


August 2008

Geology and Hydrology of Karst in West-Central and North-Central Florida

Lee J. Florea

Western Kentucky University, lflorea@bsu.edu

Follow this and additional works at: http://digitalcommons.wku.edu/geog_fac_pub

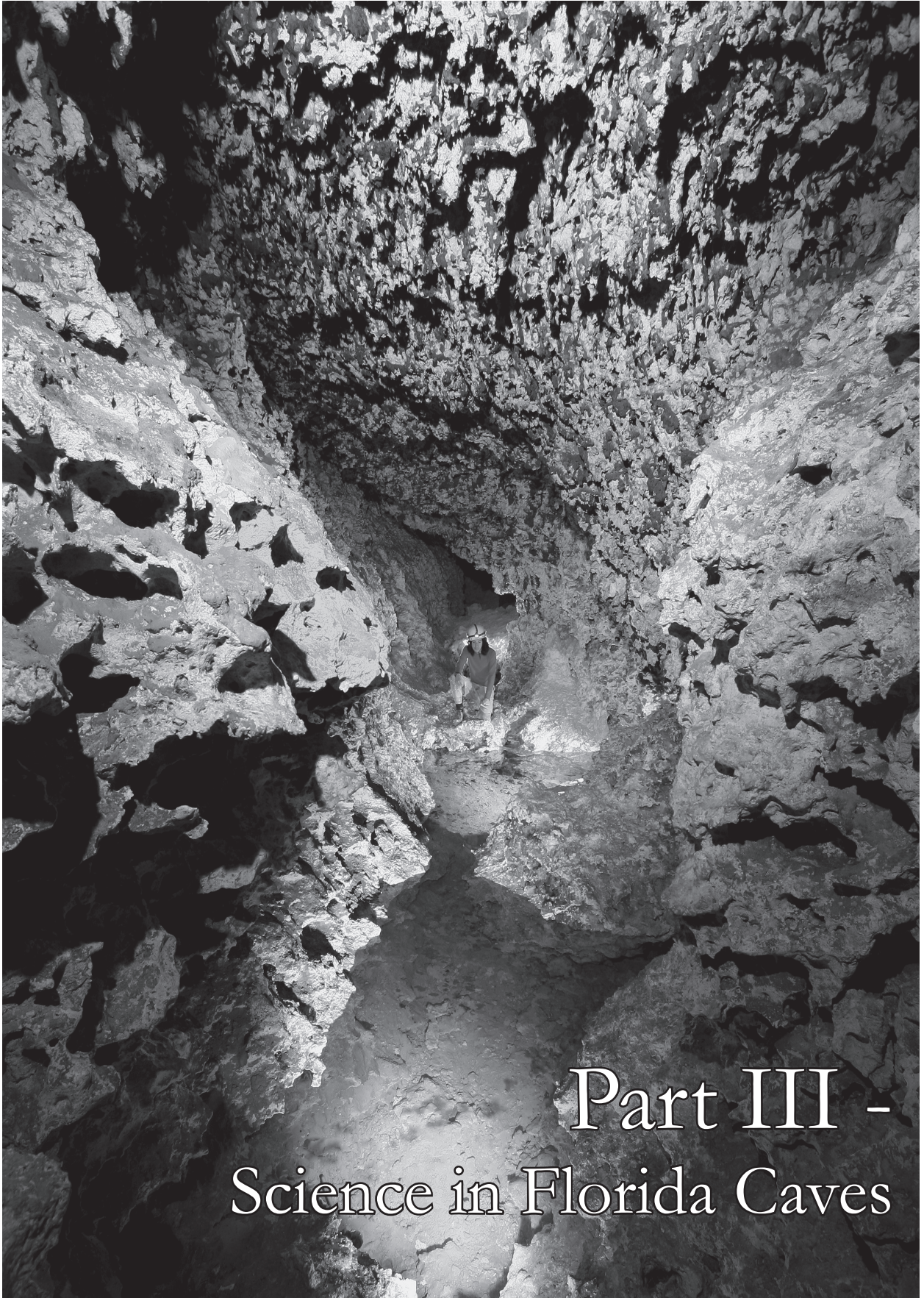
 Part of the [Climate Commons](#), [Environmental Monitoring Commons](#), [Fresh Water Studies Commons](#), [Geology Commons](#), [Geophysics and Seismology Commons](#), and the [Natural Resources and Conservation Commons](#)

Recommended Repository Citation

Florea, Lee J.. (2008). Geology and Hydrology of Karst in West-Central and North-Central Florida. *Caves and Karst of Florida*, 225-239.

Available at: http://digitalcommons.wku.edu/geog_fac_pub/17

This Contribution to Book is brought to you for free and open access by TopSCHOLAR®. It has been accepted for inclusion in Geography/Geology Faculty Publications by an authorized administrator of TopSCHOLAR®. For more information, please contact topscholar@wku.edu.



Part III -
Science in Florida Caves

SPELEOTHEMS!

The blast shattered the top of a subaqueous cavern! Stalactites varying from the diameter of a finger to over four feet were thrown out...The dipper of the dredge, terminating a boom nearly thirty feet long, was let down into the cavern and swung around in all directions without encountering any obstructions. Here in the wet Everglades is a subaqueous cave. Yet the sections of stalactites indicate great length and they could only have been formed in a cavern in which the floor, or at least the upper portion of the cavern, was elevated above the water table.

From - Historic Trails by Land and Water, by John Small. *Journal of the New York Botanical Garden*, vol. 22, 1921, p. 193-222.



Figure 3.1. Solution-enlarged joint in Werner Cave, Marion County (photo by Art Palmer).

Geology and Hydrology of Karst in West-Central and North-Central Florida

Lee J. Florea, NSS 37909

The state of Florida is blessed with the highest density of large springs in North America and hundreds of smaller springs where the water from limestone aquifers returns to the surface (Scott et al., 2004). Spectacular underwater caves supply water to these springs. Lesser known are the equally fantastic air-filled caves of Florida and South Georgia (Florea, 2006; Lane, 1986). This paper features these underwater and air-filled caves, explores the impact of changes in sea level on karst in this near-coastal environment, and establishes several geologic and hydrologic characteristics that distinguish karst in the limestones of the southeast from karst elsewhere in the U.S.

Origin of the Florida Peninsula

The origin of Florida dates to the final closure of Iapetus Ocean at the end of the Paleozoic era. Basement rocks in Florida, thousands of feet below the land surface, consist of granites and extrusive igneous rocks such as basalt that date to the late Precambrian and Cambrian (700 – 500 million years ago [Mya]), as well as early Paleozoic (500 – 400 Mya) sandstones, siltstones, and shales (Lane, 1994). The fossils in the basement sedimentary rocks bear a strong resemblance to those in rocks of the same age in northwest Africa. Southwest-northeast trends of intrusive igneous rocks at depth in the Florida Panhandle, south Alabama, and south Georgia have led scientists to conclude that Florida was sutured to the North American continent by the end of the Permian or the beginning of the Triassic (250 – 230 Mya) (Lane, 1994).

The early Mesozoic supercontinent of Pangea, in part formed when Africa and North America collided, combined the known landmass of the earth. However, the very same plate tectonics that brought Pangea together soon tore the supercontinent asunder. By the end of the

Triassic (200 Mya), North America pulled away from Africa and South America. Florida was left anchored to North America, but the intense forces of this separation left the basement rocks south of Tampa intensely faulted in a similar fashion to what is occurring today in the Great Rift Valley of east Africa.

As North America drifted from Africa and South America during the Jurassic (200 – 145 Mya), the waters from the newly forming Atlantic Ocean flooded the basement rocks of Florida. First, the waters were shallow. Evaporation of these shallow waters resulted in thick deposits of salt and gypsum. By the Cretaceous period (145 – 65 Mya), deposition of evaporates slowly gave way to a carbonate “giga” platform that included much of the circum-Caribbean region from Venezuela through the Yucatan, eastern Mexico and Texas, Florida and the Bahamas, and the east coast of the U.S. as far north as New Jersey (Hine, 1997). This massive region of limestone deposition was stable through much of the Paleogene (65 – 25 Mya), but gradually dwindled and separated into smaller platforms as the Gulf of Mexico widened and deepened. Carbonate deposition continued uninterrupted in the Bahamas and the Yucatan, but in much of Florida and the rest of the southeast U.S., limestone deposition ended as sands derived from the erosion of the Appalachian Mountains covered the platform (Hine, 1997). Only in southernmost Florida has the deposition of carbonates persisted periodically up through the modern era.

Geologic Framework of Florida Karst

Known caves and springs, with the exception of those in the Miami region, have developed within Paleogene limestones that range in age from mid-Eocene to mid-Oligocene (approximately 42 million to 29 Mya) (Figure 3.2)

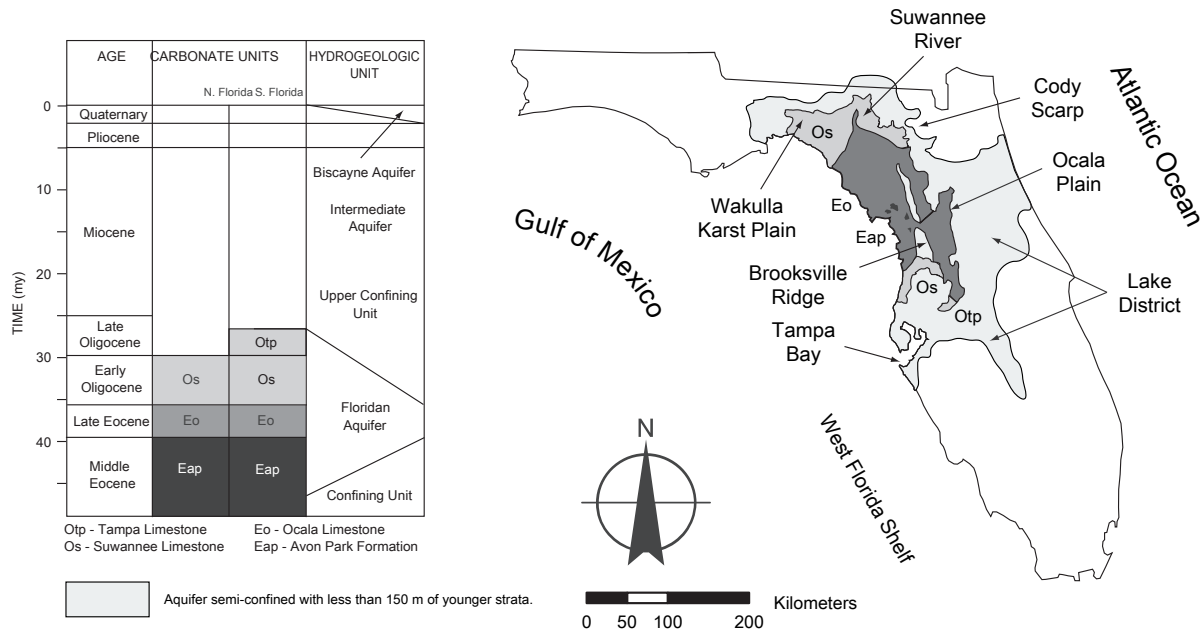


Figure 3.2. Generalized stratigraphy and outcrop of the Floridan aquifer in west-central and north-central Florida.

and cluster into regions where the limestones are exposed at the surface or are only thinly covered by younger sediments (Figures 3.2 and 3.3). One major cluster includes the Flint and Chipola River valleys of south Georgia, Alabama, and the Florida panhandle (Figure 3.3). However, the focus of this overview is the coastal lowlands of west-central and north-central Florida, bounded by the Suwannee River in the north and Tampa Bay in the south, which includes the cities of Brooksville, Ocala, Gainesville, and Lake City.

The Eocene and Oligocene limestones comprise the Floridan aquifer. Cretaceous and early Paleogene limestones and evaporates form the lower confining units for modern groundwater flow (Miller, 1986). Younger strata, including the Miocene Hawthorn Group throughout Florida (Scott, 1988), the Pliocene calcareous sands of the Tamiami Formation in south Florida (Fish and Stewart, 1991), and the mostly Pleistocene limestones of the Biscayne aquifer in southeast Florida (Cunningham et al., 2006; Parker et al., 1955), overlay and confine the Floridan where not exposed at the surface (Scott et al., 2001). The Floridan is estimated to contain over 19,000 km³ of water and is among the most productive and largest freshwater aquifers in the world

(Miller, 1986).

The thickness of the Floridan aquifer generally increases to the south and averages 600 meters (m) thick in much of west-central Florida (Miller, 1986). In peninsular Florida and south Georgia, the stratigraphic units within the Floridan are the middle Eocene Avon Park Formation, the late Eocene Ocala Limestone, the early Oligocene Suwannee Limestone, and, south of Brooksville, the late Oligocene Tampa Limestone (Miller, 1986; Figure 3.2). The Ocala and Suwannee Limestones are the two stratigraphic units directly associated with most karst features, particularly where the aquifer is unconfined (Florea, 2006; Figure 3.2).

Regionally, the Ocala Limestone was deposited on a nearly flat, distally steepened carbonate ramp during the 3-million year period of the late Eocene (Loizeaux, 1995). It contains three depositional sequences that were deposited in progressively shallowing waters. The common names for these three sequences are the Inglis, Williston, and Crystal River members. The Inglis is the oldest depositional sequence and the Crystal River is the youngest. The Inglis, Williston, and Crystal River depositional sequences range from 12 to 35 m thick. These sequences are regionally

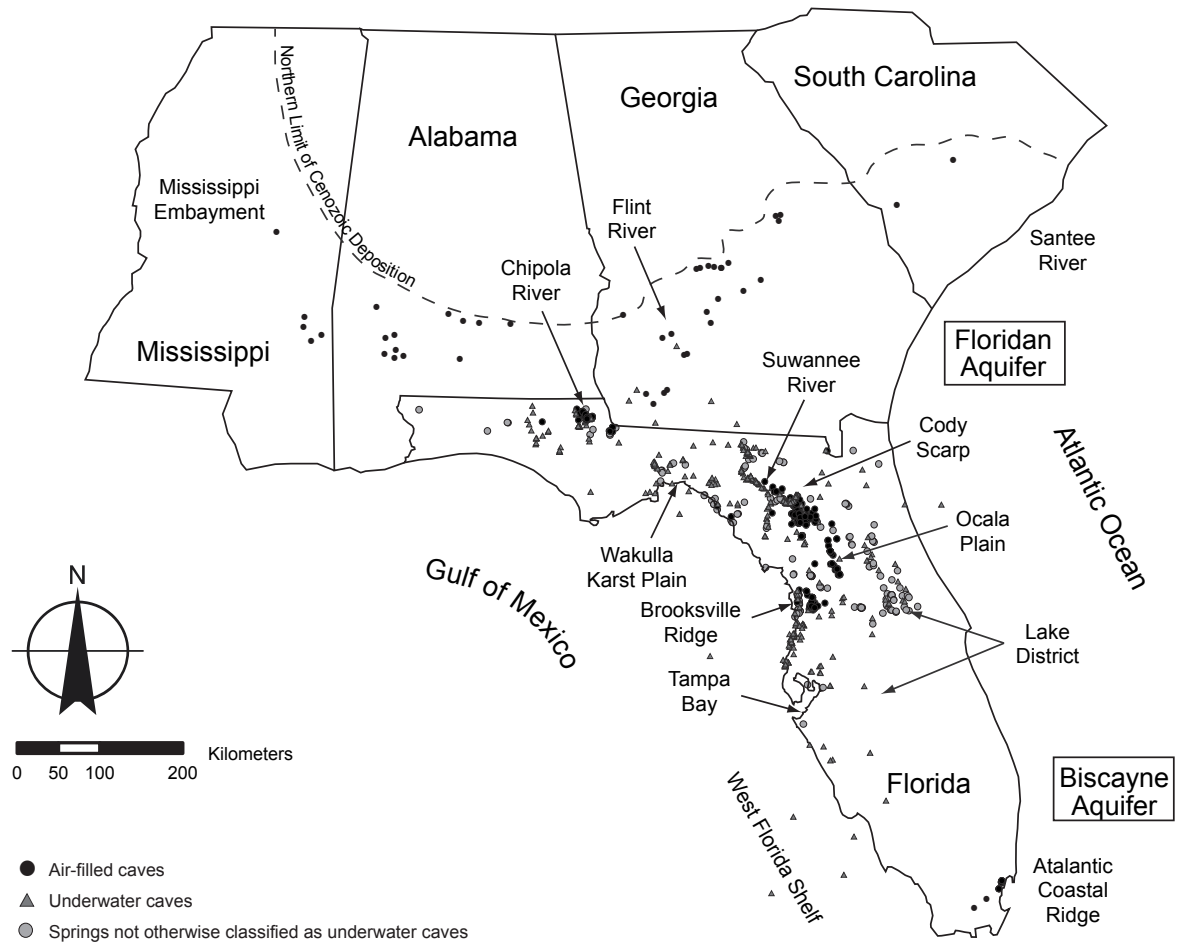


Figure 3.3. Location of springs and caves in the southeastern U.S.

correlative and are dominated by skeletal-peloidal packstone and grainstone. Each sequence contains two or three depositional cycles and each sequence is bound by a transgressive surface (Figure 3.4). The fauna is diverse and indicative of open marine conditions. The large benthic foraminifera *Nummulites* and *Lepidocyclina* dominate, but other common organisms are found including smaller benthic foraminifera, bryozoa, mollusks, large echinoids, some red algae, and rare solitary corals.

The Suwannee Limestone was deposited on a shallow, moderate- to high-energy carbonate platform (Hammes, 1992). It contains three depositional cycles, each of which is composed of a varying number of higher frequency depositional cycles. Grainstones dominate the Suwannee, with individual grainstone bodies up to 30 m thick. They generally consist of

varied mixtures of skeletal and peloidal grains of various origins. Packstones constitute most of the remaining facies; mud-supported fabrics are rare. The fauna is generally open marine and diverse but dominated by bryozoa, red algae, benthic foraminifera, mollusks, and echinoids.

Subaerial exposure surfaces, indicating periods of lower sea level, are common in the limestones of Florida, as are paleokarst features associated with these surfaces. Of particular importance is the mid-Oligocene unconformity at the top of the Suwannee Limestone as it marks the end of 100 million years (Ma) of nearly continuous carbonate deposition in the Florida peninsula. Where the Suwannee is confined in south Florida, the exposure surface is associated with varying amounts of rhizoliths, caliche, karst breccia, red-stained surfaces, pedogenetically altered limestones, infiltrated sediment, and

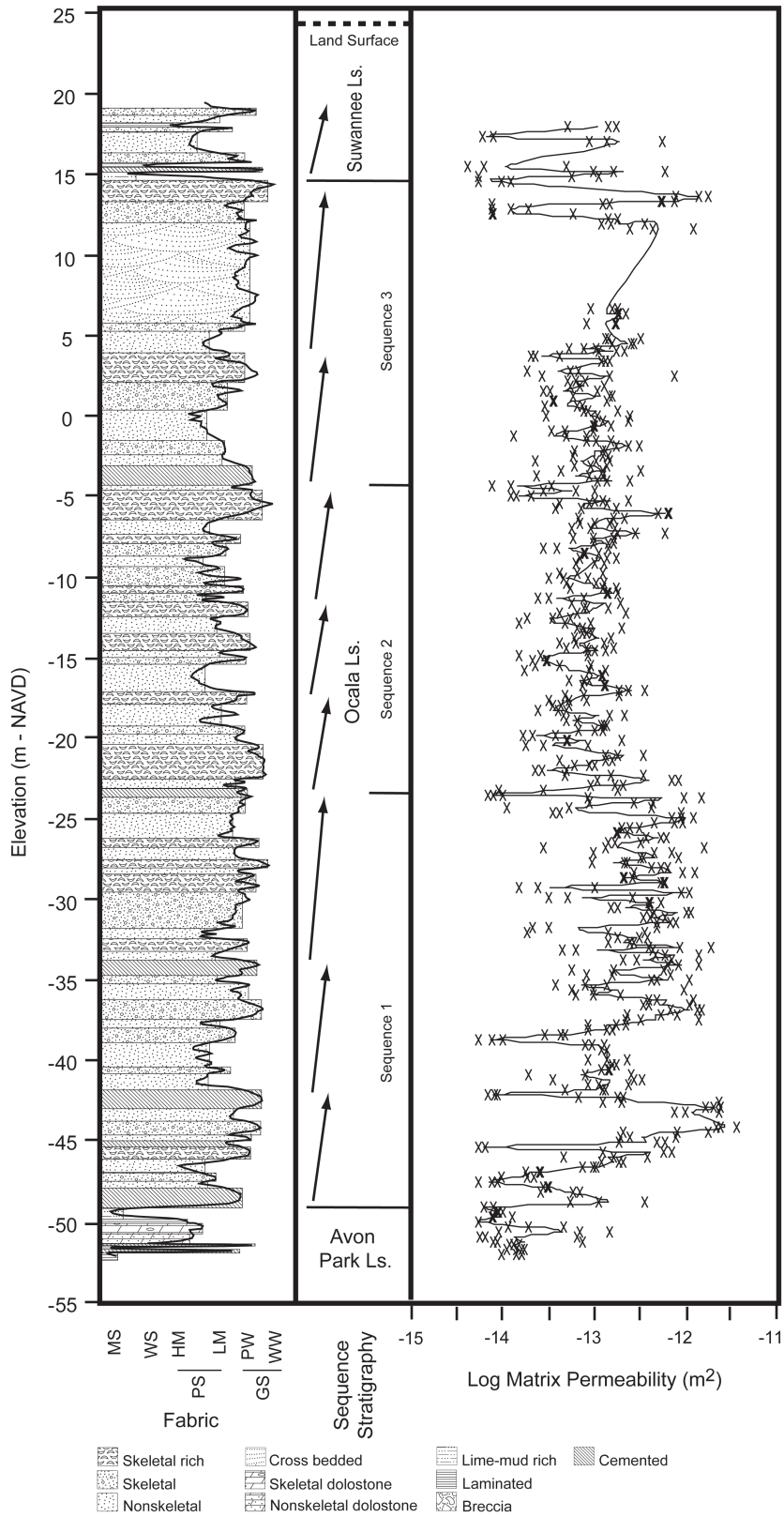


Figure 3.4. Elevation log that includes depositional fabric and lithology, sequence stratigraphy, and matrix permeability for a core at Radar Hill in Citrus County, Florida.

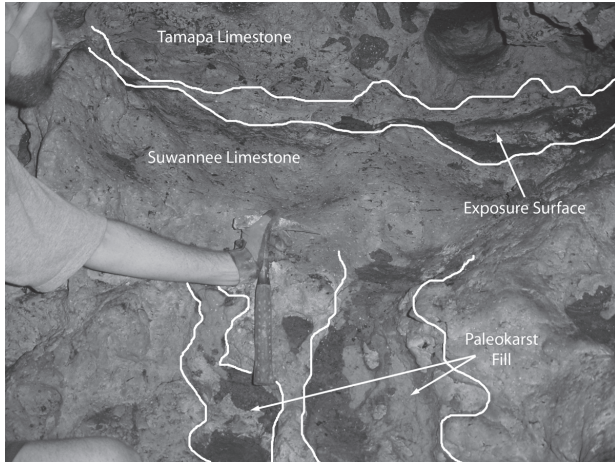


Figure 3.5. Exposure surface at the contact between the early Oligocene Suwannee Limestone (below) and the late Oligocene Tampa Limestone (above) within Rivard Cave in Southern Hernando County. Note the mid-Oligocene paleokarst in the form of solution pits within the Suwannee Limestone that are filled with silts and clays from the time period of the exposure surface (photo by Dorien McGee).



microkarst (Budd et al., 2002; Figure 3.5). On the depositional high of the Ocala Platform, however, the Suwannee Limestone has been partly or entirely removed and late Oligocene and early Miocene siliciclastic sediments fill large sinkholes and solution-enlarged fractures that penetrate deep into the Ocala Limestone (Yon and Hendry 1992; Florea et al., 2007; Figure 3.6). These paleokarst deposits often include paleontological remains of vertebrates 24-29 Ma in age (Morgan and Czaplewski, 2003).

Several generations of Miocene and younger karst features are present in Florida. The origin of these paleokarst features is tied to the complex sea level history during the past 30 million years. Younger sediments fill many of the older features. Others remain open as caves. Deciphering the multigenerational history of Florida karst is a complex undertaking and it is far from complete (Florea et al., 2007; Figure 3.7).

Hydrology and Climate of Florida Karst

Florida karst is broadly characterized as eogenetic karst (Florea, 2006) because the limestones retain significant primary porosity and permeability (Vacher and Mylroie, 2002), with porosities as high as 30-40% (Budd and Vacher, 2004) and permeabilities of the rock matrix ranging between 10^{-11} and $10^{-14.5}$ m² (Florea and Vacher, 2006; Budd and Vacher, 2004). This contrasts with the Paleozoic, telogenetic limestones of the Mammoth Cave region, where the limestone porosity averages 2-3% and the matrix permeability is on the order of $10^{-17.7}$ m² (Worthington et al., 2000).

Eogenetic karst primarily occurs in modern or geologically recent carbonate depositional environments in tropical to subtropical latitudes. The climate characteristics of eogenetic karst

Figure 3.6. Paleokarst in the form of chert fill within a solution enlarged fracture within the Eocene Ocala Limestone. The early Oligocene Suwannee Limestone was entirely removed during the late Oligocene and the early Miocene, and is the inferred date for this paleokarst feature near Belleview in southern Marion County (photo by Jason Polk).

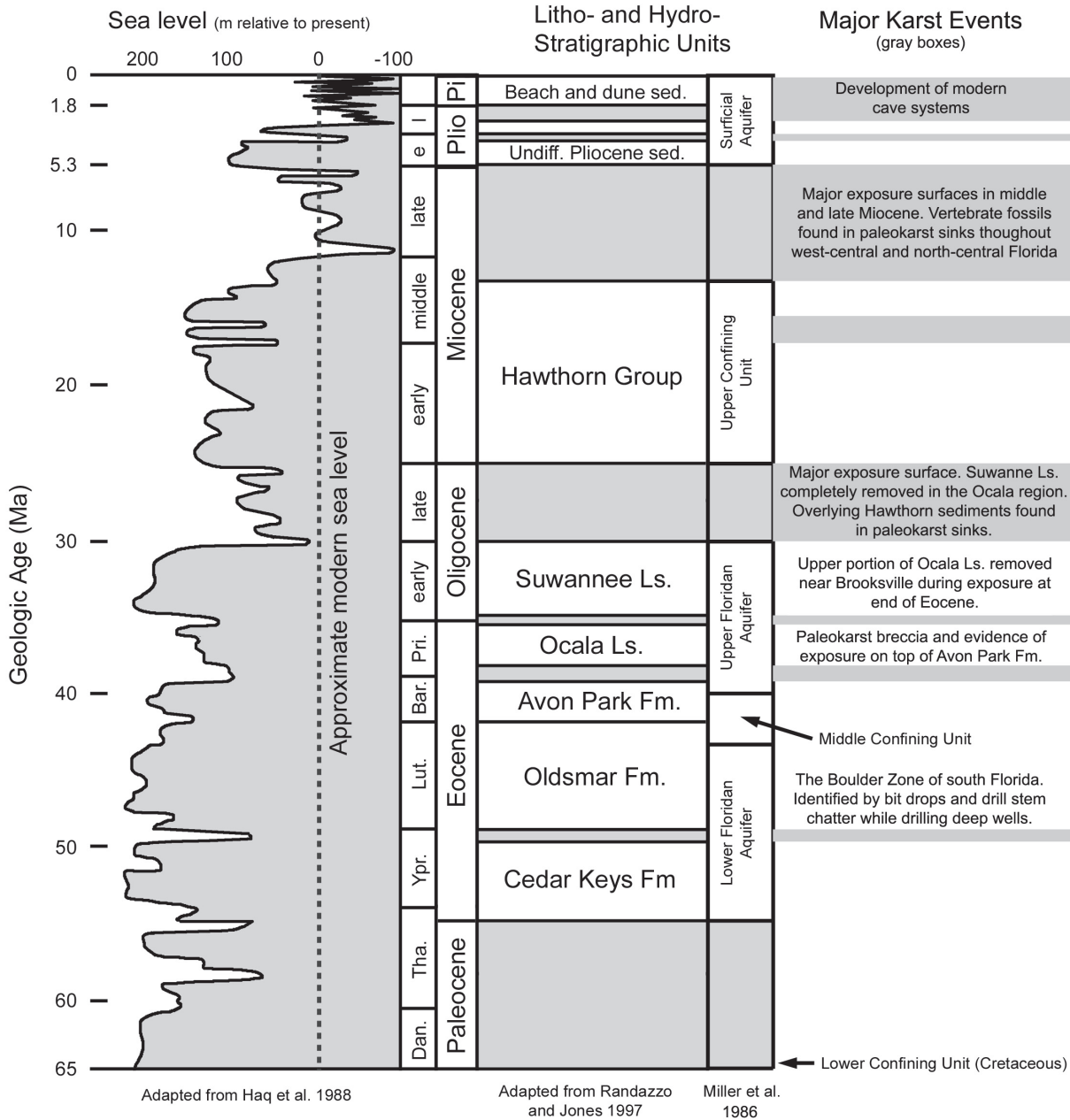


Figure 3.7. Geologic time scale with relative sea level, stratigraphic units, and major karst events on the Florida Platform.

reflect low-latitude locations and proximity to warm marine water. Rainfall is seasonal, with intense but short-lived convective thunderstorms during the summer, infrequent tropical cyclones during the late summer and early fall, and a dry season that typically lasts from December to May.

The geologic and climatic distinctions of eogenetic karst are apparent in the hydrology of the Floridan aquifer. For example, it cannot be assumed that the storm events during

the rainy season equate to aquifer recharge. Evapotranspiration of rainfall is huge, perhaps as high as 90% during the summer (Martin and Gordon, 2000). The common, convective-style rain events during the summer do not appear as independent peaks in the hydrographs at many west-central and north-central Florida springs (Florea and Vacher, 2007). Rather, the hydrographs show smooth, seasonal or longer-period cycles (Florea and Vacher, 2006). In contrast, infrequent, large, and widespread

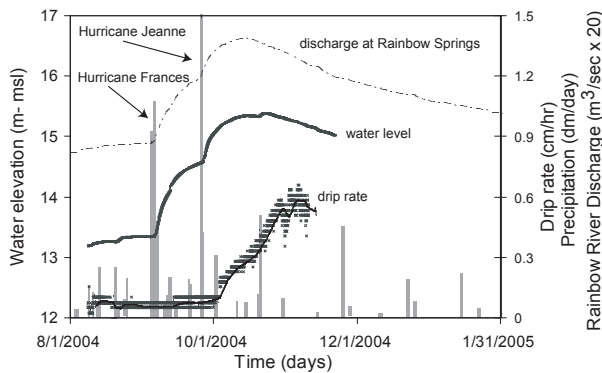


Figure 3.8. Daily precipitation (dashed line) and hourly water level measurements (thick solid line) in Briar Cave near Ocala in Marion County. Daily discharge measurements at Rainbow Springs is shown by the dash-dot line. Hourly, in-cave, drip-rate data at Briar Cave are shown as individual data points. The thin, solid line is a 3-day moving average through the drip-rate data. Note that the water-level and drip-rate data have incomplete records due to problems with the instrumentation.

storms, such as hurricanes, do appear as identifiable events in water level and spring discharge data and appear to be the principal contributor to changes of storage within the Floridan aquifer. For instance, water levels in the unconfined Floridan aquifer have been observed to rise more than two meters during the weeks following rainfall from hurricanes (Florea and Vacher, 2007; Figure 3.8).

During infrequent and widespread storms, recharge to the unconfined Floridan aquifer occurs simultaneously in caves and in the limestone matrix over large distances (Florea and Vacher, 2007). Water chemistry further indicates that water exchanges freely between caves and the rock matrix (Martin and Dean, 2001). Both are a direct consequence of the high permeability of Florida limestones. Despite the ability of the rock matrix to transmit water, recharge to the unconfined Floridan aquifer appears to be strongly controlled by fractures in the epikarst and the vadose zone (Florea and Vacher, 2007).

The relationship between recharge, water level, and discharge in the unconfined Floridan aquifer reveals another important distinction

between Florida karst and epigenic karst elsewhere in the U.S. Outside of Florida, discrete recharge occurs through sinking streams and is transmitted via conduits to springs. In Florida, the points of recharge and discharge are separated and water courses through the limestone via a complex system of disjunct caves, solution enlarged fractures, and rock matrix at several horizons (Florea, 2006). This is not to say that sink and rise systems do not exist in Florida. There are certainly many examples of “underground river” caves in Florida, particularly along the Cody Scarp in the Florida panhandle and the north-central Florida aquifer (Upchurch, 2002), which include the Santa Fe River Sinks and Rise (Martin and Dean, 2001) and the Wakulla-Leon Sinks Cave System (Loper et al. 2005; Lane, 1986).

Caves in West-Central and North-Central Florida

Caves in the Paleogene, highly permeable, coastal-karst aquifers of west-central and north-central Florida differ substantially from caves elsewhere in the U.S., especially from those in the ancient, low permeability limestones of inland karst regions like Mammoth Cave (e.g., Palmer, 2007). Two aspects of those differences are cave morphology and cave levels. For this discussion, examples of cave morphology and cave levels in west-central and north-central Florida will illustrate important components of a conceptual model for how caves organize within the unconfined Floridan aquifer.

Cave morphology

Cave exploration in west-central and north-central Florida has revealed that many cave passages are wider than they are tall and contain pillars of rock that have not dissolved (Florea, 2006). The walls of the cave passages are complex with cusped, pocket-like, or taffoni-like structures (Figure 3.1 and 3.9). Rose diagrams of cave passage orientations demonstrate a preferred alignment along a regional set of NW-SE and NE-SW fractures (Florea, 2006; Figure 3.10). Passages along fractures may have a vertical,



Figure 3.9. Robert Brooks preparing to dive in the Tangerine Entrance of Thornton’s Cave in western Sumter County. Note the complex solution sculpting of the walls (photo by Tom Turner).

fissure-like component to their morphology. Links between fracture-oriented passages are commonly low and wide (Figure 3.11). Some caves exhibit a morphology that resembles the three dimensional spongework found in the hypogenic caves of the Guadalupe Mountains of New Mexico (Hill, 1987) or the flank margin caves found on young carbonate islands (Mylroie and Carew, 1995).

Maps of air-filled caves in west-central Florida (Florea, 2006) have shown that passage soften group into dense network mazes, such as at Warren Cave (Krause, 1967). In contrast,

tributary networks linking sinking streams to springs are rare, even in large underwater cave systems that extend for miles. With few exceptions, air-filled caves do not extend great distances. Low and wide passages pinch into low crawlways. Fissure-type passages thin into narrow fractures. Sediments and structural collapses commonly block further exploration. Because of the lack of sinking streams, connections between the caves and the land surface are limited. Natural cave entrances are frequently solution enlarged fissures. Many caves are discovered because they are encountered during alteration of the land surface, particularly from limestone quarrying.

Underwater caves are often much larger than their air-filled counterparts. The average passage cross-section in air-filled caves rarely exceeds 10 m². However, the largest tunnels in the underwater caves may have a cross-section three orders of magnitude larger, or greater than 1000 m², such as at the underwater caves in Hernando County - Eagles Nest, Dipolder, Twin-Dees, and Weeki Wachee Springs.

Cave levels

Changing sea levels have a great influence in this coastal environment. In the recent geologic past, locations less than 22 m above modern sea level were flooded, and much of west-central Florida was a shallow sea. During these times, the Brooksville Ridge possibly became an archipelago

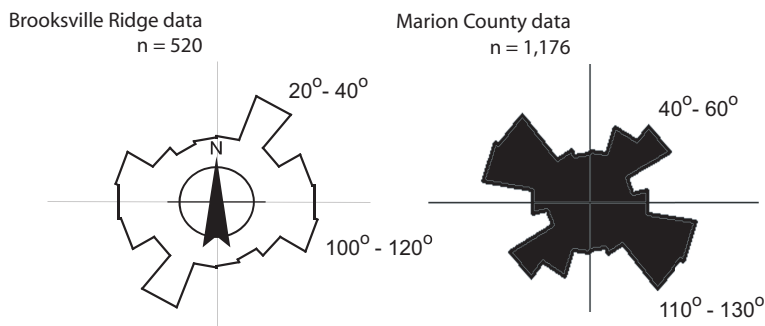


Figure 3.10. Length-weighted rose diagrams for the orientation of all segments of cave survey obtained from caves in the Brooksville Ridge (left) and from 14 caves in Marion County to the north and east. The data from this study reveal a regional WNW-ESE (100°-120°) and NNE-SSW (20°-40°). Both are related to regional fracture sets.

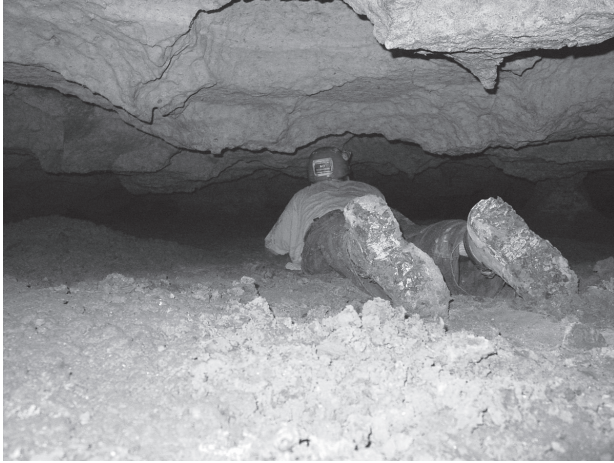


Figure 3.11. Bill Walker in a low and wide passage within Busted Well Cave near Ocala in Marion County (photo by Sean Roberts).

of islands and the cities along the Cody Scarp, such as Ocala and Gainesville, would have been located along the paleo-shoreline. In contrast, during the last ice-age, global sea levels were about 125 m lower than at present. During this ice-age, the Florida Peninsula was twice as wide and the coast was about 200 km further west of its present location. At that time, the present day springs and many of the submerged caves in west-central and north-central Florida were dry and in the center of the exposed peninsula.

Periods of stationary sea level appear to be archived in the caves of west-central Florida. Throughout the air-filled caves of the Brooksville Ridge, for example, detailed surveys reveal levels of passage at 3-5 m (Werner Cave – Citrus County), 12-15 m (Blowing Hole – Citrus County), and 20-22 m (Brooksville Ridge Cave – Hernando County) above modern sea level (Florea et al., 2007; Figure 3.12). Along the Cody Scarp, an additional, higher level of passage is found at 30 m above modern sea level – such as at Warren Cave in Alachua County. These air-filled cavities align with nearby geomorphic terraces (Cooke, 1931; Healy, 1975), which suggest cavity formation during higher paleo-altitudes of sea level and water table. Similarly, passages in underwater caves and cavities in drilled wells cluster at depths of 15 m, 35 m, 70 m, and 90-120 m below the modern water table (Florea et al., 2007; Figure 3.12). The major underwater

discoveries made in 2007 at Weeki Wachee Springs, for example, have revealed massive caverns to depths of 123 m. The depths of underwater cave levels in Florida generally agree with marine terraces submerged in the Gulf of Mexico identified using multi-beam bathymetry (Florea et al. 2007; Figure 3.12), which formed at previously lower sea levels and water tables.

Conceptual model of Karst in Florida

Figure 3.13 is a present conceptual model of where cavernous porosity occurs within the unconfined Floridan aquifer of west-central and north-central Florida. There are five components to the model:

a. At the largest scale, the caves organize along paleo-water tables that cut across geologic structure (Florea et al., 2007). However, at the scale of an individual cave, variations in the depositional permeability of the eogenetic limestones (Budd and Vacher, 2004) appear to influence passage morphology, such as at Floral City Cave in Citrus County where a horizon of low-wide passage is inclined to the modern water table (Figure 3.14). It appears possible, indeed likely, that cave levels can step between various favored intervals within the stratigraphy (Klimchouk, 2003).

b. The levels in air-filled caves occur at consistent elevations above modern sea level over widespread areas and align with nearby geomorphic terraces. For example, Brooksville Ridge Cave in Hernando County and Briar Cave in Marion County, separated by more than 35 miles, both have low-wide passages at an elevation of 20-22 m. These air-filled passages reflect higher sea levels. The shoreline was close, sea level and the water table were nearly coincident, and they organize according to a sea level datum. They represent a single generation of cave development.

c. The submerged caves reflect lower sea levels and organize according to depth below the modern water table (Florea et al., 2007). The paleo-shoreline was much further away at the time the level of passage formed along a sloping

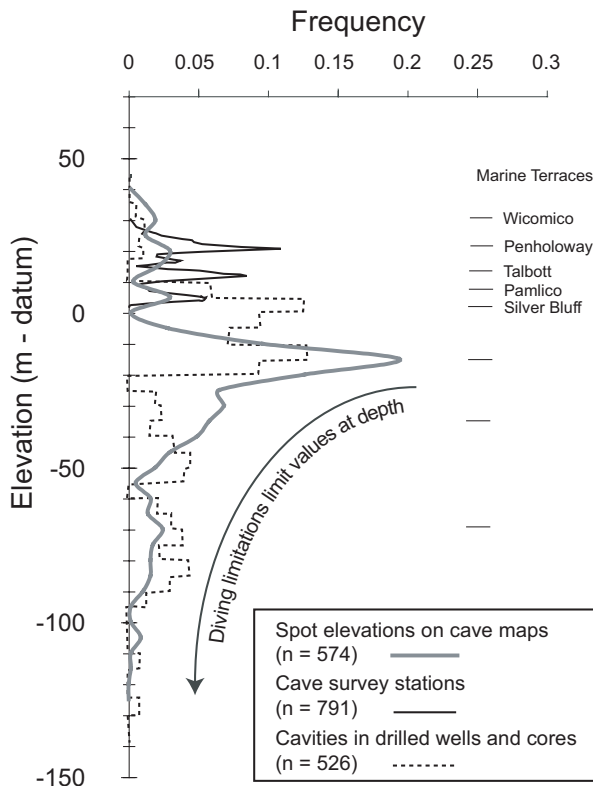


Figure 3.12. Histogram of elevations relative to datum of surveyed passages in 9 caves within the Brooksville Ridge, spot elevations in underwater caves, and cavities in drilled wells (Florea et al., 2007). The horizontal marks to the right compare these topographic elevations of geomorphic terraces of Cooke (1935) and bathymetric elevations of marine terraces in the Gulf of Mexico (Florea et al., 2007).

paleowater table. This effect is illustrated by a specific example: the case of Twin-Dees Cave vs. Peacock Springs. Both caves contain a prominent level of passage at a water depth around 15 meters. However, the water table at Twin-Dees Cave, which is near the modern shoreline of Hernando County, is near sea level. The water table at Peacock Springs, in Suwannee County 150 km north and approximately 70 km inland, is at nearly 15 meters.

d. Because paleo-water tables are not horizontal surfaces – they are at higher elevations inland than at the shore – some cave levels at or below the modern water table may represent multiple generations of passage development. This may be the case at some air-filled caves,

such as Floral City Cave, Thornton's Cave in Sumpter County, and the lower level of Briar Cave in Marion County. All of these caves occur at a similar elevation, 12-15 meters above sea level, yet remain partially flooded in the modern configuration of the water table (Figure 3.15). The deeper, underwater caves most certainly represent multiple generations of solution history, which may partially explain their greater size.

e. Finally, a single paleo-water table can pass through cave levels associated with different sea-level stands. Such stair-stepping occurs because later water tables reoccupy zones dissolved by earlier water tables. As a result, the present water table can pass through caves at a higher elevation further inland near the Cody Scarp than beneath the Brooksville Ridge, while at the same time connecting to modern sea level at the present shoreline (Figure 3.13). A great example of this process is seen at Finch's Cave in Marion County, where the modern water table has reoccupied a cave passage at 15 meters above sea level. Calcite crusts deposited on the walls of Finch's Cave at an earlier time in the cave's history are being dissolved by the present day water table (Figure 3.16).

Hazards Assessment and Resource Management of Florida Karst

Sinkholes

Rapid urbanization has characterized Florida development since the 1950s and an estimated 1000 new residents move to Florida each day. With urbanization has come an increase in groundwater consumption. Currently, more than 90% of 18-million Florida residents rely upon groundwater (Scott et al., 2004), particularly from the vast underground reservoir of the upper Floridan aquifer that yields an estimated 1.1×10^{10} liters of fresh water per day (Miller, 1986).

Concurrent with increased pressures for developable land and greater groundwater withdrawals is an increase in the report of sinkhole collapses, particularly in Pasco and

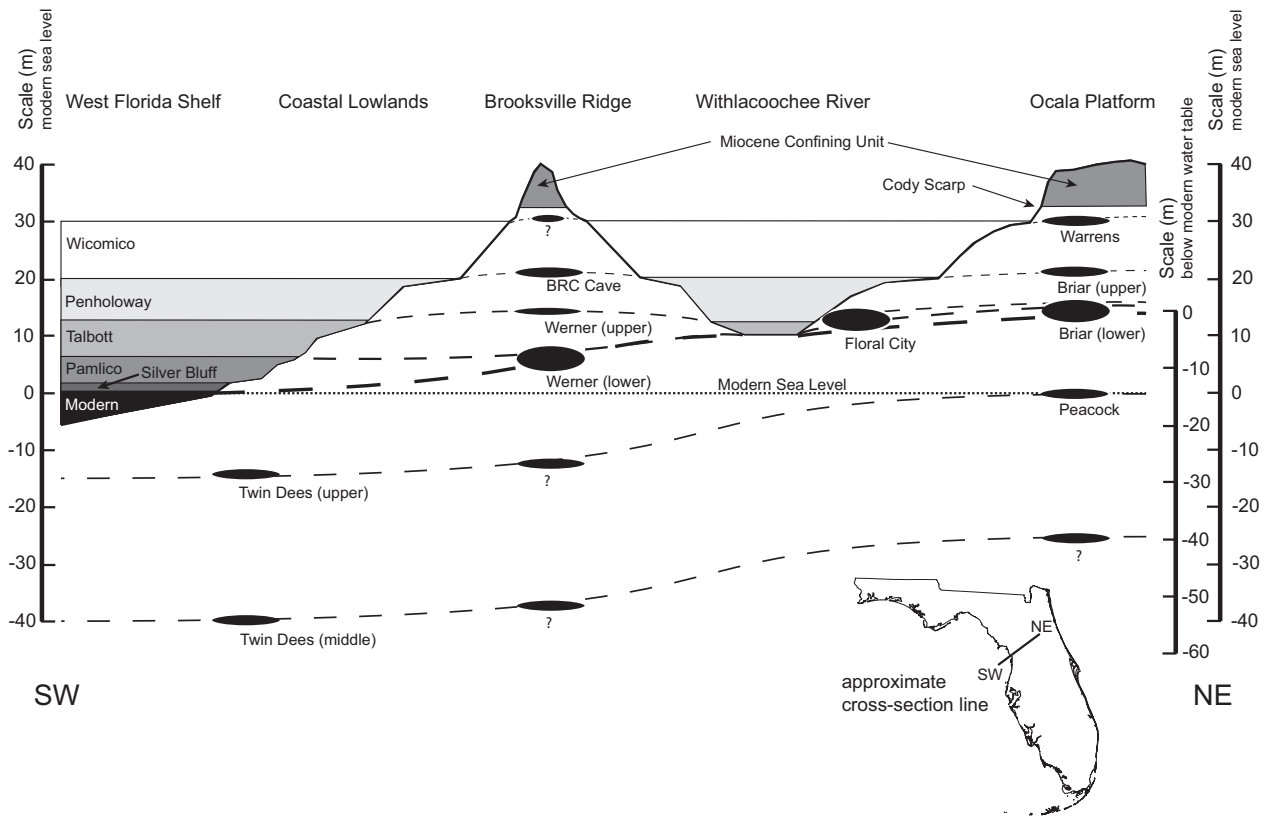


Figure 3.13. Concept sketch of how the cavernous porosity in the upper part of the Floridan aquifer of west-central Florida connects to paleo-water tables and paleo-shorelines. Index map at lower right indicates the approximate location of the vertically exaggerated cross-section that is not to scale. Note that the Withlacoochee River runs generally north-south through the cross-section and divides the uplands of the Brooksville Ridge from the Cody Scarp and the Ocala Platform. Paleo-sea levels relative to Cooke’s terraces are identified. Black ovals identify cavernous horizons. Some ovals are labeled with representative cave names from the text or figures; however, these caves do not necessarily align along the cross-section. Dashed lines indicate paleo-water tables that intersect the caves. Note that multiple paleo-water tables may occupy some cavernous horizons, as in the case of the lower level of Briar Cave. Also note that the paleo-water tables are not horizontal surfaces. Rather, they grade to their contemporaneous paleo-shorelines. The inflection in the paleo-water tables beneath the Withlacoochee River reflects recharge to the Floridan aquifer by the river and reduced permeability in the aquifer caused by sediments that infiltrate karst features in the river bed.

Hernando Counties on the Gulf coast and in the metropolitan Orlando area (Tihansky, 1999; Figure 3.17). Sinkhole and other subsidence-related phenomena caused more than 100 million dollars in structural damage in Florida in 1997 and damage estimates continue to increase every year.

By 2006, many homeowners saw their property insurance premiums triple. Many insurers have ceased writing homeowner policies in the state (hurricanes have significantly influenced this trend), leaving many with a state-funded, high-risk insurer-of-last-resort, Citizen’s

Insurance. The direct threat to personal property caused by sinkhole phenomena drives a high level of government and public interest in Florida about sinkhole processes. As the occurrence of sinkhole collapses increase, so do the number of engineering firms, environmental consulting companies, and law offices established solely for evaluation and intervention of sinkhole damage.

In the case of dramatic cover-collapse sinkholes, investigations are simple and the cause of karst activity is obvious. On the other hand, the vast majority of damage is caused by the subtle settling of the ground through the raveling of

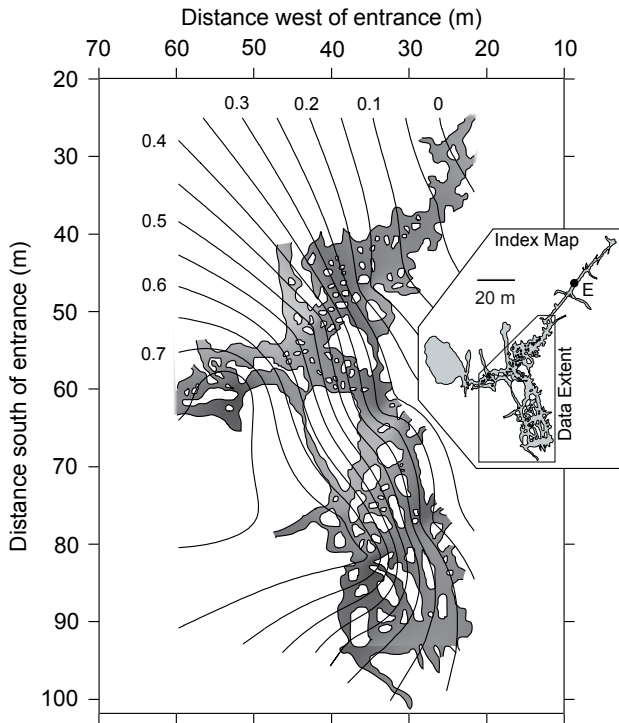


Figure 3.14. Map of a portion of Floral City Cave in eastern Citrus County (see index map inset). Contours on the map designate the elevation of a 1.5-foot tall laterally continuous horizon with respect to a water table datum of 10.8 m above sea level. The contour interval is 0.05 m. The northern and eastern sections of the cave are principally tall, narrow fractures where the laterally continuous horizon plunges beneath the level of passage.

sands into cover-subsidence sinkholes. In these cases, the ground motion is imperceptible and the damage that results manifests as cracks in walls or foundations, doors that will not close, or even floors that are no longer level. For a more-definitive determination in the cover-subsidence cases, detailed fieldwork including geophysical surveying is required. Of particular use are methods that utilize shallow seismic techniques, measure electrical resistivity (Dobecki and Upchurch, 2006), and employ ground-penetrating radar (Kruse et al., 2006).

Springshed Protection

Freshwater discharge from springs in the upper Floridan aquifer has been a ubiquitous part of human life in Florida. Native cultures established communities on spring runs, such as at the Crystal River Archeological Site. Modern towns, like Dunellon, Tarpon Springs, Silver Springs, and High Springs, grew astride their supply of freshwater. Water quality data from many springs in Florida, however, reveals unnerving trends. Nitrate levels have increased primarily as a result of anthropogenic pollution such as fertilizers for lawns, golf courses, and citrus groves (Scott et al., 2004). Chlorides and sulfates have also increased, particularly along the



Figure 3.15. A portion of passage in Thornton's Cave in western Sumter County. This cave is at an elevation of 15 meters and is occupied by the modern water table. Water from the cave discharges into the adjacent Withlacoochee River (photo by Alan Cressler).



Figure 3.16. A portion of the wall of Finch's Cave near the city of Belleview in southern Marion County. Notice the remnants of a calcite crust. The modern water table has reoccupied the cave and is dissolving the crust, which was deposited at a time when the water table was much lower (photo by Jason Polk).

coast where salt-water intrusion occurs (Scott et al., 2004). Changes in water chemistry at Florida springs greatly reduce species biodiversity and are a primary cause of algae blooms.

The protection of the quality of spring water in Florida has become a very important cause with many stakeholders. Government entities, such as the Florida Department of Environmental Protection and the National Forest Service, protect dozens of major springs in Florida. Additionally, major bottling companies, such as Nestle, Dannon, and Coca-Cola, market Florida spring water around the nation. Finally, more than 1 million visitors spend \$65-million per year at the parks that protect Florida's four largest springs (Bonn and Bell, 2003).

In part because of these economic pressures, the Florida Department of Environmental Protection with support of the Florida Legislature founded the Florida Springs Initiative and Task Force in September of 1999 and in 2001 allocated 2.5-million dollars in research funding (Scott and Means, 2003). Much of this money has been spent delineating recharge areas for major springs and identifying sources of pollution (Scott and Means, 2003). However, the Florida Geological Survey and the Florida Cave Survey have both begun to compile and archive information on

previously known and newly discovered caves.

Operating independently and in cooperation with the Springs Task Force, Florida cavers, scientists, and citizens have made major strides toward the protection of surface and subsurface karst resources. With these conservation efforts, we anticipate that the Florida Cave Survey will grow far beyond the 1,900 caves and springs presently listed in the database. Our knowledge concerning the integral role of these caves in the upper Floridan aquifer and their role in the unique ecosystems of Florida will also most certainly grow.

References

- Bonn, M.A., and F.W. Bell, 2003. Economic impact of selected Florida springs on the surrounding local areas. Report for the Florida Department of Environmental Protection, Division of State Lands, Florida Springs Task Force.
- Budd, D.A., and Vacher, H.L., 2004. Matrix permeability of the confined Floridan Aquifer. *Hydrogeology Journal* 12(5): 531-549.
- Budd, D.A., Gaswirth, S.B., Oliver, W.L., 2002. Quantification of macroscopic diagenetic subaerial exposure features in carbonate rocks. *Journal of Sedimentary Research* 72: 917-928.



Figure 17. Sinkhole at Winter Park, Florida near Orlando that formed catastrophically in one day in 1981 (United States Geological Survey photo).

- Cooke, C. W., 1931. Seven coastal terraces in the Southeastern States. *Washington Academy of Sciences Journal* 21, 503-513.
- Cunningham, K.J., Renken, R.A., Wacker, M.A., Zygnerski, M.R., Robinson, E., Shapiro, A.M., Wingard, G.L., 2006. Application of carbonate cyclostratigraphy and borehole geophysics to delineate porosity and preferential flow in the karst limestone of the Biscayne aquifer, SE Florida.. In: *Perspectives on Karst Geomorphology, Hydrology, and Geochemistry* (R. S. Harmon and C. M. Wicks, eds.), Geological Society of America Special Paper 404, 191-208.
- Dobecki, T.L., and Upchurch, S.B., 2006. Geophysical applications to detect sinkholes and ground subsidence. *The Leading Edge* 25: 336-341.
- Florea, L.J., 2006. The morphology of air-filled caves within the karst of the Brooksville Ridge, west-central Florida. *Journal of Cave and Karst Studies* 68(2): 64-75.
- Florea, L.J., and Vacher, H.L., 2006. Springflow hydrographs: Eogenetic vs. telogenetic karst. *Ground Water* 44,(3): 352-361.
- Florea, L.J., and Vacher, H.L., 2007. Hydrology of eogenetic karst illustrated by the 2004 hurricanes, Florida.. *Ground Water* 45(4): 439-446.
- Florea, L.J., Vacher, H.L., Donahue, B., Naar, D., 2007. Quaternary cave levels in peninsular Florida. *Quaternary Science Reviews* 26: 1344-1361.
- Hammes, U., 1992. Sedimentation patterns, sequence stratigraphy, cyclicity, and diagenesis of Early Oligocene carbonate ramp deposits, Suwannee Formation, southwest Florida. PhD thesis, University of Colorado, Boulder, Colorado.
- Haq, B.U., Hardenbol, J., Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. In: (Wilgus, C.K., Hastings, B.S., Posamentier, H., Wagoner, J.V., Ross, C.A. Kendall, C.G.ST.C., eds.) *Sea-level changes: an integrated approach*. Society of Economic Paleontologists and Mineralogists, Special Publications 42, pp. 71-108.
- Healy, H.G., 1975. Terraces and Shorelines of Florida.. Florida Bureau of Geology Map Series 71.
- Hill, C.A., 1987. Geology of Carlsbad Caverns and other caves in the Guadalupe Mountains, New Mexico. New Mexico Bureau of Mines and Mineral Resources Bulletin 117, 150 p.
- Hine, A.C., 1997. Structural and Paleogeographic Evolution of the Margins of the Florida Platform. In: *The Geology of Florida* (A. F. Randazzo and D. S. Jones, eds.), Gainesville, University Press of Florida, pp. 169-194.
- Klimchouk, A., 2003. Conceptualization of speleogenesis in multi-story artesian systems: a model for transverse speleogenesis. *Speleogenesis and Evolution of Karst Aquifers* 1(2): 1-18.
- Krause, A.A., 1967. Warren Cave, Alachua County, Florida. *Florida Speleologist* 4(1): 16.
- Kruse, S., Grasmueck, M., Weiss, M., Viggiano, D., 2006. Sinkhole structure mapping in covered karst terrain. *Geophysical Research Letters* 33: L16495 doi 10.1029/2006GLO16975.
- Lane, E. 1994. Florida's Geological History and Geological Resources. Florida Geological Survey Special Publication 35.
- Lane, E., 1986. Karst in Florida: Florida Geological Survey Special Publication no. 29, 100 p.
- Loizeaux, N.T., 1995. Lithologic and hydrogeologic framework for a carbonate aquifer: evidence for facies-controlled hydraulic conductivity in the Ocala Formation, West-Central Florida. MS Thesis, University of Colorado, Boulder, Colorado, 125 p.
- Loper, D.E., Werner, C.L., Chicken, E., Davies, G., Kincaid, T., 2005. Coastal carbonate aquifer sensitivity to tides: EOS Transactions, American Geophysical Union, v. 86, p. 353, 357.
- Martin, J.B., and Dean, R.W., 2001. Exchange of water between conduits and matrix in the Floridan aquifer. *Chemical Geology* 179(1-4): 145-165.

- Martin, J.B., and Gordon, S.L., 2000. Surface and ground water mixing, flow paths, and temporal variations in chemical compositions of karst springs. In: *Groundwater Flow and Contaminant Transport in Carbonate Aquifers* (I. D. Sasowsky and C. M. Wicks, eds) 65–92. Rotterdam, Netherlands: A.A. Balkema.
- Miller, J.A., 1986. Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina. United States Geological Survey Professional Paper 1403-B, 91 p.
- Morgan, G.S., and Caplewski, N.J., 2003. A new bat (Chiroptera: Natalide) from the early Miocene of Florida, with comments on Natalid phylogeny. *Journal of Mammology* 84(2): 729-752.
- Mylroie, J.E., Carew, J.L., 1995. Karst development on carbonate islands, Chapter 3. In: *Unconformities and porosity in carbonate strata* (D. A. Budd, P. M. Harris, and A. Saller, eds.), American Association of Petroleum Geologists Memoir 63: 55-76.
- Palmer, A.N., 2007. *Cave Geology*. Dayton, Cave Books, 454 p.
- Parker, G.G., Ferguson, G.E., Love, S.K., et al, 1955. Water resources of southeastern Florida, with special reference to the geology and ground water of the Miami area. U.S. Geological Water-Supply Paper 1255, 965 pp.
- Randazzo, A.F., Jones, D.S., 1997. *The Geology of Florida Gainesville*, University Press of Florida, 400 p.
- Scott, T.M., 1988. The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida. Florida Geological Survey Bulletin 59, 148 p.
- Scott, T.M., and Means, G.H., Meegan, R.P., Means, R.C., Upchurch, S.B., Copeland, R.J., Jones, J., Roberts, T., Willet, A., 2004. Springs of Florida. Florida Geological Survey Bulletin 66. Florida Geological Survey.
- Scott, T.M., Campbell, K.M., Rupert, F.R., Arthur, J.A., Missimer, T.M., Lloyd, J.M., Yon, J.W., Duncan, J.G., 2001. Geologic map of the State of Florida. Florida Geological Survey Map Series 146.
- Scott, T.M., Means, G.H., 2003. Geologists' role in defining public policy; the Florida Springs Initiative. *Abstracts with Programs - Geological Society of America* 35, no.1, 60.
- Tihansky, A.B., 1999. Sinkholes, West-Central Florida. In: *Land Subsidence in the United States*, Galloway D., Jones, D.R., Ingebritsen, S.E., eds., U.S. Geological Survey Circular 1182, 177 pp.
- Upchurch, S.B., 2002. Hydrogeochemistry of a karst escarpment. In: *Hydrogeology and Biology of Post Paleozoic Karst Aquifers* (J. B. Martin, C. M. Wicks, and I. D. Sasowsky, eds), Karst Frontiers, Proceedings of the Karst Waters Institute Symposium, p. 73-75.
- Vacher, H.L. and Mylroie, J.L., 2002. Eogenetic karst from the perspective of an equivalent porous medium. *Carbonates and Evaporites* 17(2): 182-196.
- Worthington, S.R.H., Ford, D.C, Beddows, P.A., 2000. Porosity and permeability enhancement in unconfined carbonate aquifers as a result of solution. In: *Speleogenesis: evolution of karst aquifers*. National Speleological Society, 463-472.
- Yon, J.W., Hendry, C.W., 1972. Suwannee Limestone in Hernando and Pasco counties, Florida; part I: Florida Bureau of Geology Bulletin 54, 42 p.