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The Geology of Wakulla Springs

by

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INTRODUCTION

Little was known about the geologic makeup of the Wakulla Springs system prior to the 1987 Wakulla Springs Project. Olsen (1958) explored the outer 1100 feet of the main cave and collected paleontological and archeological remains. However, a detailed geologic reconnaissance was apparently never performed. During the course of the Wakulla Springs Project, the project divers collected a series of rock specimens and sediment cores for analysis by the Florida Geological Survey. The following section provides an overview of the geomorphology and the geology of Wakulla Springs and vicinity, including a discussion of the geology of the conduit system based on the samples collected.

GEOMORPHOLOGY

Wakulla Springs are situated in the Woodville Karst Plain geomorphic zone. This zone encompasses an area extending southward from the Cody Scarp to the Gulf of Mexico, and from just west of U. S. Highway 319 eastward through Jefferson County (Figure 1). The Woodville Karst Plain is characterized as a flat or very gently rolling surface of porous sand overlying Oligocene and Miocene age limestones. Elevations range from 0 to 35 feet above mean sea level, and surface slope averages about four feet per mile southward. During the Pleistocene Epoch (two

Figure 1: Map showing the extent of the Woodville Karst Plain and the geologic cross section location.

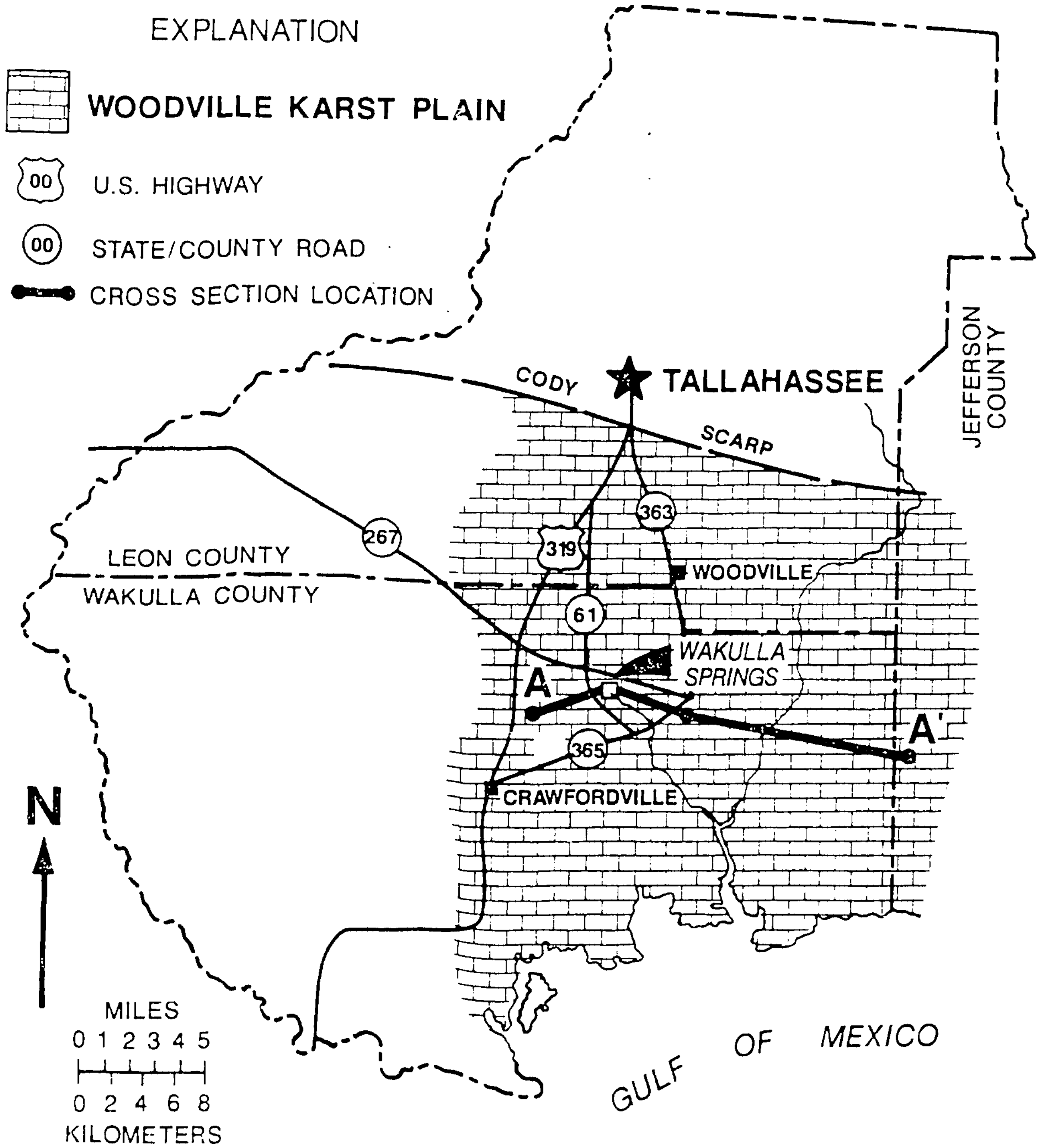
million to 10,000 years ago), sea level fluctuated in a range between 300 feet below and 150 feet above present level. The ancient shoreline was at one time, just south of Tallahassee near the Cody Scarp. Waves and currents in these highstanding Pleistocene sea reworked the sands of older formations, depositing them over limestone in a broad, flat sea floor. As the sea retreated for the final time in the late Pleistocene it left in its wake the relict dunes, bars, and thin sand veneer covering the Woodville Karst Plain today.

Limestone is within 25 feet of the surface in most of eastern Wakulla County. The top of this limestone is highly karstic, having undergone extensive dissolution by groundwater percolating through the porous overlying sands. As a result, the Woodville Karst Plain contains numerous wet and dry sinks, natural bridges, disappearing streams, and as this project has revealed, cavernous underground drainage systems.

STRATIGRAPHY

The oldest sediments underlying Wakulla County are Paleozoic age (350 - 500 million years ago) shales occuring at depths in excess of 12,000 feet below land surface (Rupert and Spencer, 1988 in press). These rocks form the foundation for an extensive series of overlying Mesozoic and Cenozoic age siliciclastic and marine carbonate rocks.

In the vicinity of Wakulla Springs, the near-surface

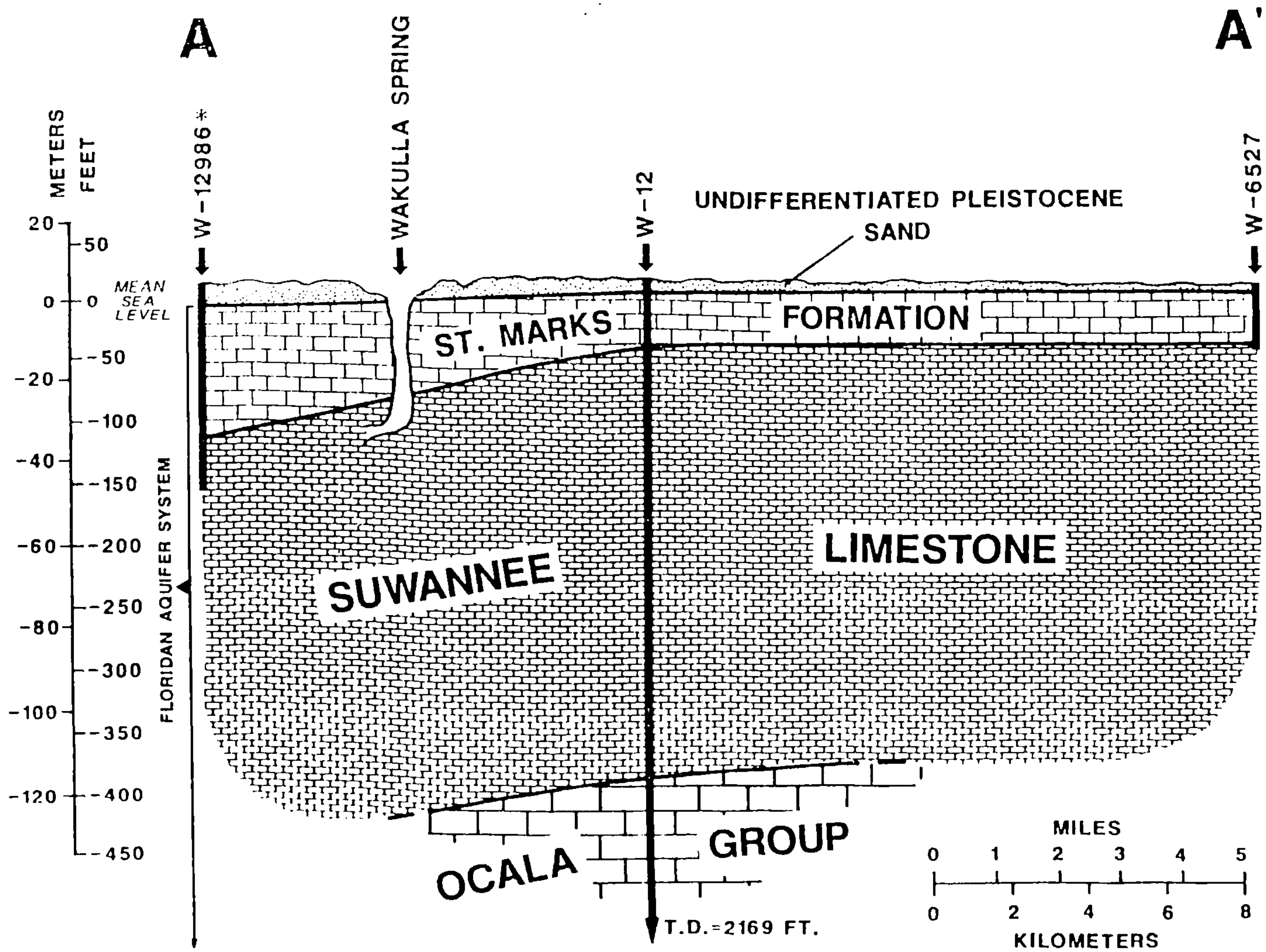

EXPLANATION
WOODVILLE KARST PLAIN
U.S. HIGHWAY
STATE/COUNTY ROAD
CROSS SECTION LOCATION
CODY SCARP
TALLAHASSEE
JEFFERSON COUNTY
LEON COUNTY
WAKULLA COUNTY
267
319
363
61
365
WOODVILLE
WAKULLA SPRINGS
A
A'
CRAWFORDVILLE
N
MILES
0 1 2 3 4 5
0 2 4 6 8
KILOMETERS
GULF OF MEXICO

formations are predominantly Eocene through Miocene-age marine limestones and dolomites, overlain by a thin veneer of undifferentiated Pleistocene sand. These carbonate rocks, along with their equivalent strata state-wide, serve as an important freshwater aquifer known as the Floridan aquifer system. The formations comprising the Floridan aquifer system in Wakulla County include the Eocene-age Ocala Group, the-Oligocene age Suwannee Limestone, and the Miocene-age St. Marks Formation. Figure 2 is a geologic cross section near Wakulla Springs illustrating the local stratigraphy.

Limestones of the Ocala Group lie below the depths attained by most water wells. The Ocala Group is comprised of Upper Eocene fossiliferous marine limestones and dolomites. These rocks were deposited in a shallow sea some 36 to 40 million years ago. Oil test wells near Wakulla Springs penetrated Ocala Group sediments at depths between 400 and 600 feet below land surface. The deepest portion of the conduits explored during the Wakulla Springs Project did not penetrate Ocala Group sediments.

The Lower Oligocene Suwannee Limestone unconformably overlies the Ocala Group in Wakulla County. This formation was also formed in a shallow sea which inundated all of Florida 30 to 36 million years ago. The Suwannee Limestone is typically a white to pale orange, calcarenitic limestone, composed of sand-sized calcareous particles and frequently containing larger fossil mollusks, echinoids, and corals. It may also contain beds

Figure 2: Geologic cross section across the Woodville Karst Plain.



VERTICAL EXAGGERATION IS 105 TIMES TRUE SCALE.

* WELL NUMBERS ARE FLORIDA GEOLOGICAL SURVEY WELL ACCESSION NUMBERS.

of tan to light brown dolomite. Some drinking-water wells draw freshwater from the Suwannee Limestone, and as discussed later, the conduits feeding Wakulla Springs are developed in this rock unit.

The Lower Miocene St. Marks Formation overlies the Suwannee Limestone and is generally the uppermost carbonate unit in the Woodville Karst Plain. Most of the karst features of the area as well as the channel of the Wakulla River are developed in the upper part of this unit. It crops out in the Wakulla Springs pool, in sinks throughout the area, and along the Gulf coast in southern Wakulla County. As shown in Figure 2, it thins to the east, ultimately pinching out against the Suwannee Limestone in Jefferson County. The St. Marks is a white to pale orange, calcilutitic marine limestone, approximately 20 to 25 million years old. It frequently contains some quartz sand, fossil mollusk molds, and clay stringers. Locally the St. Marks is the upper unit of the Floridan aquifer system. Most of Wakulla County's domestic wells draw freshwater from the St. Marks Formation.

A thin blanket of undifferentiated Pleistocene quartz sands and clayey sands overlie the St. Marks Formation. Most of these sands are relict marine deposits, stranded by the regressing Pleistocene sea. The sands are generally porous, allowing direct rainwater recharge to the underlying carbonates of the Floridan aquifer system.

GEOLOGIC SAMPLING PROGRAM

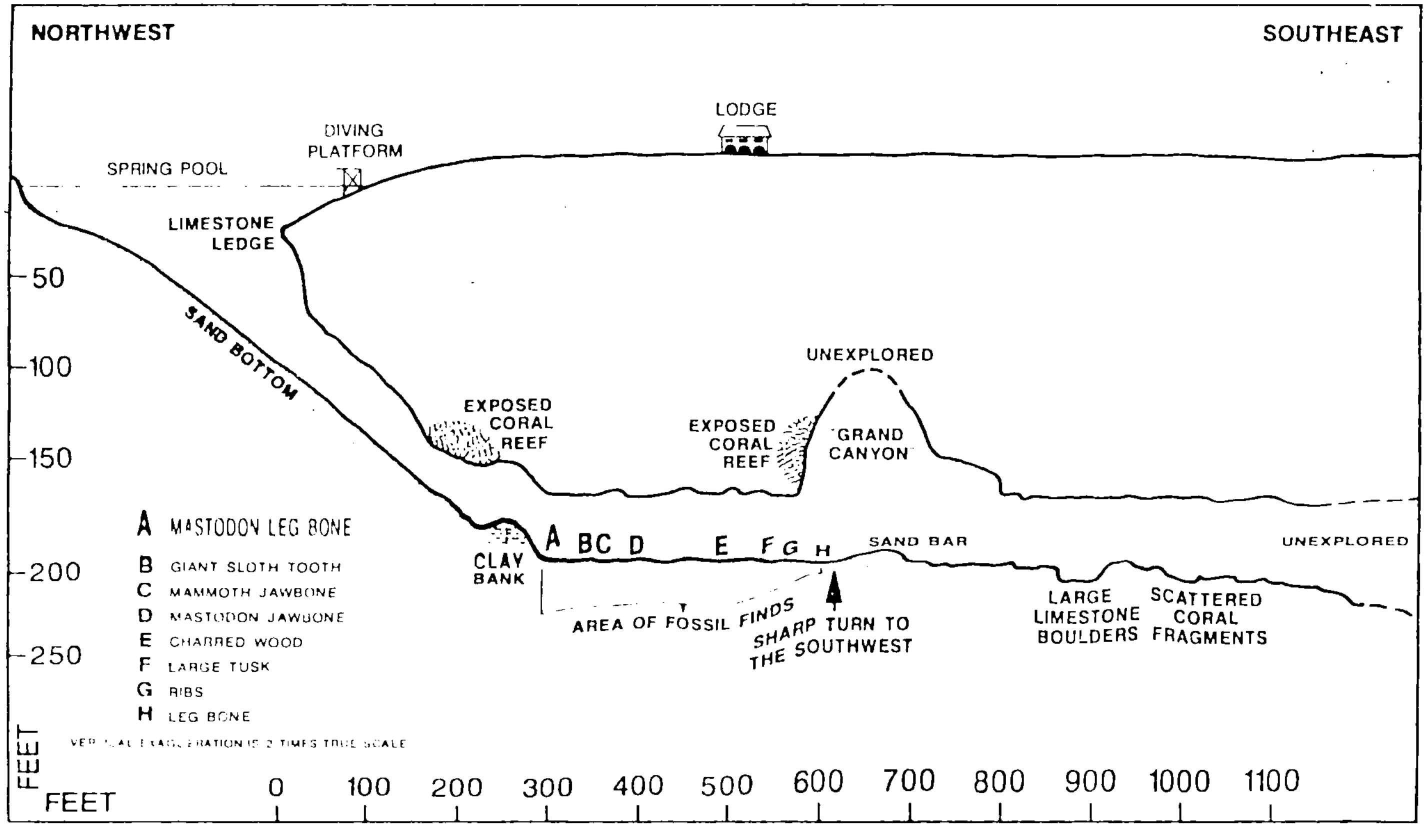
Geologic samples were collected within the Wakulla Spring cave system to better understand the local stratigraphy as well as the geology of the entire conduit network. In cooperation with the Florida Geological Survey, the divers recovered seven shallow sediment cores from the cave floor and cave-wall rock samples from 28 depth intervals ranging from 9 to 304-feet below spring pool surface (approximately four feet MSL). These samples were described and are currently cataloged in the Florida Geological Survey sample repository as M-3023. Lithologic descriptions of the samples are included in the Appendix, and sample locations are shown on Figure 5.

The entire conduit system is developed in the Oligocene age Suwannee Limestone. Throughout most of the cave, the lithology consists of white to very pale orange, poorly indurated, recrystallized, foraminiferal, biocalcarenitic limestone. Near the cave mouth, samples show a rind of iron oxide staining ranging from 0.5 to 1-inch thick on the exposed, weathered faces. The typical fossil fauna include the Foraminifera <u>Dictyoconus cookei</u>, <u>Rotalia mexicana</u>, <u>Cancris sagra</u>, <u>Operculinoids vicksburgensis</u>, and <u>Quinqueloculina</u> spp., molds of the mollusk <u>Cerithium</u> sp., corals, and recrystallized casts of the echinoid <u>Rhyncholampus gouldii</u>. A distinct lithologic change within the Suwannee Limestone, first noted at a depth of approximately 218 feet, is sporadically traceable along the tunnel walls into the caves as far as exploration progressed (Wes Skiles, personal communication, 1987). This lithologic change appears as a sharp color change on the video tapes taken of the conduit walls. The color change is caused by an abrupt transition from the soft biocalcarenite above the change to a harder, recrystallized dolomitic calcarenite below. This lower, harder layer floors most of the cave system below the 218-feet depth, and may have retarded further downward dissolution within the conduits. At the deepest sampled depth of 304 feet, the lower lithology is a brown sucrosic dolomite.

The Suwannee Limestone unconformably contacts the overlying Miocene age St. Marks Formation at a depth of approxiamtely 90 feet below water surface. This contact is exposed on the face of the limestone ledge in the spring pool directly above the spring vent. The St. Marks Formation is a white to very pale orange, fossiliferous, slightly sandy, calcilutitic limestone. Diver Bill Wilson reported several distinct coral heads and shell beds within the portion exposed in the ledge. Most of the contained fossils are recrystallized, with Foraminifera, mollusk molds, and corals dominating. Foraminifera include <u>Sorites</u> sp. and <u>Archaias</u> cf. <u>floridanus</u>. Between 20 and 40 feet deep, the lithology of the St. Marks Formation is a pale orange, generally unfossiliferous calcilutite containing some white to pale green clay stringers. The nine-foot sample is abundantly mollusk-moldic. In the vicinity of Wakulla Springs, the elevation of the top of the St. Marks Formation is variable. The shallowest samples collected in the spring pool cropped out at nine feet of water depth. Locally, this formation is generally overlain by 10 to 20 feet of undifferentiated Pleistocene sand. However, boulders of St. Marks Formation "float" may be observed along the nature trail on the park grounds.

Collection of paleontological remains was not part of the Wakulla Springs exploration project. The divers documented on videotape the extensive Pleistocene bone beds first noted by Olsen (1958) in the primary spring tunnel (see Figure 3), and also discovered a second deposit of similar bones some 1200 feet into tunnel "B", at a depth of 285 feet. The origin of these deposits is uncertain. Two hypotheses explaining the placement of these bone beds center on the 300-feet drop in sea level postulated to have occurred during the Pleistocene glacial periods (Lane, 1986). Such a drop in world-wide sea level would have lowered the freshwater table as well, leaving the spring conduits stranded as dry caves. One theory holds that the Pleistocene mammals roamed in these dry caves, perhaps looking for water, or that paleo-Indians carried animal carcasses into the cave. A second theory is that Wakulla Spring may have been a sink or "swallow hole" during lower sea level, possibly receiving the flow of an ancient stream. The water inflow, it is reasoned, may have flushed animal remains down into the cave, possibly as far as the outer bone beds noted by Olsen. However, the recent

Figure 3: Cross section of the Wakulla Cave, from Olsen(1958).



NORTHWEST
SOUTHEAST
LODGE
DIVING PLATFORM
SPRING POOL
LIMESTONE LEDGE
SAND BOTTOM
EXPOSED CORAL REEF
UNEXPLORED
EXPOSED CORAL REEF
"GRAND CANYON"
CLAY BANK
A BC D E F G H
SAND BAR
UNEXPLORED
AREA OF FOSSIL FINDS
SHARP TURN TO THE SOUTHWEST
LARGE LIMESTONE BOULDERS
SCATTERED CORAL FRAGMENTS
A MASTODON LEG BONE
B GIANT SLOTH TOOTH
C MAMMOTH JAWBONE
D MASTODON JAWBONE
E CHARRED WOOD
F LARGE TUSK
G RIBS
H LEG BONE
50
100
150
200
250
FEET
FEET
0
100
200
300
400
500
600
700
800
900
1000
1100

discovery of bones 1200 feet back into the caves may make the latter theory seem less plausible. Future radiometric and micropaleontologic study of the short core taken in the bone bed may help determine the true origin of these deposits.

HYDROLOGY

Groundwater is water that fills the pores and interstitial spaces in rocks and sediments beneath the surface of the earth. Most of eastern Wakulla County's groundwater is derived from precipitation within the county and in Leon County to the north (Hendry and Sproul, 1966; Stewart, 1980). A portion of the precipitation leaves the area via surface runoff (stream flow) or by evaporation and transpiration. The greater portion of precipitation water, however, enters the aquifer directly through sinks or percolates rapidly down through the porous surface sands of the Woodville Karst Plain. In this way, rainfall enters the shallow, karstic limestones and recharges the Floridan aquifer system rapidly.

Spring flow at Wakulla Springs shows a wide variation and correlates closely with rainfall (Rosenau et al., 1977). After heavy or sustained rainfall, plugs of tannic water are flushed into the Wakulla Springs conduits, frequently turning the normally clear water brown and decreasing visibility (Clemens, 1988). The source of the tannic water is not certain, but its color suggests it may have recently been surface water.

Potentiometric Gradient

Water confined within the Floridan aquifer system is generally under a pressure greater than atmospheric, resulting in a positive static head. The height to which water rises in tightly-cased wells penetrating an artesian aquifer forms an imaginary surface called the potentiometric surface. If the land elevation of a well or spring is below the level of the potentiometric surface, the well or spring will flow at the ground surface. Figure 4 illustrates the potentiometric surface of the Floridan aquifer system in Wakulla County. Water flow through the aquifer, the potentiometric gradient, is from the higher to lower potentiometric contours, in a direction perpendicular to the contour lines. In the vicinity of Wakulla Springs, this flow is southeastward.

The Conduit System

Figure 5 is a block diagram illustrating the relative relationships of the four conduits explored by the divers, water flow, and geology. The Wakulla Spring feeder conduits probably developed during the Pleistocene Epoch, millions of years after the rock containing them was formed. Although the mode of formation is not certain, the sheer size and lack of characteristic dry cave formations (e.g. stalagtites) suggests they were dominantly formed by flowing groundwater. Since sea level (and hence the freshwater table) fluctuated considerably during the Pleistocene, the conduit system could have evolved sporadically throughout a wide range of sea level positions.

Figure 4: Potentiometric surface of the Floridan aquifer system in Wakulla County (from Barr, 1987).

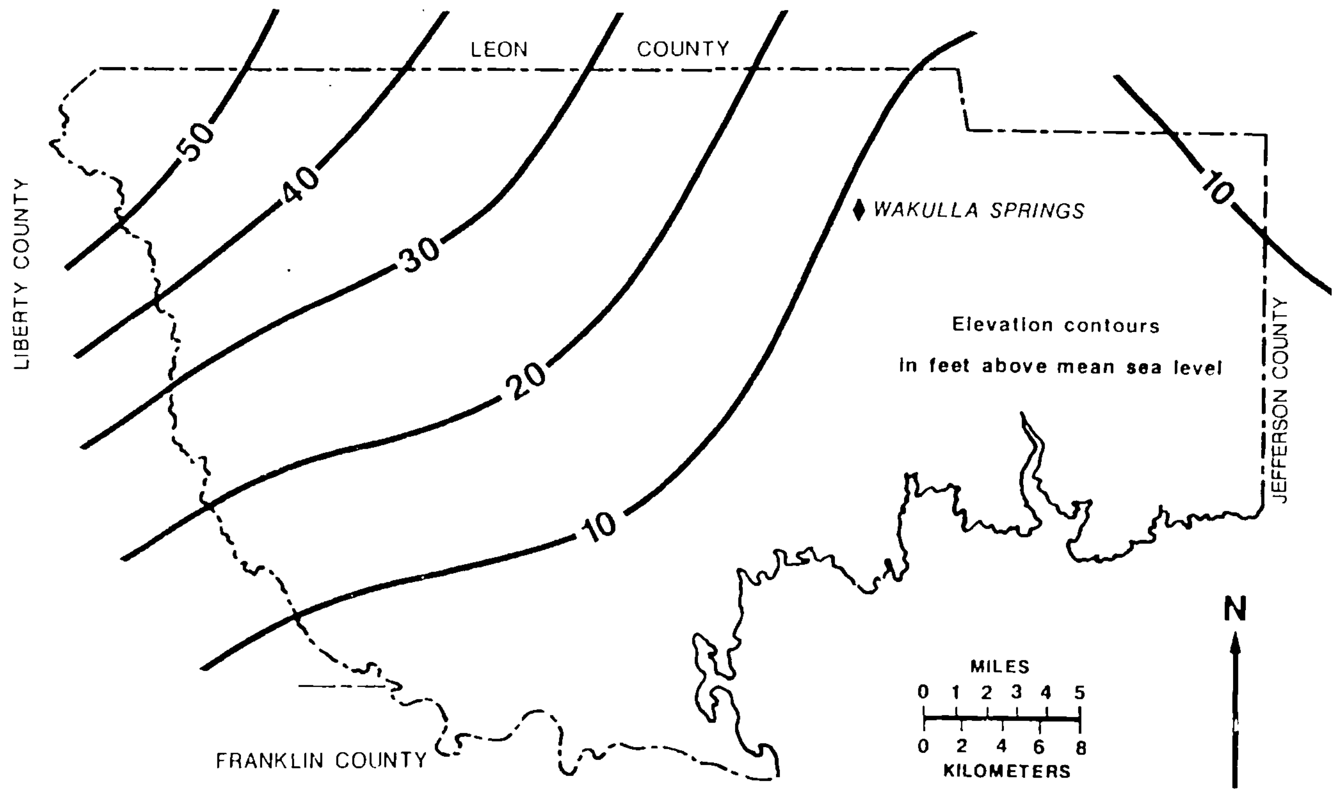
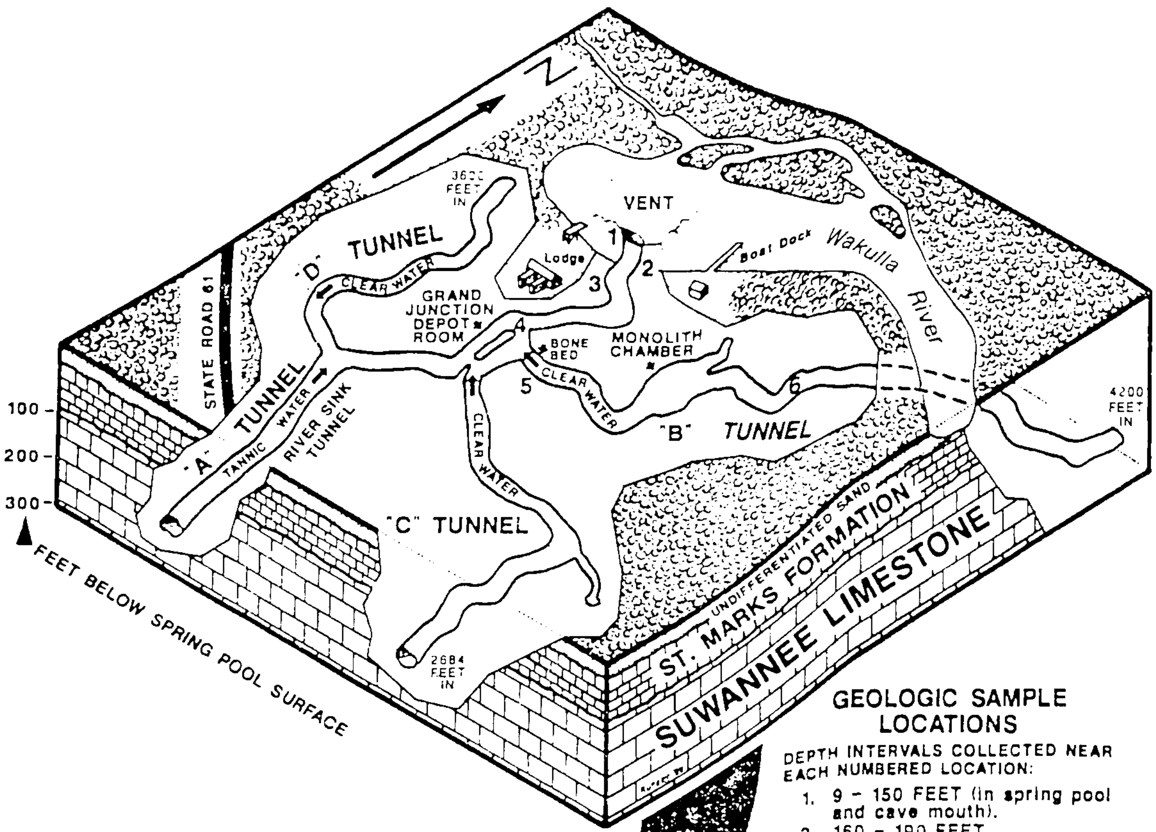

LEON COUNTY
LIBERTY COUNTY
JEFFERSON COUNTY
FRANKLIN COUNTY
WAKULLA SPRINGS
50
40
30
20
10
10
Elevation contours
in feet above mean sea level
MILES
0 1 2 3 4 5
0 2 4 6 8
KILOMETERS
N

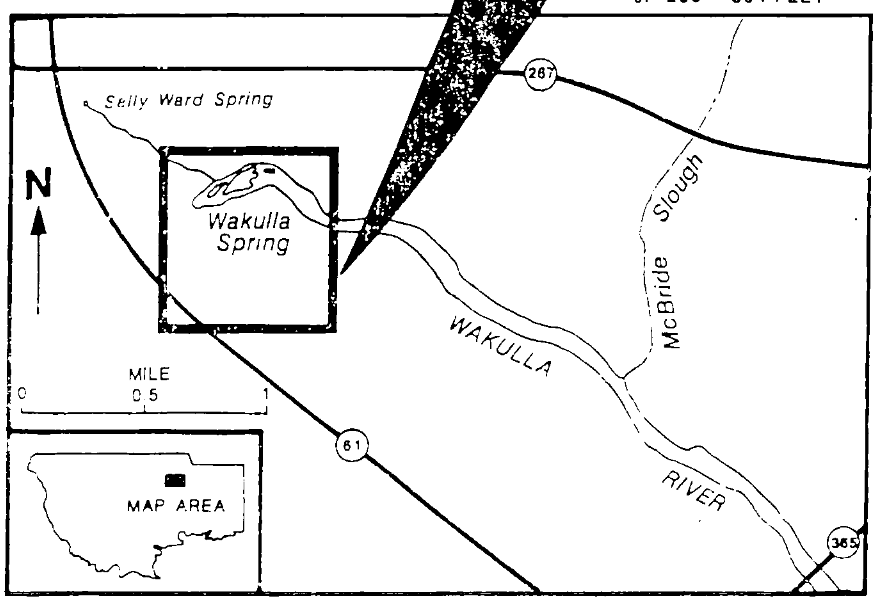
Figure 5: Block diagram of the Wakulla Spring conduit system (data from U. S. Deep Caving Team).



GEOLOGIC SAMPLE LOCATIONS

DEPTH INTERVALS COLLECTED NEAR EACH NUMBERED LOCATION:

1. 9 - 150 FEET (in spring pool and cave mouth).
2. 160 - 190 FEET
3. 200 - 230 FEET
4. 240 - 270 FEET
5. 280 - 290 FEET
6. 296 - 304 FEET



sporadically throughout a wide range of sea level positions.

The directions the conduits feeding Wakulla Spring assumed during their formation may have been largely bedding-plane and joint or fracture controlled. Limestone will naturally contain some horizontal beds which are softer or more easily exploited by water than others. In addition, natural fractures in regionally consistent orientations are common in limestone terrain. Such fracturing is often observable as linear patterns in air photographs. Over time, the dissolving action of groundwater seeping along these fractures could shape a tubular conduit. The existing fracture directions would determine the compass direction a conduit assumed. Likewise, the horizontal positions of the softest, most exploitable beds, as well as the elevation of the water table, would control the depth of the conduits. If the fracturing is widespread and intersecting, an extensive series of interconnected tunnels could develop.

Although data on linear trends in Wakulla County is lacking, Hendry and Sproul (1966) and Yon (1966) observed a series of linear patterns, trending northeast-southwest and northwest-southeast, in adjacent Leon and Jefferson Counties. The orientations of long segments in each of the Wakulla Spring conduits appear to generally correspond to these compass directions.

Water flow in all the tunnels is towards the Grand Junction Depot room, and ultimately northwestward to the spring vent

(Figure 5). Interestingly, this flow is generally in opposition to the local potentiometric gradient. Water quality within the conduits showed somewhat differing characteristics. Tunnels "B", "C", and "D" carried "air clear" water, while Tunnel "A" carried tannic (tea-colored) water. Input from the tannic-laden conduit frequently determined the spring's overall clarity on a daily basis. Clemens (1988) reported no major water quality (chemistry) differences between water samples collected by the dive team in tunnels A, B, C, the cave entrance, and Sally Ward Spring. Preliminary uranium isotope counts conducted on water samples taken within the four conduits reveals that tunnels "B" and "C" carry regional groundwater, while Tunnel "D", and possibly tunnel "A" have recent surface water components (Kenneth Osmond and Milena Macesich, Florida State Universtiy, personal communication, 1988).

The existence of such large and complex systems of underground caverns is not surprising to geologists. Similar patterns are known in dry caves, and cave divers have been exploring other submerged conduit systems throughout Florida for years. However, the discoveries made during the Wakulla Springs Project have great significance to our understanding of the hydrology of the Woodville Karst Plain. The traditional view of a limestone aquifer as a porous, consistent mass of rock through which water seeps at a predictable rate is no longer entirely accurate. We must now take into consideration the additional effects of a series of virtual underground rivers, interconnected, and moving large quantities of water rapidly.

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FIGURE CAPTIONS

Figure 1: Map showing the extent of the Woodville Karst Plain and the geologic cross section location.

Figure 2: Geologic cross section across the Woodville Karst Plain.

Figure 3: Cross section of the Wakulla cave, from Olsen (1958).

Figure 4: Potentiometric surface of the Floridan aquifer system in Wakulla County (from Barr, 1987).

Figure 5: Block diagram of the Wakulla Spring conduit system (data from U.S. Deep Caving Team).

APPENDIX

Appendix: Lithologic descriptions of the Wakulla Springs rock samples and Core #2.

Wakulla Springs Geological Samples (Depths are feet below spring pool surface)

9.0 feet — White recrystallized calcilutite. Mollusk and foraminifera moldic. Foram fauna comprised largely of:

Archaias sp.
Sorites sp.

Insoluble residue test: 24.8 weight percent insolubles, composed primarily of very fine quartz sand.

20.0 feet — White to very pale orange recrystallized calcilutite. Contains small mollusk molds, very rare foraminifera.

Insoluble residue test: 0.06 weight percent insolubles, composed of clay and minor very fine quartz sand.

25.0 feet — Very pale orange to white calcilutite, containing yellowish gray clay stringers. Contains rare foraminifera, including:

Archaias cf. *floridanus*
Quinqueloculina sp.

Insoluble residue test: 33.5 weight percent insolubles, composed of approximately 60% very fine to fine quartz sand and 40% clay.

30.0 feet — Very pale orange to white calcilutite, containing yellowish gray clay stringers. Minor iron oxide staining. Contains fossil foram molds and rare recrystallized foraminifera, including:

Sorites sp.
Amphistegina sp.

as well as echinoid spines.

Insoluble residue test: 28.5 percent insolubles, predominantly fine quartz sand.

40.0 feet

Very pale orange to white calcilutite, abundantly fossiliferous with recrystallized foraminifera, including:

Sorites sp.
Quinqueloculina spp.
Archaias cf. floridanus

Insoluble residue test: 0.09 weight percent insolubles, predominantly fine quartz sand, with minor clay.

50.0 feet

Very pale orange to white calcilutite, containing small mollusk molds and abundant recrystallized foraminifera. (May possibly be a recrystallized biocalcarenite with micrite cement). Small calcite crystal growths in vugs and cavities. Miliolid foraminifera are dominant microfauna.

Insoluble residue test: No insolubles recovered.

60.0 feet

Very pale orange unfossiliferous, recrystallized calcilutite.

Insoluble residue test: Less than 0.01 weight percent insolubles (clay).

70.0 feet

Very pale orange fossiliferous calcilutite. Contains pelecypod and coral molds and abundant foraminifera, including:

Quinqueloculina/Triloculina spp.
Archaias sp.
Cycloculina? miocenica

Insoluble residue test: None recovered.

80.0 feet

White unfossiliferous calcilutite (may be recrystallized).

Insoluble residue test: None recovered.

Miocene
St. Marks Fm.

90.0 feet Oligocene Suwannee Lmst.	Very pale orange to grayish orange, recrystallized biocalcarenite with calcite cement. Mollusk and foram molds, and abundant recrystallized foraminifera. Contains one large mollusk mold of what is probably <u>Cerithium</u> sp. Miliolid foraminifera very abundant. Insoluble residue test: None recovered.
100 feet	Very pale orange, recrystallized, poorly cemented foraminiferal biocalcarenite. Contains nearly 100 percent foram tests, with minor echinoid spines and calcareous fragments. Fauna includes: <u>Rotalia (Pararotalia) mexicana</u> <u>Dictyoconus</u> cf. <u>cookei</u> Miliolids and many others. Insoluble residue test: None recovered.
110 feet	Very pale orange recrystallized foraminiferal biocalcarenite. Sample has 3/8 to 1/2 inch thick "rind" of iron oxide staining on exposed edge. Fauna includes: <u>Rotalia mexicana</u> <u>Cancris sagra</u> <u>Quinqueloculina</u> spp. <u>Triloculina</u> sp. and others.
120 feet	As above.
130 feet	As above.
140 feet	White recrystallized biocalcarenite/calcilutite. Contains foram and small mollusk molds, and approximately 5% fine quartz sand. Also contains rare <u>Operculinoides vicksburgensis</u>.
150 feet	Very pale orange recrystallized foraminiferal biocalcarenite. Contains very abundant miliolids and minor echinoid spines.
160 feet	As above.

170 feet	As above.
180 feet	As above, with pelecypod molds.
190 feet	As above.
217 feet	Very pale orange recrystallized foraminiferal biocalcarenite. Poorly cemented and mollusk moldic. Contains abundant recrystallized foraminifera and _Ryncholampus gouldi_ echinoids. Foraminifera include: _Discorbis_ cf. _patelliformis_ _Quinqueloculina_ sp. _Triloculina trigonula_ _Discorinopsis gunteri_ _Quinqueloculina_ cf. _seminula_ and many others.
220 feet	Very pale orange, hard, recrystallized calcarenite; mollusk moldic. Small calcite crystal growth in molds and cavities. Both samples belong to the Suwannee Limestone.
230 feet	Very pale orange to white recrystallized calcarenite; calcilutite matrix. Very abundant recrystallized benthic foraminifera, rare mollusk molds.
250 feet	White to very pale orange recrystallized biocalcarenite. Calcilutite matrix. Very abundant benthic foraminifera, including: _Lepidocyclina_ spp. _Rotalia mexicana_ Miliolids, and others.
280 feet	White calcilutite. Abundant poorly preserved forams.
296 feet	Very pale orange calcilutite, containing unidentifiable recrystallized forams and rare mollusk molds.
304 feet	Yellowish gray sucrosic dolomite. No fossils observed. Note: A visible lithologic change is reported by the divers between 296 and 304 feet in the cave wall.

Sally Ward Spring Sample

90 feet	Very pale orange recrystallized biocalcarenite. Very abundant poorly preserved foraminifera, rare mollusk molds. Fossil colonial coral impression on one side of specimen. Suwannee Limestone.

Wakulla Springs Project

Core #2, taken at a water depth of 140 feet, in the mouth of the main spring tube. Collected by W. Wilson, 11-15-87.

Inches (down core; 0 = top)	Lithology
0 - 4.0	White, (yellowish-gray wet) medium to coarse quartz sand; contains organics and plant remains.
4.0 - 6.3	Greenish black clay. Contains plant remains, freshwater mollusk fragments, and approximately 2% medium, subangular quartz sand.
6.3 - 7.8	White (yellowish-gray wet) fine quartz sand; contains minor organics and plant remains.
7.8 - 11.2	Olive gray organic-rich clay, containing minor small calcareous particles.
11.2 - 15.2	White (yellowish-gray wet) fine quartz sand, containing organic material and numerous small freshwater gastropod shells. Organics include a one inch diameter portion of a tree branch (at 13 in.) and layered peat-like plant remains.
15.2 - 23.9	Olive gray organic-rich clay, containing calcareous particles.

Total length: 23.9 inches.

Pleistocene - Holocene deposits.