KARST FEATURES OF FLORIDA CAVERNS STATE PARK
AND
FALLING WATERS STATE REcreation AREA;
JACKSON AND WASHINGTON COUNTIES, FLORIDA

BY

GARY L. MADDOX

November 13, 1993
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INTRODUCTION

Florida Caverns State Park and Falling Waters State Recreation Area were both initially established to preserve unique geological features in the Florida panhandle. The centerpiece of each park is a major cave or cave system.

Both parks are within the Marianna Lowlands geomorphic province (after White, Puri and Vernon in Puri and Vernon, 1964)\(^1\). Uplift along the southern flank of the Chattahoochee Anticline has elevated the stratigraphic section; subsequent erosion has left south-dipping Tertiary limestones, thinly mantled by Plio-Pleistocene sands and clays, at or near land surface throughout northern Jackson and northeastern Washington counties. "Dry" caves (those not permanently below the water table) occur mostly within local topographic highs. These highs, limestone hills and ridges, are post-Tertiary erosional outliers. In the Marianna area, caves develop primarily in ridges of Crystal River limestone. These ridges are often capped by Marianna limestone, which is somewhat more indurated than the underlying Crystal River, acting as a "roof rock". Regional vadose karst features developed as ground water levels dropped due to lowering of the Chipola River valley through fluvial erosion and solution of underlying carbonates. The occurrence of known caves in the Marianna area roughly corresponds with the Oligocene Marianna limestone outcrop pattern.

Falling Waters Hill is one of a handful of erosional outliers in eastern Washington County, within the Holmes Creek watershed. Elevated carbonates of the Miocene Chattahoochee Formation and underlying Oligocene Suwannee Limestone provide the host rock, where solution has progressed downward along major vertical joints and fractures. These resulting vadose cave passages are deep for Florida, due to the thickness of limestone existing above the relatively low potentiometric surface of the upper Floridan aquifer system.

The observable natural geologic and hydrologic features in these parks provide geologists and the general public with direct examples of active karst systems, and can serve as a great educational tool.

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

Gary L. Maddox, P.G.
Florida Department of Environmental Protection
Tallahassee, 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 IN FLORIDA

Cave distribution by county is shown in Figure 1. From this map, one can see that Alachua County leads the state, with over 150 known caves. Jackson County is second, with about 80 known caves. These numbers reflect to some degree the intensity of exploration in known cave areas; other areas in adjacent counties may hold similar potential for new discoveries. Several new caves are found and mapped every year throughout Florida, mostly by cavers affiliated with organized chapters (grottos) of the National Speleological Society. An excellent summary of karst processes and features in Florida, including cave development, is presented by Lane (1986).

Major vadose cave development in Florida is associated with two positive regional structural features: the Ocala Arch and the Chattahoochee Anticline. A majority of the larger caves in Florida occur in these two areas (Figure 2). Caves found along the axis of the Ocala Arch are developed in Eocene Ocala Group limestones, and display a variety of morphological influences, including joint and bedding plane control. These caves are primarily the result of solution along vertical fractures and joints, extending downward to the water table. At this point, horizontal passages are developed at current or past elevations reflecting the juncture of the saturated zone with the vadose zone. Many of these lower horizontal passages contain pools of standing water, reflecting the upper potentiometric surface of the Floridan aquifer system. These caves and smaller karst conduits provide direct pathways for recharge to the aquifer. Most of these caves are relatively short lengthwise, and contain few
NUMBER OF KNOWN CAVES PER COUNTY WITH PASSAGE ABOVE MEAN WATER TABLE

- Updated by Gary Maddox from a map originally drafted by Florida State Cave Club, April, 1980

SCALE

FIGURE I - Distribution of Caves in Florida
Areas where Vadose Cave Passages are common

FIGURE 2 - Occurrence Areas of Vadose Caves in Florida
speleothems. Warren’s Cave (Alachua County), the longest known dry cave in the state (Table 1), occurs just east of the major peninsular cave zone. It is a modified network maze cave (White, 1988), developed within an anomalously thick carbonate zone in the Hawthorn Group.

**TABLE 1: Florida’s Longest "Dry" Caves**

| 1) Warren’s Cave, Alachua County | 6005 m (19,700+ ft) |
| 2) Boyer’s Discovery, Jackson County | 1219 m (4000 ft) |
| 3) Ellis Cave, Jackson County | 1097 m (3600 ft) |
| 4) Hollow Ridge Cave, Jackson County | 1006 m (3300 ft) |
| 5) Florida Caverns, Jackson County | 884 m (2900 ft) |

**SOURCE:** Pease, Young and Zymowski, 1993

Development of significant horizontal cave passage requires the existence of a gradient through which ground water must pass. This gradient can be dynamic, such as the steep elevational changes associated with phreatic cave development in the deep mountain caves of Mexico or along the margins of the Appalachian Plateau. In Florida, this gradient is much less dynamic, consisting of a chemical horizon at the local water table and extending upward along fractures and joints within the vadose zone. Chemical dissolution along vertical joints and horizontal bedding planes at and above the water table is the primary mechanism responsible for cave development. The process in Florida, though less dynamic in a physical sense, is very effective nonetheless, primarily due to the relatively granular and porous nature of the Tertiary limestones exposed in uplifted regions of the state.

**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 bryozoan 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 3). 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.

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 (Figure 3). 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 advances of continental glaciation, when sea level and groundwater levels were lower, as evidenced by possible relict vadose features.
FIGURE 3 - Distribution of Some Major Karst Features in Jackson County, FL
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 4. 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.

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 manifest 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 multilevel 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.
Caves of Florida Caverns State Park
Jackson County, Florida

Tape, compass and inclinometer surface survey made from 1979 - 1985 by members of the FLORIDA STATE CAVE CLUB, Grotto 176 of the National Speleological Society.

Bobby Hall's, Boyer's Discovery, China, Dragon's Tooth (historic), Dum, Florida Caverns, Little Miller's, Miller's, Pavilion, and Windy Crawl caves mapped by Dr. Paul Boyer and the FORT RUCKER-CZARK GROTTO of the National Speleological Society.

All-In, Alice extension of Bobby Hall's, Dragon's Belly portion of Dragon's Tooth, Frye's Bughole, Ool, Platform, Pottery, Wall's Misery and Yogi Bear caves mapped by members of the FLORIDA STATE CAVE CLUB.


Revised map digitized by Gary Maddox in October, 1993.

© 1993 by the Flint River Grotto of the National Speleological Society.

FIGURE 4

EXPLANATION

- Paved Road
- Unpaved Road
- Foot Trail
- Cave Passage
- Natural Bridge
- Rock Shelter
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 5) 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.

A good summary of the history and area geology of the Park can be found in Schmidt (1988).
FIGURE 5 - Planimetric Map of Florida Caverns
REFERENCES


Pease, Kenny, Kevin Young and David Zymowski (editors), 1993, The Rigamortis Report: newsletter of the Dead Caver's Society, Orlando, Florida; Volume 2, Number 1, p. 3.


NOTES ON KARST FEATURES WITHIN
FALLING WATERS STATE RECREATION AREA;
WASHINGTON COUNTY, FLORIDA

Gary L. Maddox, P.G.

The major attraction of Falling Waters State Recreation Area is the cave system, consisting of two mapped cave segments (North and South) accessed through numerous deep sinks on the south flank of Falling Waters Hill. Vernon (1942) was the first to describe the geology of the area in detail. Reves (1961) provides additional information on stratigraphy of the region. An excellent summary of the geology, stratigraphy and geomorphology of Falling Water Hill is provided in Rupert and Lane (1992).

The majority of the cave is developed within the upper part of the Oligocene Suwannee limestone. Cave passages are tall and narrow, and tend to follow three preferential orientations related to vertical joint or fracture orientation. The longest linear passages are developed along a N.50°W. strike. This is parallel to the general trend of the North Cave segment, as well as the direction of surface water flow. Steep-sided vertical shafts have developed. The second prevailing passage orientation is roughly north-south, and the third is approximately N.80°E.

Several steep-sided vertical shafts pierce the overlying Chattahoochee Formation and penetrate deep into the Suwannee Limestone. These shafts, for the most part, have developed at the intersection of two or more major vertical joints or fractures. Horizontal joint- or fracture-controlled cave passage usually changes direction at the point where two or more prevailing vertical joints or fractures intersect. Of fourteen non-passage terminating domes or vertical shafts shown in the North and South caves on the map (FIGURE 6), all but one occur where horizontal cave passage changes direction.

Cave system development appears to have occurred through vadose enlargement of existing joints and fractures. Both North and South caves contain flowing streams. Debris markings on cave walls indicate that the entire system floods during times of very heavy rainfall. Water flow is generally from east to west in the North Cave. Surface water enters through Falling Water Sing and flows generally west, where it disappears under the west wall of the terminal dome. Ground water in the South Cave flows generally southeastward. Inspection of the Wausau 1:24,000 topographic sheet discloses the existence of an apparent surface stream valley passing above and parallel to the general trend of the South Cave. It seems likely that the small stream which tumbles into the North Cave at Falling Water Sing was, at one time, a surface feature which was subsequently pirated underground. Although not yet proven, it seems likely that the North and South caves are hydrologically connected.
REFERENCES


FALLING WATERS CAVE SYSTEM

David O’Hara *

In November of 1983, the FSU Cave Club received permission from the Florida Department of Recreation and Parks to explore and map the Falling Waters Cave System. After three trips to Falling Waters, the exploration and mapping is almost complete. All that remains is a surface survey and checking a few small leads.

Falling Waters Cave System consists of ten interconnecting sinks, several being impressively deep by Florida standards. The Waterfall Sink was measured to be 73 feet deep, and there is one other about 60 feet deep. Passages between the sinks are very high, sometimes as high as 40 feet, and narrow - as little as one foot wide. The amount of vertical relief in this cave is also impressive. There are several places where a cable ladder is recommended. High domes in the cave may be indicative of future sinks.

Although most of the mapping has been accomplished, there are several "mop-up" operations to be done. In the northernmost part of the cave, the water flows northwest under a wall. Now that the water level is lower, we may be able to push this passage. Southeast of the Waterfall Sink is a small 18 foot chimney at the bottom of which is a tight lead that needs checking. At the bottom of the southernmost sink, a new hole has opened which may be small enough to enter. We need to do a surface survey of the stream to determine its relationship to the 73 foot dome at the extreme northern end of the cave system. There are also rumors of other nearby caves which need to be checked.

We agreed to provide the Department of Recreation and Parks with a map and any other useful information on the cave. In the southern section of the cave we have found that water exits through small cracks in the wall and floor. It was also found, by smell, that there may be a sewage pollution problem in the last dome in the lower level passage. A bat colony which used to inhabit this section of the cave was found to have been destroyed by flooding from spring rains.

We should recommend that the present restrictive entrance policy remain in effect because the sinks are dangerous to the inexperienced, and to prevent erosion of the sinks from excessive traffic. The status of the bat colony should be determined every now and then. There is obvious potential for other caves in this area.

After this article was written, we took another trip to Falling Waters at lower water. The Waterfall passage silted about ten feet beyond the 73 foot dome. We dug through a small opening at the floor of the dome and found a small room 21 feet high by 5 feet wide by 12 feet long. There did not appear to be any more passage we could get into without a lot of digging. The 18 foot sink was dropped. There are two very small passages at the bottom. One of these seems to run toward the splay shot
in the main passage on the map but was too small to enter.

* Reprinted from *The Florida State Caver*, Volume 15, Number 4, Summer, 1984. David O’Hara (NSS 24586) spearheaded the Falling Waters Cave System mapping project, begun in November, 1983 by the Florida State Cave Club. The final map was drafted from Dave’s map by the staff of the Florida Geological Survey.
RADON CONCENTRATION MEASUREMENTS OF AIR SAMPLES TAKEN FROM CLIMAX CAVE, GEORGIA AND CAVES WITHIN FLORIDA CAVERNS STATE PARK, FLORIDA

Gary L. Maddox, P.G.

INTRODUCTION

Radon retention in caves is well documented. Recently measured radon levels in the tour cave at Florida Caverns State Park caused considerable concern, prompting state officials to limit the underground exposure time of individual park personnel. Continuous monitoring equipment has been installed in Florida Caverns to measure fluctuations and long-term concentration levels. Cavers exploring wild caves within the park were at one time provided with fact sheets detailing the risks of prolonged exposure to the gas.

While extensive radon measurements have been made in the tour cave, little has been done to assess possible exposure hazards in other area caves, or to determine the potential source of the gas. With these facts in mind, the purpose of this project was to:

1) Detect the presence or absence of airborne radon in selected "wild" caves within Florida Caverns State Park, and in Climax Cave, Georgia;

2) Determine radon concentrations in different environments of the selected caves, to aid in pinpointing the source of the gas, and

3) Evaluate possible trends in radon concentration along selected sampling traverses within the caves.

Based on knowledge of the geology and cave geometry of Northwest Florida and Southwest Georgia, the following working hypotheses were developed:

1) Measurable radon enters Climax Cave primarily via outgassing of the overlying clays of the Miocene Hawthorn Group. Phosphatic lenses in the Hawthorn of Northern and Central Florida have been shown to contain relatively high uranium levels. $^{222}$Rn is a daughter product of the natural radioactive decay of $^{238}$U;

2) If hypothesis 1) is correct, radon levels in the caves of Florida Caverns State Park should be measurably lower than those in Climax Cave, Georgia, since no documented source of uranium (radon) exists within the stratigraphic section penetrated by these caves. Limestones of the upper Eocene (Ocala Group -
Crystal River fm.) and lower Oligocene (Marianna Is.), exposed in the caves of
the Marianna area, are not known to contain significant radiogenic components;

3) Radon levels should be highest in isolated rooms farthest from the entrance,
where the effects of air exchange with the outside are minimal. The number
and location of cave entrances should also affect radon levels. In Climax Cave,
additional higher levels should be measured in domes which pierce upward
into the Hawthorn Group. Conversely, radon levels should be the lowest in
small caves, or closer to the entrance in larger caves due to greater exchange
with atmospheric air.

Geological Setting:

Climax Cave is located approximately 80 kilometers north of the city of Tallahassee,
Florida, in rural Decatur County, Georgia. The only known entrance consists of three
adjacent vertical chimneys at the bottom of a 25 meter deep sink located along the
northwest edge of the Pelham escarpment, a northeast-trending topographic feature
which extends from near Chattahoochee, Florida to the vicinity of Cordele, Georgia.
The top of this escarpment has an average local elevation of 62 meters above mean
sea level, and separates Curry Hill to the southeast from the lower Dougherty Karst
Plain to the northwest. Cave development in South Georgia occurs predominantly along
this escarpment, where small intermittent surface streams are captured and diverted
underground, flowing northwestward under the scarp and below the Karst Plain, finally
discharging as springs in and along the Flint River (Beck, 1984).

Climax Cave, while in many ways typical of South Georgia caves, is currently the
second-longest in the state, containing over 12 kilometers of surveyed passage (Figure
7). The majority of the passages of the cave have formed 25-30 meters above present
mean sea level (36m below the top of the entrance sink), and are located within the
Oligocene Suwannee limestone, a tan to yellow massive to granular fossiliferous marine
limestone, with interbedded zones of vuggy, porous dolostone. It is successively
overlain by the lower Miocene Hawthorn Group, which in the entrance sink section
consists of sandy clays interbedded with thin lenses of limestone and dolostone. The
stratigraphy is important, as over twenty vertical shafts or solution domes have been
located in the cave, many reaching upward through the Suwannee limestone into the
base of the Hawthorn Group sediments. As noted previously, the Hawthorn in other
areas is known to contain significant uranium concentrations.

Cave passage development has primarily occurred along a series of predominant
north-northeast trending joints, with secondary development along west-northwest
trending fractures. Ground water pools are encountered in the lowest levels of the cave,
and several have been linked to one another through underwater mapping. These
deep, clear water pools reflect the elevation of the potentiometric surface of the
 Floridan aquifer system within the cave.
CLIMAX CAVE

Decatur County, Georgia

GSS No. 36

1970-1991 Survey by Florida State Cave Club
Grade 5

8.1 MILES THD

SCALE

0  500  1000  1500 FEET

Enlarged area shown in FIGURE 9


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FIGURE 7
Caves of the Marianna, Florida area are usually smaller than their South Georgia counterparts. Most caves in Florida Caverns State Park consist of low, wide vadose passages, connecting loftier chambers formed along primary north-northwest trending vertical fractures. Secondary passage development often occurs parallel to a secondary set of west-southwest trending fractures. These passage trends are clearly apparent when viewing the cave passage overlay map of the Park (Maddox, 1990 - see Figures 4, 9). Successive downcutting of the Chipola River has lowered the regional water table, leaving most of these caves high and relatively dry. Water, where present, usually occurs in shallow pools, perched above the present regional water table. Stratigraphically, these caves have formed in the upper portion of the Crystal River formation, a soft, white, highly fossiliferous limestone of late Eocene age. This is unconformably overlain by the lower Oligocene Marianna limestone, a more indurated cream to white, granular limestone which forms the "roof rock" of the caves in the Park. The lower Miocene Hawthorn Group, present above the Oligocene marine limestones to the east, is absent in this area. The clays of the Hawthorn often act as an aquitard, restricting rapid downward infiltration of surface water. Thus, these caves are shallow in depth and are often profusely decorated, due to rapid infiltration of rainfall derived calcite-saturated waters passing slowly through the thin Marianna limestone caprock.

METHODS

Field Methods:

Activated charcoal canisters were deployed at various locations within the caves. Climax Cave was the first to be sampled, and a trial deployment period of approximately 24 hours was used. Care was used to locate canisters away from direct water sources, such as ceiling drips. Results from Climax Cave indicated that 24 hour deployment is nearly ideal for this environment (TABLE 2). Subsequent sampling of caves in Florida Caverns State Park successfully used similar deployment intervals.

Nine canisters were deployed in Climax Cave over a four hour period on October 20, 1989, and retrieved the following day (Figure 8). Subsequently, twelve canisters were deployed in seven caves in Florida Caverns State Park on November 4, 1989 (Figure 9). Deployment occurred over an eight hour period; these canisters were recovered on the following day. At each sampling station, a sketch was made of the location, and deployment/retrieval times were noted to the nearest minute. Additional environmental data were recorded: relative water levels, outside/inside temperatures, relative barometric pressures, and air movement into or out of the caves.

Laboratory Procedures:

Weighed and numbered 7.62cm diameter metal canisters containing a known amount of activated charcoal were provided by Dr. Bill Burnett and staff of the FSU Department of Oceanography. These canisters are sealed with electrical tape along the edge, and have a patch of heavy duct tape covering the sampling port in the top lid. A
CLIMAX CAVE
Decatur County, Georgia

(entrance vicinity)

SOUTH CLIMAX
VW Dome
Ben's Bypass
Needle Room

Ara's Cafeteria

Entrance Chimneys
Blair's Dead End

Second Dig
Keyhole Passage
Stream Passage

Loch Ness

Barrel Room
Scott's Hall

(152) Party Room
Pleasant's Double Domes

Parking Area

Junction Hall

Map showing deployment locations of activated charcoal canisters

77 - Canister location and Reference number

FIGURE 8

Tape, Compass, Rangefinder and Inclinometer Survey by members of the Florida State Cave Club Grotto 175 of the National Speleological Society

Based on a map produced by Frank Hutchison February 10, 1977
FIGURE 9 - Portion of Florida Caverns State Park showing Canister Deployment Sites
gas-permeable filter is located within the canisters between the activated charcoal and the sampling port. Activation of the sampling canister at deployment is achieved by removing the duct tape from the sampling port and sticking it to the bottom of the canister. At the end of the sampling period, the tape is replaced over the sampling port, and the canisters are cleaned of excess dirt and mud.

Upon return to the lab, the canisters are again weighed, to determine the amount of water moisture sorbed onto the charcoal. After weighing, the canisters are counted on a gamma ray spectrometer utilizing shielded dual NaI detectors, connected through a preamplifier/amplifier link to a Canberra Series 40 multichannel analyzer. Output is to a printer or to an IBM PS2 microcomputer. After allowing enough time for the $^{222}$Rn and its progeny to reach secular equilibrium, gamma emissions in the $^{214}$Pb photopeaks (295 and 352 KeV) and $^{214}$Bi (609 KeV) photopeak are measured as two regions of interest (these correspond to "ROI 1" and "ROI 2", respectively). These measurements are calibrated against a reference standard of known activity, in order to determine detector efficiency. Background gamma is also measured daily.

Data Reduction and Reporting:

From the laboratory and field data, several important values are calculated:

**DETECTOR EFFICIENCY** "E" = \frac{\text{counts/min STANDARD}}{\text{known activity STANDARD}}

**NET COUNTS** "N" = (ROI1 + ROI2) - (Counting T min)(Background cpm)

**NET COUNT RATE** = N / Counting T min

**EFFECT.SAMP.RATE** "R" = \((-1.1892^{-3})(\text{Wt.gain } H_2O \text{ g}) + 1.0775^{-2}\)

**RADON CONTENT** = \frac{\text{Net counts/min}}{(E \text{ cpm/pCi})(g \text{ min})(te \text{ min})(R \text{ L/min})}

**EFFECTIVE COUNT TIME** "g" = \frac{e^{-1.264E-4(t1)} - e^{-1.264E-4(t2)}}{1.264^{-4}}

t1 = end of sampling to beginning of counting (min)
t2 = end of sampling to end of counting (min)

**EFFECTIVE SAMPLING TIME** "te" = 1 - \frac{e^{-1.264E-4(Ts)}}{1.264^{-4}}

Ts = sampling (deployment) time (min)
TOTAL ERROR = +/- ((Rn content pCi/L)(0.11)),

which is a fairly close approximation to the 2σ counting error (Gray, 1987), calculated as:

\[ 2\sigma \text{ counting error} = \frac{2(\text{Net Counts cpm} + \text{Background cpm})^{0.5}}{\text{Net Counts cpm} - \text{Background cpm}} \]

A Lotus 1-2-3 custom spreadsheet was set up by Dr. Burnett to automate data collection and to perform the above calculations. TABLE 2 is a summary of these values for data from Climax Cave and Florida Caverns State Park.

RESULTS AND DISCUSSION

A deployment time of 24-48 hours was found to be nearly ideal for measuring radon in caves. These measurements were made over about 24 hours, with a weight gain due to adsorbed water of less than 1 gram. Since air in the caves is saturated with respect to water vapor, there was some concern that excessive moisture would interfere with radon adsorption.

Radon concentrations were plotted against distance from the nearest humanly passable entrance of each cave. Traverses along the most direct path were drawn on cave maps and the distance to the closest known entrance measured in meters. Circled numbers on these maps depict canister deployment locations and reference numbers. The data are summarized in Figures 10 and 11 for Climax Cave and Florida Caverns State Park, respectively. Error bars represent total counting error.

The Climax Cave data was plotted in two subsets, corresponding to two traverses into the cave: one into "North Climax" and the other into "South Climax". This was done as the entrances are clustered together in the center of the cave; there is roughly the same length of known passage north and south of these entrances. The two traverses are linked to Station #7, a small clay "shelter cave" located outside the entrance chimneys in the lower Hawthorn (at the bottom of the sink), where a canister was deployed.

Figure 10: Data from Climax Cave, Georgia
The data from Climax Cave shows some interesting trends. The North Climax measurements are fairly uniform with respect to those from South Climax. This relates well with the geology and passage morphology in the two sections. The area of North Climax where these measurements were made is characterized by large, sand-floored passages formed almost entirely within the Suwannee limestone, and interconnected by occasional crawlways. Domes leading up into the overlying Hawthorn are largely absent. Measurements from South Climax show a pronounced trend of radon increase with increasing distance from the entrances. These more tortuous passages are smaller and wetter than those to the North, and are floored by a clay-sand mix. Domes reaching up through the Suwannee limestone into the Hawthorn group are common. The highest radon measurement made in the cave was in "VW Dome", an 8 meter high dome stoping upward into the Hawthorn in an isolated area of the cave with minimal air exchange.

The air exchange issue forces one to take into account "cave weather" when interpreting these results. Air exchange occurs between the cave and outside atmosphere in relation to differential barometric pressures. The cave pressures lag behind surface changes; the approach of a low pressure front will cause higher pressure air trapped within deep cave passages to flow outward, causing the cave to "blow". The opposite effect occurs after the low passes through, and high pressure is established. Certainly these atmospheric exchanges affect radon concentrations in many parts of the cave; therefore, the results obtained are likely to change with time, and display greater variability as one nears the entrance. Cave geometry also plays a role, as isolated low volume chambers do not have the high air flow potential that exists in narrow crawlways separating voluminous cave passages from the entrance. Temperature and humidity are also affected by cave weather, but the direction and intensity of air flow is the most noticeable of these. As was done in this study, sampling is best accomplished in intervals between drastic weather changes, as low air flow allows radon partial pressures to equilibrate somewhat in the cave. TABLE 3 summarizes atmospheric conditions at the time of sampling.
| TABLE 2: Summary of $^{222}$Radon Measurements - Data from Climax Cave, Georgia and Florida Caverns State Park, Florida |
|--------------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **CLIMAX CAVE**                                 | **Station**     | **Wt. Gain**    | **Effective**   | **Radon**       | **Total**       |
| Dougherty County, GA - cans deployed 10/20/89    | (Can) Number    | Canister (grams)* | Samp Time (min) | conc. (pCi/L)   | Error (pCi/L)   |
| - Clay shelter in Ent. sink                      | 7               | 0.67            | 1244            | 12.0            | +/- 1.3         |
| - Register Room                                  | 302             | 0.69            | 1287            | 24.5            | +/- 2.7         |
| - Scotts Hall near Loch Ness                     | 340             | 0.73            | 1265            | 25.5            | +/- 2.8         |
| - Second Dig Crawlway                            | 14              | 0.81            | 1285            | 22.2            | +/- 2.4         |
| - Near Wet Chimney                               | 254             | 0.82            | 1242            | 33.6            | +/- 3.7         |
| - Party Room                                     | 289             | 0.70            | 1262            | 32.7            | +/- 3.6         |
| - VW Dome                                        | 152             | 0.70            | 1255            | 58.5            | +/- 6.4         |
| - Pleasants Double Domes                         | 112             | 0.73            | 1245            | 43.4            | +/- 4.8         |
| - Entrance to Ben's Bypass                       | 295             | 0.96            | 1248            | 57.2            | +/- 6.3         |

| FLORIDA CAVERNS STATE PARK                       | **Station**     | **Wt. Gain**    | **Effective**   | **Radon**       | **Total**       |
| Jackson County, FL - cans deployed 11/4/89       | (Can) Number    | Canister (grams)* | Samp Time (min) | conc. (pCi/L)   | Error (pCi/L)   |
| - Boyer's: back Bonnie's Rm                      | 86              | 0.78            | 1357            | 51.5            | +/- 5.7         |
| - Boyer's: Larson's Lake                         | 127             | 0.79            | 1358            | 55.6            | +/- 6.1         |
| - Boyer's: Formation Room                        | 51              | 0.78            | 1370            | 64.1            | +/- 7.1         |
| - Boyer's: Discovery Crawl                       | 334             | 0.88            | 1352            | 79.6            | +/- 8.8         |
| - Dragon's Tooth: low crawl                      | 80              | 0.77            | 1412            | 38.7            | +/- 4.3         |
| - Dragon's Tooth: D. Belly                       | 48              | 0.76            | 1409            | 86.7            | +/- 9.5         |
| - Dum Cave                                       | 74              | 0.74            | 1372            | 56.4            | +/- 6.2         |
| - Miller's Cave                                  | 258             | 0.64            | 1379            | 3.6             | +/- 0.4         |
| - Ooid Cave                                      | 172             | 0.76            | 1376            | 7.6             | +/- 0.8         |
| - Pottery Cave: Twin Pits                        | 52              | 0.71            | 1394            | 3.2             | +/- 0.4         |
| - Pottery Cave: Vandal Room                      | 149             | 0.67            | 1389            | 4.0             | +/- 0.4         |
| - Tunnel Cave: side passage                      | 58              | 0.69            | 1377            | 2.0             | +/- 0.2         |

* Weight gain due to water adsorption by activated charcoal.
TABLE 3: Weather Conditions at Canister Deployment and Retrieval

<table>
<thead>
<tr>
<th></th>
<th>Date</th>
<th>T&lt;sub&gt;atm&lt;/sub&gt;*</th>
<th>T&lt;sub&gt;ave&lt;/sub&gt;*</th>
<th>Weather / Air exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIMAX CAVE</td>
<td>10/20/89</td>
<td>8</td>
<td>20</td>
<td>Cave slightly sucking; surface P&lt;sub&gt;atm&lt;/sub&gt; high</td>
</tr>
<tr>
<td></td>
<td>10/21/89</td>
<td>10</td>
<td>20</td>
<td>Cave slightly blowing; surface P&lt;sub&gt;atm&lt;/sub&gt; high</td>
</tr>
<tr>
<td>FL CAVERNS SP</td>
<td>11/4/89</td>
<td>22</td>
<td>20</td>
<td>No detectable air flow; surface P&lt;sub&gt;atm&lt;/sub&gt; high</td>
</tr>
<tr>
<td>CAVES (av)</td>
<td>11/5/89</td>
<td>24</td>
<td>20</td>
<td>Boyer’s slightly blowing; surface P&lt;sub&gt;atm&lt;/sub&gt; high</td>
</tr>
</tbody>
</table>

* Temperatures expressed in degrees Celsius

Climax Cave Station #7, the shelter cave previously mentioned, was sampled to qualitatively determine whether radon was emanating from the Hawthorn Group sediments. This shelter cave is entirely within the Hawthorn, and penetrates about 4 meters into orange clay at the bottom of the sinkhole outside and above the main entrance chimneys. The 12 pCi/L measured here is considerably higher than atmospheric background, indicating a probable geological link to high 222Rn from the Hawthorn Group sediments.

Data from seven caves sampled within Florida Caverns State Park is plotted as Figure 11. The data fall into two domains: a cluster of points near the origin which corresponds to small short caves with low radon concentrations, and longer/larger caves with relatively greater radon concentrations. This relationship is not unexpected; what is unexpected are the relatively higher concentrations found in the larger caves relative to Climax Cave. No known significant source of radon occurs within the formations in which these caves are found. The highest radon measurement made in this study, 86.7 pCi/L, occurred in the "Dragon’s Belly" room of Dragon’s Tooth Cave. This is the largest single cave room known within the Park, and has only one passable entrance - a tight crawlway.

The line on Figure 11 links the four stations sampled in Boyer’s Discovery, the longest cave in the park. The plot depicts a trend opposite to those seen in Climax Cave - radon seems to decrease with distance from the only currently known entrance. Two possible but unlikely explanations may account for this:

1) The unknown source of radon is not uniformly distributed (geographically or stratigraphically). This is possible; however, the three stations farthest from the entrance were in relatively large passages, while the one closest to the entrance was located in the crawlway leading into the main cave. All sampling stations lie at about the same stratigraphic elevation within the upper Crystal River formation;

2) An as-yet undiscovered entrance to the cave lies at the back, which allows for greater air exchange than the presently known (tight) entrance (this is unlikely however, as the back of the cave lies directly below the Visitor Center, a heavily explored and developed area).
CONCLUSIONS

Measurable radon was detected in all caves, and in general increases with distance from the entrance (Climax Cave) and with increasing cave length or volume (Florida Caverns State Park).

The Climax Cave data seems to corroborate the first working hypothesis - that the primary source of radon in this cave is derived from outgassing of the overlying Hawthorn Group sediments. The data from Florida Caverns State Park however, shows that the Hawthorn is not necessarily the only source of high radon. Higher levels were measured there despite the absence of the Hawthorn Group. This negates the argument put forth in the second working hypothesis. The third hypothesis - higher radon levels in isolated cave rooms - was supported by data from both study areas.

Potential Health Effects:

How dangerous is it for cavers exploring these caves? According to the U.S. Environmental Protection Agency, confirmed airborne concentrations above 4 pCi/L in structures is considered potentially hazardous. The average $^{222}$Rn concentration measured in Climax Cave was 34.4 pCi/L, and in measured caves within Florida Caverns State Park, 37.7 pCi/L. The 4 pCi/L EPA threshold value assumes 24 hour exposure to airborne $^{222}$Rn. Using the above average figures, an eight hour Climax trip will expose the caver to the same radiation dosage as would be obtained by spending 68.8 hours (2.87 days) in a house which had airborne $^{222}$Rn levels at the minimum level of concern (4 pCi/L). For average Florida Caverns caves, eight hours underground would be roughly equivalent to 75.4 hours (3.14 days) at 4 pCi/L. For the worst case, eight hours in Dragon’s Belly, the equivalent exposure jumps to 173.4 hours, or 7.23 days at 4 pCi/L. The adverse biological effects of radiation exposure are cumulative - the potentially harmful effects would be nearly the same in each environment for the same time durations stated above. Although 4 pCi/L is EPA’s threshold value for concern, that agency advises homeowners who measure 4 to 20 pCi/L in their structures to remediate the problem within two years. Immediate action is not recommended until confirmed levels jump to 200 pCi/L. Although not much is known about the long term health effects of exposure to low level radiation, occasional (one to two days a week) visitation to these caves should not cause concern. Persons who work in, or regularly spend significantly longer time periods in these caves should be aware of the potential $^{222}$Rn hazard, and should probably carry a dosimeter with them to monitor cumulative radiation exposure.
Future Studies:

It should be kept in mind that these results only present a "snapshot" of radon levels in the caves. Because of several interactive factors (temperature, atmospheric pressure, humidity, stratigraphy, sedimentation and cave morphology), radon concentrations can vary significantly at a particular location in the cave. A comprehensive study would investigate temporal changes in addition to geographical differences. Time integration of radon measurements is especially important when studying health effects, as radon concentrations are known to fluctuate rapidly (Cohen, 1983). Continuous radon monitoring has only recently begun at Florida Caverns, the tour cave.

Soil and rock sampling at both locations would be a logical next step in determining more precisely the source of radon in the caves. The radon source in the Marianna caves may well be cave floor sediments. The Chipola River periodically rises high enough to inundate the lower portions of many Park caves; fluvial sediments deposited throughout numerous flooding cycles may contain radiogenic decay products which are then concentrated by the confinement of the cave systems. Additional sampling farther into North and South Climax would extend the profiles presented in this report, and indicate whether concentrations continue to increase with distance from the entrance, level off, or decrease.

ACKNOWLEDGEMENTS

Dr. Bill Burnett and his staff at the Florida State University Department of Oceanography prepared the canisters used in this study and weighed and counted them upon retrieval from the caves. This study would not have been possible without his training and help.

Tim Glover accompanied me on both Climax Cave trips as well as the retrieval trips in Florida Caverns State Park; Ron and Cindy Maddox accompanied me into the caves of Florida Caverns State Park during canister deployment. Their help was crucial in conducting this study.
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SOUTHEASTERN GEOLOGICAL SOCIETY

KARST FEATURES OF FLORIDA CAVERNS STATE PARK AND FALLING WATERS STATE RECREATION AREA; JACKSON AND WASHINGTON COUNTIES, FLORIDA

Field Trip Log

Saturday, November 13, 1993

STOP 1 - Florida Caverns State Park, Jackson County

Mileage starts at intersection of U.S. 90 and SR 167, downtown Marianna.

CUMULATIVE MILEAGE
0 2.7 North on SR 167, to entrance to Florida Caverns State Park, on left. SR 167 traverses hummock-and-swale karst topography; note the wide, flat-floored valley, which is the karstified floodplain of the Chipola River, and road cuts through Marianna and Suwannee Limestones, just before the state park.

A trip into Florida Caverns proper will be followed by a walk along the Flood Plain Trail, where numerous karst features can be seen. Lunch will follow at one of the Park's picnic pavilions.

STOP 2 - Falling Waters State Recreation Area, Washington County

Return to Marianna, start mileage again at U.S. 90 and SR 167.

CUMULATIVE MILEAGE
0  1.6 West (right turn) on U.S. 90 to SR 276;
4.2 South 2.6 miles on SR 276 to Interstate 10. Go West 17.3 miles on 1-10 to Chipley;
21.5 Exit 18, intersection of I-10 and SR 77. South (left), one mile on SR 77 to SR 77A (note Falling Waters sign).
24.1 SR 77A east (left) to STOP sign; proceed straight to Falling Waters entrance (1.6 miles).

We will inspect the series of sinks and vertical shafts leading down into Falling Waters Cave System.

Sunday, November 14, 1993

(Optional) Canoe trip down Chipola River, from SR 167 bridge north of Marianna to Canoe Livery (just south of I-10 bridge). Note exposures of Bumpnose Member of the Crystal River Formation, Marianna Limestone and Suwannee Limestone as the river traverses progressively upward through the section. Karst features such as springs and caves will be seen.
FIGURE 13 - Portion of USGS Marianna 1:24,000 Topographic Sheet
FIGURE 15 - Portion of USGS Wausau 1:24,000 Topographic Sheet