

**SOUTHEASTERN GEOLOGICAL SOCIETY
FIELD TRIP GUIDEBOOK 55**

**A FIELD GUIDE TO FLORIDA CAVERNS
AND THE BROOKS QUARRY**

Edited By John Herbert



**February 25 & 26, 2012
Southeastern Geological Society
P.O. Box 1634
Tallahassee, Florida 32302**

A FIELD GUIDE TO FLORIDA CAVERNS AND THE BROOKS QUARRY

SOUTHEASTERN GEOLOGICAL SOCIETY

**Field Trip Guidebook 55
Spring Field Trip
February 25-26, 2012**

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**Guidebook Compiled And Edited By:
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**Published by:
THE SOUTHEASTERN GEOLOGICAL SOCIETY
P.O. Box 1634 Tallahassee, FL 32302**

TABLE OF CONTENTS

Introduction/Acknowledgments	1
Field Trip Overview (John Herbert.)	2
Historical Overview of the Florida Caverns (FDEP Division of Recreation and Parks)	3
Ecology of Florida Caverns (FDEP Division of Recreation and Parks)	5
Overview of the Geology of the Marianna Lowlands Province – Including a Discussion of the Brooks Quarry Exposure (FDEP Division of Recreation and Parks and Carl R. Froede Jr.)	7
Conceptual Models for Karstic Aquifers (William B. White)	16
Conceptual Models for the Genesis and Growth of Cave Systems in Karstic Aquifers (Todd Kincaid)	19
Florida Caverns Karst (Gary L. Maddox, P.G.)	29
“Farmed” Cave Calcite Chemistry: A Guide to Speleothem Paleoclimate Interpretations (Darrel M. Tremaine – PhD Candidate, FSU)	34
Field Trip Stops (Carl R. Froede Jr.)	35

INTRODUCTION/ACKNOWLEDGEMENTS

This field trip examines the processes that lead to the formation of conduit/cave systems and to processes that modify caves via speleothem formation after lowering of base level. Stops are planned at the Florida Caverns show cave and the Marianna Lime Products, Inc quarry (also known as the Marianna Hi-Cal Pit or Brooks Quarry). At the Brooks Quarry we will be able to see the stratigraphic section in which the caverns formed at the Florida Caverns State Park. Relevant portions of SEGS Guidebook #43 entitled “The Floridan Aquifer within the Marianna Lowlands” are modified and presented here – primarily as relate to geologic setting.

I want to thank David DeWitt, Harley Means, and Todd Kincaid for providing source material for this guidebook and Marc Hurst and Harley Means for their editorial and IT support – recognizing that any errors in this document are mine. SEGS needs to thank Mr. Darrel Tremaine (PhD candidate at FSU) for sharing his research on dripwater and speleothem chemistry and what that means to our understanding of paleoclimate and the growth of speleothems at various points within a cave. Darrel also took time out of his busy schedule to give a presentation at the annual SEGS business meeting and accompanied us on a tour of the Florida Caverns.

We need to express our gratitude to Mr. Brooks and Marianna Lime Products, Inc for allowing SEGS repeated access to their quarry. Finally I want to thank Geohazards, Inc./GeoHydro Consultants for underwriting production of this guidebook.

John Herbert
Gainesville, Florida
February 2012

SOUTHEASTERN GEOLOGICAL SOCIETY 2012 ANNUAL FIELD TRIP OVERVIEW

Florida Caverns State Park is unique on many levels. Since its establishment in 1942, the park has been one of the "crown jewels" of the Florida State Park System. The park is significant in the history of Florida as one of nine elements of the New Deal-inspired Florida State Park System. Park development was initiated by the Civilian Conservation Corps (CCC) and Works Progress Administration (WPA) including the preparation of the tour cave. Today, Florida Caverns is the only state park in Florida to offer cave tours. The caves contain stalactites, stalagmites, soda straws, columns, rimstones, flowstones, and draperies. They are home to unique species such as blind salamanders, cave crayfish, and the federally endangered gray bat. The park's unusual geology supports an exceptional diversity in above-ground natural resources too, with extremely rare habitat types and many species occurring at their extreme southern range limits.

This field trip will allow participants to observe the results of chemical and physical processes that form subsurface conduits/caverns/caves in karst terrains - processes that occurred at a higher sea level and that are ongoing now in the submerged limestone aquifer. As geologists, we must understand that the caverns at Florida Caverns State Park are one example of potential conduit morphology that may form in carbonate karst; hence the inclusion of a discussion of the dynamics of cave formation and growth of cave systems. We might ask ourselves how the caverns we will observe fit into the conceptual model presented in this guidebook.

While at the Brooks Quarry, field trip participants will be able to observe the Eocene/Oligocene contact within the Bumpnose Member of the Ocala Limestone and to collect fossils there. The Bumpnose Limestone (overlying the Ocala) is essentially a coquina of *Lepidocyclina*, some of which are several centimeters in diameter. The fossil assemblage includes common bivalves *Amusium ocalanum*, *Chlamys anatipes*, *Spondylus dumosus*, gastropod *Xenophora*, nautiloid *Aturia alabamensis* (at very top of Bumpnose), echinoid *Clypeaster rogersi*, trace fossils, and shark teeth. The underlying Ocala Limestone at this location is essentially a coquina of smaller and larger foraminifera, bryozoa, echinoid spines, and brachiopods, all in a matrix of finer-grained, comminuted bioclastic debris. Larger foraminifera include *Asterocyclina*, *Lepidocyclina*, *Pseudophragmina*, and *Nummulites*. Bivalve *Amusium ocalanum* is especially abundant in the upper half. Other macrofossils include echinoids, moldic molluscs, and crab carapaces. (lithologic descriptions modified from SEGS Guidebook #43).

A HISTORICAL OVERVIEW OF THE FLORIDA CAVERNS AREA

(Edited from the Florida Caverns State Park Unit Management Plan,
FDEP, Division of Recreation and Parks, June 9, 2006)

Human beings are known to have used portions of what is now Florida Caverns State Park for at least 5,000 years. Many upland areas of the panhandle once supported Native American village life, and two village sites have been recorded within the park. Most of the aboriginal sites at Florida Caverns are located in upland areas near cave entrances. This is probably due to an understandable tendency to locate campsites near a natural shelter. As recently as the 1940s, archaeologists working during the initial park development period discovered barefoot tracks in "New Cave", which they believed may have been those of Native Americans (Fairbanks 1941).

One reportedly nineteenth century resource, Carter's Mill, has been identified. Remnants of the mill foundation and dam are still visible along the Blue Hole run adjacent to the Federal Fish Hatchery site.

The largest cultural resource, both in term of acreage and number of components, is the park itself, which has been open for public recreation and enjoyment since 1942. Florida Caverns State Park is significant in the twentieth century history of Florida as one of nine elements of the New Deal-inspired Florida state park system and as one of the physical expressions of early twentieth century recreation planning. Until the 1930s the State of Florida sponsored, owned, or operated parks as monuments or memorial facilities. The idea that Floridians, increasingly members of an urban population, needed and indeed possessed a right to communion with nature was one of the intellectual underpinnings of the conservation movement of the Progressive Era (1890-1920). That movement realized its most widespread expression during the peacetime administrations of Franklin Delano Roosevelt (1933-1941).

The ideas of conservationists were made real as the Great Depression (1929-1941), brought widespread unemployment and near economic collapse. Floridians had already suffered nearly five years of unrelieved economic disasters, with Mediterranean fruit fly infestations, hurricanes, and the collapse of the land boom bubble. The Wall Street Crash of 1929 only confirmed that the whole nation faced hard times. The land, too, had fallen upon hard times having experienced massive land and topsoil degradation. The South was particularly beset with the consequences of strip mining, timber exploitation, single crop agriculture, and poor farming practices; sterilized landscapes, river floods, enormous erosion gullies.

Among the New Deal programs organized to address aspects of the problems of youth unemployment, the Civilian Conservation Corps, or CCC, may have had the most emotionally profound effect. This agency hired the unskilled and unemployable young, put them to work under military administration, and employed skilled local men to transmit the rudimentary skills required to do a job. The CCC took on two jobs, usually at the same time. The first was improving or restoring the degraded landscape (some of those actions are now frequently viewed as inappropriate land management actions), and the second, developing public recreation facilities according to professionally drawn plans. An impressive collection of facilities was constructed throughout Florida, and a considerable portion of them survives in daily use.

Among the earliest recognized twentieth century cultural elements on the park was the Federal Fish Hatchery located on the west end of the property. The site features earthworks, floodgates, stone walls, and stone posts. It was developed at approximately the same time as the Visitor Center and Florida Cavern tour cave, though it opened slightly earlier, in the late 1930s.

The managers of Florida Caverns State Park work to strike a balance between promoting public visitation, while at the same time protecting extremely fragile and sometimes irreplaceable natural resources. At a cave park, perhaps more than any other, visitor access and types of permissible recreational activities must be carefully evaluated and supervised in order that the least possible impact to cave resources occurs. This is the reason tours of the Florida Cavern are staff-guided, and adheres to a strict maximum number of participants. The federal government directs, through the 1993 Federal Cave Resources Protection Act, that managing agencies inventory and close (if necessary) significant caves for resource protection reasons, as well as withholding location information for caves with particularly vulnerable or important characteristics (Anon. 1993).

During the late 1970s and 1980s, park-sanctioned recreational wild caving was conducted at Florida Caverns. Due to a number of difficulties associated with resource protection, staff radon exposure, visitor safety and administrative issues, this activity was discontinued in 1992. Currently, access to wild caves is regulated under District 1 Administration Scientific Research and Collecting Permit procedures. This mechanism has proven satisfactory in protecting the resource and allowing access for valid cave research and exploration projects.

References

- Anon. 1993. Federal Register. Department of the Interior, Office of the Secretary 43 CFR Part 37 Cave Management; Final Rule 58:189 (51550-51555).
- Fairbanks, C.H. 1941. Report of collections from Florida Caverns State Park. Unpublished manuscript.

ECOLOGY OF THE FLORIDA CAVERNS

(Edited from the Florida Caverns State Park Unit Management Plan)

The park's unusual geology supports an exceptional diversity in above-ground and underground biota, with extremely rare habitat types and many species occurring at their extreme southern range limits. In fact, the park supports over 40 plant and animals species listed as Florida Threatened and Endangered and/or tracked by the Florida Natural Areas Inventory. The caves are also home to unique species such as blind salamanders, cave crayfish, and the federally endangered gray bat. Some rare species in the park occur nowhere else in Florida. Some unique aspects of the park ecology are discussed below.

Two natural communities that are unique to this park are the aquatic cave community and the terrestrial cave community.

Aquatic cave: The most important example of an aquatic cave on the park is Salamander Pond Cave, located on the extreme southern edge of the park. Several other park caves, notably China, Ellis, and Boyer's have relatively permanent pools or "blue holes" in them. However, only Salamander Pond could be accurately called an Aquatic Cave. It provides important habitat for two cave-endemic organisms, the Dougherty plain cave crayfish (*Cambarus cryptodytes*) and the Georgia blind salamander (*Haideotriton wallacei*) (see Franz et al. 1994). Aquatic caves at Florida Caverns State Park, together with Florida Fish and Wildlife Conservation Commission's (FFWCC's) Judge's Cave (also Jackson County) represent the only protected localities in Florida for the blind cave salamander.

The underground lake inside Salamander Pond Cave is approximately 183 feet in length and averages about 13 feet wide. Its mean depth in July of 1996 was 8.5 feet (see Hydrology). The cave has three dry entrances; the lowest and southernmost is located just 37 feet from the park's south boundary – making it highly vulnerable to adjacent off-site contamination and development.

Terrestrial cave: Florida Caverns State Park contains over 30 named caves (Ludlow 1997). Of those, 24 are significant enough to have been mapped by caving groups. They vary greatly in condition; some being severely damaged and others remaining in a near-pristine state. Regrettably, Miller's Cave serves as an example of a severely vandalized cave. It contains over 2000 broken formations, which resulted from 30 years of unrestricted public access. A number of the most significant caves have been gated or fenced to protect geological formations or rare cave biota. Overall the terrestrial cave resource of the park is diverse, well protected by existing statutes and management practices, and represents a unique asset to the Florida State Park system. The Florida Cavern remains an outstanding example of a lighted tour cave, comparable to other major cave attractions throughout the country.

Designated Species

Designated species are those that are listed by the Florida Natural Areas Inventory (FNAI), U.S. Fish and Wildlife Service (USFWS), Florida Fish and Wildlife Conservation Commission (FFWCC), and the Florida Department of Agriculture and Consumer Services (FDACS) as endangered, threatened or of special concern.

Thirty-three species of designated plant species are known to occur at Florida Caverns State Park. Some of these species are known from several localities in Florida. However, there are several rare plants that are virtually unique to Florida Caverns. The Florida Natural Areas Inventory has identified 11 S1 plant species from the park, which are critically imperiled in the state, and are known from five or fewer locations. Several of these plants are fairly common in the Upland Hardwood Forest community of the park and will benefit simply by the perpetuation of this natural community.

Fourteen species of designated animals are known from the unit. Both the Dougherty plain cave crayfish (*Cambarus cryptodytes*) and the Georgia blind cave salamander (*Haideotriton wallacei*) are highly dependent on maintaining the Aquatic Cave natural community in good condition. These organisms are vulnerable to off-site disturbance and contaminants that could reach Salamander Pond Cave from adjacent private property. The USFWS has recently completed a survey and listing of several now-endangered freshwater mussel species. At least two and perhaps four of these rare bivalves occur in the section of the Chipola within the park. The Barbour's map turtle (*Graptemys barbouri*) and Suwannee cooter (*Pseudemys cocinna suwanniensis*) are known occur in the park. They will benefit from prohibiting removal of submerged logs (dead heading) from the river, and control of feral hogs that may raid their nests. The beautifully marked fox squirrel (*Sciurus niger*) is a common sight on the Florida Caverns golf course. Jackson County is located within the transition zone between the ranges of the Sherman's fox squirrel (*S. n. shermani*) and its western relatives (*S. n. niger*) (Humphrey, Ed 1992). The Sherman's fox squirrel is a Species of Special Concern under FFWCC endangered species designation (Anon. 1997). It is unclear to which race of the fox squirrel the Caverns population belongs (J. Gore pers comm).

Four species of colonial, cave-roosting bats have been recorded from the park. The long-eared bat (*Myotis keeni septentrionalis*) and Indiana bat (*Myotis sodalis*) were both collected from Old Indian Cave in the 1950s (Rice 1955b, Jennings and Layne 1957). These bats were at the extreme southern limit of their ranges, and have not been observed in recent years. The southeastern bat or Mississippi myotis (*Myotis austroriparius*) is the most common colonial cave roosting-species in Florida. Typical winter counts of *austroriparius* in Old Indian Cave are 3,000 individuals, whereas as many as 13,000 have been recorded emerging from this cave in the fall. Conversely, one of the most imperiled mammals in the state is the gray bat (*Myotis grisescens*). It is known to hibernate in only two caves in the Florida: Old Indian Cave and Dugong Cave (Ludlow and Gore 2000). The latter is located about 180 feet to the south of the park boundary on private property. The current population of resident gray bats is estimated to be 150-200 individuals (Gore, unpublished data). During the summer, a number of additional gray bats migrate into the Jackson County region and bear young at FFWCC's Judge's Cave, located two miles southeast of Old Indian Cave. Protection and monitoring of bat populations is an important resource management issue at Florida Caverns.

References

- Anon. 1997. Florida's Endangered Species, Threatened Species, And Species of Special Concern, Official Lists. 1 August 1997. Florida Game and Fresh Water Fish Commission.
- Franz, R., J. Bauer and T. Morris. 1994. Review of biologically significant caves and their faunas in Florida and South Georgia. *Brimleyana* 20:1-109.
- Humphrey, S.R. (Ed.) 1992. Rare and Endangered Biota of Florida. Volume 1 Mammals. University of Florida Press, Gainesville.
- Jackson County. 2001. Jackson County Comprehensive Plan 2001. Jackson County, Florida.
- Jennings, W.L. and J.N. Lane. 1957. *Myotis sodalis* in Florida. *J. Mammalogy* 38:259.
- Lee, D.S. and M.D. Turtle. 1970. Old Indian Cave: Florida's first bat sanctuary. *Fla. Nat.* 44:150-152.
- Ludlow, M.E. 1997. Florida Caverns State Park Cave Management Plan. Department of Environmental Protection, Division of Recreation and Parks. 71 pp.
- Ludlow, M.E. and J.A. Gore. 2000. Effects of a cave gate on emergence patterns of colonial bats. *Wildlife Society Bulletin* 28:(1) 192-196.
- Rice, D.W. 1955b. *Myotis keeni* in Florida. *J. Mammalogy* 36:567.

OVERVIEW OF THE GEOLOGY OF THE MARIANNA LOWLANDS PROVINCE

Introduction

(Edited from the Florida Caverns State Park Unit Management Plan,
FDEP, Division of Recreation and Parks, June 9, 2006)

The panhandle region of Florida can be subdivided into four provinces: the Western Highlands, the Marianna Lowlands, the Coastal Lowlands and the Tallahassee Hills (Randazzo and Jones 1997). Florida Caverns State Park is situated in the Marianna Lowlands province. It is an area characterized by gently rolling hills, interspersed with sinks, springs, limestone bluffs and rocky streams. The Marianna Lowlands are considered to be an erosional feature of first the Chattahoochee River, and later the Flint and Apalachicola Rivers. These systems have since migrated out of the area, leaving behind the Chipola River, a western tributary of the much larger Apalachicola. Natural erosion and dissolution of the soft limestone in the Marianna Lowlands has created an irregular, pot-holed landscape, termed karst. Some of the most striking examples of karst topography in Florida are found in Jackson County and particularly at Florida Caverns State Park.

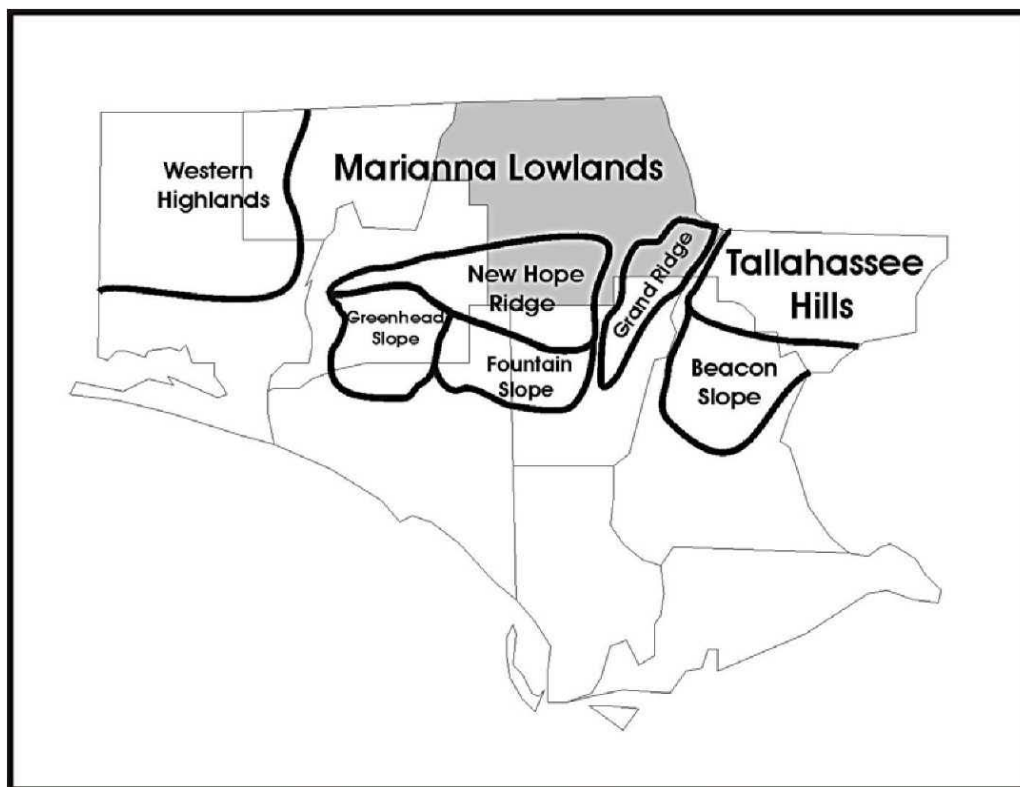


Figure 1. The Marianna Lowlands Province Redrawn from Scott (1992). Jackson County is highlighted in gray and contains the field trip stops described within this guidebook. (Source: SEGS Guidebook #43)

The Marianna Lowlands of Florida Caverns can be subdivided into Remnant Highlands, Calcareous Slopes and Bluffs, and Chipola River Floodplain components. These units are closely correlated with the distribution of the underlying limestone formations. The remnant hills occur where un-eroded Miocene clays and Plio-Pleistocene

sands remain over the limestone. In the western portions of the park, these hills slope gently down to the floodplain, but on the east side of the Chipola and on the park's southern boundary, erosion has left outcrops exposed, creating slopes and bluffs. About 38 million years before present, when Ocala Limestone was being deposited as coral and shell, the sea was probably less than 600 feet deep. The Ocala Limestone contains abundant large foraminifera, mollusks, bryozoans and corals and other marine fossils. It was probably deposited on a warm continental shelf or in a carbonate bank-lagoonal setting. Fluctuating sea levels periodically flooded the park throughout much of the Miocene, depositing deltaic and marine clays and carbonates of the Chattahoochee Formation and Alum Bluff Group of the Marianna and Suwannee Limestones. Subsequent erosion of these clays began in the late Miocene and continued through the Pliocene and Pleistocene epochs, erasing much of their geologic record.

Concurrent with the erosion of the Marianna Lowlands was the continuous lowering of sea levels during the Plio-Pleistocene. As in the preceding epochs, the lowering occurred in stages and left erosion slopes and sandy terraces, still visible in present topography. In the park, the Okefenokee (Sunderland) terrace occurs above 100 feet, the Wicomico terrace occurs between 70 and 100 feet, and the Penholoway terrace extends up to about 70 feet.

Associated with fluctuating seas levels were fluctuating water tables. When high, the ground water followed fissures and cracks along the bedding planes and joints of the Ocala Limestone, where they were capped by the harder Marianna Limestone. The fissures and cracks were slowly enlarged by the acidic groundwater, forming caverns through which underground rivers flowed. When the seas and water tables dropped, these underground passages drained and the development of typical cave drip formations began. Thus, the dry caves at the park, although occurring in Eocene limestones, have developed much more recently. Caves below the present water table continue to develop today, as ground water acidified by percolating rainfall, dissolves the limestone. This kind of solution activity is greater throughout the Marianna Lowlands because the erosion has exposed the bedrock limestones to the elements.

The present-day Chipola River is now actively eroding the Ocala Limestone along its course. Typical karst features such as springs, depressions and sinks are evident within the floodplain. A prominent feature in the park is the River Sink and Natural Bridge, a one-half mile section of the Chipola south of the park drive that originally flowed underground. The various dry caves on the park, including the tour cave, occur adjacent to the Chipola floodplain in Ocala Limestone, where their elevation is (usually) above the water level.

Stratigraphy - Brooks Quarry Exposure

(Edited from SEGS Guidebook #43)

The Marianna Lowlands is located on the Gulf Coastal Plain and provides a unique setting in which to examine surficial exposures of strata that compose the Floridan aquifer (Figure 1). The study of this karstic plain reveals a complex geological story, one that is only beginning to be understood.

Walter Schmidt (1988) provided an excellent summary on the geology of the Florida Caverns. Schmidt noted the importance of tectonism and sea-level change to cavern formation (1988), a critical concept which has recently been reinforced by workers seeking to explain cave formation in other areas in Florida (Brinkmann and Reeder, 1994). Florida Geological Survey geologist, Frank Rupert (no date) has published an interesting and up-to-date overview of the caverns in a pamphlet available at the park visitors center.

Generalized Stratigraphy and Hydrogeology of the Panhandle of Florida

SYSTEM	SERIES	Lithostrat Units	Hydrostrat Units
Quaternary	Holocene	Undifferentiated Pleistocene-Holocene Sediments	Surficial Aquifer System
	Pleistocene		
Tertiary	Pliocene	Citronelle Formation Miccosukee Formation Coarse elastics	Intermediate Confining Unit
	Miocene	Alum Bluff Group Pensacola Clay Intracoastal Formation Torreya Formation Bruce Creek Limestone St. Marks Formation Chattahoochee Formation	
	Oligocene	Chickasawhay Um&stone Suwannee Limestone Marianna Limestone Bumpnose Limestone	Floridan Aquifer System
	Eocene	Bumpnose Member Ocala Limestone Claiborne Group Undifferentiated Sediments	
	Paleocene	Undifferentiated Sediments	
	Cretaceous and older	Undifferentiated Sediments	Sub-Floridan

Figure 1. Stratigraphy-Hydrostratigraphy of the Panhandle of Florida (Modified from Scott, 1992; Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986)

Only in the last few years have geologists begun a more detailed reexamination of this particular area of the state, one that is redefining our understanding of the limestone and overlying clastic units and their former depositional setting (Bryan, 1991; Green, et al., 2002). The ongoing nature of this work should result in a better understanding of the interrelationship between the stratigraphy of the area and the protection of valuable natural resources like the Floridan aquifer.

One of the best exposures in which to examine the stratigraphy of the area can be found in Brooks Quarry. This locale exposes several limestone layers ranging from the Ocala Limestone (Eocene) to the Marianna Limestone (Oligocene). Dr. Jonathan Bryan, a geology professor at Okaloosa-Walton Community College, has spent considerable time in the quarry studying the various exposed carbonate units and he (personal communication, 2003) defines the stratigraphy in the following manner:

<u>Formation</u>	<u>Thickness(m)</u>	<u>Description</u>
Residuum	Variable	Highly oxidized silty clay with numerous limonitic nodules.
Marianna Limestone	2.6	Grayish-yellow (5Y 8/4) dolosilt. Top 20 cm is partially-indurated, crumbly, and bioturbated marl. Limonitized <i>Ledocyclina</i> , pectinid bivalves, and turritellid gastropods are common. Other fossils include a small <i>Schizaster</i> echinoid, carbonized impressions of seagrasses, dugong ribs, and other marine vertebrate bones.
	5.0	Variably indurated, white, fine-grained limestone (mudstone to wackestone). Top partly silicified (chert).
	0.5-1.0	Irregular, nodular chert. Same lithology as underlying bed, but variably silicified (which may represent lithification at a bedding contact). Bryozoa <i>Lunulites</i> and some aragonitic molluscs <i>Xenophora</i> present

Marianna Limestone (Con't)	4.0	Soft, white, wackestone, with minor bioclastic debris. In the northern most exposure in the quarry complex (and about 2 m above the Bumpnose) is a cross-bedded sequence consisting of laminated, fossiliferous sand (packstone/grainstone) and micrite (mudstone) in what appears to be channel deposits or tempestites, with several truncated cross-bedded sets. Marianna bioclastic laminae are composed of <i>Lepidocyclina</i> tests and bryozoa, limestone and are speckled with iron-oxide that appear to be altered glauconite grains. Micritic beds 13 to 16 cm in thickness are also common, and micritic rip-up clasts are found in some of the bioclastic debris. The maximum apparent dip of the cross-bedded strata is 15 degrees to the north. A shark tooth and fish vertebra have been found in the cross-bedded debris, perhaps indicating some lag concentration from water-current activity. A discontinuous, nodular dark brown chert is found at one location 2-3 meters above the Bumpnose.
	0.3	Irregular, nodular, burrowed, cherty limestone.
	0.96	White mudstone/wackestone. Some <i>Lepidocyclina</i> present. Bumpnose-Marianna contact is sharp and very similar to the Ocala-Bumpnose contact. The upper Bumpnose is a well-indurated ledge, above which is a nodular zone (31 to 61 cm thick), overlain by the typical mudstones and wackstones of the Marianna.
Bumpnose Limestone	3.5	Well-indurated, white, fossiliferous limestone (grainstone to packstone). Nearly a coquina of <i>Lepidocyclina</i> , some of which are several centimeters in diameter. Common bivalves <i>Amusium ocalanum</i> , <i>Chlamys anatipes</i> , <i>Spondylus dumosus</i> , gastropod <i>Xenophora</i> , nautiloid <i>Aturia alabamensis</i> (at very top of Bumpnose), echinoid <i>Clypeaster rogersi</i> , trace fossils, and shark teeth. Top is a very well-indurated, bioturbated, glauconitic, nodular ledge. Ocala-Bumpnose contact is sharp, and occurs at the top of a well-indurated ledge (0.5 m thick), above which is a nodular zone (up to 0.5 m thick), which is overlain by the typical <i>Lepidocyclina</i> -rich packstone lithology of the Bumpnose.
Ocala Limestone	4.25	Densely fossiliferous, white- to pale-yellow limestone, poorly indurated grainstone. Essentially a coquina of smaller and larger foraminifera, bryozoa, echinoid spines, and brachiopods, all in a matrix of finer-grained, comminuted bioclastic debris. Larger foraminifera include <i>Asterocyclina</i> , <i>Lepidocyclina</i> , <i>Pseudophragmina</i> , and <i>Nummulites</i> . Bivalve <i>Amusium ocalanum</i> becomes especially abundant in upper half. Other macrofossils include echinoids, moldic molluscs, and crab carapaces.



Figure2 - Brooks Quarry. The wall exposed in this image displays most of the limestone section described by Bryan in this guidebook

According to Bryan (2003), the limestones exposed in this quarry represent a paleogeographical midpoint between the classic Gulf Coastal Plain sections in Alabama and Mississippi (which are geochronologically well-constrained) and the carbonate sequences of the Florida Platform. The strata were deposited on the northern flank of the Gulf Trough and therefore represent a unique and transitional facies between the coastal plain and the Florida platform (see Figure 2, page 4). The Gulf Trough for a time separated the clastic sequences common to the Gulf Coastal Plain from the carbonates found out on the peninsula. Work by Chen (1965), Bryan (1991), and Huddleston (1993) have documented the facies differences between chronostratigraphically equivalent units on both sides of the trough. Their work is integral to defining the geologic history of the area.

The fossiliferous limestone layers exposed in Brooks Quarry likely reflect a stacked series of shallow marine carbonate shelf paleoenvironments with the intervening chert layers likely condensed sections and/or periods of minor terrigenous sedimentation. A similar setting can be found today in Florida Bay and the Bahamas where occasional African dust storms contribute silica to the shallow water carbonate environments (c.f. Tihansky, Prager, and Shinn, 1997; Shinn, Halley, and Hine, 2000).

The small caverns exposed within Brooks Quarry and the caverns that are found within Florida Caverns State Park are believed to be formed within the Jacksonian age Ocala Limestone (Upper Eocene) and capped by the Vicksburgian age (Lower Oligocene) Bumpnose and Marianna limestones (Beck and Arden, 1983; Brooks, 2003; Bryan, 2003; Randazzo and Jones, 1997; Rupert, no date; Schmidt, 1988). According to Randazzo (1997, p. 51), dissolution of the carbonate rocks:

... has produced significant changes in rock fabric, accompanied by development of many different types of pore spaces. Moldic, vug, and interparticle pore types are most common. Extensive dissolution can create caves and caverns, the underlying cause of sinkholes and karst landscapes.

Generalized descriptions of the various stratigraphic units found within the Marianna Lowlands province are not presented here, instead the reader is advised to review this information in Scott (1992). However, one interesting historic note on the Marianna Limestone. According to Murray (1961, p. 397), the Marianna Limestone:

... is widely known in this region, as well as in the formal geologic literature, as "chimney rock." The name is derived from the extensive use, earlier during the settlement of this region, of the limestone as a building material, especially for foundation blocks and chimneys.

The Florida Caverns State Park Visitor Center is covered in limestone blocks which in some instances exhibits various micro- and macroscopic fossilized life forms. The building walls make for an interesting and easily accessible "outcrop" while waiting for the next cave tour. Remember that there is NO collecting in the Park.

Hydrogeology

The Floridan aquifer is generally divided into upper and lower aquifers, separated by less-permeable beds of highly variable hydrogeologic properties [Figure 1] (Miller, 1986). According to Johnston and Bush (1988), regionally the Upper Floridan aquifer:

... forms one of the world's great sources of ground water. This highly permeable unit consists principally of three carbonate units: the Suwannee Limestone (Oligocene), the Ocala Limestone (upper Eocene), and the upper part of the Avon Park Formation (middle Eocene).

The lower Floridan aquifer is less known stratigraphically and hydraulically and has not been investigated as the Upper Floridan provides sufficient yield to meet the current withdrawal demands (Johnston and Bush, 1988). The Marianna Lowlands contains areas of hydraulic transmissivity ranging from 10,000 to 250,000 square feet per day (Johnston and Bush, 1988). This represents tremendous groundwater yield and also reflects the speed and extent in which contamination can travel within this hydraulic unit.

Tectonics

The Chattahoochee Anticline formed during the middle to late Eocene and affected deposition across this elevated feature during its development (Galloway and others, 1991). The area of uplift was first noted by Veatch and Stephenson (1911) along the Chattahoochee River. The feature is most prominent in Jackson County (Applin and Applin, 1944; Schmidt and Coe, 1978), and extends into southwestern Georgia contributing to the formation of the Dougherty Karst Plain.

Most of what little clastic deposition that occurred across the anticline has been eroded away leaving carbonate rocks exposed at the surface across most of the county. The uplift also aided in the development of the now-exposed Florida Caverns. Scalloped marks along the surfaces of the cave walls testify to prehistoric fluid flow through the formerly submerged passages. Only when subaerial conditions eventually resulted did speleothem formation and development occur.

Paleontology

The area around Marianna offers many interesting fossilized life forms as exemplified by the list provided in the stratigraphic description of Brooks Quarry (Bryan, 2003). The alternate stop of this field trip also offers a Marianna Limestone exposure with some invertebrate fossils. Pleistocene vertebrate fossils occur in the upper reaches of the Chipola River south of Marianna (Rupert, 1994). Another excellent resource for locating and identifying various fossils within the area is found in Rupert (1989). In years past, I have collected a few small Pleistocene vertebrate fossils (mostly pieces) from just south of the dam at Merritt's Mill Pond.

References

- Applin, P. L., and E. R. 1944. Regional subsurface stratigraphy and structure of Florida and southern Georgia. *American Association of Petroleum Geologists Bulletin* 28:1673-1753.
- Beck, B. F., and D. D. Arden. 1983. *Hydrology and geomorphology of the Dougherty Plain, southwest Georgia*. Southeastern Section of the Geological Society of America. Field Trip Guidebook. Georgia Southwest College. Americus, GA.
- Brinkmann, R., and Reeder, P. 1994. The influence of sea-level change and geologic structure on cave development in west-central Florida. *Physical Geography* 15:52-61.
- Brooks, L. 2003. Personal communication. Marianna, FL.
- Bryan, J. 1991. *Stratigraphic and paleontologic studies of Paleocene and Oligocene carbonate facies of the eastern Gulf Coastal Plain*. Unpublished Ph.D. dissertation. University of Tennessee, Knoxville, TN.
- _____. 2003. Personal communication. Okaloosa-Walton Community College. Niceville, FL.
- Chen, C. S. 1965. *The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida*. Florida Geological Survey Bulletin 45. Tallahassee, FL.
- Galloway, W. E., D. G. Bebout, W. L. Fisher, J. B. Dunlap, Jr., R. Cabrera-Castro, J. E. Lugo-Rivera, and T. M. Scott. 1991. Cenozoic. In Salvador, A. (Editor). *The Gulf of Mexico Basin*. The Geology of North America, Volume J. Geological Society of America. Boulder, CO. pp. 245-324.
- Green, R. C., W. L. Evans III, J. R. Bryan, D. T. Paul, and M. M. Gaboardi. 2002. *Surficial and bedrock geology of the western portion of the U.S.G.S. 1:100,000 scale Marianna quadrangle, northwestern Florida*. Florida Geological Survey Open File Map Series No. 91. Tallahassee, FL.
- Huddleston, P. F. 1993. *A revision of the lithostratigraphic units of the Coastal Plain of Georgia*. Georgia Geologic Survey Bulletin 105. Atlanta, GA.

- Johnston, R. H., and P. W. Bush. 1988. *Summary of the hydrology of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama*. U.S. Geological Survey Professional Paper No. 1403-A. Washington, D.C.
- Miller, J. A. 1986. *Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina*. U.S. Geological Survey Professional Paper 1403-B. Washington, D.C.
- Moore, W. E. 1955. *Geology of Jackson County, Florida*. Florida Geological Survey Bulletin 37. Tallahassee, FL.
- Murray, G. E. 1961. *Geology of the Atlantic and Gulf Coastal province of North America*. Harper and Brothers Publishers. New York, NY.
- Randazzo, A. F. 1997. The sedimentary platform of Florida: Mesozoic to Cenozoic. In Randazzo, A. F., and D. S. Jones (Editors). *The geology of Florida*. University Press of Florida. Tallahassee, FL. pp. 39-56.
- Reves, W. D. 1961. *The limestone resources of Washington, Holmes and Jackson Counties, Florida*. Florida Geological Survey Bulletin 42. Tallahassee, FL.
- Rupert, F. R. No date. *The geology of Florida Caverns State Park, A State Geological Site*. Florida Geological Survey. Tallahassee, FL.
- _____. 1989. *A guide map to geologic and paleontologic sites in Florida*. Florida Geological Survey Map Series No. 125. Tallahassee, FL.
- _____. 1994. *A fossil hunter's guide to the geology of panhandle Florida*. Florida Geological Survey Open File Report No. 63. Tallahassee, FL.
- Schmidt, W. 1988. *Florida Caverns State Park, Jackson County, Florida*. Florida Geological Survey Open File Report No. 23. Tallahassee, FL.
- Schmidt, W., and C. Coe. 1978. *Regional structure and stratigraphy of the limestone outcrop belt in the Florida panhandle*. Florida Bureau of Geology Report of Investigation No. 86. Tallahassee, FL.
- Scott, T. M. 1992. *A geological overview of Florida*. Florida Geological Survey Open File Report No. 50. Tallahassee, FL.
- Shinn, E. A., R. B. Halley, and A. C. Hine. 2000. *SEPM field guide to the Florida Reef Tract, Key Largo Area*. SEPM Field Trip Guidebook. SEPM Tulsa, OK.
- Southeastern Geological Society (SEGS) Ad Hoc Committee on Florida hydrostratigraphic unit definition. 1986. *Hydrogeological units of Florida*. Florida Geological Survey Special Publication 28. Tallahassee, FL.
- Tihansky, A., E. Prager, and E. A. Shinn. 1997. *Geological environments of Florida Bay and the Florida Keys Reef Tract*. SEGS Field Trip Guidebook 37. SEGS, Tallahassee, FL.
- Veatch, O., and L. W. Stephenson. 1911. *Preliminary report on the geology of the coastal plain of Georgia*. Georgia Geologic Survey Bulletin 26. Atlanta, GA.

CONCEPTUAL MODELS FOR KARSTIC AQUIFERS

(Modified from William B. White, Conceptual models for karstic aquifers; Speleogenesis and Evolution of Karst Aquifers, The Virtual Scientific Journal, Re-published by permission from: Palmer, A.N., Palmer, M.V., and Sasowsky, I.D. (eds.), Karst Modeling: Special Publication 5, The Karst Waters Institute, Charles Town, West Virginia (USA), 11-16)

Karstic carbonate aquifers are extremely heterogeneous with a distribution of permeability that spans many orders of magnitude. They often contain open conduit flow paths with hydraulic characteristics more like surface streams than ground water. Karstic carbonate aquifers have highly efficient interfaces with surface water through swallets and springs. Characterizing parameters include: area of ground-water basin, area of allogenic recharge basins, conduit carrying capacity, matrix hydraulic conductivity, fracture hydraulic conductivity, conduit system response time, and conduit/fracture coupling coefficients. The geologic setting provides boundary conditions that allow the generalized conceptual model to be applied to specific aquifers.

Plumbing

The essential components of the karst aquifer flow system are sketched in Fig. 1. Not all of these components are present in all aquifers, and their presence and relative importance are an important part of distinguishing one aquifer from another.

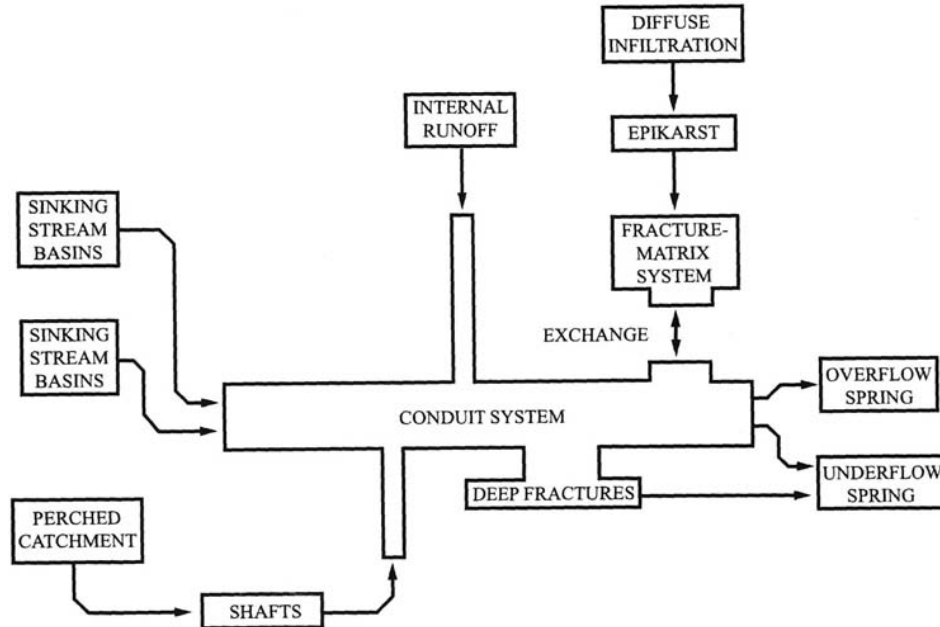


Fig. 1. Conceptual model for a carbonate aquifer

Recharge

At least four sources of recharge for karst aquifers can be recognized:

1. Allogenic recharge: Surface water injected into the aquifer at the swallets of sinking streams.
2. Internal runoff: Overland storm flow into closed depressions where it enters the aquifer through sinkhole drains.
3. Diffuse infiltration: Precipitation onto the land surface, where it infiltrates through the soil and may be held for days or weeks in the epikarst before it migrates downward through the rock matrix or along fractures to reach the water table.
4. Recharge from perched catchments: Many geologic environments support locally perched groundwater systems above carbonate aquifers. This water reaches the main aquifer by means of vadose shafts and open fracture systems along the margins of the perched aquifers.

Permeability

The "karstification" of an aquifer is in large part measured by its permeability distribution. For many years, this has been discussed in terms of the "triple permeability" model. Karst aquifer permeability consists of

1. The matrix (or granular) permeability of the bedrock itself.
2. Fracture permeability
3. Conduit permeability

The flow fields through each of these permeability types operate on different scales (Teutsch and Sauter, 1991). The hydraulic conductivity of the rock matrix can be measured on test blocks at the laboratory scale. The hydraulic conductivity produced by the fracture permeability must be averaged over a large volume of rock at a scale of hundreds of meters. Values calculated from pump and packer tests on appropriately sited wells can probe the aquifer at the fracture scale. The conduit system operates on the scale of the entire groundwater basin - a scale of kilometers to tens of kilometers. Travel times in the conduit system can be very short.

Although both the matrix and conduits have units of velocity, it is not appropriate to speak of a hydraulic conductivity of the conduit system because conduit flows are often turbulent. Two measurements can provide a surrogate for hydraulic conductivity. One is travel time determined by quantitative tracer breakthrough curves from swallets to spring. The other is response time(s) computed from the recession limbs of storm hydrographs measured at the springs. Travel time and response time are not equivalent measurements, but each will tell something of the rate of movement of water through the conduit system and thus indirectly how well the conduit system is developed..

Young limestones such as those of Florida and the Caribbean islands may have very high matrix permeabilities. There is indeed a continuum, and actual measurements are needed to determine the importance of matrix permeability. Fracture permeability requires two parameters, the fracture aperture and the fracture spacing. Both are statistical and have a range of values within the same aquifer. Fracture permeability is modified by solution so that fracture apertures range from tens or hundreds of micrometers in unmodified limestone up to 10 millimeters.

Conduits can range in size from 10 mm to tens (sometimes hundreds) of meters. Hydrologically, they behave much like storm drains. In map view, conduits take on many different patterns depending on local geology and various characteristics of the flow field itself. To understand the dynamics of a karst aquifer, then, it is necessary to understand the rate of recharge into the various components of the permeability and the exchange of water between these components.

Discharge

A distinguishing feature of karst aquifers is that most of the groundwater is discharged through a small number of large springs. In some aquifers, the entire discharge is through a single spring. In other aquifers there is a distributary system to a small number of springs. One or a few of these carry the base-flow discharge and are called "underflow springs" while other springs flow only during periods of high discharge and are called "overflow springs" (Worthington, 1991).

The discharge from karst springs is a composite of all water moving through the aquifer. The spring (or springs) therefore is an optimum location for measuring hydrographs, chemographs, and also for monitoring the aquifer for contaminants.

Groundwater basins

In contrast to granular aquifers, where the lateral extent of an aquifer is often only loosely defined, hydrogeologists borrow a concept from surface water when dealing with karst aquifers - that of the "ground-water basin." Much like surface-water basins, but without the definitive boundary provided by topographic highs, groundwater basins can be delineated, although basin boundaries may shift with water levels and piracy and flood-overflow routes across basin divides are common. Within the confines of a karst groundwater basin, all recharge water makes its way to a single spring or related group of springs. The spring outlets define the downstream end of the basin. The head difference between recharge area and springs is the primary driving force for the movement of water through the aquifer.

What no quantitative measurement will provide, however, is the geometry of the conduit system itself. Direct exploration and survey of active conduits, including water-filled portions mapped by divers, gives very precise information, albeit in descriptive form. In very few karst aquifers, however, is a sufficient sampling of the conduit system possible.

REFERENCES CITED

- Teutsch, G., and Sauter, M. 1991. Groundwater modeling in karst terranes: Scale effects, data acquisition and field validation. Proc. Third Conf. Hydrogeology, Ecology, Monitoring, and Management of Ground Water in Karst Terranes, Nashville, TN, 17-35.
- Worthington, S. R. H. 1991. Karst hydrogeology of the Canadian Rocky Mountains. Ph.D. thesis, McMaster University, Hamilton, Ontario. 227 p.

CONCEPTUAL MODELS FOR THE GENESIS AND GROWTH OF CAVE SYSTEMS IN KARSTIC AQUIFERS

(Modified from Todd R. Kincaid , Storage-Dominated vs. Flow-Dominated Caves: A Hydraulic Model for Cave Development ; GeoHydros, LLC; Global Underwater Explorers)

Background

Hydraulic models for cave development focus on three separate but related mechanisms, hydraulic gradient, convergence of flow, and dissolution kinetics. Hydraulic gradient has been described as the controlling variable because it drives ground water circulation that, in turn localizes dissolution of the host rock (Figure 1). Ewers (1982) showed experimentally that conduit development proceeds most rapidly along the hydraulic gradient wherein multiple conduits emanating from independent inputs converge in the down-gradient direction. Subsequently, Huntoon (1985) showed through a deductive model that cave development will be favored in regions of a karst aquifer that have the steepest hydraulic gradient because the steep gradients concentrate flow and thus dissolution. In support of that conclusion, Palmer (1991) showed that conduit development will proceed along routes of greatest hydraulic efficiency (least expenditure of head per unit discharge). The net effect of the hydraulic gradient is to concentrate regional ground water flow toward discrete down-gradient springs thus creating convergence of flow (Figure 1).

Convergence of flow was proposed early on by Mandel (1967) as the driving mechanism for cave development at springs. He concluded that numerous dissolution channels should develop in the up-gradient direction from springs that capture flow from progressively larger parts of an aquifer. Competition between flow paths would eventually promote the development of one large spring that captures all of the flow through a regional flow system thus localizing the largest caves. Though Mandel's model capitalized on sound hydrologic principles, it received little support in the karst community largely because contemporary theories of dissolution kinetics focused on inputs to the flow system and were ill equipped to explain the concentration of dissolution at the output end. Convergence of flow has remained the most plausible explanation for the development of branchwork caves (Ewers, 1982; Palmer, 1991) and the expansion of conduits at the up-gradient side of a flow system (Groves and Howard, 1994b; Hanna and Rajaram, 1998).

The process causing convergence of flow is best described as a self-initiated positive feedback loop wherein dissolution in any part of a flow system increases permeability thereby increasing flow to the region and consequently fostering further dissolution.

The concept of self-initiated feedback loops in natural systems was developing at nearly the same time in geochemistry. Ortoleva and others (1987a) described the process as "geochemical self-organization" wherein they showed that positive and negative reaction-transport feedbacks in non-equilibrium geochemical systems were responsible for the development of several types of oscillatory patterns observed in nature including scallops, cement bands, pressure dissolution of stylolites, and dissolution holes in karstified limestones. Furthermore, Ortoleva and others (1987b) showed that dissolution of a porous media by fluid flow leads to an unstable growth phenomenon that they termed "reactive infiltration instability." The process accounts for the formation of dissolution fingers that advance ahead of the average dissolution front, which produces convergence of flow into the fingers (Figure 2). Their experimental and modeling work demonstrated that the dissolution fingers develop as a consequence random porosity variations or irregular fracture geometries in the permeability field of the medium.

Two mechanisms for the dissolution of CaCO_3 in natural waters work in concert with convergence of flow to enhance limestone dissolution and thus cave development. Most attention has focused on the "kinetic trigger" (White, 1977) which describes the sharp drop in the rate of CaCO_3 dissolution as chemical saturation is approached (Berner and Morse, 1974; Plummer et al., 1978). The "kinetic trigger" ensures that circulating ground water will remain undersaturated with respect to CaCO_3 which leads to sustained, albeit slow dissolution over long flow paths. This results from the fact that the dissolution reaction rate is divided into low and high order kinetics. Low order kinetics dominate when the solution is far from equilibrium where the dissolution rate is proportional to the 1.7 power of the CaCO_3 saturation deficit. High order kinetics dominate when the solution exceeds 70% saturation where the dissolution rate is proportional to the fourth

power of the CaCO_3 deficit (e.g., Groves and Howard, 1994a; Dreybrodt, 1988). The problem with models stemming from this mechanism is that incipient fractures must connect recharge sources with discharge locations otherwise conduit development times are unrealistically long (Groves and Howard, 1994b).

The second mechanism is mixing corrosion and is considered by this author to be the more important of the two mechanisms for CaCO_3 dissolution. Mixing corrosion describes the enhanced dissolutional capability of a mixture of waters each saturated with respect to CaCO_3 (e.g., Bogli, 1980; Dreybrodt, 1981). When two waters that are saturated with respect to Ca^{2+} mix, renewed dissolutional capacity is achieved because the resulting Ca^{2+} and H_2CO_3 compositions are a linear function of the volumetric ratio of the two initial solutions which renders the mixed solution below the Ca^{2+} solubility curve (Figure 3). Critics of this mechanism point out that the renewed dissolutional capacity is reduced when the mixing waters are not completely saturated or not of significantly different composition, however mixing corrosion is accepted as the best explanation for observed cavity expansion along intersecting flow paths (Ford and Williams, 1989). It should also be recognized that mixing corrosion will be enhanced at the down-gradient end of a flow system both because of the convergence of flow at springs and because the mixing waters are closest to saturation with respect to Ca^{2+} and from the most distant and thus potentially different sources.

Discriminating between flow and storage-dominated caves

Planimetric maps and profiles of saturated cave passages reveal two general passage geometries. Some caves contain large and irregularly shaped passages while others contain distinct conduits with tubular profiles. Caves that contain the irregularly shaped passages are characterized by small ground water through-flow velocities whereas caves that contain tubular conduits are characterized by rapid through-flow.

Caves containing tubular conduits will be termed flow-dominated because they convey ground water to springs at high velocities (sufficient to create turbulent flow). Caves containing irregular shaped passages will be termed storage-dominated because they primarily function as discrete ground water storage reservoirs.

Flow-dominated caves

Flow-dominated caves are comprised of one or more dissolved conduits in the saturated zone of a karst aquifer that concentrate ground water flow in the down-gradient direction and physically connect to a single spring or a small number of discrete springs. The conduits convey ground water to the springs at velocities sufficiently large to cause turbulent flow. Conduits in flow-dominated caves are characterized by tubular and consistent profiles, and fast ground water through-flow velocities that have been persistent over geologic time.

Wakulla is an example of a flow-dominated cave system. Wakulla cave is the one of the most laterally extensive and best-documented underwater conduit networks in the world. A map of Wakulla cave is provided on Figure 4

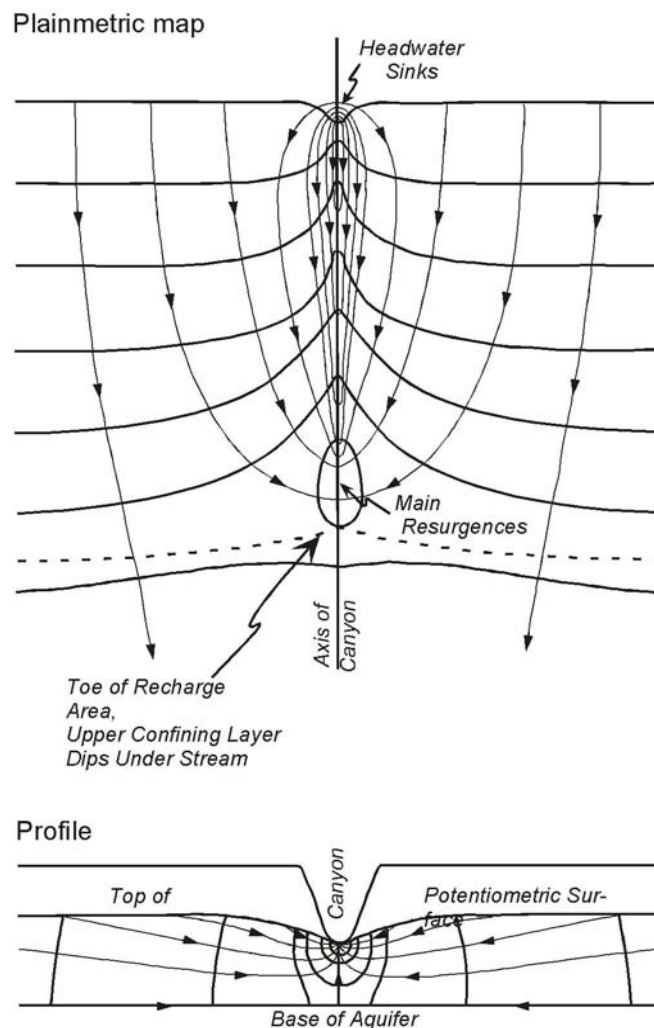
The diagnostic morphologic feature of all flow-dominated caves is tubular conduit profiles with consistent dimensions when considered along the length of an individual conduit. Low and broad profiles are associated with conduit trends that do not correlate with vertical fractures while conduits that have developed along vertical fractures have taller but narrower profiles. In either case, the tubular conduit profile is commonly associated with rapid ground water flow beneath the water table (e.g., Palmer, 1981; 1991).

Storage-dominated caves

Storage-dominated caves are comprised of one or more large and irregular chambers that are connected by smaller conduits or dissolutionally widened fractures and are characterized by slow ground water velocities and diffuse discharge to the surrounding environment (land surface or aquifer matrix).

The Diepolder caves that have developed in the Floridan aquifer near Brooksville are examples of storage-dominated caves. Diepolder is comprised of two large chambers with diameters in excess of 100 m. The chambers are connected to closed water-filled depressions on the land surface by dissolutionally widened vertical fractures that are approximately 1 m wide and 90 m long. The chambers have developed at the base of the dissolutionally widened part of the fractures where they intersect bedding planes in the limestone host rock. Chamber depths reach -110 m and terminate abruptly in all directions. The Diepolder caves do not discharge water to the land surface but rather into fractures in the limestone host rock. Ground water velocities are small as indicated by both temperature and water clarity stratification.

Figure 1. Conceptual model from Huntton (1985) that shows a hydraulic gradient configuration which concentrates ground water flow beneath the floor of a canyon that has incised through a confining layer and intersects the potentiometric surface of an underlying carbonate aquifer. Convergence of flow promotes dissolution which causes permeabilities under the canyon to become increasingly anisotropic. Consequently, caves will develop in the direction of the steepest hydraulic gradient which is along the canyon axis.



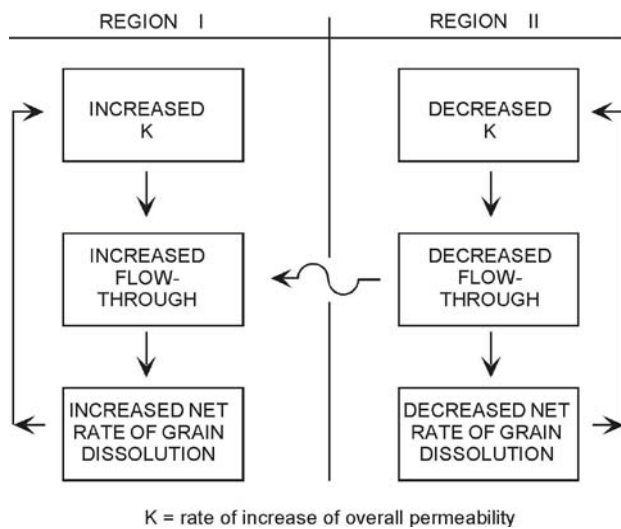


Figure 2. Diagram from Ortoleva and others (1987a) that illustrates how positive and negative feedback loops selectively increase dissolution rates in one region while at the same time decrease dissolution rates in an adjacent region.

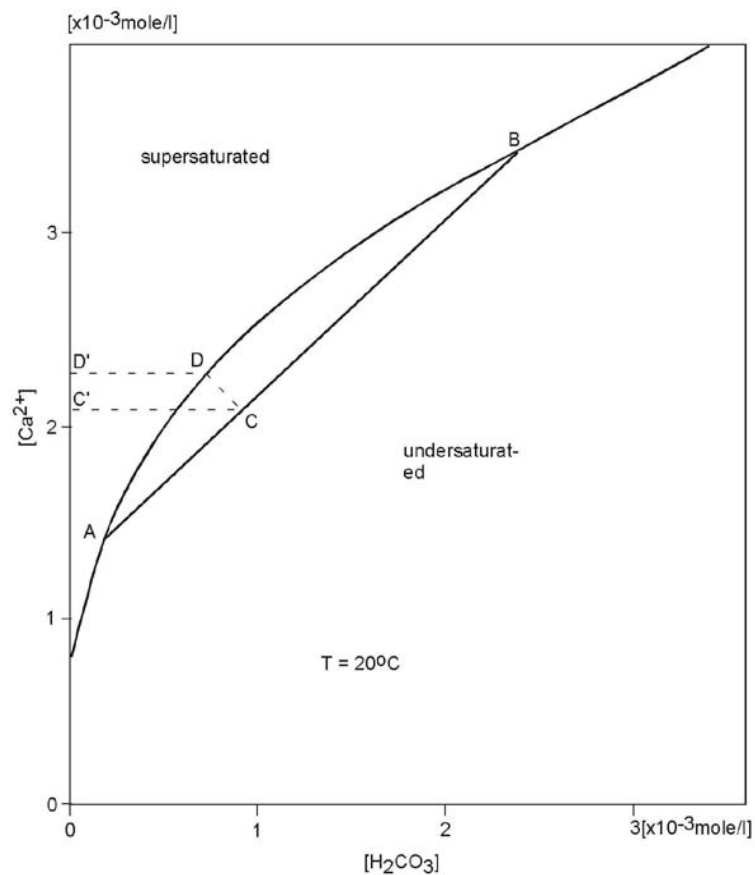


Figure 3. Ca^{2+} equilibrium curve for the $H_2O-CO_2-CaCO_3$ reaction system (from Dreybrodt, 1988). Waters A and B, each saturated with respect to Ca^{2+} mix along line A-B producing water C which is undersaturated with respect to Ca^{2+} . The amount of Ca^{2+} that can be dissolved by water C is defined by the quantity $D'-C'$

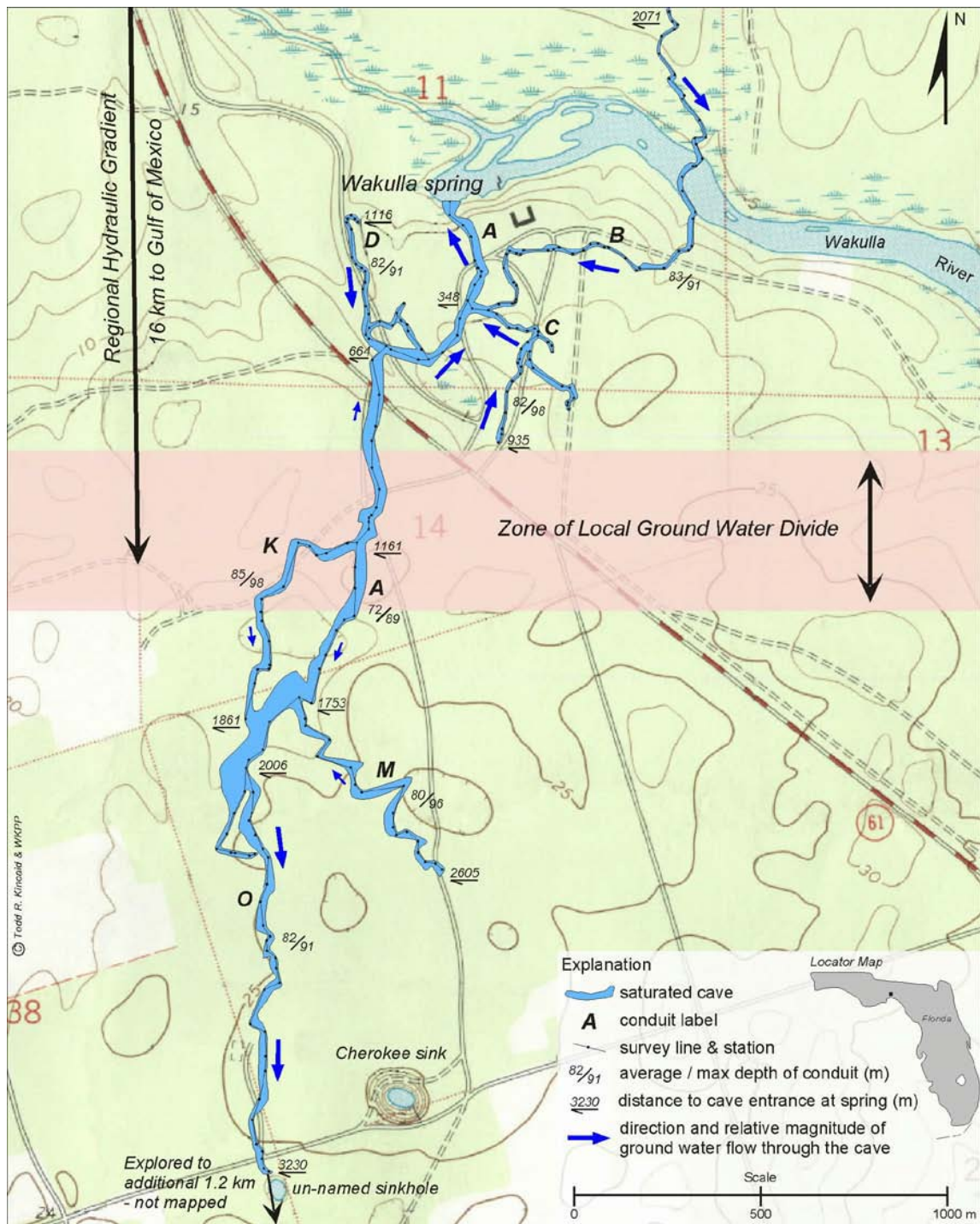


Figure 4. Map of Wakulla cave and surrounding topographic features, Floridan aquifer, north Florida. Topography is from the USGS Crawfordville East, FLA. (1972) topographic quadrangle. Regional hydraulic gradient is south toward the Gulf of Mexico. A local ground water divide crosses the conduits and is marked by a broad zone of low ground water velocities. The southern conduits convey ground water toward the Gulf of Mexico while the northern conduits convey ground water to Wakulla spring.

Storage-dominated caves (i.e. caves with morphologic and ground water through-flow characteristics similar to those described above) have been observed in many other locations and probably include all of the spongework and ramiform caves described by Palmer (1991). The two groups are combined here because their morphologies and plan patterns are similar to the caves described above which indicates that their dominant hydraulic function is that of ground water storage rather than preferential flow paths.

Storage-dominated caves share four diagnostic characteristics. (1) The caves are volumetrically large compared to lateral development and have irregular cavity profiles. (2) The caves are connected to a source of calcite aggressive (undersaturated with respect to Ca^{2+}) water that dissolves the host rock. (3) The caves discharge water into diffuse outlets. (4) Ground water through-flow velocities are slow due to the large size of the cavities and the diffuse character of the regional ground water flow regime.

Hydraulic Model of Cave Development

Flow and storage-dominated caves are two end-members along a continuum of saturated cave development (Figure 5) that occurs during the karstification of a carbonate aquifer (Kincaid, 1999). The conceptual model described below will show that cave evolution progresses through four stages. The key hydraulic variable that determines cave morphologies at each stage of development is ground water velocity.

Initiation stage

The development of saturated caves is self-initiated (not dependent on processes external to the flow system). The process is caused by positive feedback loops between flow and dissolution that are created by small and random variation in the initial distribution of permeabilities. Dissolution into zones of larger permeability enhances dissolution that, in turn, enhances the convergence of flow into those zones (Figure 5a). The feedback process is both geochemical and hydrodynamic and was first described by Ortoleva and others (1987).

As the flow system evolves, caves develop at both the recharge (up-gradient) and discharge (down-gradient) ends (Kincaid, 1999). At the up-gradient end, the feedback process is predominantly geochemical. Random variations in the permeability field (i.e. porosity or fracture aperture variation) yield fingers of enhanced dissolution that advance ahead of the average dissolution front (Ortoleva et al., 1987; Hanna and Rajaram, 1998). The dissolution fingers create preferential zones of dissolution that eventually develop into caves.

At the down-gradient end of the flow system, the feedback process is hydrodynamic and is enhanced by mixing corrosion (Bogli, 1980; Dreybrodt, 1981). Discharge is concentrated into zones of slightly enhanced permeability, which eventually develop into springs. As dissolution proceeds, hydraulic head is reduced because the zones are connected to the springs. Local hydraulic gradients adjust to the new head configuration generating fingers in the dissolution front that capture more flow from the surrounding aquifer. Since most of the flow is focused toward the most up-gradient part of the finger, reaction infiltration instability and mixing corrosion promote the development of near-linear conduits that grow in the up-gradient direction.

Immature stage

Caves forming at the up-gradient and down-gradient ends of a flow system develop different physical and hydraulic characteristics owing to different ground water through-flow velocities (Figure 5b). Largest through-flow velocities occur in the dissolution fingers developing at the down-gradient end of a flow system because of steeper gradients between the aquifer matrix and the spring discharges. Large through-flow velocities promote the development of tubular conduit profiles because convergence of flow and dissolution are maximized in the most up-gradient section of the largest dissolution finger. Cave expansion at the down-gradient end of a flow system will proceed faster than at the up-gradient end because discharge of water from the aquifer at springs ensures that convergence of flow and thus ground water velocities, mixing corrosion, and dissolution are maximized. Conduits in these caves typically become larger in the down-gradient direction toward the spring discharge. These types of caves are classified as “flow-dominated” (Kincaid, 1999) and include the majority of the explored water-filled caves in Florida.

In contrast, small through-flow velocities occur at the up-gradient end of a flow system wherein water flowing through the dissolution fingers must re-enter the aquifer matrix through smaller permeability features such as a network of distributed fractures. Slower through-flow velocities promote irregular cavity shapes because dissolution is distributed throughout the down-gradient end of the dissolution finger where flow is re-entering the aquifer matrix. These caves develop in the down-gradient direction from recharge sources as a result of carbonate dissolution by calcite aggressive in-flowing water. Cave expansion is slower because the slow ground water velocities inhibit dissolution wherein through-flowing water quickly approaches saturation with respect to CaCO_3 causing the dissolution reaction rate to drop (Weyl, 1958; Berner and Morse, 1974; Plummer et al., 1978; Groves and Howard, 1994a). The resulting caves are typically large voluminous chambers with little or no conduit type passages such as have developed in Kirkgoz-Suluin and Finike-suluin in Turkey and the Diepolder caves in Florida (Kincaid, 1999).

Mature flow-dominant stage

Given enough geologic time, immature flow and storage-dominated caves will join and form a mature flow-dominated cave that connects recharge sources with the most prominent spring (Figure 5c). The resulting cave is termed flow-dominated because it becomes the primary flow path through the aquifer. Hydraulic gradients adjust such that flow converges on the conduit, which conveys the water to a spring discharge. This is the case with Wakulla cave that collects most of the groundwater flow through the Woodville Karst Plain and directs it to Wakulla spring and submarine springs in the Gulf of Mexico (Kincaid, 1999).

Mature storage-dominant stage

If the geologic environment remains stable, flow-dominated caves will evolve into a mature saturated karst as a result of continued cave expansion (Figure 5d). Conduits expand until the transmission capacity of the cave equals the recharge rate. Hydraulic gradients in the aquifer reduce and hydraulic head potentials straighten which reduces the convergence of flow into the cave thereby reducing the rate of cave expansion. Through-flow velocities reduce which causes the morphologic structure of the cave to evolve toward irregular cavities and chambers similar to those described in the storage-dominated caves and away from tubular shaped conduits that characterized the cave during the earlier flow-dominant stage. In addition to functioning as a preferential flow path, the cave becomes large enough to provide significant ground water storage.

Note that widespread dissolution at the down-gradient end of the flow system will be particularly enhanced in coastal aquifers where fresh water / seawater mixing increases dissolution rates. Cave development in the Yucatan Peninsula is a perfect analog wherein multiple conduits have coalesced in the down-gradient direction forming broad zones of extensive dissolution that have lost all semblance of conduit structure (Back et al., 1986; Stoessell et al., 1989; Whitaker and Smart, 1997).

Discussion

This research recognizes that saturated caves develop into two different general morphologies that reflect ground water through-flow velocities and the mode of discharge from the cave into the surrounding environment (land surface or aquifer matrix). The important conclusion is that passage geometries describe the hydraulic function of a cave within the encompassing karst aquifer.

To accurately characterize cave development within any flow system, it must be recognized that modern cave patterns can result from any combination of present and pre-existing hydraulic configurations in an aquifer. Geologic events such as uplift, sea level changes, and erosion of overlying confining layers change the boundary conditions imposed on a flow system by changing the base level of discharge and/or changing the mode of recharge to the aquifer. After such events, caves can either be left in the unsaturated zone as relics of pre-existing flow systems or be modified by changing hydraulic conditions in the aquifer. In the second case, cave patterns can be overprinted with multiple periods of development wherein parts of the overall pattern develop in response to the hydraulic configuration of the flow system that was active during that period of development.

There are two fundamental differences between the proposed model and other general models of cave development. (1) The key independent variables responsible for cave development are hydraulic rather than geologic, i.e. cave development is controlled more by hydraulic gradient and convergence of flow than by the location and trends of fractures. (2) The dissolution that causes cave development occurs at both the up-gradient and down-gradient ends of a flow system.

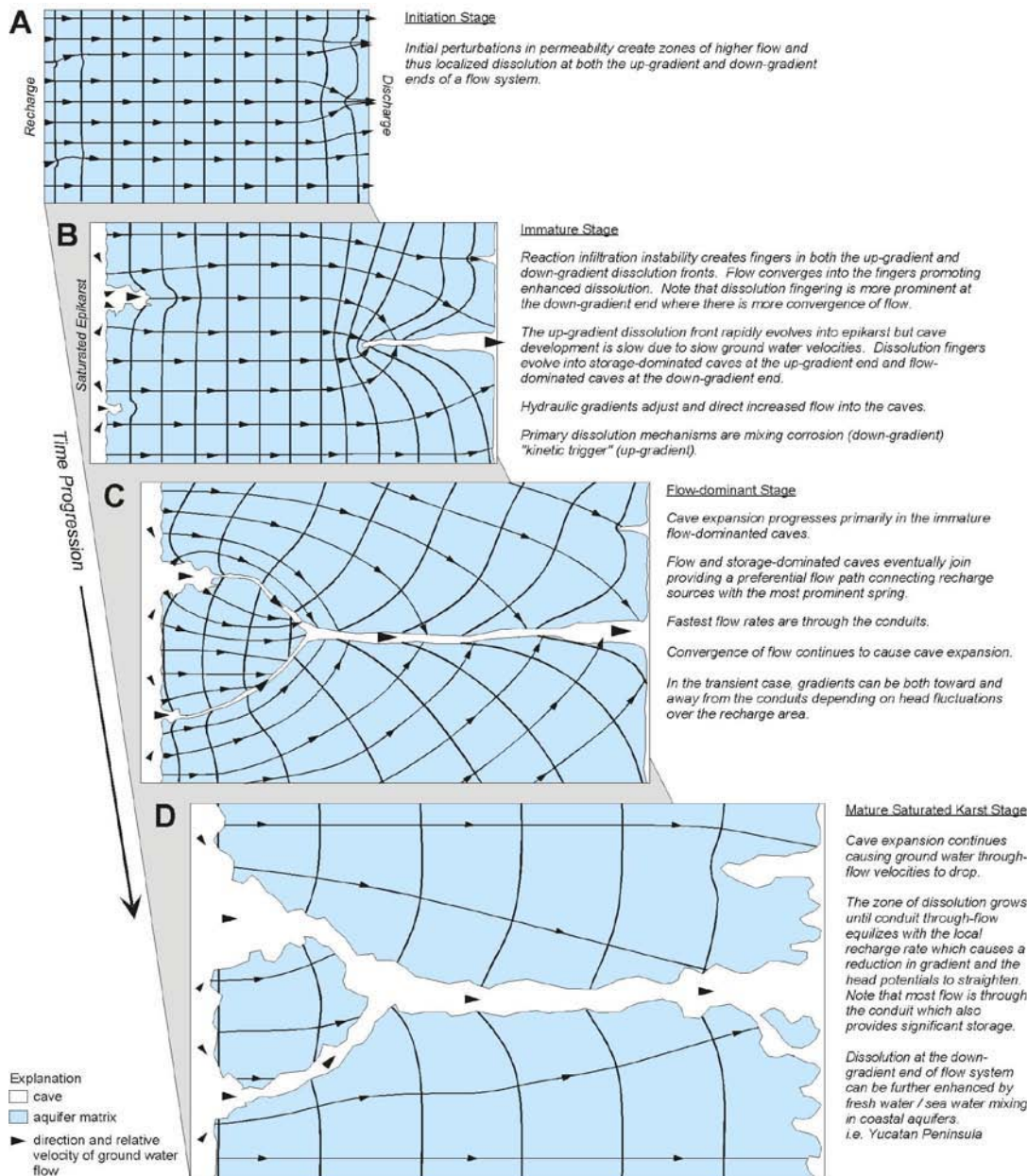


Figure 5. Conceptual model of steady-state saturated cave development in an unconfined karst aquifer. (A) Initiation stage wherein flow through the incipient carbonate aquifer is through inter-granular or fracture permeability. (B) Immature stage wherein dissolution fingers develop at the up-gradient and down-gradient ends of the flow system due to reaction infiltration instability. (C) Flow-dominant stage wherein the dissolution fingers join thereby connecting recharge sources with the most prominent spring. (D) Mature saturated karst stage wherein cave expansion broadens the zone of dissolution in the aquifer. Note that initial input conditions are responsible for the resulting cave pattern. Branchwork caves are formed as a result of multiple inputs to confined or semi-confined aquifers. Epikarst and anastomose caves form as a result of diffuse input to unconfined aquifers

REFERENCES

- Back, W., Hanshaw, B.B., Herman, J.S., and Van Driel, J.N., 1986, Differential dissolution of a Pleistocene reef in the ground-water mixing zone of coastal Yucatan, Mexico, *Geology*, vol. 14, pp. 137-140.
- Berner, R.A. and Moorse, J.W., 1974, Dissolution kinetics of calcium carbonate in sea water, IV, theory of calcite dissolution, *American Journal of Science*, vol. 274, pp. 108-134.
- Bogli, A., 1980, *Karst Hydrology and Physical Speleology*, Springer-Verlag, New York.
- Dreybrodt, W., 1981, Mixing corrosion in $\text{CaCO}_3\text{-CO}_2\text{-H}_2\text{O}$ systems and its role in the karstification of limestone areas, *Chemical Geology*, vol. 32, pp. 221-236.
- Dreybrodt, W., 1988, *Processes in Karst Systems*, Springer Verlag, New York, 288 p.
- Ewers, R.O., 1982, An analysis of solution cavern development in the dimensions of length and breadth, Ph.D. Dissertation, Department of Geography, McMaster University, Hamilton, Ontario, Canada.
- Ford, D.C. and Williams, P.W., 1989, *Karst Geomorphology and Hydrology*, Unwin Hyman, London, 601 p.
- Groves, C.G. and Howard, A.D., 1994a, Minimum hydrochemical conditions allowing limestone cave development, *Water Resources Research*, vo. 30, no. 3, pp. 607-615.
- Groves, C.G. and Howard, A.D., 1994b, Early development of karst systems: 1. preferential flow path enlargement under laminar flow, *Water Resources Research*, vol. 30, no. 10, pp. 2837-2846.
- Hanna, R.B. and Rajaram, H., 1998, Influence of aperture variability on dissolutional growth of fissures in karst formations, *Water Resources Research*, vol. 34, no. 11, pp. 2843-2853.
- Huntoon, P.W., 1985, Gradient controlled caves, Trapper-Medicine Lodge Area, Bighorn Basin, Wyoming, *Ground Water*, vol. 23, no. 4, pp. 443-448.
- Kincaid, T.R., 1999, *Morphologic and Fractal Characterization of Saturated Karstic Caves*, Ph.D. Dissertation, University of Wyoming, 174 p.
- Mandel, S., 1967, A conceptual model of karstic erosion by groundwater, *International Association of Scientific Hydrology*, vol. 11, pp. 5-7.
- Ortoleva, P., Chadam, J., Merino, E., and Sen, A., 1987a, Geochemical self organization I: reaction-transport feedbacks and modeling approach, *American Journal of Science*, vol. 287, pp. 979-1007.
- Ortoleva, P., Chadam, J., Merino, E., and Sen, A., 1987b, Geochemical self organization II: the reactive-infiltration instability, *American Journal of Science*, vol. 287, pp. 1008-1040.
- Palmer, A.N., 1981, *A Geological Guide to Mammoth Cave National Park*, Zephyrus Press, Teaneck, New Jersey, 196 p.
- Palmer, A.N., 1991, Origin and morphology of limestone caves, *Geological Society of America Bulletin*, vol. 103, no. 1, pp. 1-21.

Plummer, L.N., Wigley, T.M.L., and Parkhurst, D.L., 1978, The kinetics of calcite dissolution in CO₂-water systems at 5 to 60 °C and 0.0 to 1.0 atm CO₂, *American Journal of Science*, vol. 278, pp. 179-216.

Stoessell, R.K., Ward, W.C., Ford, B.H., and Schuffert, J.D., 1989, Water chemistry and CaCO₃ dissolution in the saline part of an open-flow mixing zone, coastal Yucatan Peninsula, Mexico, *Geological Society of America Bulletin*, vol. 101, pp. 159-169.

Weyl, P.K., 1958, The solution kinetics of calcite, *Journal of Geology*, vol. 66, pp. 163-176.

Whitaker, F.F. and Smart, P.L., 1997, Groundwater circulation and geochemistry of a karstified bank-marginal fracture system, South Andros Island, Bahamas, *Journal of Hydrology*, vol. 197, pp. 293-313.

White, W.B., 1977, Role of solution kinetics in the development of karst aquifers, *Memoirs of the International Association of Hydrogeology*, vol. 12, pp. 503-517.

FLORIDA CAVERNS KARST
(Edited from the 1993 SEGS guidebook)

**CAVE PASSAGE ORIENTATION AND DEVELOPMENT WITHIN FLORIDA CAVERNS
STATE PARK; JACKSON COUNTY, FLORIDA**

INTRODUCTION

Cave development in Florida Caverns State Park is primarily the result of vadose solution within the upper Eocene Crystal River formation of the Ocala Group. Fluvial erosion and the resultant lowering of the Chipola River valley through the uplifted Tertiary limestones provides the gradient and successively lower water table elevations responsible for development of dry cave passages. Passage orientation is controlled by two predominant vertical joint sets, combined with solution along bedding plane-parallel horizons. The caves are mature karst features, containing profusely decorated chambers.

CAVE DISTRIBUTION AND DEVELOPMENT IN JACKSON COUNTY

Uplift along the southern flank of the Chattahoochee Anticline in the late Tertiary (Schmidt and Coe, 1978) has elevated Oligocene and older marine carbonates to an average elevation of 45 m (150 ft) above mean sea level in northern Jackson County. These elevated carbonates, thinly mantled by Pleistocene and younger sediments and dipping gently southward, enabled the development of mature karst features in the area. The northeastern portion of the Jackson County is a mature karst plain, underlain by upper Eocene Crystal River limestone. Shallow dolines, mostly cover subsidence sinks, are widely distributed throughout the region. Surface streams are rare; the area is mostly internally drained. In many ways this area appears to be geologically similar to, and perhaps the southwestern extension of the Dougherty Karst Plain of southwestern Georgia (see Beck and Arden, 1984).

Dry caves in the Marianna region occur primarily in a series of remnant limestone ridges adjacent to and roughly paralleling the Chipola River, downdip at the southern margin of the northern Jackson County karst plain. Successive downcutting of the Chipola River channel has eroded the uplifted Tertiary limestones, providing a vertical component for ground water movement. The existence of many springs along the Jackson County portion of the Chipola River demonstrates that this process continues today. The elevation of the Chipola River valley floor in the vicinity of Florida Caverns State Park is about 21 m (70 ft). Horizontal cave development along formerly higher water table horizons has caused development of most of the larger caves of the area. This development is most pronounced in the Bumpnose member of the Crystal River formation. The development of cave passage at the upper juncture of former saturated zones may have been influenced by higher Pleistocene sea level stillstands, which would influence the ability of the Chipola River to deepen and widen its valley. Inundation of some cave passages by clastic fill during periods of higher sea level may have also occurred (Boyer, 1975b).

Horizontal vadose passage development benefits from the existence of a resistant caprock. In the Marianna area, most large caves are developed in the upper Bumpnose member of the Crystal River formation, a soft, white fossiliferous limestone characterized by abundant *Lepidocyclina* (*Nephrolepidina*) *chaperi*. It is very soft and granular, owing to the presence of many bryozoa and foraminifera (Moore, 1955). Overlying the Bumpnose member is the more resistant Oligocene Marianna limestone, a hard to soft cream to white fossiliferous limestone containing highly indurated zones and characterized by the occurrence of *Lepidocyclina* (*Lepidocyclina*) *mantelli*. Marianna limestone was once quarried in the area

for use as a building stone. The Marianna limestone acts as a caprock, protecting horizontal cave development in the softer underlying limestones of the Ocala Group. The distribution of major caves in Jackson County, therefore, occurs in a generally northwest-southeast trending band centered along and passing through Florida Caverns State Park (Figure 1). This band roughly corresponds to the outcrop pattern of the Marianna limestone along and adjacent to the Chipola River (see geologic map of Jackson County in Moore, 1955). Interestingly, the Marianna limestone has been eroded and is largely absent from most of the cave-bearing ridges within Florida Caverns State Park.

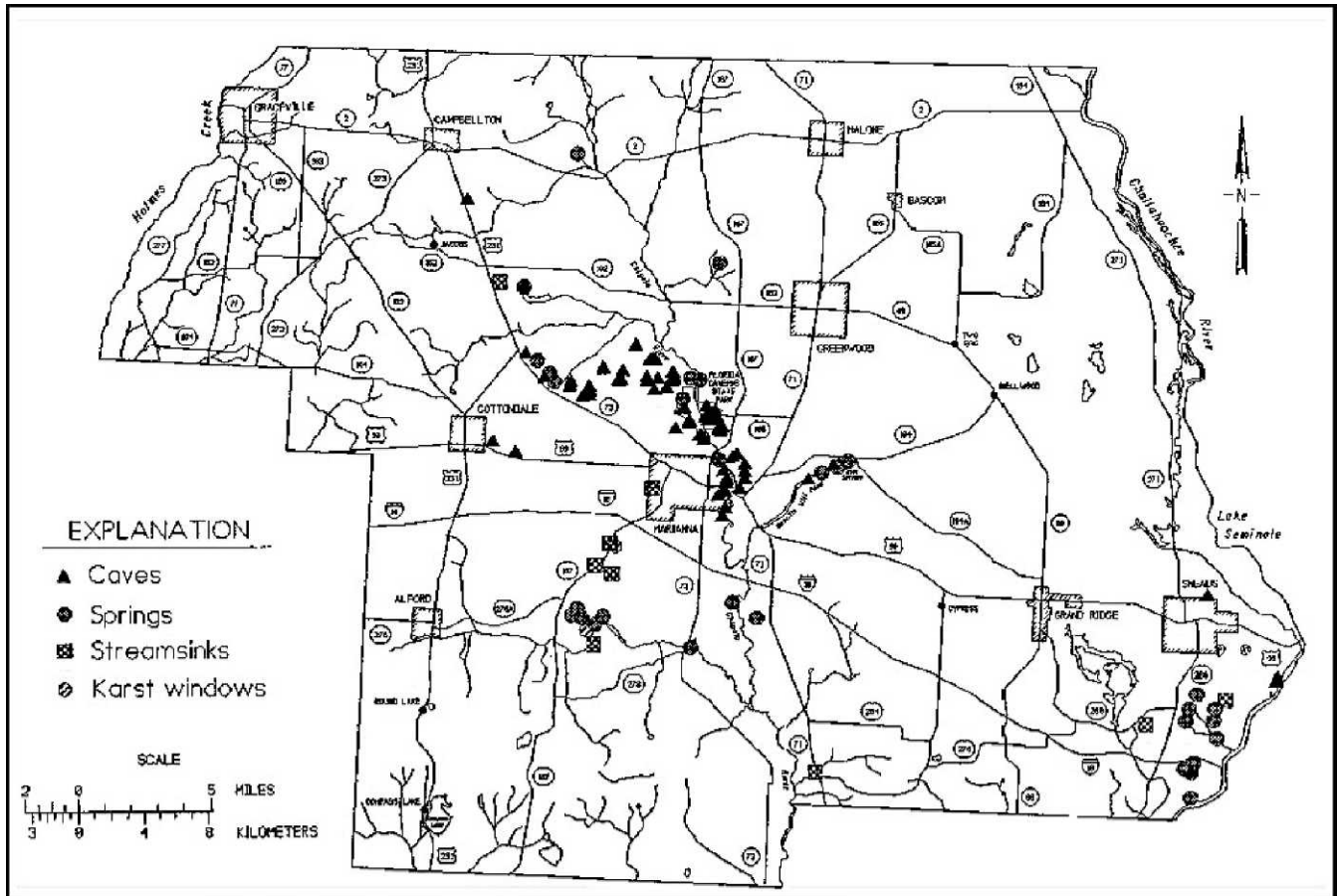


Figure 1. Distribution of some major karst features in Jackson County, Florida

Besides the Park caves and those of similar morphology in the Marianna area, two other types and areas of cave development exist. A small number of caves are located along the Chattahoochee River corridor in eastern Jackson County. These are primarily short, vadose stream caves with secondary phreatic solution enlargement. Most are contained within the lower Miocene Chattahoochee Formation.

There are many underwater caves present in the county. Most are associated with springs discharging into the Chipola River or its tributaries, particularly Merritt's Mill Pond and Spring Lake. These underwater caves are generally larger in section and much longer than their "dry" counterparts. Many display well-developed passage at particular depth horizons parallel to bedding. Many of these were possibly "dry" water table caves during past episodes of continental glaciation, when sea level and ground water levels were lower, as evidenced by possible relict vadose features.

CAVE PASSAGE ORIENTATION

Caves within Florida Caverns State Park and surrounding areas display preferential development along three planes: two vertical joint directions at roughly right angles to each other, and a horizontal direction parallel to bedding.

The predominant vertical controlling joints of the region strike at approximately N 30° W. This major orientation is responsible for development of the largest and most predominant vadose cave passages in the Park. China, Tunnel, Miller's and Dragon's Tooth Caves display this preferential development orientation exceptionally well, as shown on Figure 2. The western half of Miller's Cave, the "Dragon's Belly" room in Dragon's Tooth Cave and the "Vandal Room" in Pottery Cave are all developed along the same joint. "Dragon's Belly," the largest single cave room in the Park, is dimensionally approximately 41 m (135 ft) long, 17 m (55 ft) wide and 6 m (20 ft) high. This north-northwest trending fracture orientation may also be responsible for controlling the course of the Chipola River, which is oriented in the same direction.

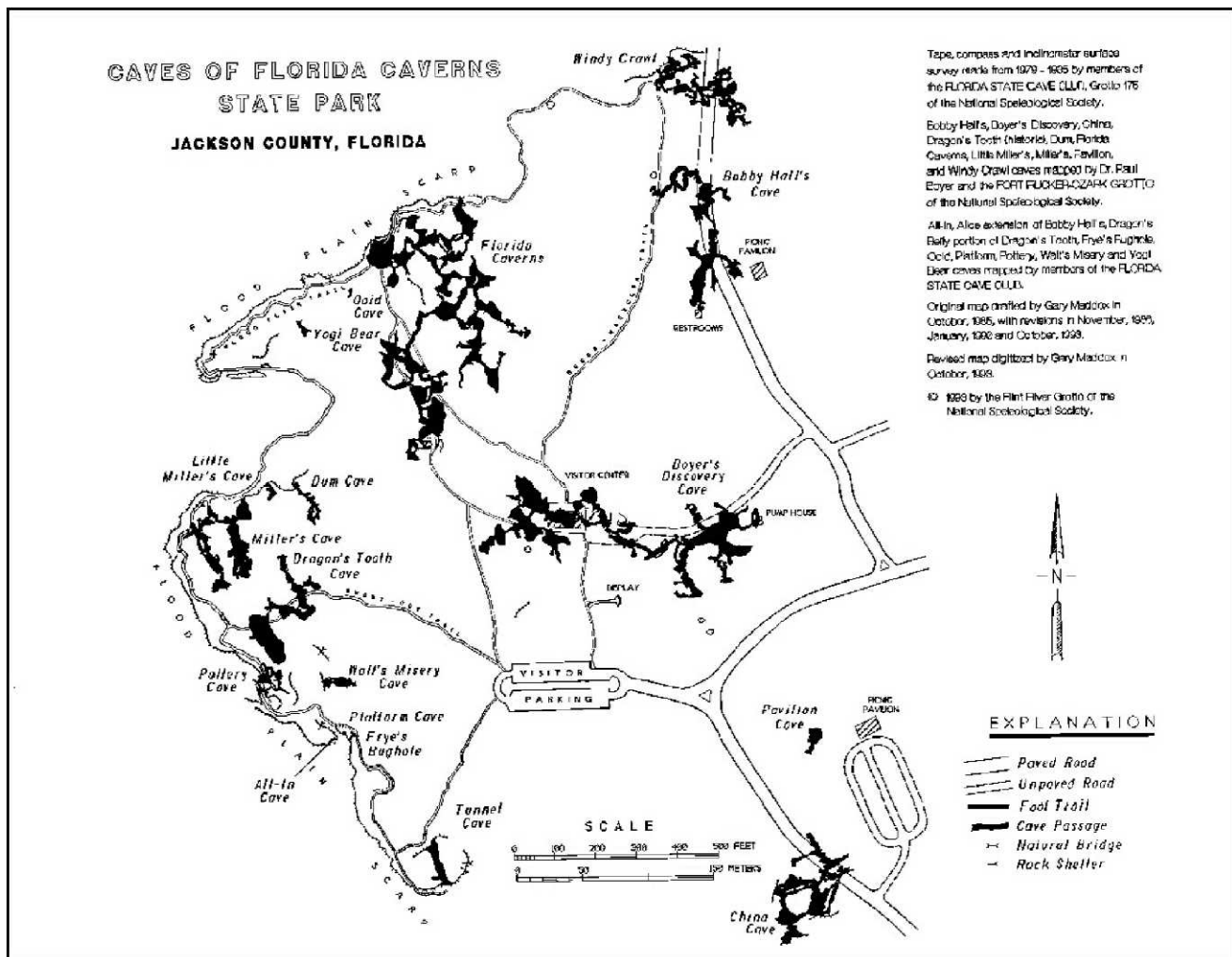


Figure 2. Caves of Florida Caverns State Park, Jackson County,

A conspicuous secondary vertical joint orientation strikes at approximately N 60° E. Passages developed along these joints can be seen in Boyer's Discovery, China and Miller's Cave. These passages are usually lower than the passages developed along the primary joints, and more poorly defined. They often form low connector passages between the larger north-northwest trending chambers.

A third vertical fracture or joint orientation of approximately N 20°E. is well developed in China Cave and Bobby Hall's Cave. This orientation is rarely manifested in preferential passage development in other Park caves.

Virtually all caves within the Park contain areas of low, wide passage parallel to bedding. These lower passages are most likely best developed along the unconformity separating the Ocala Group Bumpnose Member of the Crystal River formation from the underlying lower Crystal River formation. Because most of these passages contain significant clastic infill, this relationship is difficult to investigate. Morphological features, such as certain conduit cross-sections, suggest that some of these passages may have initially developed as phreatic conduits, which were later modified through vadose solution. Dum Cave and Windy Crawl both possess excellent examples of bedding plane parallel passage development.

Many Park caves are located along the limestone scarp above the Chipola River floodplain. Some of these are relict cave segments, remnants of larger systems which have been destroyed by enhanced solution and mass wasting along the scarp. Pottery Cave is a good example of this, displaying truncated passage, "dead" speleothems and multi-level cave development. At least three distinct levels have developed in this cave. Other related karst landforms, such as rock shelters and natural bridges, can also be seen along the scarp.

Known caves in the Park contain from one to five entrances. Caves with only one humanly passable entrance are most common. Because many of the caves now exist above the zone of saturation, dissolution of overlying calcium carbonate via downwardly percolating meteoric water produces extensive speleothem development in many of the Park caves. Stalactites, stalagmites, columns, flowstone, rimstone dams, cave pearls, "popcorn" and draperies are all commonly found in these caves. Of particular note are the "bedpost" stalagmites present in several of the caves. Speleothem development of this type is indicative of the last stages in the "life cycle" of the cave. Speleothems are developed in the cave at the expense of overlying roof rock, the source of calcium carbonate, which will eventually weaken to the point of collapse. Several Park caves already have precariously thin roof zones. In Florida Caverns, during heavy rainfall events the thin, perforated roof zone allows numerous small waterfalls to cascade from the ceiling to the floor in the northern part of the cave.

Florida Caverns, the commercial tour cave in the Park, actually consisted of two smaller caves joined by a tunnel dug through the surrounding limestone by Civilian Conservation Corps workers in the 1930's. The cave was discovered in 1937, when the original entrance was exposed by the roots of a fallen tree. The present map of the cave (Figure 3) was produced by Dr. Paul Boyer and members of the Fort Rucker-Ozark Grotto and the Florida State Cave Club (Boyer, 1975a). The cave displays most of the aspects of passage development discussed above, and is heavily decorated.

An excellent summary of the history and area geology of the Park can be found in Schmidt (1988).

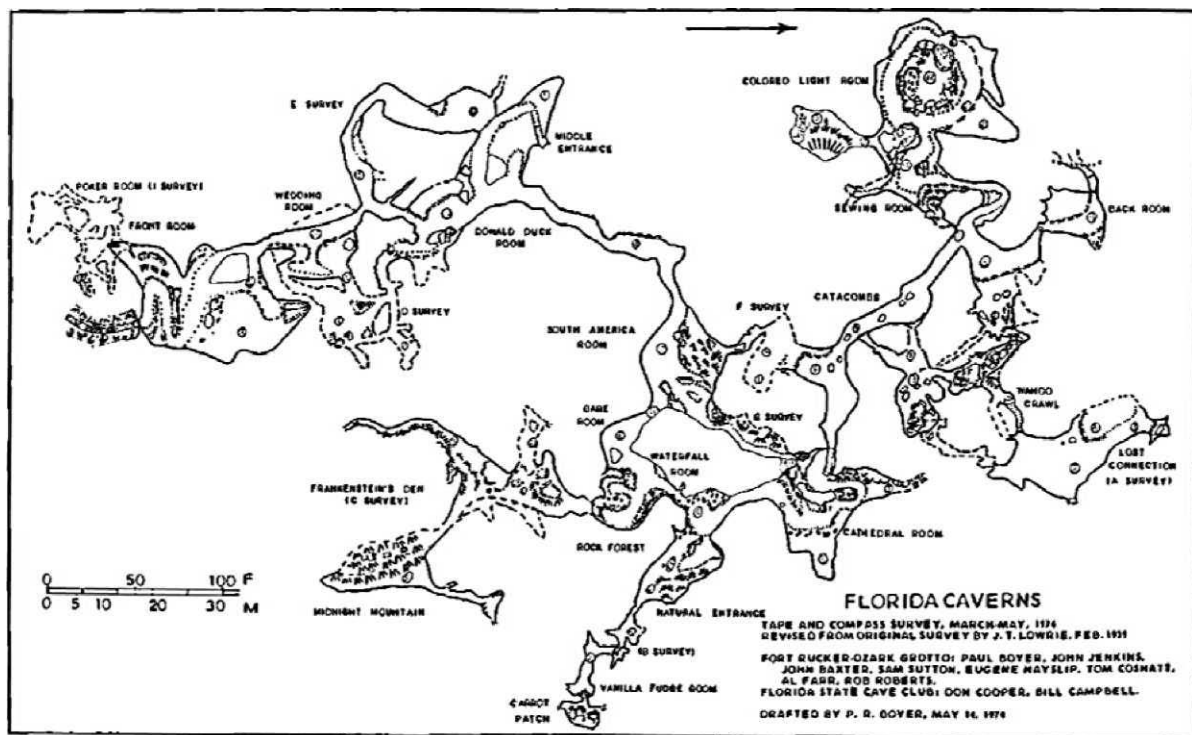


Figure 3. Planimetric Map of Florida Caverns

REFERENCES

- Beck, B. F. and D. D. Arden, 1984, *Karst hydrogeology and geomorphology of the Dougherty Plain, southwest Georgia*: Southeastern Geological Society Guidebook No. 26, 59 p.
- Boyer, P., 1975a, Florida Caverns: *NSSNews*, Volume 33, Number 10, p. 155.
- Boyer, P., 1975b, Hollow Ridge Cave: *Southeastern Karst Survey - General Report*, 2 p.
- Maddox, G. L., 1993, Cave passage orientation and development within Florida Caverns State Park: Jackson County, Florida, pgs. 4-14, In Maddox, G. L. (Editor). *Karst features of Florida Caverns State Park and Falling Waters State Recreational Area; Jackson and Washington counties, Florida*. SEGS Guidebook No. 34. SEGS, Tallahassee, FL.
- Moore, W., 1955, Geology of Jackson County, Florida: *Florida Geological Society Bulletin No. 37*, p. 29-42, geological map.
- Schmidt, W., and C. Coe, 1978, Regional structure and stratigraphy of the limestone outcrop belt in the Florida panhandle: *Florida Bureau of Geology Report of Investigation No. 86*, p. 6-10.
- Schmidt, W., 1988, Florida Caverns State Park, Jackson County, Florida: *Florida Geological Survey Open File Report 23*, 8 p.

“FARMED” CAVE CALCITE CHEMISTRY: A GUIDE TO SPELEOTHEM PALEOCLIMATE INTERPRETATIONS

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Stable isotope (carbon and oxygen) and trace element records in cave stalagmites are often interpreted as climate changes in rainfall amount, cave air temperature, overlying vegetation and atmospheric pCO₂. However, these records are difficult to verify without direct calibration of changes in cave microclimate (e.g., net rainfall, interior ventilation changes) to contemporaneous variations in dripwater and speleothem chemistry. In this study at Hollow Ridge Cave (HRC) in Marianna, Florida, cave dripwater, bedrock, and modern calcite (farmed in situ) were collected in conjunction with continuous cave air pCO₂, temperature, barometric pressure, relative humidity, radon activity, airflow velocity and direction, rainfall amount, and drip rate data. [1]

We compare rain and dripwater isotopes and chemistry, cave air CO₂, and farmed calcite isotopes to examine the relationships among cave air ventilation, cave air temperature, calcite growth rate, and calcite isotopic composition. These comparisons show that when the cave is strongly ventilated (during the winter) calcite growth is approximately 10x faster than when the cave is stagnant (summer), suggesting that most HRC speleothems record winter-time climate conditions. Due to ventilation there is a significant gradient in calcite carbon isotopes; “heavier” near the ventilated cave entrance, becoming ~ 7-10‰ “lighter” toward the deep interior during all seasons. Similar to other cave investigations at various latitudes and altitudes, calcite oxygen isotopes are found to be ~ 0.8‰ offset from theoretical and laboratory-based predictions. [2]

We analyzed dripwater, bedrock, and farmed calcite chemistry to examine the relationships between net rainfall, drip rates, drip water chemistry, and calcite chemistry. Dripwater Mg/Ca and Sr/Ca ratios are a function of mixing between three geochemical endmembers: rainwater, dissolved dolomite, and dissolved limestone. Farmed calcite trace cation/Ca ratios faithfully track short-term seasonal variations in dripwater chemistry for Na, Mg, Sr, Ba and U. However, speleothem calibrations are unique to each drip site regardless of proximity to one another, suggesting that individual speleothems are unlikely to be useful as a whole-cave hydrologic proxy. [3]

This presentation will focus on two themes: (1) air exchange between the atmosphere and cave, and how it affects calcite isotopes; and (2) mixing between rainwater and dissolved limestone, and how mixing affects dripwater chemistry over short time periods.

[1] Kowalczyk, A. J., Froelich, P. N., 2010. Cave air ventilation and CO₂ outgassing by radon-222 modeling: How fast do caves breathe? *Earth & Planet. Sci. Lett.* **289**, 209-219.

[2] Tremaine, D. M., Froelich, P. N., Wang, Y., 2011. Speleothem calcite farmed *in situ*: Modern calibration of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ paleoclimate proxies in a continuously-monitored natural cave system. *Geochim. Cosmochim. Acta* **75**, 4929-4950.

[3] Tremaine, D. M., Froelich, P. N., 2012. Speleothem trace element signatures: A modern hydrologic geochemical study of cave drip waters and farmed calcite. *Geochim. Cosmochim. Acta* (submitted)

**FIELD TRIP STOPS
FLORIDA CAVERNS
AND BROOKS QUARRY**

STOP DESCRIPTIONS

(Edited from SEGS Guidebook #43)

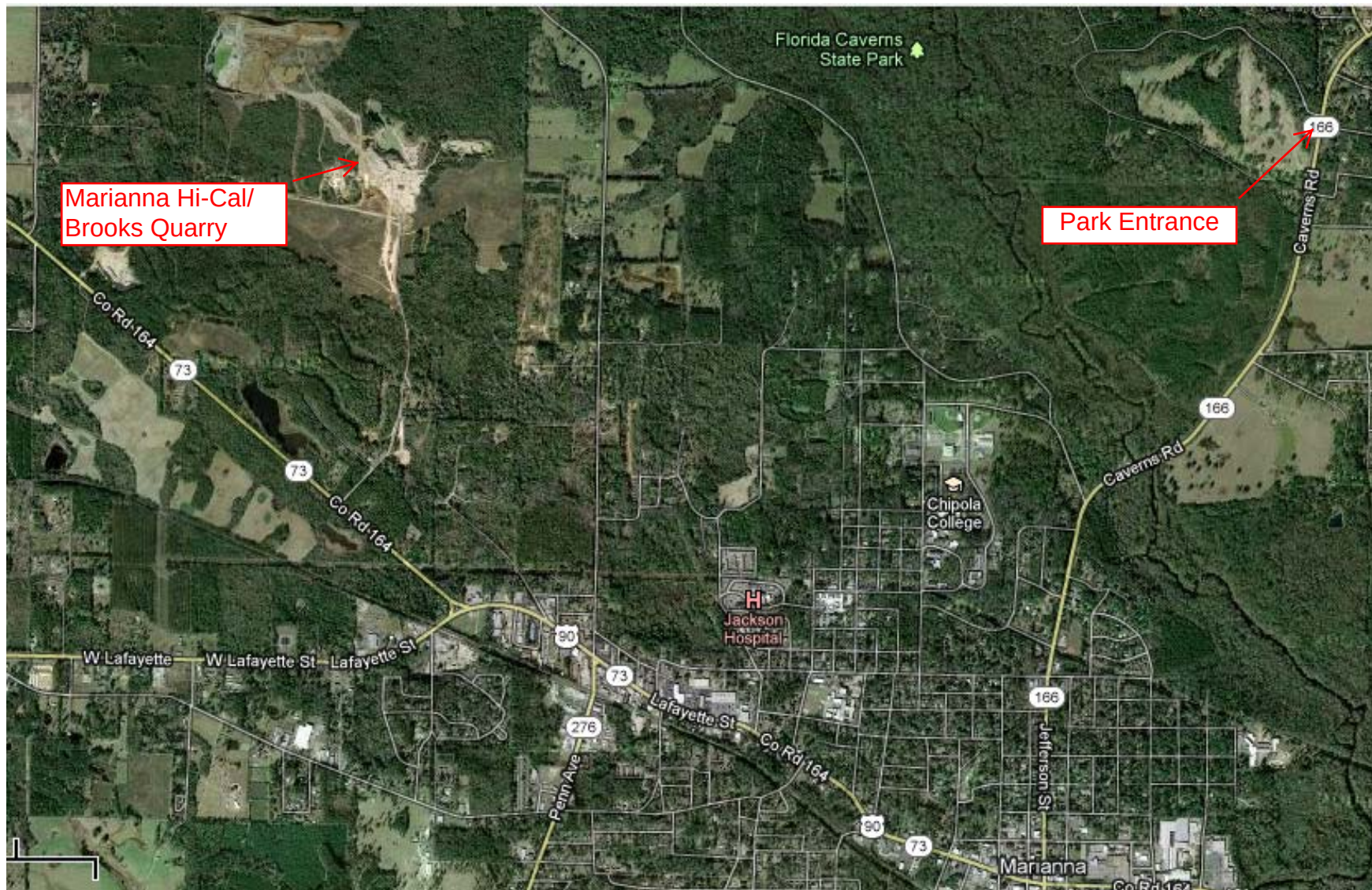
Stop 1 - Florida Caverns Tour

The park contains many interesting and beautiful areas-more than we will experience in this quick trip. It encompasses approximately 1300 acres packed with a fabulous variety of animals and plants. At a later time you should return and explore the park and discover all that it has to offer. It is a great place to camp and bring the family. The caverns were developed by the Civilian Conservation Corps from 1938 to 1942 (see historical review of the caverns in the article by Dr. Brian Rucker). Scallop marks on cave wall passages reveal the subaqueous development of the cave system by flowing water. Following subaerial exposure, speleothem development occurred resulting in the beautiful stalactites and stalagmites we witness today. A small museum is located above the visitors center along with restrooms for changing clothes, if necessary. We will take the cave tour and enjoy cooler temperatures and beautiful cave geology

Stop 2 - Marianna Lime Products, Inc. (HI CAL Limerock)

(GPS Coordinates: N 30° 48.398 W 85° 15.575)

Vehicle parking will be dictated by the weather. Best areas to collect fossils are from the small spoils piles and the exposed blocks of limestone. Please keep away from overhanging walls. See stratigraphic description by Dr. Jon Bryan in the geology section of the guidebook. The quarry is owned by Mr. Leon Brooks of Marianna. Over 69 feet of section is exposed in the quarry, including the Ocala, Bumpnose, and Marianna Limestone. This very fossiliferous sequence includes the Eocene-Oligocene boundary (Within the Bumpnose Member).



Field Trip Stop Locations