figure 25) until we near Stop 3 this afternoon. The karst of the province is characterized by thin cover over the Eocene Ocala Limestone. We will see many small, shallow depressions (cover-filled sinkholes; Figure 31) along our route. The province also includes many uvalas, several notable karst windows, and, where the province abuts the Santa Fe and Suwannee rivers, springs.
132.9	1.1	Turn left (south) on NW 143rd Street (CR 241).
137.3	4.4	Turn right (west) on SR 26 (Newberry Road).
140.9	3.6	Turn right (north) on NW 202nd Street.
141.9	1.0	**STOP 2: Haile Quarry and lunch** (2: Figure 25): Turn left (west) into the Limestone Products, LLC's Haile Quarry. This historic mine complex began in the late 1800s as a hard-rock phosphate mine. Today, the Ocala Limestone is being mined for aggregate. The quarry is famous to geologists because of its exceptional karst features and fossils (see stop description above).

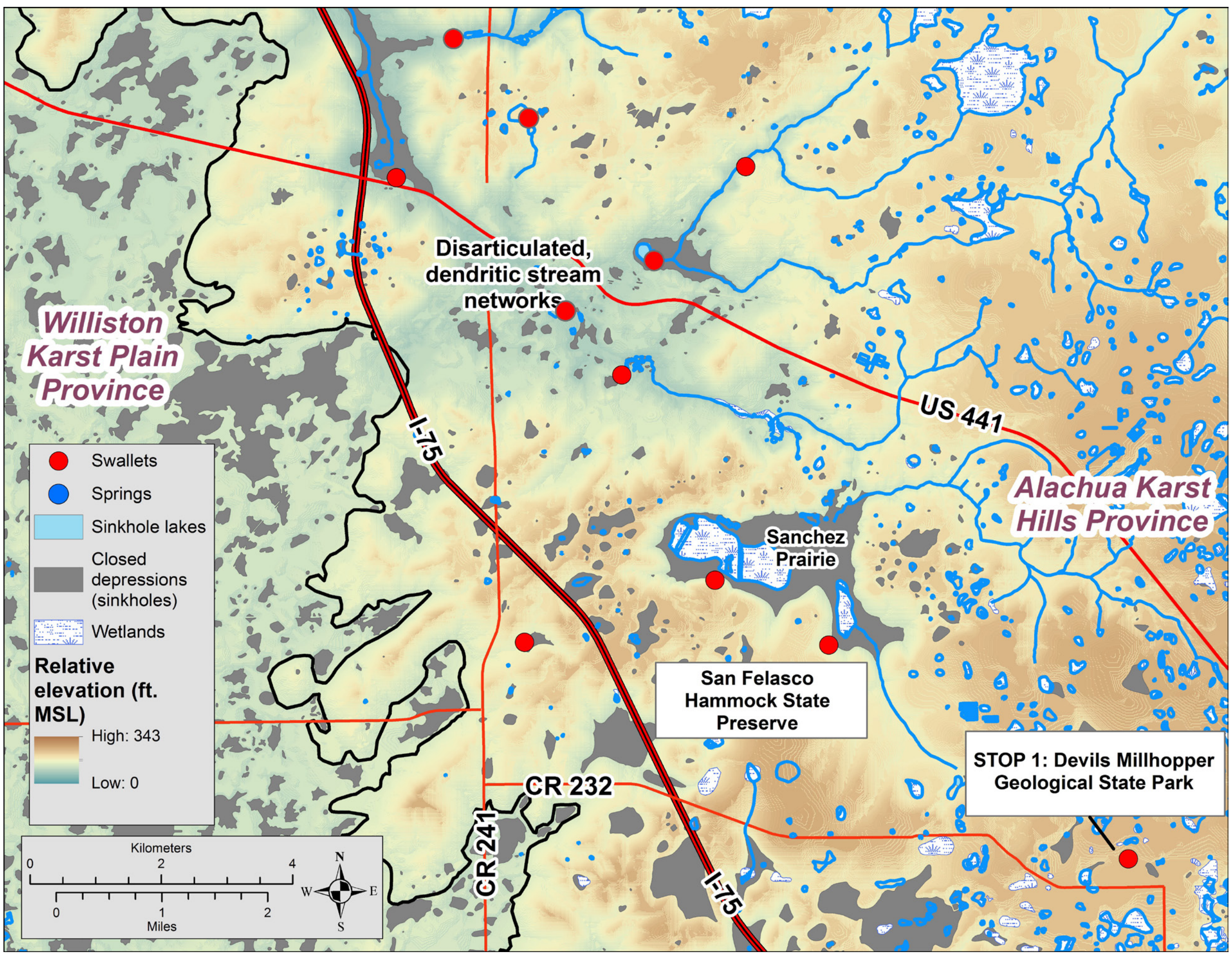

__Figure 30.__ The area near the Devils Millhopper Geological State Park and San Felasco Hammock Preserve State Park. Note the truncated and disarticulated drainage systems of the Alachua Karst Hills fluviokarst. The north-south trending area with high relief marked Alachua Karst Hills Province constitutes the fluviokarst Cody Escarpment (Williams et al., 2022).

Total Miles	Miles since last landmark	Route directions and landmarks
		The quarry is located within the Williston Karst Plain Province. After driving through several miles of the relatively flat landscape dotted by shallow sinkholes (Figure 31), we can see the karst at depth. The abundant solution pipes, scattered, cone-shaped sinkholes, and caves developed as the escarpment migrated eastward through the area, and continues to evolve because of dissolution. Return to NW 202nd Street and turn right (south).
142.3	0.4	Turn right (west) on SR 26 (Newberry Road).
145.3	3.0	Turn left (south) on US 41 and 27 in Newberry. **Newberry's Sinkhole Issues** (Q; Figure 25): There is very little clay under the thin sand mantle in the Newberry area, and the underlying Ocala Limestone is dotted with solution channels in this area. As a result, suffosion and cover-collapse sinkholes are common over the solution pipes. For example, the local sewage treatment plant uses treatment ponds and spray irrigation to dispose of treated wastewater in prepared basins. Figure 32 is an example of suffosion sinkholes that developed when the sandy sediments were loaded with water. **Problems Caused by Buried Sinkholes:** One of the problems with modern sinkholes affecting structures is the presence of the marine terrace sands that mantle the karst. This sand mantle and residual soils fill and mask many relict sinkholes and karst conduits, which are prone to reactivation when stressed by water loading on the land surface or by groundwater pumpage. The path we are following between the towns of Newberry and Archer is an example where sand mantling of the karst is evident. Fortunately, much of the area is sparsely populated, so modern sinkhole development is not a widespread problem. In urban areas, it is highly problematic.

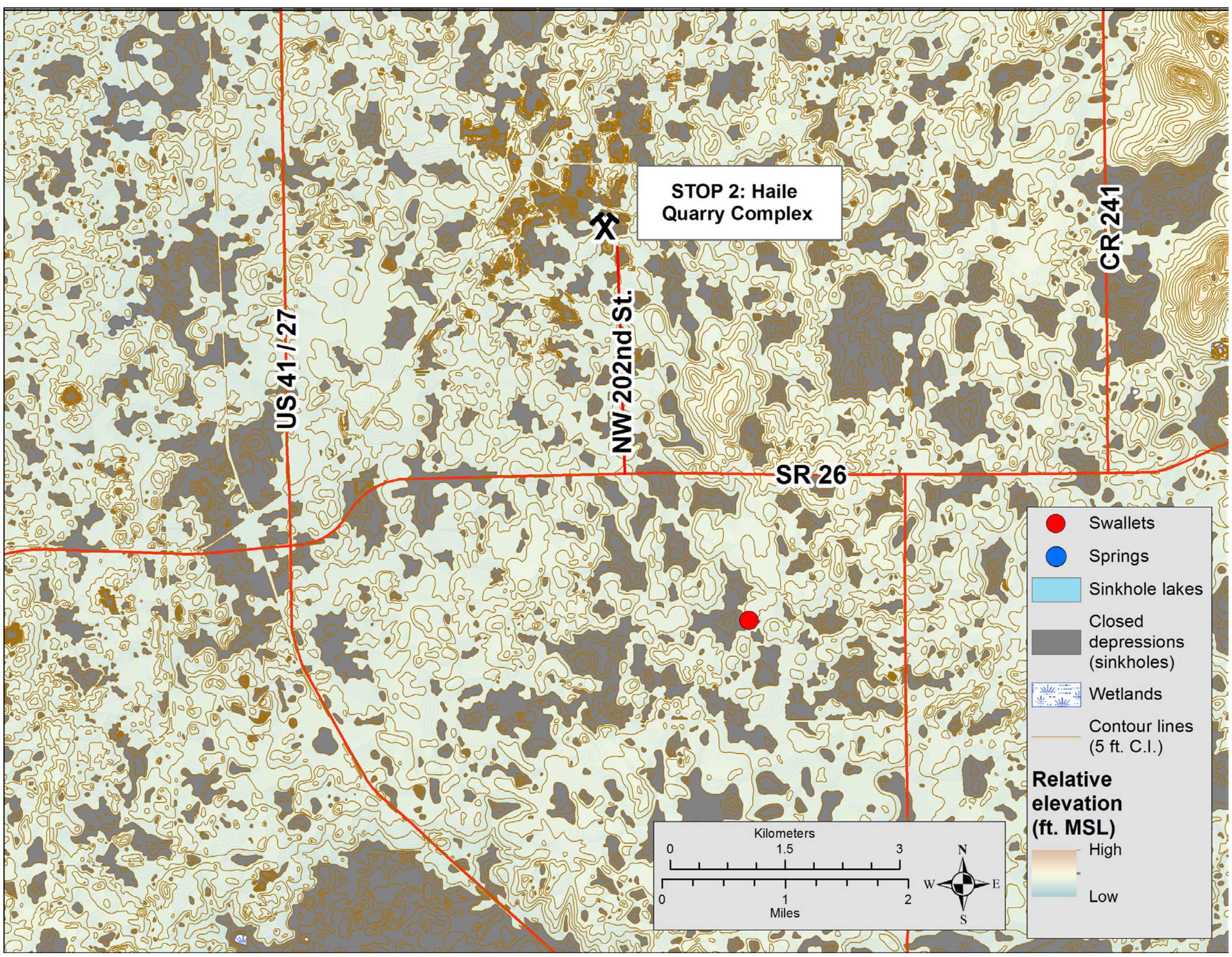

__Figure 31.__ Example topography of the Williston Karst Plain Province in the vicinity of the Haile Quarry (Stop 2).

Total Miles	Miles since last landmark	Route directions and landmarks
		Western Williston Karst Plain: Between Newberry and Archer, US 41/27 skirts the boundary between the Brooksville Ridge Province to the west and Williston Karst Plain Province to the east. The Brooksville Ridge is lower here than to the south and Pleistocene marine terrace and coastal sand was deposited on top of lower areas of the ridge. This sand mantle obscures relict sinkholes and presents a subdued pattern of karst landforms.
154.6	9.3	Junction with SR 21, Continue straight ahead (south) on US 41/27 in Archer.
166.4	11.8	Turn right (west) on US 41 in Williston.
166.9	0.5	**Williston's Karst Windows** (R; Figure 25): Turn left (south) on US 41 in Williston. Williston is something of a mecca for karst and diving enthusiasts because of two, nearby, commercial dive centers in karst windows that penetrate the Floridan aquifer system. These centers, Blue Grotto and Devil's Den, are in rock-collapse sinkholes where karst features abound. Devil's Den (Figure 33) has received considerable attention because of the early to middle Pleistocene fauna (Webb, 1974; Morgan and Hulbert, Jr., 2007) and Native American artifacts found in its sediments.
185.6	18.7	**Brooksville Ridge** (S; Figure 25): Our route is climbing on to the southern end of the northern section of the Brooksville Ridge Province (Figure 2). Unlike the sand-mantled ridge to the north, the topography here is distinctively karstic and the sand mantle is less well developed. Of importance here is the development of hard-rock phosphate deposits in ancient, Neogene sinkholes.
186.6	1.0	Turn left (east) at the sign for Rainbow Springs State Park (SW 81 Place Road).
186.9	0.3	**Ghost Town of Juliette and its Mines** (T; Figure 25): Abandoned, hard-rock phosphate mine on the left. Beginning in the 1850s, there was a farming community surrounding Rainbow Springs known as Juliette (Dinkins, 1969). Hard-rock phosphate was discovered nearby in the late 1880s and many of the residents quit farming to mine phosphate (Figure 34). There are several abandoned mines within Rainbow Springs State Park (Figure 35), but they are overgrown and there are few exposures of the ore. The mine to the left is one of the most easily explored. Juliette is long gone, and the mine pits are about all that remain.

Figure 32. *Suffosion sinkholes developed at the Newberry Sewage Treatment Plant. Photo courtesy of SDII Global Corporation.*

Total Miles	Miles since last landmark	Route directions and landmarks
187.4	0.5	Park in the lot on the left and proceed to the Rainbow Springs State Park entry kiosk to the south. The parking lot is within the Brooksville Ridge Province, but the springs and run are in the Tsala Apopka Plain Province (Figure 36). **Rainbow Springs** (3, Figure 25): See the stop discussion above. Rainbow Springs is a popular swimming and tubing site today. On our visit, we will discuss the karst nearby, hard-rock phosphate, and challenges to Florida's springs.
187.7	0.3	Abandoned hard-rock phosphate mine on the left.
188.0	0.3	Turn left (south) on US 41.
189.0	1.0	**City of Dunnellon**: Dunnellon is the city that hard-rock phosphate built (Dinkins, 1969). The phosphate deposits were discovered by Albertus Vogt in 1889 at a spring (Renfro Spring, now known as Vogt Spring; Figure 34) just northwest of Dunnellon. The spring, and resulting, hard-rock phosphate mine, were located at river level in the western side of the Dunnellon Gap. Dunnellon became a boom town with all the characteristics of a "wild west" mining town including gunfights in the streets, bawdy houses, and saloons. It was also a shipping port for the mined phosphate with access to the Gulf of Mexico to the west by way of the Withlacoochee River.
191.1	2.1	**Dunnellon Gap** (U; Figure 25): Bridge over the Withlacoochee River. US 41 crosses the Dunnellon Gap near its narrowest point. The Withlacoochee River that we also crossed at mile 40.8 originates in the Green Swamp Province northeast of Tampa and flows north, parallel to the Brooksville Ridge. At the city of Dunnellon, the river turns west and passes through the Brooksville Ridge in a gap known as the Dunnellon Gap (Figure 35; White, 1958). White argued that the gap was formed by headward erosion of a stream on the western side of the ridge. After forming the gap, this stream captured the ancestral Withlacoochee River causing a reversal of flow from southward to northward. He argued that dissolution of carbonate rocks enabled the river to form the gap. Proof of the role of karst processes includes sinkhole depressions and abandoned phosphate mines within the gap.

Figure 33. *Swimmers enjoying the Devil's Den karst window. Image courtesy of Mark Long, Mark Long Photography, from Upchurch et al. (2019).*

Total Miles	Miles since last landmark	Route directions and landmarks
		White (1958) argued that the river and lakes of Tsala Apopka Lake (see below) were a result of a Pleistocene lagoon and river system that drained to the south to Hillsborough Bay in Tampa by way of what later became the Hillsborough River. The headwaters of this ancestral Withlacoochee River were perhaps at Rainbow Springs. Stream capture at the Dunnellon Gap reversed the river flow to the north.
191.2	0.1	Bear left on US 41. The highway is climbing out of the Dunnellon Gap and back on the Brooksville Ridge.
204.6	13.4	City limits of Inverness.
207.5	2.9	Turn left (south) on US 41 (Main Street).
208.5	1.0	Turn left (east) on SR 44. The road immediately drops from the Brooksville Ridge Province into the Tsala Apopka Plain Province.
209.0	0.5	**Tsala Apopka Lake** (V; Figure 25): Tsala Apopka Lake (Figure 36), on the left, is a complex, scarp-toe lake with karst origins. The islands and peninsulas that extend into the lake have been subject of many sinkhole investigations. Standard penetration testing (SPT) at these sites revealed numerous examples of cover sediments that were weakened by apparent subsidence over a pinnacled Ocala Limestone surface. White (1958) suggested that the lake complex was a remnant of a Pleistocene lagoon that has been modified by dissolution. Many of the islands are the remains of small, coastal dunes that have been partly inundated (Figure 35). The lake complex has been modified to allow for shipping of fruit, timber, phosphate, and other products by the construction of canals between pools and to the Withlacoochee River to the east.
215.1	6.1	Bridge over the Withlacoochee River.
223.2	8.1	Turn right (south) onto I-75. Continue south to Exit 265 (the Fowler Avenue exit) which you will follow west for 3.6 miles.
288.1	64.9	University of South Florida campus. **End of field trip.**

Acknowledgments

We are grateful to Larry Rogers and Sandy Owens from Limestone Products, LLC, for allowing access to the Haile Quarry, and to the management and staff at the Devil's Millhopper and Rainbow Springs State Parks for their support.

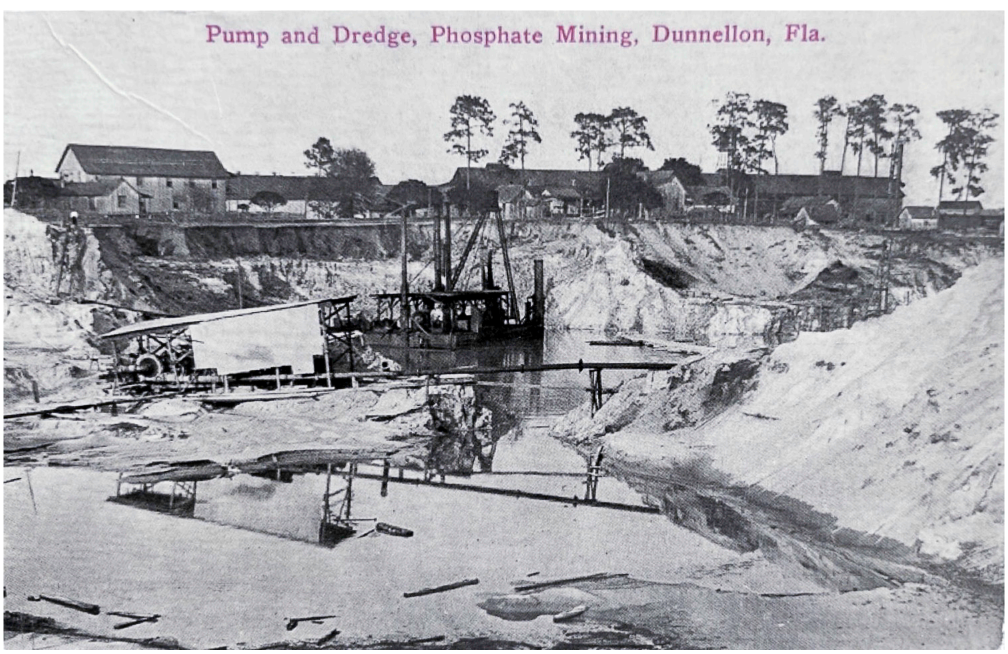

Figure 34. *Hard-rock phosphate mine near Juliette, about 1900, showing pit, dredge, and pump. Courtesy Sam Upchurch postcard collection.*

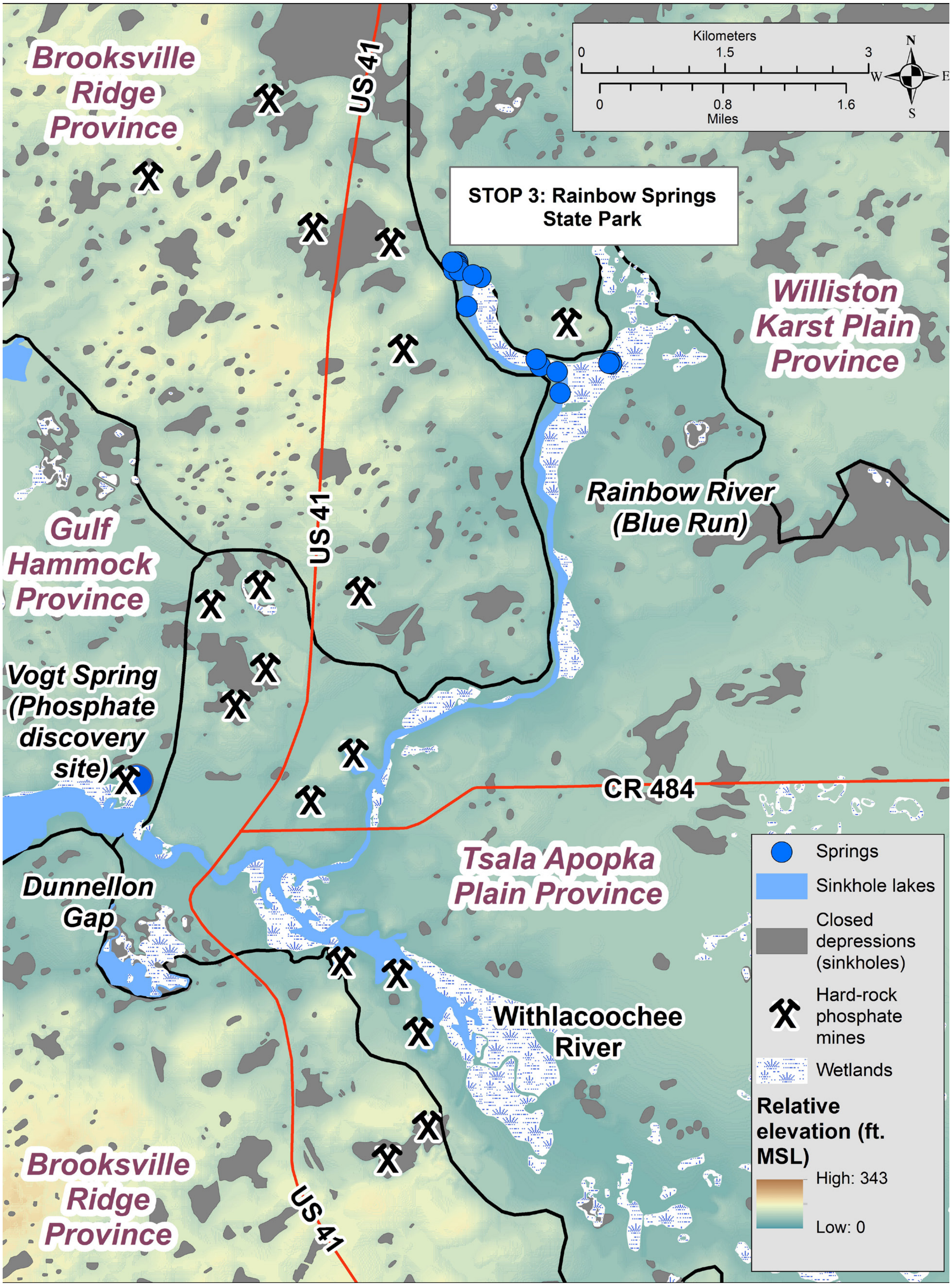

Figure 35. *Rainbow Springs and River, karst landforms, the Dunnellon Gap, and other features.*

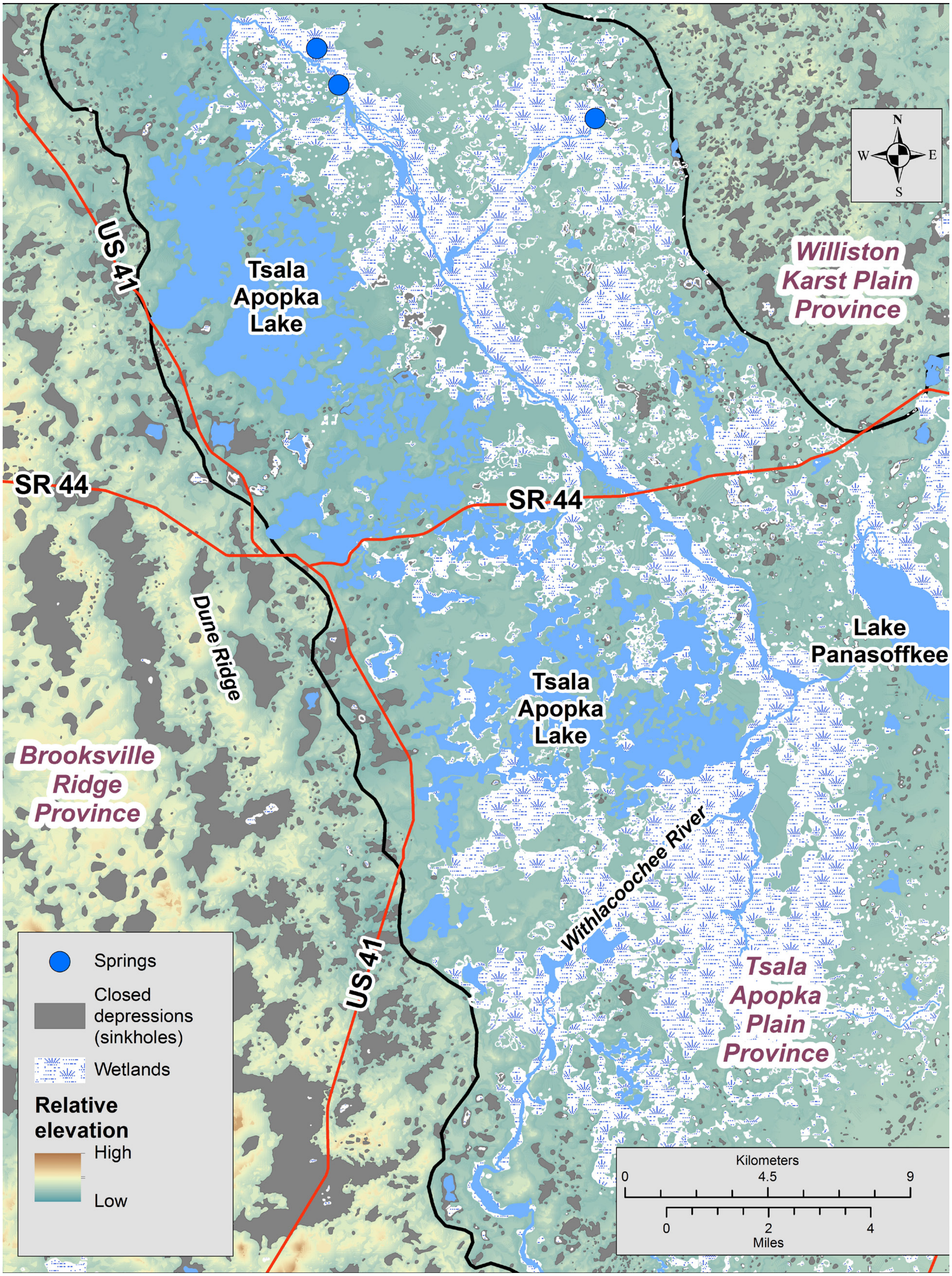

Figure 36. *Tsala Apopka Lake, a complex, scarp-toe lake at the eastern base of the Brooksville Ridge. The complex shoreline is a combination of coalescing sinkholes and small, partly drowned sand dunes.*

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Sinkhole lakes near Land O'Lakes, Pasco County. Similar lakes are a common feature of the Land O'Lakes Karst Plain Province which is visited by both trips in this field guide. Photo courtesy of Sam Upchurch.

Roles of Karst in Flood Control and Water Supply Management in West-Central Florida

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Introduction
This half-day field trip will visit two Florida karst-related flood control and water supply management sites: Morris Bridge Sink, in Hillsborough County, and Peck Sink Preserve, in Hernando County (Figure 1).

The Morris Bridge Sinks complex is located at the Flatwoods Park associated with the Lower Hillsborough River Flood Detention Area north of Tampa, Florida. Morris Bridge Sink is a classic Florida karst window into the Upper Floridan aquifer. The sink has been studied as a potential source of water for environmental augmentation of the lower Hillsborough River during periods of protracted drought. A discussion on the history of Morris Bridge area, flood control and water supply management in metropolitan Tampa and the greater Tampa Bay region will highlight complexities of managing water resources in an urban setting.

Peck Sink is a large drainage feature located south of the City of Brooksville in Hernando County, Florida. A series of sinkholes at Peck Sink Preserve occur as a central terminus for drainage over a 44.5-km² water-shed into the Upper Floridan aquifer. Peck Sink is on the western margin of the Brooksville Ridge, a prominent landform in west-central Florida, that provides the geologic setting and topographic relief for karst development and contains many closed depressions, sinkhole lakes that dominate the internal drainage features found on the ridge.

Logistics
No special equipment is required for this trip. Closed-toe shoes are encouraged. The digital version of this field guide on the NCKRI website includes hyperlinks to some locations, organizations, and other items of interest.

The road log provides directions to the two stops of this field trip. While NCKRI uses the International System of Units (the metric system) in its research and reports, road log distances below are given in miles since those are the units used on highway distance markers and in most US vehicles.

Morris Bridge Sink
The Morris Bridge Sinks complex is nestled in the flatwoods of northeastern Hillsborough County, about 1 km south of the Hillsborough River, east of Interstate 75, and near the Tampa Bypass Canal and in Flatwoods Park. It is associated with the Lower Hillsborough River Flood Detention Area north of Tampa, Florida (Figure 2). Morris Bridge Sink is a classic Florida karst window into the Upper Floridan aquifer, part of the massive Floridan aquifer system that exists throughout Florida and parts of Alabama, Georgia, and South Carolina (Miller, 1986). The sink has been studied as a potential source of water for environmental augmentation of the lower Hillsborough River during periods of protracted drought. A discussion on the history of Morris Bridge area, flood control, and water supply management in metropolitan Tampa and the greater Tampa Bay region will highlight complexities of managing water resources in an urban setting.

Morris Bridge Sink is approximately 41 m in diameter, and 60 m deep (Figure 3). The land surface elevation at the sink is about 10 m above mean sea level with a surface water elevation averaging around 7.6 m. The sinkhole was formed by the development of large solution openings in the limestone followed by collapse or subsidence of the roofs of these openings. The first 15 m of the sink is constricted to about 13.7 m in diameter within the resistant sand and clay overburden. Below 15 m, the sink widens into a 67-m diameter cavern in the soluble limestone below. The volume of the sink is estimated to be at 53,000 m³.

The Morris Bridge Sinks complex (Figure 4) occurs in a subregion of west-central Florida characterized by three principle hydrogeologic units from the land surface: the surficial aquifer, a semi-confining unit, and the Upper Floridan aquifer. The unconfined surficial aquifer is comprised of unconsolidated Pleistocene to recent sand ranging in thickness of about 1 m to as much as 6 m. The surficial aquifer is separated from the underlying Upper Floridan aquifer by a thin semi-confining unit comprised of silt, sandy clay, and clay of the Miocene age Hawthorn Group. The semi-confining unit slows the downward movement of water

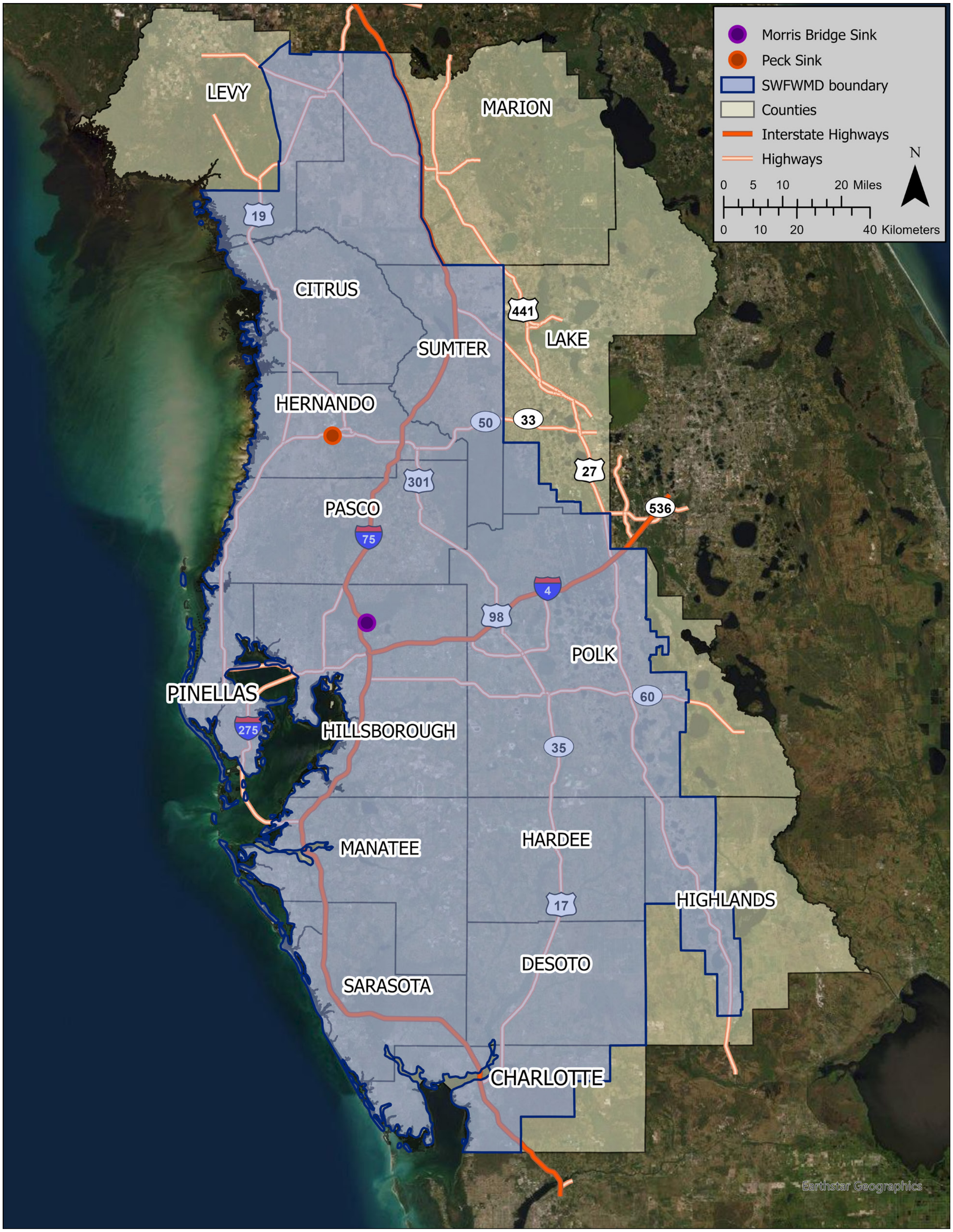

Figure 1. *Map of the Flood Control and Water Supply Management field trip area within the boundaries of the Southwest Florida Water Management District (SWFWMD) and associated counties.*

Road Log

Total Miles	Miles since last landmark	Route directions and landmarks
0.0	0.0	Exit from the north side of the University of South Florida campus and turn right (east) on Fletcher Avenue
3.6	3.6	Pass I-75. Continue east where Fletcher Avenue become Morris Bridge Road.
4.3	0.7	Look for the parking area for Trout Creek Park on the right side of the road. The street address is 12550 Morris Bridge Road, Thonotosassa, Florida 33592. **Stop 1: Morris Bridge Sink**
4.9	0.6	Follow Morris Bridge Road west and turn right (north) onto I-75.
24.3	19.4	Following I-75, exit on SR 52 and turn left (west).
26.4	2.1	Head west on SR 52 and turn right (north) on Bellamy Brothers Blvd.
38.5	12.1	Follow Bellamy Brothers Blvd. north (becomes Culbreath Road after 8 miles) and turn left on Powell Road.
41.9	3.4	Head west on Powell Road and turn right (north) on US Hwy 41.
45.1	3.2	Head north on US Hwy 41 north and turn left (west) on Wiscon Road.
46.6	1.5	Head west on Wiscon Road. The entrance to Peck Sink Preserve is on the right. The street address is 17711-18157 Wiscon Road, Brooksville, Florida 34601. **Stop 2: Peck Sink Preserve**. Return to the University of South Florida by the same route.

but is frequently breached by karst collapses into the underlying limestone. The Upper Floridan aquifer in this area is approximately 300 m thick and comprised of a thick sequence of middle Eocene to Miocene age limestones and dolostones that include (oldest to youngest) the upper part of the Avon Park Formation, the Ocala Limestone, the Suwannee Limestone, and often the Tampa Member of the Arcadia Formation.

Three pumping tests have been performed at Morris Bridge Sink (Basso, 2010). One test was performed by the city of Tampa in 1972 to evaluate the sink as a potential water supply source. The sink was used as an emergency water supply by Tampa Bay Water during an extreme drought in 2000 and it was evaluated as a potential augmentation source for the lower Hillsborough River in 2009. During the most recent pumping test, the sink was pumped at 15,140 m^3/day for 30 days yielding a drawdown of approximately 0.6 m.

Peck Sink Preserve

Peck Sink is a large drainage feature located approximately 3 km southwest of Brooksville in Hernando County, Florida. It is part of the Peck Sink complex, located within the Peck Sink Preserve, a 0.46-km^2 county-owned property (Figure 5) acquired in 2008 under the county's Environmentally Sensitive Lands Program (with partial State appropriation) primarily for groundwater protection and environmental education. The topography is relatively level, except for the steep ravines that lead to Peck Sink (Figure 6).

A series of sinkhole swallets at Peck Sink Preserve occur as a central terminus for drainage over a 44-km^2 watershed into the Upper Floridan aquifer, part of the massive Floridan aquifer system that exists everywhere in Florida as well as parts of Alabama, Georgia, and South Carolina. Peck Sink lies at the northeastern edge of the Land O' Lakes Karst Plain, immediately adjacent to the Brooksville Ridge to the north and east. The Brooksville Ridge is a prominent geomorphic landform in west-central Florida that provides the geologic setting and topographic relief for karst development and contains many closed depressions and sinkhole lakes that dominate the internal drainage features found on the Ridge.

The geology of the Peck Sink complex is undifferentiated Hawthorn Group sediments of Miocene age (with thin sand overburden), overlying Suwannee Limestone of Oligocene age that is exposed in the ravines, stream, and sinks. Hydrogeologically, the Peck Sink complex occurs in the northern province of west-central Florida where confinement between the limestone and sand overburden is absent due to erosional removal, fragmentation, or extensive karst breaching of Hawthorn Group clays. As a result, the surficial aquifer is not present, and the Upper Floridan aquifer is unconfined and represented by the water table. However, immediately to the east on the Brooksville Ridge, thick clay-rich soils and sediments of Hawthorn Group origin support numerous localized, perched lakes and water tables with head differences of 6 m to more than 30 m above that of the underlying Upper Floridan aquifer (Basso, 2019).

The sinkhole complex is of high hydrological value due to its ability to drain large amounts of stormwater

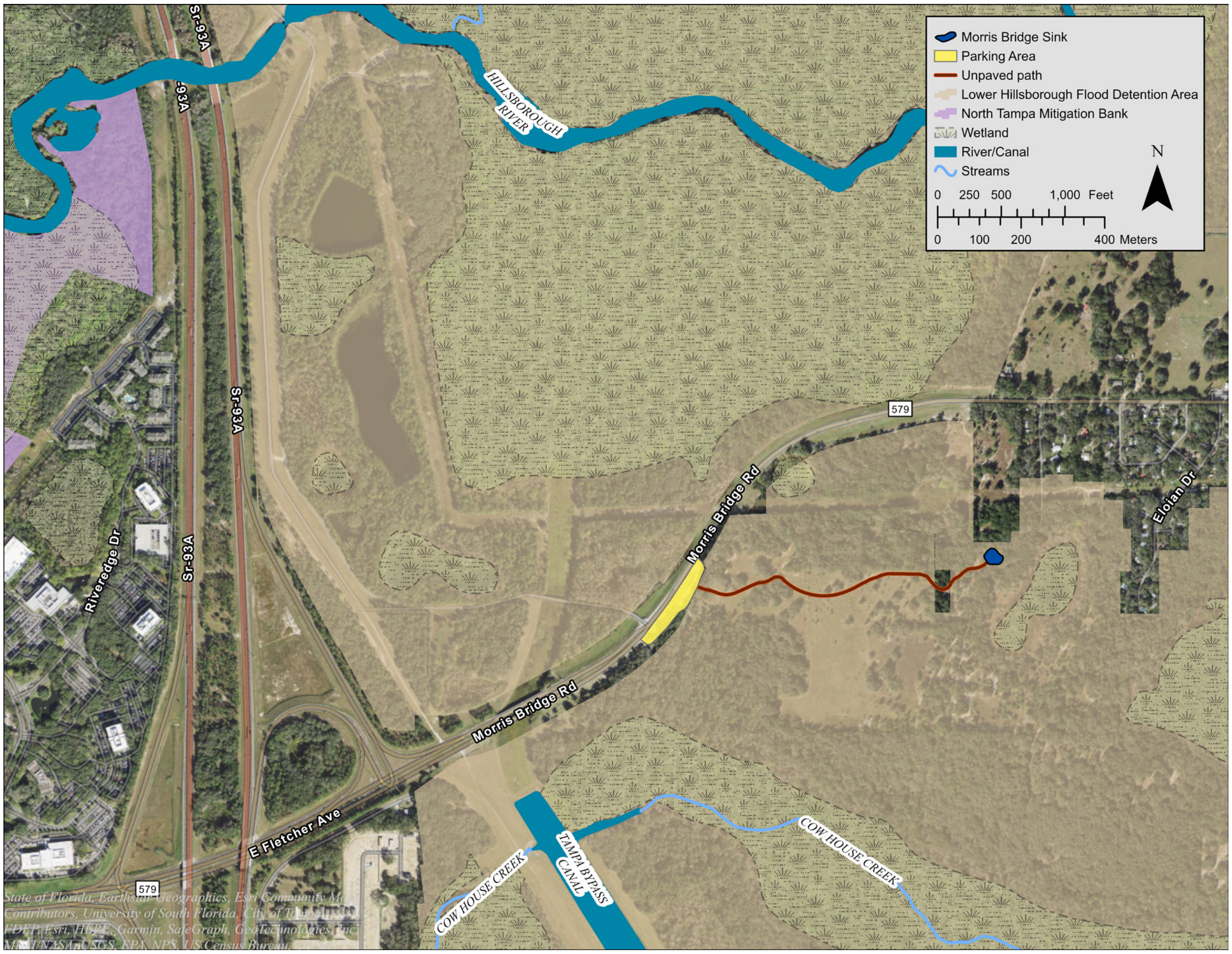

Figure 2. *Map of the Morris Bridge Sink area.*

Figure 3. *Morris Bridge Sink. Photo courtesy of Robin Speidel.*

Figure 4. *Nursery Sink is the second major sinkhole of the Morris Bridge Sinks complex. Located about 220 m due east of Morris Bridge Sink, it is 24 m in diameter by 75 m deep. A staff gauge serves as a quick visual measure of its water level. Photo courtesy of Robin Speidel.*

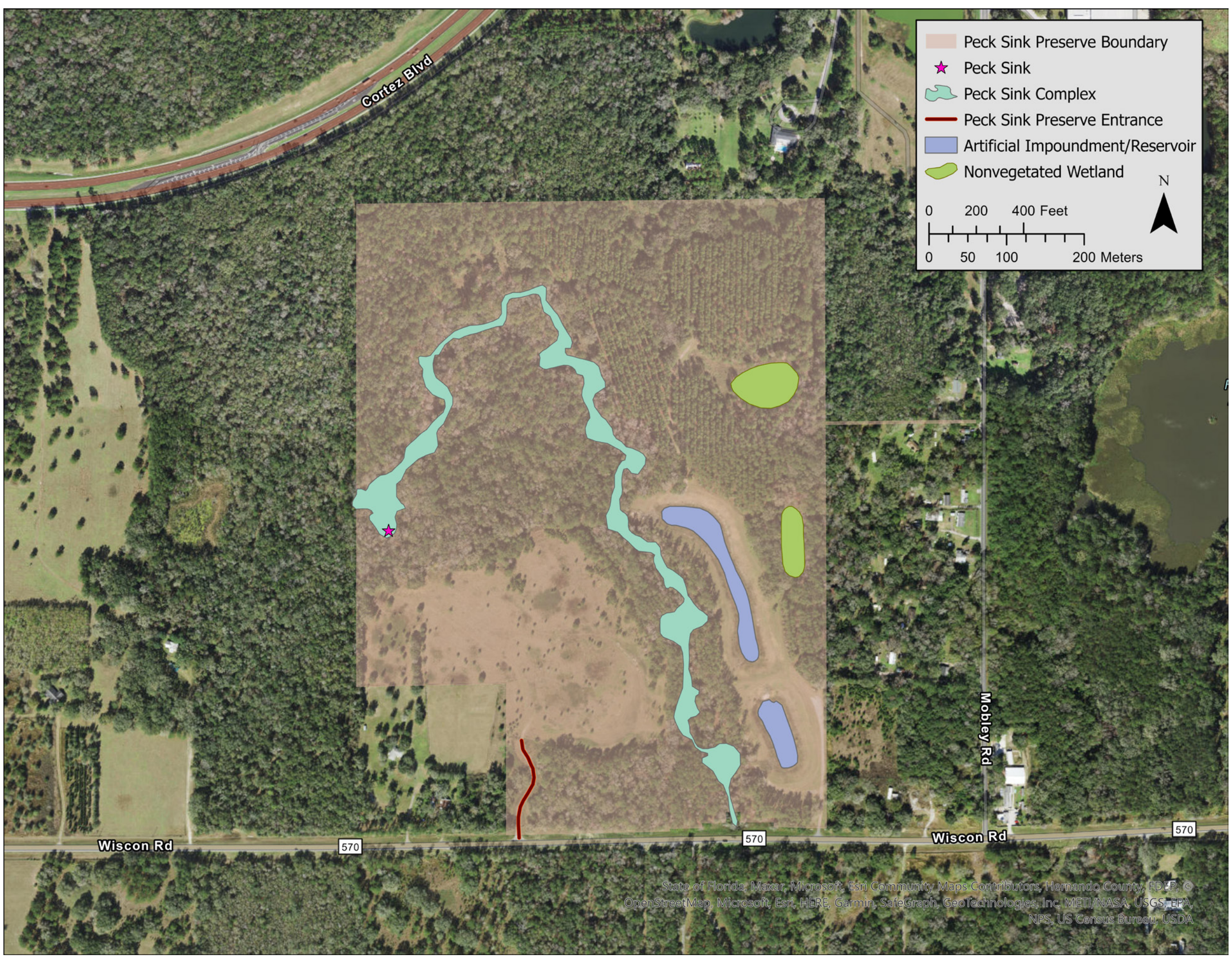

Figure 5. *Map of the Peck Sink Preserve and its major features.*

from the 44.5-km² watershed that includes the urbanized west side of the City of Brooksville.

The following is an excerpt from the Hernando County Preserves Master Land Management Plan (Hernando Board of County Commissioners, 2022), Hydrology section:

…The Peck Sink Watershed covers approximately 17 square miles [44 km²] *with an impressive elevational range of 20 to 250 feet* [6 to 76 m] *(Karlin et al. 2016). The combination of topographic relief and clay soils near the surface has produced a history of flooding in the watershed. A stormwater mitigation area and management plan were developed to improve the quality of stormwater before it enters the sinkhole complex, help relieve flooding from the surrounding area, and improve the water quality in the sink by developing a regional stormwater treatment system… The mitigation area consists primarily of the two artificial impoundments/reservoirs, which include a diversion structure, an inlet structure, a stilling basin, marsh (in the reservoirs), and an outfall to the stream channel that flows into Peck Sink.* [Figure 7.]

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Figure 6. *Peck Sink, with in-feeding ravine in the distance. Photo courtesy of David DeWitt.*

Figure 7. *Sand-filled stream cut channel that feeds stormwater runoff into Peck Sink. Photo courtesy of Jason LaRoche.*

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ISBN 978-0-9795422-9-9
90000>