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Natural Resource Program Center

Big Cypress National Preserve
Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/021

THIS PAGE:
West Mud Lake Cypress Dome, Big Cypress N Pres

ON THE COVER:
Dwarf Cypress Prairie, Big Cypress N Pres

Photos by: Paul C. Murphy

Big Cypress National Preserve

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
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Executive Summary

This report accompanies the digital geologic map for Big Cypress National Preserve in Florida, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research.

Located in the part of South Florida that also includes the Everglades, Big Cypress National Preserve is part of a unique area on Earth. Habitats at Big Cypress National Preserve include estuarine areas, slow- flowing freshwater sloughs, saline marshes, freshwater marshes, cypress swamps, prairies, domes, strands, mangrove zones, buttonwood ridges, coastal prairies, freshwater marl prairies, hardwood hammocks, and pinelands. The geology of the area has shaped these environments. Geology influences surface water flow, thus contributing to climate, weather, hydrology, and topography in Florida. Geologic units and structures are the basis for the extensive aquifers and the presence of oil and gas beneath Big Cypress National Preserve.

The Big Cypress area is one of the lowest, youngest, and most geologically stable platforms of North America. This overall stability belies dynamic geologic processes at work on the landscape of South Florida. With its low-lying landmass, South Florida has been repeatedly submerged and exposed with variations in sea level over the past 50,000 years. Beneath the surface at Big Cypress are thousands of feet of roughly horizontal geologic layers that are rich in carbonate minerals. These minerals dissolve in rainwater and groundwater made acidic by decaying organic materials. Dissolution of interconnected spaces in the subsurface of South Florida ultimately results in a karst landscape defined by solution holes, sinkholes, disappearing streams, and springs. Such a landscape can store a great deal of water.

From the late 1800s, human population has steadily increased in South Florida. Canals, ditches, dams, and levees drained swamps for agriculture, oil and gas exploration, and urban development. Thus people have forever altered the once- steady, slow flow of fresh water from Lake Okeechobee south to Florida Bay along the "River of Grass"—the Everglades. This ecosystem is rapidly changing and is threatened with destruction. A comprehensive, multiagency cooperative research effort is underway to restore water flow and preserve what remains of the once vast wetlands of South Florida. An increased understanding of geologic resources is important to these efforts at Big Cypress National Preserve.

The subsurface rock units at Big Cypress produce oil and gas, the development of which has been and continues to be one of the key resource management issues that face park management. Roads leading to active production pads provide access to the remote heart of the preserve. These roads may also provide access for recreational vehicles. However, most access roads that lead to active oil and gas wells are not currently used by recreational vehicles except for crossing at designated locations. The Bear Island Grade in South Bear Island also allows street- legal vehicles on designated roads. The remote areas of the preserve are difficult to patrol, and widespread recreational use is destroying fragile habitat at the preserve. Abandoned oil and gas production pads require careful reclamation, and future exploration and drilling is always a possibility at the preserve.

The following selected issues, features, and processes have geological importance and a high level of significance for resource management within the preserve:

- The hydrogeologic system.
  The Big Cypress Swamp is a western extension of the Everglades hydrologic system. The Big Cypress basin provides approximately 42% of the water flowing into Everglades National Park and is a vast hydrologic network—among the least altered remaining in South Florida. Water flows on the surface in marshes and sloughs and below ground through porous substrate in aquifers. Big Cypress Swamp is a significant aquifer recharge area. In the wet season, approximately 90% of the preserve is inundated. Conditions in the dry season reduce this inundated area to approximately 10% of the preserve. Understanding the hydrogeologic system at the preserve to is crucial to managing restoration efforts and predicting future conditions.
- Oil and gas issues.
  Oil and gas development has been ongoing at Big Cypress for over 50 years. These efforts pose a number of resource management issues, including increased access to the heart of the preserve, alterations and interruptions to the natural overland water flow, potential contamination of natural resources, and the presence of abandoned oil well pads and roads that require remediation.
- Off-road-vehicle (ORV) management.
  ORV use has been a recreational pastime at Big Cypress National Preserve for generations. Resource managers at the preserve are attempting to limit ORV use to designated areas. However, many sections of the preserve are remote and difficult to patrol. Areas affected by ORV trails are vast and require restoration. An understanding of the long- term effects of surface disturbance by ORVs would help in restoration efforts.
- Disturbed Lands.
  Disturbed lands include areas directly affected by oil and gas operations (e.g. well pads and access roads), borrow pits excavated for the construction of oil and gas pads, and roads built to access remote sites.

Introduction

The following section briefly describes the National Park Service Geologic Resource Evaluation program and the regional geologic setting of Big Cypress National Preserve.

Purpose of the Geologic Resource Evaluation Program

The Geologic Resource Evaluation (GRE) Program is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to their specific geologic resource issues. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRE team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRE products.

The goal of the GRE Program is to increase understanding of the geologic processes at work in parks and provide sound geologic information for use in park decision making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem. Geology is the foundation of park ecosystems. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS- 75, Natural Resources Inventory and Monitoring Guideline.

To realize this goal, the GRE team is systematically working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non- geoscientists. During scoping the GRE team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes. Scoping meetings are usually held for individual parks and on occasion for an entire Vital Signs Monitoring Network. The GRE mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their innovative GIS Data Model. These digital data sets bring an exciting interactive dimension to traditional paper maps by providing geologic data for use in park Geographic Information Systems and facilitating the incorporation of geologic considerations into a wide range of resource management applications. The newest maps come complete with interactive help files. As a companion to the digital geologic maps, the GRE team prepares a park-specific geologic report that aids in use of the maps and provides park managers with an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and up to date GRE contact information please refer to the Geologic Resource Evaluation Web site (http://www2.nature.nps.gov/geology/inventory/).

History and Overview of the Preserve

Established on October 11, 1974, during Gerald Ford's presidency, Big Cypress was the first national preserve incorporated into the National Park Service (16 U.S.C. § 689f et seq.). The preserve covers 720,567 acres of a water- dependent ecosystem in southwestern Florida; it includes much of the western Everglades.

Big Cypress National Preserve spans the area northwest of Everglades National Park (fig. 1). It stretches as far east as Shark River Slough and the Florida State Miccosukee Indian Reservation. The northern boundary is the Big Cypress Seminole Indian Reservation (north of Interstate Highway 75). The western boundary consists of Florida State Highway 29, the Fakahatchee Strand State Preserve, and the Florida Panther National Wildlife Refuge. The northerwestern boundary of Everglades National Park defines the southern edge. Together, these two National Park Service units cover the southern tip of the Florida peninsula and most of Florida Bay between the peninsula and the Florida Keys.

Great biodiversity is characteristic of Big Cypress. Environments include sawgrass prairies, estuaries, mangrove forests, pinelands, cypress swamps (strands and domes), hardwood tree islands and hammocks, slow- flowing freshwater sloughs, and coastal marshes. As much as 90% of the preserve is inundated from May to October.

The preserve is heavily used for recreation. It also contains two active oil and gas fields.

Geologic Setting

South Florida lies within the Atlantic Coastal Plain physiographic province. In the area of Big Cypress National Preserve, this province is divided into several subprovinces: Big Cypress Swamp, Everglades, Southern Atlantic Coastal Strip, Ten Thousand Islands, Florida Keys, and Southwestern Flatwoods (fig. 2) (Brooks 1981).

The Big Cypress Swamp subprovince defines the western boundary of the Everglades subprovince. The rocks underlying this area are among the oldest in South Florida and are composed of silt, sand, and carbonate minerals. This area is slightly higher in elevation than the Everglades basin because it is underlain primarily by the coral- rich limestone of the Pliocene Tamiami Formation (3- 4 Ma), which is exposed in large areas of Big Cypress

National Preserve. Elevation in the Big Cypress Swamp ranges from 3.6 to 12 m (12 to 39 ft) above mean sea level in the northern reaches to just slightly above sea level in mangrove zones in the south. Drainage in the province is primarily to the south and southwest.

The Everglades subprovince forms a south- dipping, spoon- shaped, low- lying area between the Southern Atlantic Coastal Strip to the east, and the Big Cypress Swamp to the west. The basin has very low relief. The elevation change is only 3.6–4.3 m (12–14 ft) from the maximum near Lake Okeechobee to sea level. Prior to the digging of canals and ditches and building of dams, flow in this drainage system was slow and steady from north to south.

The Southern Atlantic Coastal Strip subprovince comprises Pleistocene marine limestone covered by thin sheets of quartz sand. The marine limestone is composed of tiny ooids of carbonate that longshore currents pushed into a linear ridge during the Pleistocene ice age. The subprovince ranges in elevation from 1.5 to 6 m (5 to 20 ft) in the southernmost parts. The width of the linear ridge ranges from 16 km (10 mi) in southern Miami–Dade County to 5–8 km (3–5 miles) farther north.

The southern parts of the ridge are breached in places by sloughs (transverse marshes) oriented perpendicular to the trend of the ridge. The subprovince wraps around the southern end of Florida containing vast tracts of coastal marshes and mangrove swamps. These environments cover an area from the northeastern part of Florida Bay, around the southern Florida peninsula, and west into the Gulf of Mexico as far as the Ten Thousand Island region near Everglades City. Strips of swamps and brackish marshes that are just above sea level characterize this area. Freshwater runoff and tidal fluxes cause the salinity to vary dramatically. The mangrove, capable of enduring such salinity changes, thrives in this area.

The Ten Thousand Islands subprovince is along the southwestern edge of Big Cypress Swamp. Cast areas of mangrove forest, tidal sloughs, and open lagoons characterize this area. Seaward of the forest is a sand ridge which has built up above sea level. Miocene and Pliocene sedimentary rocks and sediments underlie the Southwestern Flatwoods subprovince to the north of Big Cypress Swamp. Recent deposits are thin or nonexistent. Landforms of this area include flatwoods, cypress swamps, rocklands, and marl plains. The Florida Keys contain long, narrow islands of limestone or carbonate sand and mud that stretch in an arcuate pattern from the southeastern tip of Florida to the Dry Tortugas. Coral rock underlies the northern keys. Between these limestone keys and the bioclastic, carbonate sand and mud of the Dry Tortugas are islands composed of oolitic limestone.

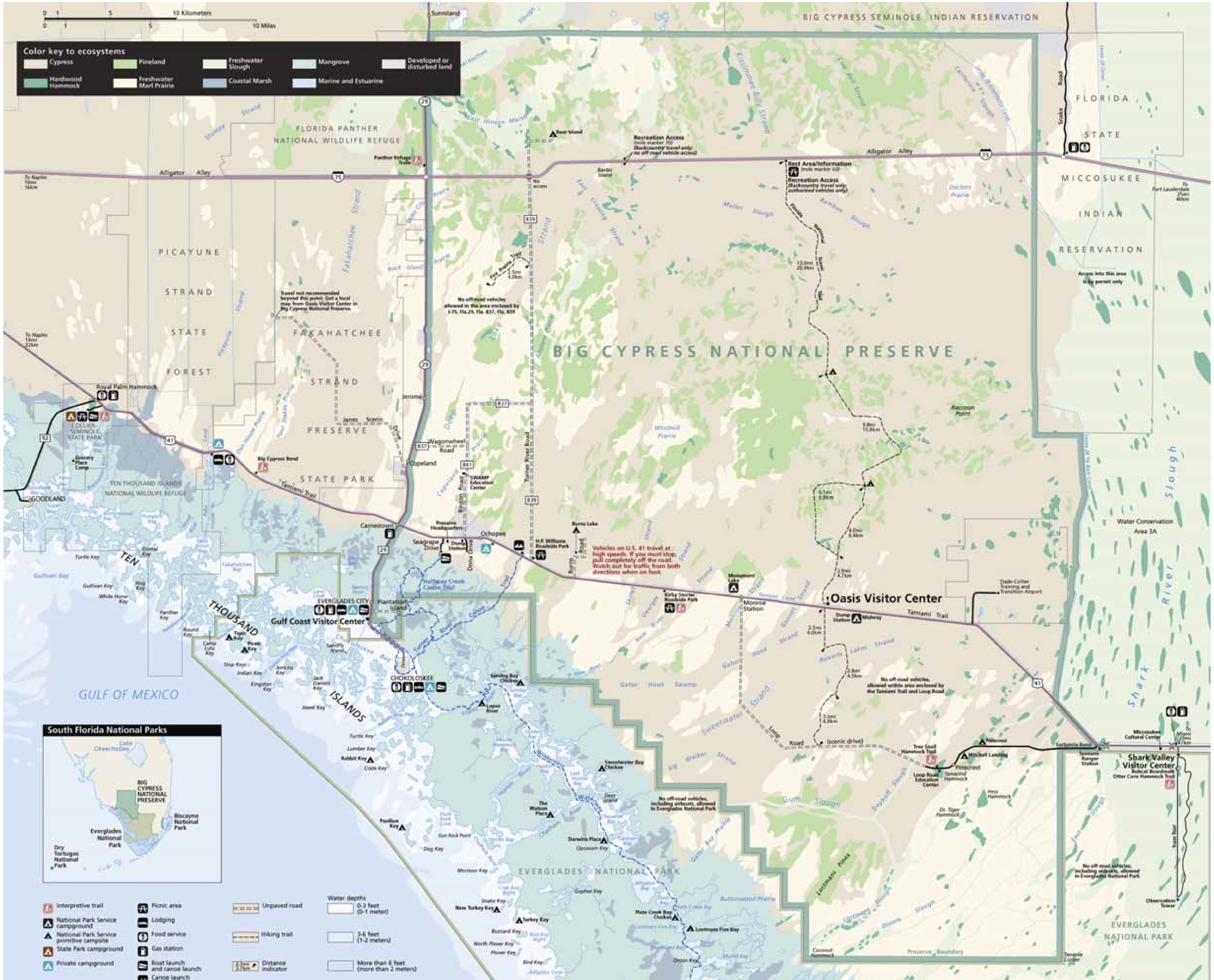

Figure 1: Location and ecosystem map for Big Cypress National Preserve and vicinity. Many of the locations mentioned throughout this report are identified here. Also note the inset map depicting the location of Big Cypress on the Florida peninsula.

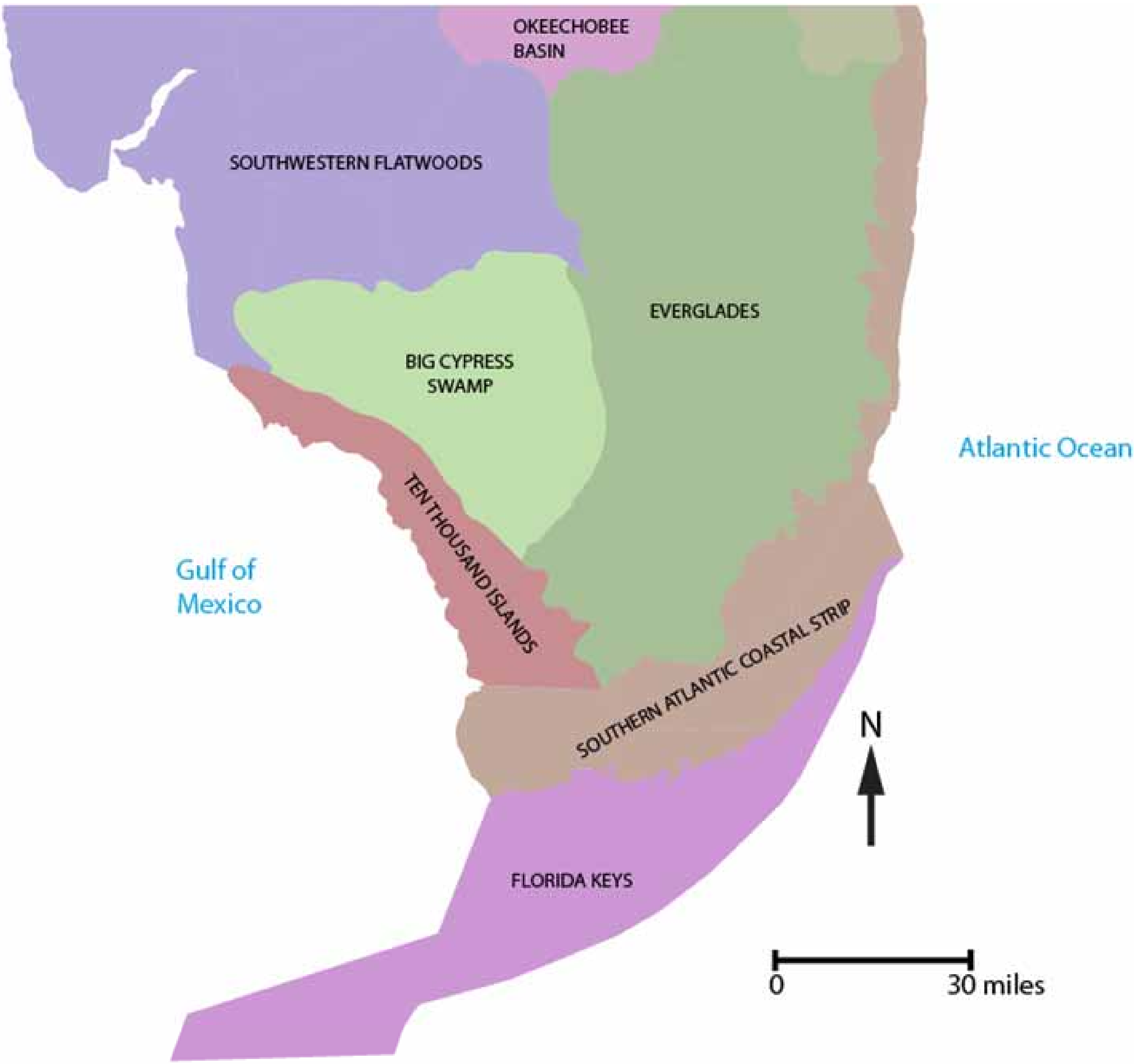

Figure 2: Map of physiographic subsections in South Florida as defined by Brooks (1981). Geographic data provided by St. Johns River Water Management District (http://www.sjrwmd.com; accessed February 21, 2006). Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Issues

A Geologic Resource Evaluation scoping session for Big Cypress National Preserve was held on January 27–28, 2005, to discuss geologic resources, to address the status of geologic mapping, and to assess resource management issues and needs. The following section synthesizes the scoping results, in particular those issues that may require attention from resource managers.

Issues in this section are identified in relative order of resource management significance with the most critical listed first. Potential research projects and topics of scientific interest are presented at the end of this section.

Hydrogeologic System at Big Cypress National Preserve

The Big Cypress Swamp is a western extension of the Everglades hydrologic system. The Big Cypress basin provides approximately 42% of the water flowing into Everglades National Park (Dorney and Mott 1983). As part of the freshwater wetland, Big Cypress Swamp is a vast resource (Spiker et al. 1995). It is among the least altered hydrologic systems remaining in South Florida (Miller and McPherson 2001). Water flows on the surface in marshes and sloughs and below ground through porous substrate in aquifers. In the wet season, approximately 90% of the preserve is inundated, with water depths ranging from several centimeters to more than 0.9 m (a few inches to 3 ft). Conditions in the dry season reduce this inundated area to approximately 10% of the preserve (Miller and McPherson 2001).

As water level declines during the dry months, physical, chemical, and biological processes increase the rate of decomposition of organic matter. Similarly, the concentrations of organic waste, nutrients, and contaminants increase in the remaining surface waters (Miller et al. 2004). The environment at the preserve is dependent on the seasonal flow of non- polluted water across the landscape. Managing this flow is complicated. The present topographic and hydrogeologic information is too coarse and/or inadequate for resource management. More scientific study and modeling is necessary to understand the true water budget of the preserve.

Water quality is an important management issue at Big Cypress National Preserve. The wetland soils and sediments, in addition to being a reservoir of water and nutrients, also contain a record of information about the system, including changing vegetation, biogeochemistry, predevelopment conditions, and increased human influences (Spiker et al. 1995). In sediment samples collected from the Barron River Canal and Turner River, lead, copper, zinc, normalized aluminum, phthalate esters, arsenic, cadmium, and zinc were higher than background levels. Pesticides, mercury, polynuclear aromatic hydrocarbons, and p- cresol were also detected in sediments within the preserve (Spiker et al. 1995; Miller and McPherson 2001). These contaminants are likely anthropogenic in origin, stemming from roads, vehicular traffic, encroaching development, an old creosote wood- treatment facility, and agriculture. Chloride concentrations in nearby Taylor and Shark River Sloughs doubled from 1960 to 1990 and the pesticide Atrazine is present in the waters at Big Cypress (Miller et al. 2004). It is unknown what collective effect these contaminants have on the ecosystem at Big Cypress.

The construction of roads, trails, oil pads, canals, and levees has altered the flow of water through the preserve. State and local water extraction policies control a vast proportion of water input to Big Cypress Swamp. Pumping can control basin groundwater dynamics. A major goal of the preserve is the restoration of the original flowways as closely as possible (Scoping participants 2005). A focus area is in- channel construction near U.S. Highway 41 in the Turner River basin (9–12 m [30–39 ft] wide). Restoration efforts include reconnecting flows through canals and under roads (building causeways). The Bear Island area is another area to focus restoration efforts. Cooperation is necessary between resource managers and local agencies that control water volume to coordinate and organize the timing of gates and pumps.

Hydrostratigraphic studies of cores within the preserve (including time domain electromagnetic [TDEM] and direct- current [DC] resistivity) suggest the geologic framework and aquifer system beneath Big Cypress Swamp is complex (Shoemaker 1998). Due to karstic dissolution, most of Florida acts as a limestone sponge, storing and moving groundwater through underground conduits. Big Cypress Swamp is a recharge area for the aquifers (Dorney and Mott 1983). The interaction between groundwater flow and the overall ecological quality of freshwater must be quantitatively determined at Big Cypress National Preserve. The karst aquifer system of South Florida is open to recharge of water from precipitation, surface flow, and man- made diversions (such as canals, ditches, ponds). The underlying Tamiami Formation forms part of the near surface aquifer beneath Big Cypress National Preserve.

Understanding the nature of the hydrologic exchange between surface and ground waters is critical to understanding the movement of water and dissolved nutrients, wastes, metals, and other substances in the Big Cypress ecosystem (Bruno et al. 2003).

Various hydrogeologic models of regional water flow have been used to characterize Big Cypress National Preserve. These models have varied in their success. The South Florida Water Management Model (SFWMM) ignores roads and uses an outdated climatic scheme. The Natural Systems Model (NSM) uses vegetation patterns to predict an improved pseudotopography. The Across Trophic- Level System Simulation (ATLSS) correlates species with hydrology, hydroperiod, and vegetation. The Everglades Landscape Model (ELM) covers the hydrology of bounded systems of canals and structural control with rain- driven triggers. The Interim Structural and Operational Model (ISOP), which was slated for implementation in 2007- 8, is probably the closest to successfully modeling the water budget needed to manage the preserve, but it still uses core data from the SFWMM model. Cell size (minimum mappable unit) and vertical precision vary on these models from 3.2 km (2 mi) to 30 m (100 ft) and from 15 to 3 cm (6 to 1 in.), respectively. Lidar surveys would vastly improve the vertical precision (Scoping participants 2005).

Inventory, Monitoring, and Research Needs for the Hydrogeologic System

- Study the spatial distribution of rainfall and its effects on the hydrologic system.
- Use flow studies and depth- to- bedrock measurements to determine quantifiable relationships between the water budget and substrate thickness.
- Compare hydraulic changes in the surface and groundwater flow at Big Cypress National Preserve caused by natural processes with those caused by anthropogenic alterations.
- Monitor hydrologic response to storm events.
- Continue to support sediment sampling to determine baseline conditions and monitor changes in contaminant levels (Miller and McPherson 2001).
- Cooperate with regional lidar mapping efforts to obtain surveys of sloughs at Big Cypress National Preserve for small- scale topographic changes.
- Increase hydrologic sampling and install hydrologic monitoring stations in key locations.
- Determine more stage- level measurement points; determine baseline conditions and continuously monitor stage levels, especially related to spatial and seasonal variations.
- Seek further support from the Comprehensive Everglades Restoration Program (CERP) efforts.
- Cooperate with federal, state, and local agencies to monitor and clean up ground and surface water; examples of pollution include creosote (from Copeland sawmill in the 1960s) and agricultural runoff (including pesticides from tomato farms).
- Map and study karst landscapes and features in and surrounding Big Cypress National Preserve to determine the nature of Deep Lake (27 m, or 89 ft, deep), the southernmost sinkhole in Florida (fig. 3).
- Focus geologic studies on geomorphologic processes and biologic influences rather than just on surficial features.
- Categorize, describe, and model the near- surface, mid- and deep aquifers below Big Cypress National Preserve.

Oil and Gas Issues

When Big Cypress National Preserve was created in 1974 and additional lands were added to the preserve in 1988, surface ownership within both areas was acquired by the U.S. government. Private entities or the State of Florida retained the subsurface mineral rights on these lands, with private entities retaining most (approximately 99%) of these rights. The federal government does not own any of the subsurface oil and gas rights in the preserve, yet the NPS is required by its laws, policies, and regulations to protect the preserve from any actions, including oil and gas operations, that may adversely impact or impair park resources and values.

Management of oil and gas activities within the original preserve are guided by a Minerals Management Plan (MMP) prepared in 1991. The MMP does not apply to the addition lands. Preserve staff are currently preparing an Oil and Gas Management Plan to address oil and gas exploration and development throughout the entire preserve, as well address new technologies, regulations, NPS policies and orders, and scientific information that have come about since development of the 1991 MMP.

Oil and gas exploration began in south Florida in 1923. The first oil discovery in south Florida occurred northwest of the preserve in 1943 with the discovery of the Sunniland field. The most active drilling period was in the mid 1970s. The main petroleum- producing geologic unit is the Sunniland Formation. Over 200 wells have been drilled along the northwest- southeast oriented Sunniland trend.

Today oil and gas exploration in the preserve is rapidly declining. As of August 2007, there were 14 wells producing from 8 fields along the trend. Eight of these producing wells are located within the preserve at the Raccoon Point and Bear Island fields. Through November 2007, cumulative production from these two fields totaled 30.5 million barrels of oil and 3.2 billion cubic feet of natural gas (http://www.dep.state.fl.us/geology/programs/oil_gas/prod_report/nov_2007_fla_mon_prod.xls accessed February 2008).

Oil and gas wells in the preserve are directionally drilled from four common pads. In addition to the two oil fields, located entirely or partly within the preserve boundaries, there are two small, inactive fields—Pepper Hammock and Baxter Island. As of 2007, with the exception of one inactive disposal well, south Bear Island wells have been plugged and abandoned (Don Hargrove, written communication 2007). Other significant fields, such as the Sunniland, Seminole, and Forty Mile Bend fields, are located within the greater Big Cypress Swamp drainage and therefore have relevance to park resource management (Pollastro et al. 2000).

The oil and gas reservoir rocks have 10–30% porosity. They are composed of carbonate grainstone (oyster shoals) and dolomite sealed by evaporites and/or nonporous carbonate minerals. The overall success rate of drilling based on two- dimensional seismic surveys and on gravity and magnetic data has been about 3%. (Norby 2005).

Drilling and production activities in Big Cypress National Preserve have created a large environmental footprint in the form of roads, well pads, and production facilities. The pads and roads left behind when a well is plugged and abandoned leave a large scar on the landscape and affect the hydrologic system at Big Cypress (figs. 4 and 5). Roads built of borrow pit material are elevated above the surrounding drainage. Culverts are irregularly spaced, and many are in disrepair (fig. 6).

These roads also provide access for off- road vehicles and impact a larger area of the preserve. However, most access roads that lead to active oil wells do not allow recreational vehicle use except for crossing at designated locations. The Bear Island Grade in South Bear Island allows street- legal vehicles on designated roads (Don Hargrove, written communication 2007). The responsibility for monitoring, compliance with regulations, restoration, and remediation is often unclear, and pipes, wells, and structures remain at abandoned pads.

Reclamation of access roads and oil well pads, and removal of flow lines, drilling pads, and equipment infrastructure are the responsibility of the operator (36 CFR § 9.38). The NPS Nonfederal Oil and Gas Rights regulations cover nonfederal oil and gas operations in NPS units. Operations that are not covered by an approved plan of operations must meet reclamation requirements as described in 62C – 25- 30 (Florida Administrative Code) and are subject to federal regulatory authority (Don Hargrove, written communication 2007).

Inventory, Monitoring, and Research Needs for Oil and Gas Issues

- Continue work with the Geologic Resources Division to develop a new oil and gas management plan.
- Work with Geologic Resources Division on current and proposed oil and gas exploration and development activities to avoid and mitigate adverse impacts.
- Collect depth- to- bedrock measurements to provide stratigraphic information available to preserve resource managers. Such data may be available through cooperative efforts with drilling and seismic survey teams.
- Obtain seismic information to incorporate into GIS. Private mineral owners are not required to share their propietary seismic information with the NPS so it may be difficult to obtain this data.
- To aid reclamation efforts and reduce the use of quarried rocks, use road and pad fill from abandoned oil wells to construct new trails and develop areas for visitor use

ORV Management

In 2005, more than 400,000 visitors came to the preserve for recreational purposes. Recreational activities include camping, kayaking, hiking, bird watching, canoeing, hunting, off- road- vehicle (ORV) use, and airboat access. A significant issue for resource management at the preserve has been public access to remote areas (Dorney and Mott 1983). ORV and airboat use have been popular recreational activities in the preserve for many years, the type of vehicle evolving with increased access to wild areas of the preserve. The preserve is attempting to concentrate visitor access and reduce environmental impacts from visitation.

An ORV management plan, completed in 2001, requires all ORV users to obtain a permit (quota is 2,000), specifies time restrictions, controls ORV types, and mandates a restriction to 644 km (400 mi) of trails in the preserve. It is estimated that at least 35,000 km (22,000 mi) of trails currently exist throughout the preserve. ORVs must depart from designated access points. Sensitive areas such as marl prairies, Cape Sable, the Loop and Deep Lake Units, and areas south of lower and upper Wagonwheel Road are closed. Seasonal closures (of about 60 days) are planned for rest and restoration of resources (NPS 2006). Management and enforcement of established trails and ORV activity is difficult for rangers on duty at Big Cypress National Preserve: The preserve is the size of Rhode Island, and many areas are too remote to patrol regularly.

ORV use at Big Cypress has caused and continues to cause major damage to the hydrology, water quality, and soils. Extensive areas of marl prairies within the preserve are being irreparably rutted (Rice et al. 2003). By churning and burying the substrate, buggies and other ORVs destroy living algae (terraphytes) populations in the soils. The entire ecosystem is based on these microorganisms, which lie dormant in dry conditions. When they are churned up and buried by passing ORVs, the landscape loses its capacity to support native vegetation. Soil characteristics, chemistry, depth, structure, and resiliency at the preserve are not well understood and merit further study.

Most of the access roads in the preserve are elevated, constructed with gravel, and pebbles with intermittent drainage culverts (fig. 7). Raised roadbeds across South Florida have impeded the natural, low- relief, slow- moving sheet- flow from Lake Okeechobee to Florida Bay.

In addition, access to the heart of the Big Cypress National Preserve has increased due to seismic exploration and production activities. Roads leading into pristine areas of the preserve, such as Raccoon Point, to access oil production pads, now allow ORV users to access wild areas of the preserve more than ever before (fig. 8). ORV users have largely thwarted attempts to gate, block, and/or patrol these access roads (Dorney and Mott 1983). Active oil and gas access roads are prohibited for ORV use. At present, gates, regulations, and law enforcement attempt to mitigate potential impacts from use of unauthorized ORVs on these roads. Today there are few documented violations of use of access roads to active wells. Only the oilfield operator and contractors, state and federal administrative officials, researchers, and fire fighters have authorized access to these roads (Don Hargrove, written communication 2007).

In addition to overuse by traditional buggies and ORVs, unauthorized airboat use is also a resource management issue affecting water quality, plant and animal populations, noise levels, and marshy soils. The ORV management plan contains specific regulations regarding airboat access and vessel requirements (NPS 2006).

Inventory, Monitoring, and Research Needs for ORV Management

- Using land- use patterns mapped in a GIS, determine the best sites for a designated trails system.
- Study cores of sediments containing a pollen record within ORV- affected areas to determine local vegetation differences (distribution and abundance) that result from anthropogenic activity (Willard et al. 1996).

Geologic and Topographic Mapping

Water flowing through the natural Everglades slowly trickles down to the sea from central Florida. This water exits the south shore of Lake Okeechobee, travels 160 km (100 mi) and drops only 6 m (20 ft) to the southern terminus at Florida Bay (Dorney and Mott 1983). The gradient at Big Cypress National Preserve is approximately 6 cm/km (2 in/mile), or 4.6 m over 145 km (15 ft over 90 mi). This low relief allows for the development of plentiful sloughs, swamps, and marshes at Big Cypress.

Geologic units and structures in the subsurface and surficial variations in rock unit composition, bedding structures, and sediment thickness control the minor changes in relief at Big Cypress National Preserve. Interdisciplinary, large- scale geologic mapping would help determine the effect of these parameters on the water budget at Big Cypress.

Combining spatial geologic information with current vegetation patterns, anthropogenic landscape alterations, and high- resolution topographic mapping data would provide resource managers with a powerful tool for analyzing interrelationships between these systems. Incorporated into a GIS, this information may aid resource managers in targeting areas for restoration, preservation, and visitor use.

Inventory, Monitoring, and Research Needs for Geologic and Topographic Mapping

- Study the correlation of small topographic differences with the locations of hardwood hammocks and pinelands at the preserve.
- Map exposures of Tamiami Limestone, including compositional variations and bedding structures.
- Focus on key areas for topographic mapping and construction of cross sections (coordinate with the original flow- way restoration efforts).
- Incorporate mapping of karstic dissolution features into surveys of canals and locations of rock pits.
- Cooperate with the slough- mapping project through the Audubon Society.
- Describe in greater detail the type section for the Tamiami Formation, which is located within the preserve. Further, define unit composition, structures, bioturbation, and sedimentary features.
- Using current maps of strands and paleochannels, determine through analysis in a GIS if these features at Big Cypress are related.
- Using new geologic and topographic mapping, attempt to determine why the boundary between Big Cypress and The Everglades is distinctive. Also, use this information to determine the nature of the boundaries between strands.
- Support studies to create Digital Elevation Models (DEMs) which could help determine original flow ways.
- Promote more interagency (e.g., U.S. Geological Survey, Bureau of Land Management, Natural Resources Conservation Service, South Florida Water Management District, Florida Department of Transportation) cooperative geologic mapping projects.

Disturbed Lands

Human activities have led to the deterioration of the stability, biodiversity, extent, and productivity of the freshwater wetland ecosystem of South Florida (Spiker et al. 1995). Agricultural activities and flood control, including the diversion of water through canals, ditches, and levees, have altered the hydrology of the region and limited freshwater flushing of Florida Bay, south of Big Cypress National Preserve. Many of these anthropogenic structures and activities are outside the preserve but have a lasting effect on the ecosystem within it.

The preserve itself contains hundreds of sites where fill was either excavated or brought in to elevate the area. As the preserve boundaries continue to change, additional disturbed areas will undoubtedly need to be inventoried and remediated. Some sites have been mapped and incorporated into a GIS to measure type of fill (debris such as trash, stones, building material), depth of fill, volume of fill, and other site characterization (NPS 2006).

Disturbed lands include areas directly affected by oil and gas operations (pads and fields), borrow pits excavated for the construction of oil and gas pads, and roads built to access remote sites. Access roads may pose the largest lasting threat to the hydrologic system at Big Cypress National Preserve because they interrupt water flow, introduce contaminants associated with motorized vehicles, and permit access to the heart of the preserve.

Inventory, Monitoring, and Research Needs for Disturbed Lands

- Quantitatively identify disturbed sites and explore remediation possibilities to restore natural water flow.
- Remove and remediate the access roads to the Bear Island oil field and other remote, unused areas.
- Remediate borrow pits. Use recycled paving materials for building future visitor facilities.
- Focus on roads perpendicular to the overall direction of water flow, research ways to build bridges and culverts along established (permanent?) roads to restore natural flow conditions.

Figure 3. Deep Lake, Big Cypress National Preserve, the southernmost large sinkhole in Florida. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 4. Remains of oil and gas extraction operations at an oil pad in Big Cypress National Preserve. Photograph was taken in 2005. This pump station at South Bear Island has since been removed by Enron, but other still exist within the preserve (Don Hargrove, written communication 2007). Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 5. Abandoned oil pad at Big Cypress National Preserve. Photograph was taken in 2005. This operation at South Bear Island has since been removed by Enron, but other still exist within the preserve (Don Hargrove, written communication 2007). Photograph by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 6. Rusting culvert along an access road to an oil pad at Big Cypress National Preserve. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 7. Intact culverts along an access road within Big Cypress National Preserve. Photo is taken from the road. Note the height of the road above the water level and the degree of ponding behind the roadway. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 8. Rutted ORV trail through the forest near the western boundary of Big Cypress National Preserve. Photograph by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Big Cypress National Preserve.

Freshwater Sloughs and Strands

Water is the predominant resource at Big Cypress National Preserve. Water at the preserve does not flow in well- defined streams and rivers (NPS 2006). Instead, water flows around elongated bands of cypress trees called "strands," cypress domes, and through extensive, meandering marshy areas referred to as "sloughs" that characterize the Big Cypress Swamp (Miller et al. 2004). Cypress swamps are present in areas that are continuously inundated for 240 to 290 days annually (National Audubon Society 2006). Nearly 150 cm (59 in.) of rainfall each year floods the cypress strands and prairies before slowly flowing over the surface and through sloughs towards Everglades National Park (NPS 2006). This rainfall supplies the watershed, and the slow flow rates allow recharge to the surficial aquifer within the preserve.

In the southeastern United States, a slough refers to a type of swamp or shallow lake system that is similar to a bayou with trees (Neuendorf et al. 2005). At Big Cypress National Preserve, a slough forms where the surface of the ground coincides with the shallow water table (fig. 9). Sloughs are a critical source of fresh water for wildlife, especially during seasonal droughts. Sloughs also accumulate nutrients for soils and vegetation (Taylor Schoettle 2006).

Shark River Slough separates Big Cypress National Preserve from the northwestern corner of Everglades National Park. Other large sloughs in the preserve include Dixons, Lostmans, Dayhoff, Gum, Bamboo, Mullet, Okaloacoochee, and California. These broad, slow- moving waterways separate higher, tree- supporting strands such as Sig Walker, Cow Bell, Kissimmee Billy, Sweetwater, Roberts Lakes, Gator Hook, Gannet, Monroe, New River, Georges, Skillet, East Crossing, and Deep Lake. The strands and sloughs at Big Cypress are all parallel and trend more or less northeast to southwest.

Cypress trees cover approximately one- third of the preserve, in many places lining the sloughs in strands (NPS 2006). Strands form where high water level and sufficient flow result in a channel along a depression (USDA Forest Service 2006). Most of these trees are dwarf pond cypress (*Taxodium distichum*), with a few areas of giant, bald cypress trees, some of which are 600–700 years old.

The cypress may also be present in cypress domes, mixed hardwood and cypress swamps, and "hatrack" cypress (a dwarf species) communities. Cypress domes are relatively small, discrete areas of freshwater swamp dominated by bald cypress trees.

The term "dome" refers to the characteristic configuration of larger trees growing in the center of the area with progressively shorter trees growing towards the edges. These domes and forests tend to coincide with solution collapse (karst processes) of near- surface limestone caprock. The depression collects nutrients and allows deeper root penetration for larger tree species (NPS 2006; USDA Forest Service 2006).

South Florida Basin and the Sunniland Trend

Big Cypress National Preserve lies within the northeastern part of the South Florida basin (200,000 km^2, or 80,000 mi^2), the thickest part of which is northwest of the Florida Keys, beneath Florida Bay. Deposition of mixed carbonate, evaporite, and clastic sediments in the subsiding basin has been more or less continuous since the Late Jurassic. Several large, positive structural features surround the basin: the Florida escarpment to the west (a major barrier reef complex that separates the Florida Shelf from the deep Gulf of Mexico basin), the Peninsular arch to the east, the Pine Key arch to the southeast, and the Tampa- Sarasota arch to the northwest (fig. 10). The most prominent of these—the Peninsular arch—is a crystalline basement feature of Paleozoic age that plunges south- southeast along the length of the Florida Peninsula. This arch controlled the deposition patterns of Jurassic and Cretaceous sediments. Beneath South Florida, units of these ages onlap, wedge, or pinch out against the arch (Pollastro et al. 2000).

The Sunniland Formation is among the Cretaceous units that pinch out along the Peninsular arch (fig. 11). The sediments that became the Sunniland Formation were deposited in tidal shoals and carbonate reef environments; the lower beds of the formation contain fractured carbonate rubble (Norby 2005). The Sunniland is sealed below and above by the salt and evaporite deposits of the Punta Gorda Anhydrite and the Lake Trafford Formation, respectively (fig. 12) (Pollastro et al. 2000) and have been found to trap hydrocarbons along the Sunniland Trend in south Florida

The Sunniland and Dollar Bay Total Petroleum System is 32 km (20 mi) wide and 240 km (150 mi) long; it trends northwest to southeast through Lee, Hendry, Collier, and Dade Counties and passes through the north and east boundaries of Big Cypress National Preserve. The petroleum is located at depths of between 3,350 and 3,660 m (11,000 and 12,000 ft) below the surface. The porous reservoir developed on a subtle structural high within the Sunniland Formation.

More than 200 wells in 14 fields (8 of which are still active) have been drilled along the Sunniland trend. It is estimated that Big Cypress National Preserve covers 6% of the trend. Other exploration continues in a second defined petroleum system, the Pre Punta Gorda Total Petroleum System (4,570–4,880 m [15,000–16,000 ft] deep). This second system is part of the Wood River Formation, which contains lower Cretaceous dolomite and clastic rocks. The Wood River pinches out against a structural high, creating a natural trap for petroleum storage. Big Cypress National Preserve covers 8% of the area of this system (Norby 2005).

Sinkholes and Karst

"Karst" is a term for a characteristic terrain produced by the chemical erosion of carbonate rocks such as limestone or dolomite. Acidic water reacts with carbonate rock to dissolve it along cracks and fractures. Most meteoric water (precipitation), so- called acid rain, is of relatively neutral pH and becomes more acidic as it flows through decaying plant debris and soils (Florida Geological Survey 2005).

Most of the limestone and dolomite in South Florida are inherently porous. Over hundreds of thousands of years, dissolution within intergranular pores and along fractures has created increasingly larger voids (fig. 13).

The system of underground voids in South Florida is extensive. Collapse of overlying rock and soil into a void produces a sinkhole such as Deep Lake at Big Cypress National Preserve. If the sinkhole develops in a streambed, it may capture the water flow and thus create a disappearing stream.

When groundwater, under hydraulic pressure, discharges from an underground drainage system, a spring is formed (Florida Geological Survey 2005). In areas of dense karst terrain, solution holes generally provide preferential pathways for water and contaminants to reach the underlying aquifers (Arthur et al. 2005)

At Big Cypress National Preserve, the predominant geologic units exposed at the surface are the Miami Limestone and the Tamiami Formation. The Pleistocene Miami Limestone is ≈125 – 130 ka and contains two facies, the oolitic facies and the bryozoan facies (Cunningham 2005). The Pliocene Tamiami Formation is ≈4.1 – 2.1 Ma and composed of mixed carbonate and siliciclastic rocks. This unit is very complex and contains several aquifers as described below (Scott 2001). The carbonate- rich layers in these units are highly susceptible to dissolution from acidic rain and groundwater.

The extensive carbonate rocks of Florida have been exposed to terrestrial weathering processes since the last significant interglacial period led to the flooding of the Florida platform some 130,000 years ago. Since that time, much of the original rock has been altered and/or dissolved by acidic rainwater and groundwater undersaturated with respect to calcium carbonate. Large solution holes formed in the Miami Limestone when sea level and the water table were lower than present levels.

As sea level has risen during the Holocene (a trend that continues in South Florida), many of the solution holes at lower elevations have filled with organic material and marl. As organic material continues to decay, lowering the pH of the groundwater with addition of carbonic acid, dissolution of the near- surface limestone will also continue at Big Cypress National Preserve. Deep Lake is the southernmost identified sinkhole in Florida, but others are likely to form when overburden collapses in areas throughout the preserve. Continued research is necessary to determine the degree of active dissolution and the connectivity between subsurface conduits.

Hydrogeology

Possibly the most distinctive features of the South Florida wetland ecosystem are the gently sloping landscape and its large capacity for long- term water storage. Prior to anthropogenic alterations and water management practices, water flowed very slowly through the system, buffering the ecosystem from extreme changes caused by droughts and floods. Understanding this system means understanding the relationship between geology and water flow at Big Cypress National Preserve (Florida Department of Environmental Protection 2005).

"Hydrogeology" refers to the study of groundwater movement with specific emphasis on its relation to the surrounding geology, modes of movement, and water chemistry (Florida Geological Survey 2005). This study combines hydrology, geology, chemistry, physics, biology, mathematics (modeling), and engineering to understand the characteristics of groundwater movement in the complex and enigmatic subsurface.

Groundwater is the most available source of potable water in South Florida. Water- bearing rocks at Big Cypress National Preserve include carbonate limestone, sandstone, and dolostone (a rock rich in dolomite, a carbonate mineral). As described above in connection with karst, the carbonate rocks in the subsurface are extensively dissolved and highly permeable, meaning that water is able to flow freely through the rock (Florida Geological Survey 2005).

A zone in the subsurface in which groundwater collects is referred to as an aquifer. A viable aquifer typically yields water in sufficient quantities to support agriculture and domestic use, for example. Aquifers are classified as unconfined, confined, or semi- confined on the basis of the physical parameters that define the aquifer. Unconfined aquifers have the general water table as an upper boundary. Unconfined aquifers are open to meteoric water filtering through the soil and subsurface and are thus susceptible to pollution from agricultural and domestic use. A confined aquifer is any water-bearing layer that is sandwiched between two aquitards, layers of rock that are so impermeable they cannot transmit useful amounts of groundwater (Idaho Geological Survey 2006). Semi- confined aquifers have characteristics of both confined and unconfined aquifers in different places.

The Florida aquifer system contains all three types of aquifers described above. This system underlies all of Florida and is the main source of water for most human use (Florida Geological Survey 2005). This system is located at different stratigraphic levels in the subsurface. The unconfined surficial aquifer (often referred to as the Biscayne aquifer in South Florida) comprises karstic platform carbonate rocks of the Pleistocene Miami Limestone and other Holocene to Pleistocene sandstone units (Cunningham 2004a, 2004b). The high porosity and permeability of these units allows considerable exchange between surface and ground waters (Bruno et al. 2003). In some parts of South Florida, a cap rock cover on the porous limestone controls the surface flow of water and its subsequent infiltration of the groundwater. Cap rock, bedrock structures (pinnacles), and dissolution features such as solution cavities, buried sinkholes, and conduit networks complicate hydrogeologic modeling at the preserve (Kruse et al. 2000).

At various stratigraphic levels below the surficial aquifer, other aquifers and aquitards create a complex system of layered water- bearing units. Terminology for these units varies depending on specific location. There are at least three aquifers (including the surficial aquifer) divided by three aquitards in the upper geologic units below Big Cypress National Preserve (fig. 14; model from Wexler 2004).

A significant aquifer lies within the Tamiami Formation. This aquifer, referred to as the Gray Limestone Aquifer, is being studied as a possible potable water resource for South Florida. The upper and lower confining units are predominantly clastic mud, sand, and clay (Shoemaker 1998). This aquifer is less permeable than the surficial aquifer and located at depths that vary over short distances. The depth to the base of this aquifer decreases from 45 m (150 ft) in eastern Collier County to 15 m (50 ft) in western Collier County. This variability requires careful and thorough study to understand the nature of the aquifer (Shoemaker 1998).

With the recent funding of the Comprehensive Everglades Restoration Plan (CERP), innovative and vital studies are underway to understand the changes in the natural habitats of The Everglades and, by extension, Big Cypress National Preserve, as a result of human activities. The CERP includes restoration of natural patterns of water flow. Data related to the hydrogeologic system at Big Cypress National Preserve, as a major contributor to the water budget of The Everglades, is critical to this goal.

The CERP is a cooperative effort of the National Park Service, National Oceanic and Atmospheric Association, U.S. Geological Survey, Florida Department of Environmental Protection, South Florida Water Management District, U.S. Army Corps of Engineers, Florida Geological Survey, South Florida Natural Resources Center, and Florida International University, among others (Loftus et al. 2001; South Florida Water Management District 2002).

Hardwood Hammocks

Hardwood hammocks are areas of closed canopy forests of dense vegetation dominated by evergreen and semi-deciduous tree and shrub species (U.S. Fish and Wildlife Service 2007). Hammocks in the Big Cypress National Preserve include the Tamarind, Hess, Dr. Tiger, and Coconut Hammocks. At the preserve, as well as in neighboring Everglades National Park, the hammocks contain some of the rarest and most unusual plant and animal species in South Florida. In the northern hammocks more than 100 species of trees and shrubs, ranging from red maple and laurel oak trees in the lower hammock areas to live oak and cabbage palm in the higher parts, can be found. To the south, tropical species such as strangler fig, wild tamarind, pigeon plumb, gumbo limbo, poisonwood, coco plum, redbay, and other broad- leaved tropical trees and shrubs dominate the hammocks (McPherson et al. 1976). Major hammock types include 1) rockland hammock "islands" on limestone substrate in or on the edges of pine rockland or marl prairies, 2) Keys rockland hammock on limestone substrate (Florida Keys), 3) coastal berm hammock on storm- deposited berms, 4) tree island hammock in Everglades marsh and marl prairies, 5) shell mound hammock on aboriginal sites (U.S. Fish and Wildlife Service 2007).

The existence of the hammocks is dependent upon the underlying geology and hydrogeologic processes. Hammocks develop on land that is slightly higher than that of the surrounding marshes and prairies. In South Florida, this elevation difference is generally less than 3 ft (1 m). Hammocks develop slowly because organic material must build up over many years to create a topographic high (McPherson et al. 1976). Soils of hammocks are typically moist, but rarely inundated (U.S. Fish and Wildlife Service 2007). Of interest to cultural resource studies, this higher land supported ancient human occupations such as the Calusa Indians, as evidenced by pottery fragments, metal containers, shell mounds, burial sites, and planted exotic species (McPherson et al. 1976). Aboriginal garbage mounds and mollusk shell mounds in turn provided a foundation for hardwood, closed canoy forest development (U.S. Fish and Wildlife Service 2007).

Bay heads, precursors to hammocks, are tree islands dominated by broad- leaved, evergreen, and swamp hardwood species. These areas occupy high peat benches above the surrounding marsh. Bay heads often develop at solution holes or depressions in the solid bedrock. Peat and other organic materials accumulate in the depressions and nurture the development of larger trees and forests. Peat continues to accumulate until a topographic high is created (see fig. 13). If the peat is not lost to fires, hardwood hammocks ultimately develop. Hammock forests are a climax community of plants developed in the long- standing absence of fire. Deeper water and/or high humidity produce dense vegetation that shelters the hammocks from fire. Any hammocks on limestone substrates, such as those in Big Cypress Swamp are dependent on the underlying water table to keep humidity levels high (U.S. Fish and Wildlife Serviece 2007). However, temperature and salinity can limit the development of hardwood hammocks (McPherson et al. 1976). Many hammocks require the presence of fresh water or low salinity lenses in their soils and substrates (U.S. Fish and Wildlife Service 2007). If salt water incursion or increased evaporation leads to higher salinities, the health of the hammock may suffer. Similarly, hammocks flourish at near constant temperatures. The dense canopy minimizes temperature fluctuations by reducing soil warming during the daytime and preventing excess heat loss at night (U.S. Fish and Wildlife Service 2007).

Stratigraphic Record

Cores drilled during oil and gas exploration reveal a thick and time- extensive stratigraphic sequence underlying the preserve. In the oil and gas producing areas of Big Cypress, the sedimentary sequence is 4,572–5,182 m (15,000–17,000 ft) thick (Pollastro et al. 2000). This sequence overlies Jurassic volcanic rocks (rhyolite and basalt) and consists of some of the oldest rocks in Florida. The sedimentary rocks of Big Cypress fill the South Florida basin, described above.

The earliest sediments, part of the Wood River Formation, are continental clastic rocks overlain by salt, limestone, anhydrite, and brown dolomite. Between the Wood River and the oil- producing Sunniland Formation lie the predominantly carbonate- evaporite Bone Island and Pumpkin Bay Formations, and the Glades Group of shale, dolomite, and anhydrite (Faulkner and Applegate 1986). The Lower Cretaceous Sunniland Formation is composed of anhydrite, a thin limestone layer, and dolomite. The Sunniland; the anhydrite and limestone of the Lake Trafford Formation; and the dolomite, limestone, and anhydrite of the Rattlesnake Hammock Formation make up the Ocean Reef Group (Pollastro et al. 2000).

The Big Cypress Group and Naples Bay Group overlie the Ocean Reef Group. These are largely dolomite and anhydrite beneath Big Cypress National Preserve. The Upper Cretaceous Pine Key Formation is composed of chalky limestone and dolomite. It is approximately 914 m (3,000 ft) thick. The Paleocene to present- day sedimentary layers overlie the Pine Key Formation at Big Cypress (Faulkner and Applegate 1986). Relatively uninterrupted Tertiary deposition amassed the grand carbonate platform of South Florida. These sediments reach great thicknesses, approximately 1,676 m (5,500 ft).

Cores drilled in nearby Everglades National Park help determine the stratigraphy of younger units at Big Cypress National Preserve. Eocene to late Oligocene deposition resulted in the marine carbonates of the Avon Park Formation, the Suwannee Limestone, the Ocala Group, and the Arcadia Formation of ramp- setting carbonates with scant quartz content increasing northward (Cunningham 2005).

A major disconformity marks the boundary between the Arcadia Formation and the overlying Peace River Formation. In other areas of Florida, the Hawthorn Group (Miocene) is between the Arcadia and Peace River Formations. The Peace River Formation contains two distinct units: a lower diatomaceous mudstone, and an upper muddy, fine- grained quartz sandstone (Cunningham et al. 1998). Deposited atop the Peace River Formation is the Tertiary age Tamiami Formation. This unit comprises much of the surface outcrop at Big Cypress.

Figure 9: Slow-flowing slough at Big Cypress National Preserve. During the dry season the slough is an essential water source for local wildlife and vegetation. Photograph (January 2005) is by Trista L. Thornberry-Ehrlich (Colorado State University).

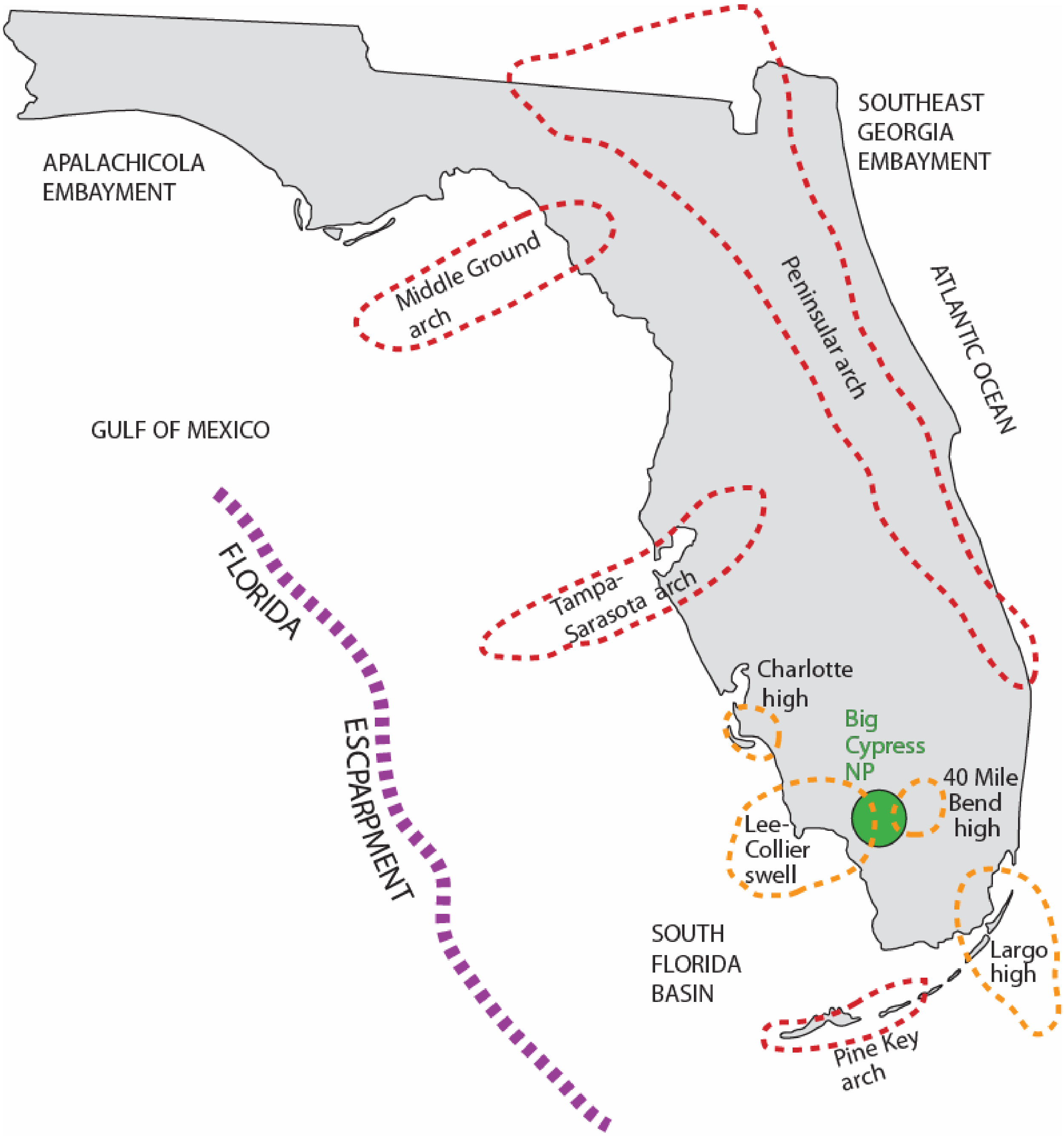

Figure 10. Map of Florida showing location of Big Cypress National Preserve relative to major positive structural elements of the South Florida basin. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University) based on information from Pollastro et al. (2000).

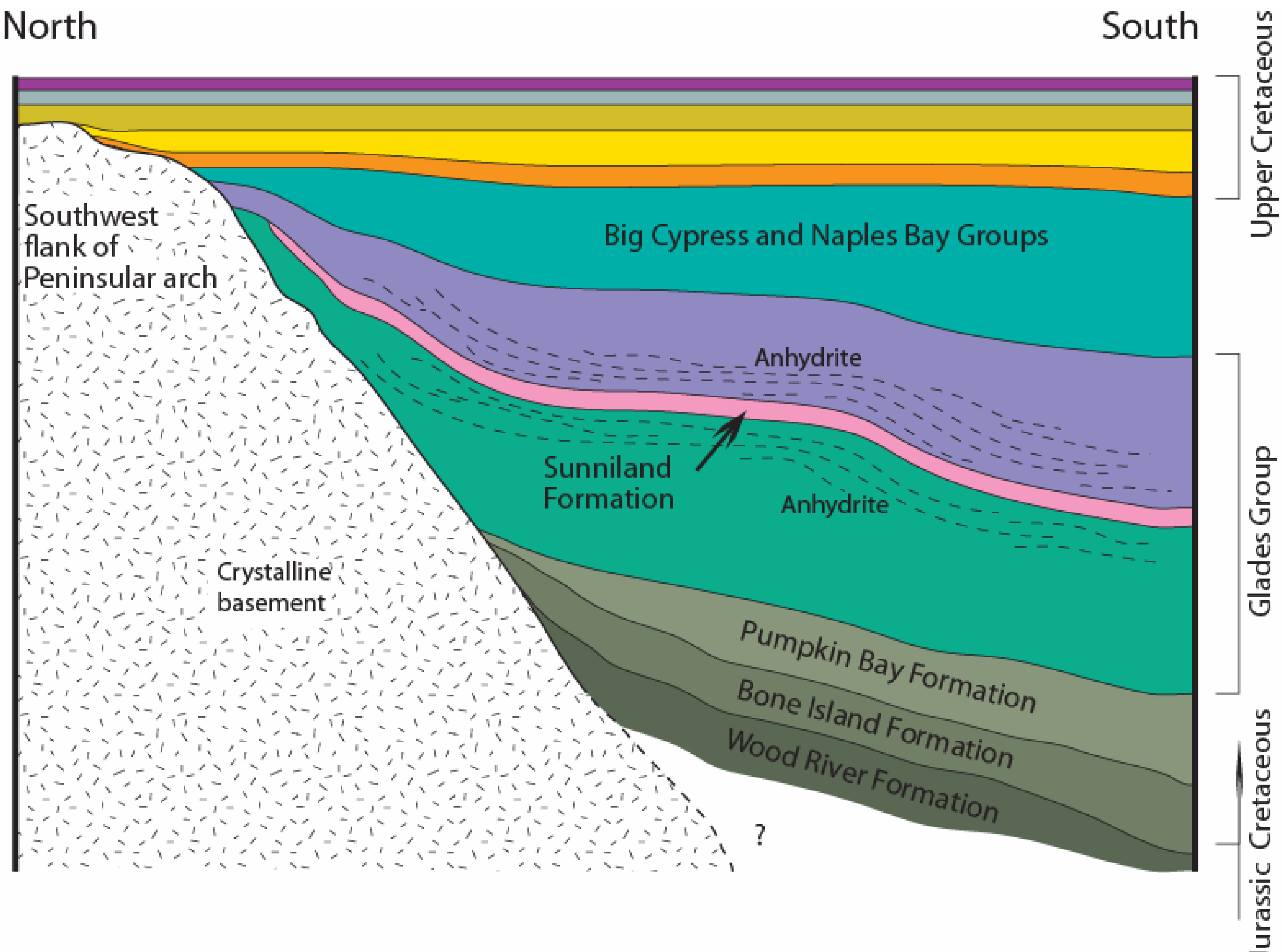

Figure 11. A simplified cross section showing Late Jurassic and Cretaceous rocks from the central part of the Peninsular arch across South Florida basin and south to the Florida Keys. The cross section shows stratigraphic patterns controlled by the location of the structural high. Note: Diagram is not to scale. To show the various units clearly, the section is exaggerated in the vertical dimension; thus, units appear thicker than they really are. Stratigraphic nomenclature is after the Florida Geological Survey. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University), adapted from figure 2 in Pollastro et al. (2000).

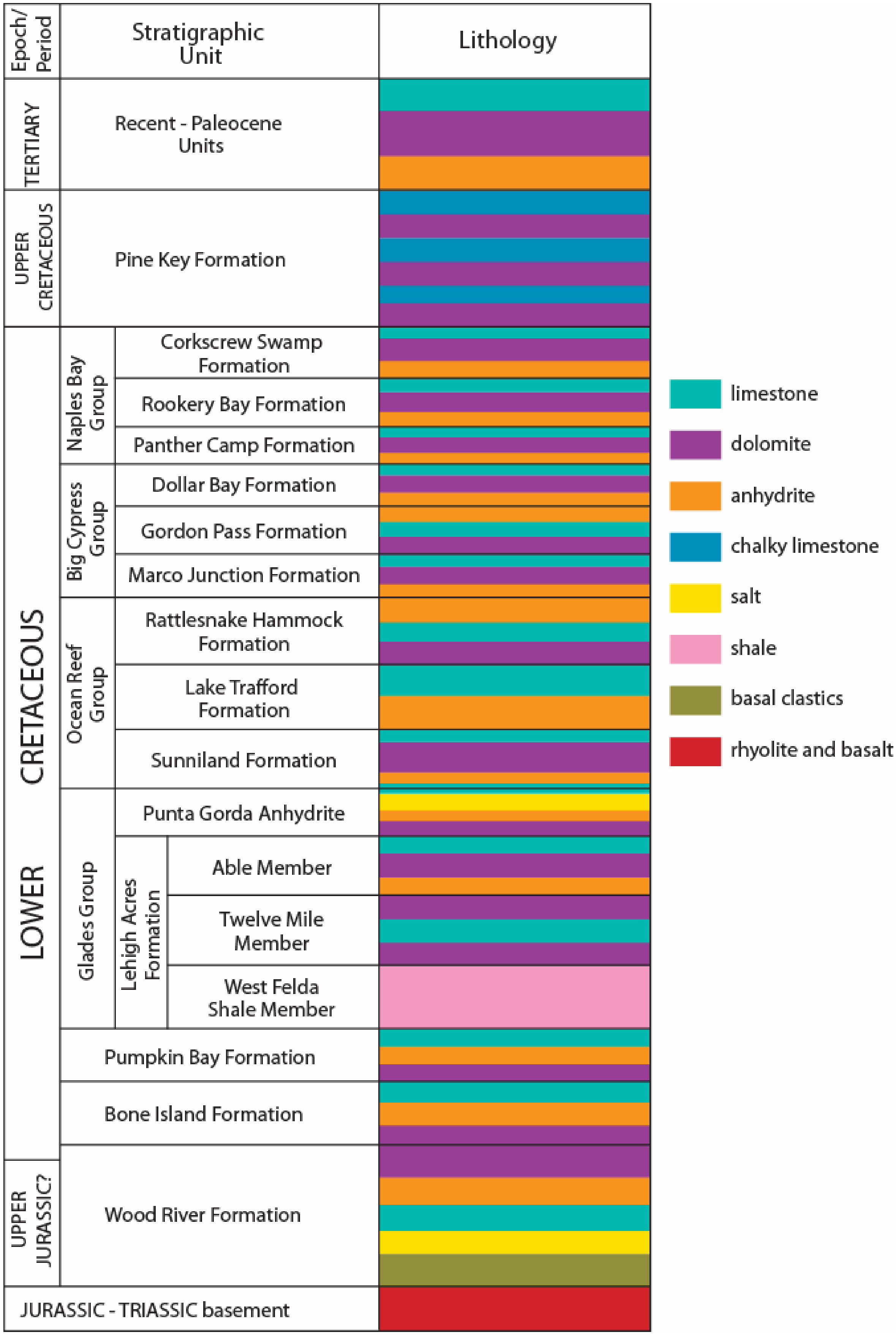

Figure 12: Stratigraphic section for South Florida basin along the Sunniland trend. showing units from the late Mesozoic Era. Diagram is not to scale. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University), after figure 3 in Pollastro et al. (2000).

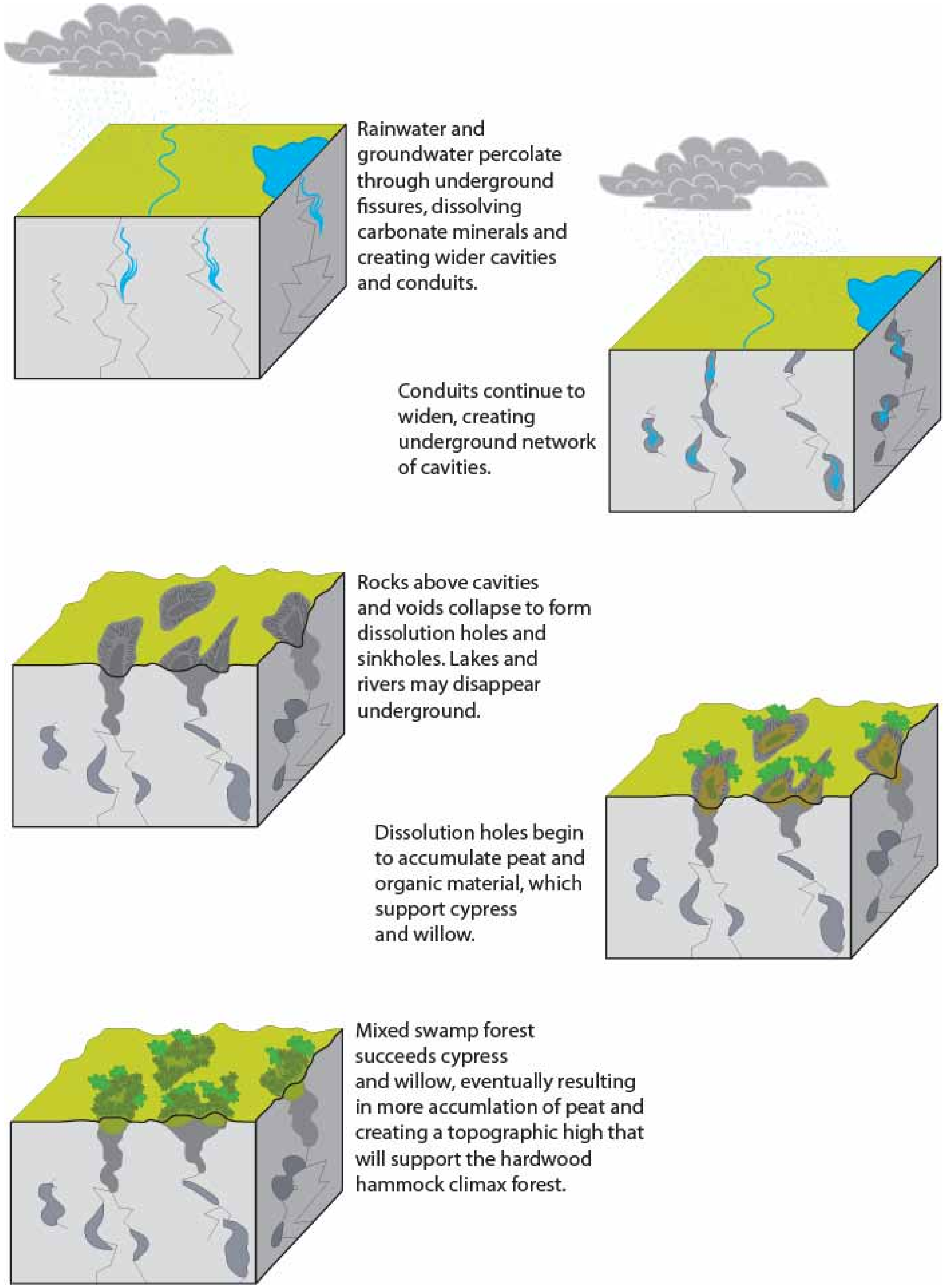

Figure 13: Development of a karst landscape from initial dissolution of bedrock to the ultimate formation of a hardwood hammock at Big Cypress National Preserve. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University).

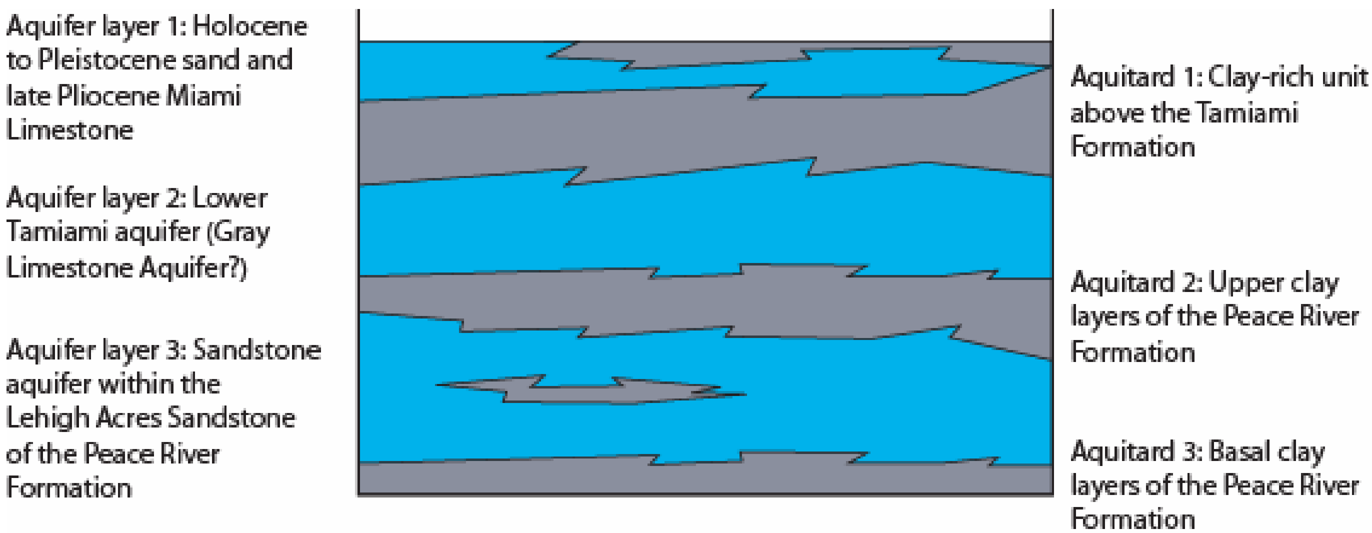

Figure 14: Conceptual diagram showing cross section of the aquifers beneath Big Cypress National Preserve. Diagram is not to scale. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University), using information from Wexler (2004).

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resource Evaluation digital geologic map of Big Cypress National Preserve. The accompanying table is highly generalized and is provided for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table. More detailed map unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the National Park Service Geologic Resources Division.

Map units exposed at the surface at Big Cypress National Preserve are limited to the Tamiami Formation, shell-bearing sediments, the Miami Limestone, undifferentiated Holocene and Pleistocene deposits, and Holocene sediments (Scott 2001).

The complex Tamiami Formation may be roughly subdivided into lower clastic rocks, the Gray Limestone, and the upper clastic rocks. The lowermost part comprises quartz sandstone, mud, clay, and limestone cobbles. The Gray Limestone is lightly cemented, fossiliferous, sandy limestone. The uppermost clastic layer comprises sandstone interbedded with mud, clay, and limestone cobbles (Shoemaker 1998).

Tertiary through Quaternary shell- bearing sediments underlie the Miami Limestone, which is exposed at the surface. Two facies exist in the Miami Limestone. The western part of the unit is predominantly the bryozoan facies; the unit then becomes more oolitic eastward towards Everglades National Park (Hoffmeister et al. 1974; Cunningham 2005). The Miami Limestone is extensively dissolved to form karst topography in the Big Cypress area.

Overlying the Miami Limestone are relatively undifferentiated Pleistocene and Holocene unconsolidated surficial units of sand, mud, freshwater peat and organic muck, freshwater marl, and cyanobacteria mats in the swampy marsh, strands, and pinelands at Big Cypress (Scott 2001; Cunningham 2005).

The peat and muck typically occur in low- lying sloughs and solution holes and are dark and fine- grained. During the standing- water phase of the wet season, extracellular precipitation of calcium carbonate by cyanobacteria forms fresh limestone marls (Cunningham 2005).

Map features for Big Cypress National Preserve also include karst- related topographic depressions, such as sinkholes for south Florida as captured on Florida Department of Environmental Protection (FDEP) Digital Elevation Model map (DEMs) at a resolution of 30–15 m (enhanced) and U.S. Geological survey 1:24,000 topographic maps (Arthur et al. 2005).

The following pages present a tabular view of the stratigraphic column and an itemized list of features for each map unit. This sheet includes several properties specific to each unit present in the stratigraphic column, including map symbol, name, description, resistance to erosion, suitability for development, hazards, potential paleontologic resources, cultural and mineral resources, habitat, potential for recreational use, and global significance.

Map Unit Properties Table

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Development	Hazards	Paleontologic Resources	Cultural Resources	Mineral Occurrence	Habitat	Recreation	Significance
HOLOCENE	Holocene sediments (Qh).	Sediments include quartz sand, carbonate sand, mud, organic material, peat, and shell fragments; typically present near the coastline at elevations less than 1.5 m (5 ft).	Very low	Unit is ubiquitous in South Florida; very permeable and unstable if undercut or undermined by karst dissolution.	If high clay content, unit may be very slippery and mucky when saturated with water.	Freshwater mollusks and shell fragments, plant debris, roots, and pollen.	Land- use evolution studies, Native American settlement sites.	None documented.	Surficial unconsolidated unit supports coastline habitat, including mangrove zones.	If mud content is high, avoid visitor use when ground is saturated.	Records Holocene coastal changes in South Florida, including recent anthropogenic alterations.
PLEISTOCENE - HOLOCENE	Pleistocene–Holocene undifferentiated (Qu).	Undifferentiated siliciclastic sediments (light gray, tan to black, clean to clayey with silt lenses), organic material (plant debris, roots, peat), and freshwater carbonate sand and mud (marl—commonly buff colored to tan and fossiliferous with sand, silt, clay, and organic matterl); differentiated where deposits exceed 6.1 m (20 ft) in thickness (not at Big Cypress National Preserve).	Very low	Unit is ubiquitous on land surface in South Florida; very permeable and unstable if thick and undercut or undermined by karst dissolution.	If clay content is high, unit may be very slippery and mucky when saturated with water; karst dissolution may be highly irregular and make for poor footing.	Freshwater mollusks, plant debris, roots, and logs.	Land- use evolution studies, Native American settlement sites.	None documented.	Surficial unconsolidated unit supports wetland and grassland species; may support terraphytes in muddy areas.	If mud content is high, avoid visitor use when ground is saturated.	Records Pleistocene to Holocene transition in South Florida.
PLEISTOCENE	Miami Limestone (Qm).	Unit consists of two facies: an oolitic facies (white to orangish- gray, poorly to moderately indurated, sandy, oolitic limestone) and a bryozoan facies (white to orangish- gray, poorly indurated to well-indurated, sandy limestone); some quartz sandstone beds present.	Low to moderate.	Unit is highly porous and permeable and forms much of Biscayne aquifer system; susceptible to karst processes; unsuitable for waste- treatment facilities.	Sinkhole and solution-hole collapse probable in this unit; high permeability lets contaminants pass through quickly.	Scattered fossils, including a bryozoan zone, mollusks, and corals. Casts and molds are common.	None documented.	Oolite, bryozoan layers.	Solution holes support tree islands and copepods.	Commonly forms irregular surfaces with solution holes; avoid for most visitor facilities.	Oolite and bryozoan facies record shoreline to lagoonal paleo-environments.
TERTIARY–QUATERNARY	Shell- bearing sediments (TQsu).	Highly fossiliferous unit, equivalent to the informal Okeechobee unit, which is subdivided into the latest Pliocene- early Pleistocene Caloosahatchee Formation, early Pleistocene Bermont Formation (informal), and late Pleistocene Fort Thompson Formation, all fossiliferous sandstones and carbonates. Unit contains variably calcareous and fossiliferous quartz sandstone, and sandy limestone with some clayey sandstone and sandy clay present in lenses. Unit is biostratigraphically differentiated.	Low to moderate.	Unit is highly porous and permeable and forms much of surficial aquifer system; susceptible to karst processes; unsuitable for waste- treatment facilities.	Heterogeneity of unit may make it unstable underfoot; carbonate dissolution may form hazardous solution holes.	Marine fossils	Fossil shells may have provided early trade material.	Fossil shells	Supports cypress swamps and grasslands.	Geologic complexity and dissolution may yield irregular surfaces; avoid for most visitor facilities.	Fossil record differentiates biostrati-graphically different ages within Tertiary in South Florida.
TERTIARY	Tamiami Formation (Tt).	Mixed carbonate and siliciclastic layers containing several members, including an oyster facies, a sandstone facies, several marl and limestone layers, and a reefal member. Unit includes light gray to tan, fossiliferous sandstone; greenish, sandy clay; calcareous, gray sandstone; sandy, fossiliferous limestone; and white to light- gray, well-indurated, fossiliferous, sandy limestone. Some packstone and pelecypod sandstone members are present locally.	Low to moderate.	Variably highly permeable to impermeable layers form a complex aquifer system, some of which is exposed as part of the surficial aquifer system. Lower beds form part of the intermediate, confined aquifer system.	Carbonate- rich layers are susceptible to collapse of sinkholes and solution holes. Contaminants pass quickly through dissolution voids.	Molds & casts; fossils include: barnacles, coral, echinoids, foraminifera, calcareous nannoplankton, pelecypods, gastropods, serpulids, and ostracodes.	May have provided material for early trade.	Fossils; phosphate present as sand- to gravel- size grains	Supports cypress forests and wetland flora.	If highly dissolved, solution holes may present hazard to visitors.	Type section is present in Big Cypress National Preserve; records Pliocene lagoonal and reefal paleo-environments.

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Big Cypress National Preserve, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.

The Florida platform is among the younger additions to the North American continent. Thousands of meters of interlayered carbonate and siliciclastic rocks represent a generally stable deposition environment punctuated by erosional and high- energy events. The rocks deep below Florida give clues to its origin and geologic history (fig. 15).

Late Paleozoic Era

During the Mississippian, the landmass that underlies the grand carbonate platform of Florida today was not part of the North American craton. It is speculated that it was attached to the northwestern part of the African continent (Condie and Sloan 1998). Marine carbonate sediments were being deposited over much of the area atop a Paleozoic crystalline basement high, the Peninsular arch (Pollastro et al. 2000).

In the Pennsylvanian, a collision event known as the Ouachita orogeny sutured the Florida landmass to the continent as Gondwanaland and North America collided, eventually forming the supercontinent Pangaea. Many north- to northeast- trending strike- slip and thrust faults were active as a result of multi- directional tectonic stresses at this time (Amsbury and Haenggi 1993). The land was still submerged, and South Florida was located at the junction of the North American, South American, and African plates (fig. 16). Through the Permian, Pangaea remained intact (Condie and Sloan 1998). Highlands to the north of the Florida landmass eroded quickly when compressional tectonic forces subsided during the Permian.

Early Mesozoic Era

At the beginning of the Triassic Period, Pangaea began to break up (≈220–245 Ma). During the late Triassic–Jurassic periods, South and Central America and Africa began to rift away from North America. This established the long- standing passive margin along the eastern seaboard that persists today. The Florida and Cuba blocks detached from northwestern Africa, and the Gulf of Mexico opened (Condie and Sloan 1998). This created large basins for deposition of sediments shed from the rapidly eroding Ouachitan highlands. In the early stages, a series of discontinuous rift basins developed parallel to the edge of the opening ocean basin. These basins extended from Mexico to Nova Scotia (Hentz 2001).

Accompanying the rifting of Pangaea was the widespread extrusion of volcanic rocks consistent with mantle plume upwelling due to crustal tension (Heatherington and Mueller 1991). This continental rifting also opened the Atlantic Ocean basin.

Middle Mesozoic Era

Underlying the South Florida basin are igneous rhyolitic- basaltic rocks (Thomas et al. 1989). These rocks were sampled in a core from 5.7 km (3.5 mi) deep in Collier County. Geochemical composition of these rocks indicates they formed within a mantle plume in a continental rifting environment consistent with the breakup of Pangaea. Geologists surmise a hotspot initiated local rifting off the southern tip of the Florida platform (Heatherington and Mueller 1991; Cunningham 2005).

These igneous rocks were exposed on the surface and eroded during the late Triassic to middle Jurassic. Deposits of sand and silt covered local areas, which upon exposure formed redbeds. Accompanying the opening of the proto- Atlantic Ocean, the Caribbean basin, and the ancestral Gulf of Mexico were major lateral displacements along transform faults such as the North Bahamas fracture zone (Condie and Sloan 1998).

As the Atlantic Ocean and Caribbean basin continued to develop, deltaic and shallow marine sediments were deposited over the Florida platform in the late Jurassic. Restriction of marine circulation at this time resulted in periodic accumulations of evaporite and marine carbonate sediments (Cunningham 2005). Deposition of Jurassic and Cretaceous sediments was controlled by the south- southeast- plunging axis of the Peninsular arch. Basal sediments onlap and pinch out against the arch (Pollastro et al. 2000).

Late Mesozoic Era

As marine transgression (rise in sea level) proceeded during the early Cretaceous, the Florida platform was the site of more widespread deposition of marine carbonate sediments and building of reefs. Reefs clustered along the margin of the ancestral Gulf of Mexico and the edges of the Florida platform (Cunningham 2005). From the middle Cretaceous to the late Paleogene, the Suwannee Strait (often called the "Gulf Trough") separated the carbonate Florida platform from a clastic shelf and slope that was developing along the southeastern margin of North America. These clastic sediments eroded from the Appalachian Mountains.

Currents running through the strait prevented the clastic sediments from interrupting the continuous accumulation of carbonate sediments on the Florida platform. As currents changed and the seaway was infilled, by the late Eocene, some of the siliciclastic sediments mixed with the deep carbonate sediments (Cunningham et al. 2003).

Further transgression and global warming during the Late Cretaceous established an open marine accumulation of carbonate sediments over the entire Florida Peninsula. Accompanying this widespread accumulation was the development of deposition of rudistid bivalves in reefs around the southern margin of the Florida area.

By the Late Cretaceous, the Gulf of Mexico was completely open. The new crust formed by igneous extrusion during extension was now the Proto-Caribbean tectonic plate. This oceanic crust separates the Gulf of Mexico and the Yucatan from South America. At this time, the Antilles arc (parts of which now belong to Hispaniola and Puerto Rico) moved eastward and was subducting beneath the Cuba block (Condie and Sloan 1998).

Cenozoic Era

Cenozoic development of the Florida platform included additional deposition of marine carbonate sediments and deposition of siliciclastic sediments (grains of silicate minerals such as quartz) from northwestern highland sources and longshore oceanic currents. Tertiary faulting occurred south of Florida as the Cuban block continued to collide with the Antilles arc and carbonate accumulation continued in Florida (Condie and Sloan 1998). In southern Florida, the open marine depositional setting continued during the Paleocene as more restricted flow to the north resulted in deposits of mixed carbonate sediments and intermittent evaporites (during restricted marine conditions). Eocene and Oligocene deposition is marked by shallow- water carbonate rocks. Sedimentary deposits were intermittently exposed during this time, forming erosional surfaces and scant redbeds associated with local oceanic regressions.

Deposition in South Florida during the Miocene changed with the introduction of more widespread siliciclastic sediments from a fluvio- deltaic system that developed from north to south on the peninsula. These deposits were derived from the rapidly eroding southern Appalachian Mountains as the Atlantic coastal plain continued to grow eastward. Phosphates and the carbonate ramp of the Arcadia Formation were deposited during the Miocene in southeastern Florida (Cunningham 2005). Siliciclastic deposits of the Peace River Formation then buried this carbonate ramp during the Miocene. Marine upwelling at this time is responsible for the diatomaceous mudstone and plentiful organic matter represented by the lower beds of the Peace River Formation (Cunningham et al. 1998).

Some of the Miocene siliciclastic deposits of the Peace River Formation were eroded and reworked during a marine regression. This Pliocene lowstand caused a disconformity between the Peace River and the overlying Long Key Formation. South of Big Cypress National Preserve, the Peace River Formation is absent—either it was never deposited or was eroded away completely. During the Pliocene, a thick wedge of sand eroded from the Miocene deposits was deposited in the Everglades area, east of Big Cypress. This sand was being transported south to eventually form the Long Key Formation (Guertin et al. 1999; Cunningham 2005). It covered the area that is now Everglades National Park and extended as far south as the Florida Keys. The sand was deposited in fluctuating outer and inner shelf conditions with depths ranging from 150–180 m (≈500–600 ft) to 10–50 m (≈30–160 ft), respectively (Guertin et al. 1999).

In addition to Pliocene siliciclastic deposition, carbonate sediments also accumulated in South Florida. In the western reaches of the peninsula was a mid- Pliocene reef environment. Near the lower Florida Keys and the southwest Florida shelf, the carbonate sediments of the Stock Island Formation were deposited at the same time that the reef was built. These sediments were perhaps associated with currents originating in the Gulf of Mexico, flowing eastward through the Straits of Florida (Cunningham et al. 1998; Cunningham 2005).

The Pleistocene Epoch experienced numerous and extensive glacial events called ice ages. Although glacial ice never extended as far south as Florida, the accompanying global- scale climatic and sea level shifts played a major role in the formation of the geologic units and the overall landscape exposed today at Big Cypress National Preserve. During the Pleistocene, deposition shifted from siliciclastic sediments mixed with carbonate accumulation to more widespread carbonate sedimentation with occasional, localized siliciclastic contributions (Cunningham 2005). Global sea- level changes during the intermittent ice ages of the Pleistocene controlled the rate and distribution of carbonate sediments.

At 120 ka, the last major fall in sea level occurred as the mixed carbonate- siliciclastic, shell- rich sediments formed the units underlying the Miami Limestone. Deposition was in a restricted lagoonal environment (rich in marine fossil remains) during successive sea-level highstands (Cunningham 2005). The western area of the Miami Limestone, including the Big Cypress National Preserve, contains the lower energy, more restricted bryozoan facies of the unit, indicative of lagoonal depositional conditions.

At about 15–16 ka, sea level began to rise rapidly and southern Florida was extensively flooded around 7 or 6 ka (Shinn et al. 1997). Sea level has continued to rise, but estimates vary as to the actual rate and continuity.

The sediments at Big Cypress National Preserve indicate several episodes of marine inundation. However, most marine regressions and transgressions lead to erosion and subsequent reworking of sediments, which obscures all but the largest events. Around 5 ka, the rate of rise in sea level slowed and shoreline deposits became thin and narrow (Mitchell- Tapping et al. 1996). Sea level then rose steadily and flooded coastal lagoons, estuaries, and mangrove swamps and marshes. Florida Bay was completely flooded at this time. At about 3 ka, a sharp transgression and regression is evident from core samples from Big Cypress National Preserve. This event lasted approximately 200–400 years and was 0.5–2 m (1.6–6.6 ft) in amplitude. During this time, marine sediments were reworked and redeposited in stable areas such as Estero Bay (Mitchell- Tapping et al. 1996).

Holocene geologic activity in the Big Cypress area consists of the pervasive dissolution of carbonate bedrock units, the surficial accumulation of carbonate mud, marine and freshwater marl, marine sand terraces (including the Talbot and Pamlico terraces), and swamp deposits (Mitchell- Tapping et al. 1996; Cunningham 2005). The underlying geology, sea level, climate, and vegetation patterns control Holocene sediment distribution (Cunningham 2005).

Sea level rise slowed further after about 3 ka, with nearshore marine environments becoming more shallow and stable coastlines developing. Between 2,900 and 2,500 years before present, a regression lowered relative sea level and promoted stabilizing vegetation growth across the area.

Today mangrove peat and storm levees create a natural barrier between the landward freshwater environments and Florida Bay (Mitchell- Tapping et al. 1996). In lower sloughs and solution holes, deposition of organic muck and peat soils predominates (Craighead 1971). Freshwater marl and cyanobacteria mats characterize the open prairies and deeper sloughs, where calcium carbonate precipitates *in situ* to cover the ground and vegetation (fig. 17). Marine marls are common in the coastal areas of Florida Bay. Floods are responsible for the formation of these natural levees composed of aragonitic mud and shell fragments (Cunningham 2005).

Eon	Era	Period	Epoch	Ma		Life Forms	N. American Tectonics
Phanerozoic (Phaneros = "evident"; zoic = "life")	Cenozoic	Quaternary	Holocene	0.01	Age of Mammals	Modern humans	Cascade volcanoes (W)
			Pleistocene	1.8		Extinction of large mammals and birds	Worldwide glaciation
		Tertiary	Pliocene	5.3		Large carnivores	Uplift of Sierra Nevada (W)
			Miocene	23.0		Whales and apes	Linking of N. and S. America
			Oligocene	33.9			Basin-and-Range extension (W)
			Eocene	55.8		Early primates	Laramide Orogeny ends (W)
			Paleocene	65.5			
	Mesozoic	Cretaceous		145.5	Age of Dinosaurs	**Mass extinction** Placental mammals Early flowering plants	Laramide Orogeny (W) Sevier Orogeny (W) Nevadan Orogeny (W)
		Jurassic		199.6		First mammals	Elko Orogeny (W)
		Triassic		251		**Mass extinction** Flying reptiles First dinosaurs	Breakup of Pangaea begins Sonoma Orogeny (W)
	Paleozoic	Permian		299	Age of Amphibians	**Mass extinction** Coal-forming forests diminish	Supercontinent Pangaea intact Ouachita Orogeny (S) Alleghenian (Appalachian) Orogeny (E)
		Pennsylvanian		318.1		Coal-forming swamps Sharks abundant	Ancestral Rocky Mts. (W)
		Mississippian		359.2		Variety of insects First amphibians First reptiles	Antler Orogeny (W)
		Devonian		416	Fishes	**Mass extinction** First forests (evergreens)	Acadian Orogeny (E-NE)
		Silurian		443.7		First land plants	
		Ordovician		488.3	Marine Invertebrates	**Mass extinction** First primitive fish Trilobite maximum Rise of corals	Taconic Orogeny (NE)
		Cambrian		542		Early shelled organisms	Avalonian Orogeny (NE) Extensive oceans cover most of N. America
Proterozoic ("Early life")		Precambrian		2500		First multicelled organisms Jellyfish fossil (670 Ma)	Formation of early supercontinent Grenville Orogeny (E) First iron deposits Abundant carbonate rocks
Archean ("Ancient")				≈4000		Early bacteria and algae	Oldest known Earth rocks (≈3.96 billion years ago)
Hadean ("Beneath the Earth")				4600		Origin of life?	Oldest moon rocks (4-4.6 billion years ago) Earth's crust being formed
						Formation of the Earth	

Figure 15. Geologic time scale; adapted from the U.S. Geological Survey. Red lines indicate major unconformities between eras. Included are major events in the history of life on Earth and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years (Ma. or mega-annum).

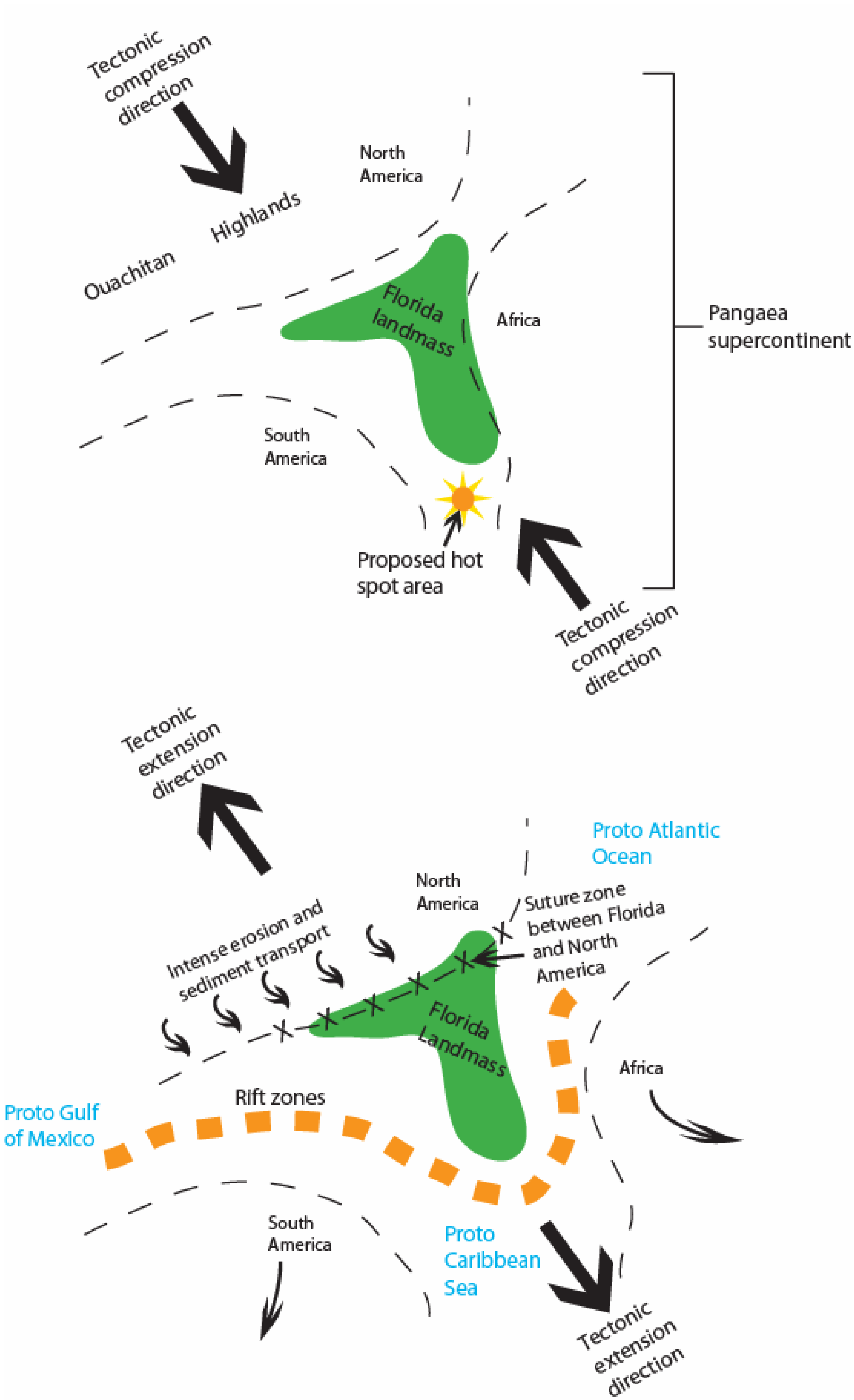

Figure 16: Evolution of the landscape in the Florida Platform area from the Mississippian-Pennsylvanian Ouachita orogeny through the Triassic-Jurassic extensional event opening the Gulf of Mexico, the Caribbean Sea, and the Atlantic Ocean. The Florida landmass sutured to the North American continent at this time. Diagram is not to scale. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 17. Open prairie area largely underlain by freshwater marly limestone at Big Cypress National Preserve. Photograph is by Trista L. Thornberry-Ehrlich (Colorado State University).

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html.

active margin. A continental margin where significant volcanic and earthquake activity occurs; commonly a convergent plate margin.

alluvium. Stream- deposited sediment that is generally rounded, sorted, and stratified.

aquifer. Rock or sediment that is sufficiently porous, permeable, and saturated to be useful as a source of water.

asthenosphere. Weak layer in the upper mantle below the lithosphere where seismic waves are attenuated.

baseflow. Stream flow supported by groundwater flow from adjacent rock, sediment, or soil.

baselevel. The lowest level to which a stream can erode its channel. The ultimate base level for the land surface is sea level, but temporary base levels may exist locally.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie the rocks of interest.

basin (structural). A doubly plunging syncline in which rocks dip inward from all sides (also see “dome”).

basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.

beach. A gently sloping shoreline covered with sediment, often formed by action of waves and tides.

bed. The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two and distinguishable from beds above.

bedding. Depositional layering or stratification of sediments.

bedrock geology. The geology of underlying solid rock as it would appear with the sediment, soil, and vegetative cover stripped away.

calcareous. A rock or sediment containing calcium carbonate.

carbonaceous. A rock or sediment with considerable carbon, esp. organics, hydrocarbons, or coal.

cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.

chemical sediment. A sediment precipitated directly from solution (also called “nonclastic”).

chemical weathering. The dissolution or chemical breakdown of minerals at Earth’s surface via reaction with water, air, or dissolved substances.

clastic. Rock or sediment made of fragments or pre-existing rocks.

clay. Clay minerals or sedimentary fragments the size of clay minerals (>1/256 mm).

continental crust. The type of crustal rocks underlying the continents and continental shelves; having a thickness of 25- 60 km (16- 37 mi) and a density of approximately 2.7 grams per cubic centimeter.

continental drift. The concept that continents have shifted in position over Earth (see and use ”plate tectonics”).

continental rise. Gently sloping region from the foot of the continental slope to the abyssal plain.

continental shelf. The shallowly submerged part of a continental margin extending from the shoreline to the continental slope with water depths of less than 200 m (656 ft).

continental shield. A continental block of Earth’s crust that has remained relatively stable over a long period of time and has undergone only gentle warping compared to the intense deformation of bordering crust

continental slope. The relatively steep slope from the outer edge of the continental shelf down to the more gently sloping ocean depths of the continental rise or abyssal plain.

convergent boundary. A plate boundary where two tectonic plates are moving together (i.e., a zone of subduction or obduction).

craton. The relatively old and geologically stable interior of a continent (also see “continental shield”).

cross section. A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in an oriented vertical plane.

crust. The outermost compositional shell of Earth, 10–40 km (6–25 mi) thick, consisting predominantly of relatively low density silicate minerals (also see “oceanic crust” and “continental crust”).

crystalline. Describes the structure of a regular, orderly, repeating geometric arrangement of atoms.

dip. The angle between a structural surface and a horizontal reference plane measured normal to their line of intersection.

disconformity. An unconformity at which the bedding of the strata above and below are parallel.

drainage basin. The total area from which a stream system receives or drains precipitation runoff.

estuary. The seaward end or tidal mouth of a river where fresh and sea water mix. Many estuaries are drowned river valleys caused by sea level rise (transgression) or coastal subsidence.

eustatic. Relates to simultaneous worldwide rise or fall of sea level in Earth’s oceans.

evaporite. Chemically precipitated mineral(s) formed by the evaporation of solute- rich water under restricted conditions.

extrusive. Of or pertaining to the eruption of igneous material onto the surface of Earth.

facies (sedimentary). The depositional or environmental conditions reflected in the sedimentary structures, textures, mineralogy, fossils, etc. of a sedimentary rock.

fault. A subplanar break in rock along which relative movement occurs between the two sides.

formation. Fundamental rock- stratigraphic unit that is mappable and lithologically distinct from adjoining strata and has definable upper and lower contacts.

fracture. Irregular breakage of a mineral; also any break in a rock (e.g., crack, joint, fault)

geology. The study of Earth, including its origin, history, physical processes, components, and morphology.

hammock. A term applied to an area rising slightly above a plain or swamp, often supporting an island of dense tropical undergrowth.

igneous. Refers to a rock or mineral that originated from molten material that is one of the three main classes or rocks—igneous, metamorphic, and sedimentary.

intrusion. A body of igneous rock that invades older rock. The invading rock may be a plastic solid or magma that pushes its way into the older rock.

island arc. A line or arc of volcanic islands formed over and parallel to a subduction zone.

ka. Kiloannum, a period of one thousand years.

karst topography. Topography characterized by abundant sinkholes and caverns formed by the dissolution of calcareous rocks.

lithology. The description of a rock or rock unit, especially the texture, composition, and structure of sedimentary rocks.

lithosphere. The relatively rigid outmost shell of Earth's structure, 50–100 km (31–62 mi) thick, that encompasses the crust and uppermost mantle.

longshore current. A current parallel to a coastline caused by waves approaching the shore at an oblique angle.

Ma. Megaannum, a period of one million years.

magma. Molten rock generated within Earth that is the parent of igneous rocks.

mantle. The zone of the Earth's interior between crust and core.

marl. Unconsolidated earthy deposits consisting chiefly of an intimate mixture of clay and calcium carbonate formed under marine and freshwater conditions.

matrix. The fine- grained interstitial material between coarse grains in porphyritic igneous rocks and poorly sorted clastic sediments or rocks.

meanders. Sinuous lateral curves or bends in a stream channel.

mechanical weathering. The physical breakup of rocks without change in composition (syn: physical weathering).

member. A lithostratigraphic unit with definable contacts that subdivides a formation.

ivergent tectonic margin)s) in the world's oceans.

mineral. A naturally occurring, inorganic crystalline solid with a definite chemical composition or compositional range.

nonconformity. An erosional surface preserved in strata in which crystalline igneous or metamorphic rocks underlie sedimentary rocks.

normal fault. A dip- slip fault in which the hanging wall moves down relative to the footwall.

obduction. The process by which the crust is thickened by thrust faulting at a convergent margin.

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6–7 km (3–4 mi) thick and generally of basaltic composition.

ooid. Small (< 2 mm), spheroidal, layered grains, often composed of calcium carbonate, that usually form on the sea floor in shallow environments.

oolitic. Reference to a rock type containing characteristic abundant ooids as the primary constituent.

orogeny. A mountain- building event, particularly a well- recognized event in the geological past (e.g., the Laramide orogeny).

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.

overthrust. A nondescript and not recommended term for a large- scale, low- angle thrust fault.

Pangaea. A theoretical single supercontinent that existed during the Permian and Triassic Periods (also see "Laurasia" and "Gondwana").

passive margin. A tectonically quiet continental margin indicated by little volcanic or seismic activity.

pebble. Generally small, rounded rock particles from 4 to 64 mm in diameter.

permeability. A measure of the ease or rate that fluids move through rocks or sediments.

plateau. A broad, flat- topped topographic high of great extent and elevation above the surrounding plains, canyons, or valleys (both land and marine landforms).

plate tectonics. The theory that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid asthenosphere.

plunge. The inclination of a fold axis or other linear feature measured in the vertical plane.

porosity. The proportion of void space (cracks, interstices) in a volume of a rock or sediment.

recharge. Infiltration processes that replenish groundwater.

red beds. Sedimentary strata composed largely of sandstone, siltstone, and shale that are predominantly red due to the presence of ferric oxide (hematite) coating individual grains.

regression. A long- term seaward retreat of the shoreline or relative fall of sea level.

reverse fault. A contractional, high- angle (>45°), dip- slip fault in which the hanging wall moves up relative to the footwall (also see "thrust fault").

rock. A solid, cohesive aggregate of one or more minerals or mineraloids.

sandstone. Clastic sedimentary rock of predominantly sand- sized grains.

sediment. An eroded and deposited, unconsolidated accumulation of lithic and mineral fragments.

sedimentary rock. A consolidated and lithified rock consisting of detrital and/or chemical sediment(s).

sequence. A major informal rock- stratigraphic unit that is traceable over large areas and defined by a major sea level transgression- regression sediment package.

shale. A clastic sedimentary rock made of clay- sized particles that exhibit parallel splitting properties.

siliciclastic. Pertaining to clastic noncarbonate rocks that are almost exclusively silicon- bearing, either as forms of quartz or as silicates.

silt. Clastic sedimentary material intermediate in size between fine- grained sand and coarse clay (1/256–1/16 mm).

siltstone. A variably lithified sedimentary rock with silt-sized grains.

slough. A sluggish body of water in a bottomland area often with marshy, waterlogged ground.

soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and often overlying the parent rock from which it formed.

spring. A site where water flows out at the surface due to the water table intersecting the ground surface.

strand. The land bordering any large body of water.

strata. Tabular or sheetlike masses or distinct layers (e.g., of rock).

stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, age, etc. of rock layers, especially sedimentary rocks.

stream. Any body of water moving under gravity flow and confined within a channel.

strike. The compass direction of the line of intersection that an inclined surface makes with a horizontal plane.

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

suture. The linear zone where two continental landmasses become joined due to obduction.

tectonic. Relating to large- scale movement and deformation of Earth's crust.

terraces (stream). Step- like benches surrounding the present floodplain of a stream due to dissection of previous flood plain(s), stream bed(s), and/or valley floor(s).

thrust fault. A contractional, dip- slip fault with a shallowly dipping fault surface ($<45^{\circ}$) where the hanging wall moves up and over relative to the footwall.

topography. The general morphology of Earth's surface including relief and location of natural and anthropogenic features.

total petroleum system. All genetically related petroleum that occurs in shows and accumulations generated by a pod or by closely related pods of mature source rock existing within a limited mappable geologic volume.

transgression. Landward migration of the sea due to a relative rise in sea level.

trend. The direction or azimuth of elongation or a linear geological feature.

type locality. The geographic location where a stratigraphic unit is well displayed, is formally defined as a typical section, and derives its name.

unconformity. A surface within sedimentary strata that marks a prolonged period of nondeposition or erosion.

volcanic. Related to volcanoes; describes igneous rock crystallized at or near Earth's surface (e.g., lava).

water table. The upper surface of the saturated (phreatic) zone.

weathering. The set of physical, chemical, and biological processes by which rock is broken down in place.

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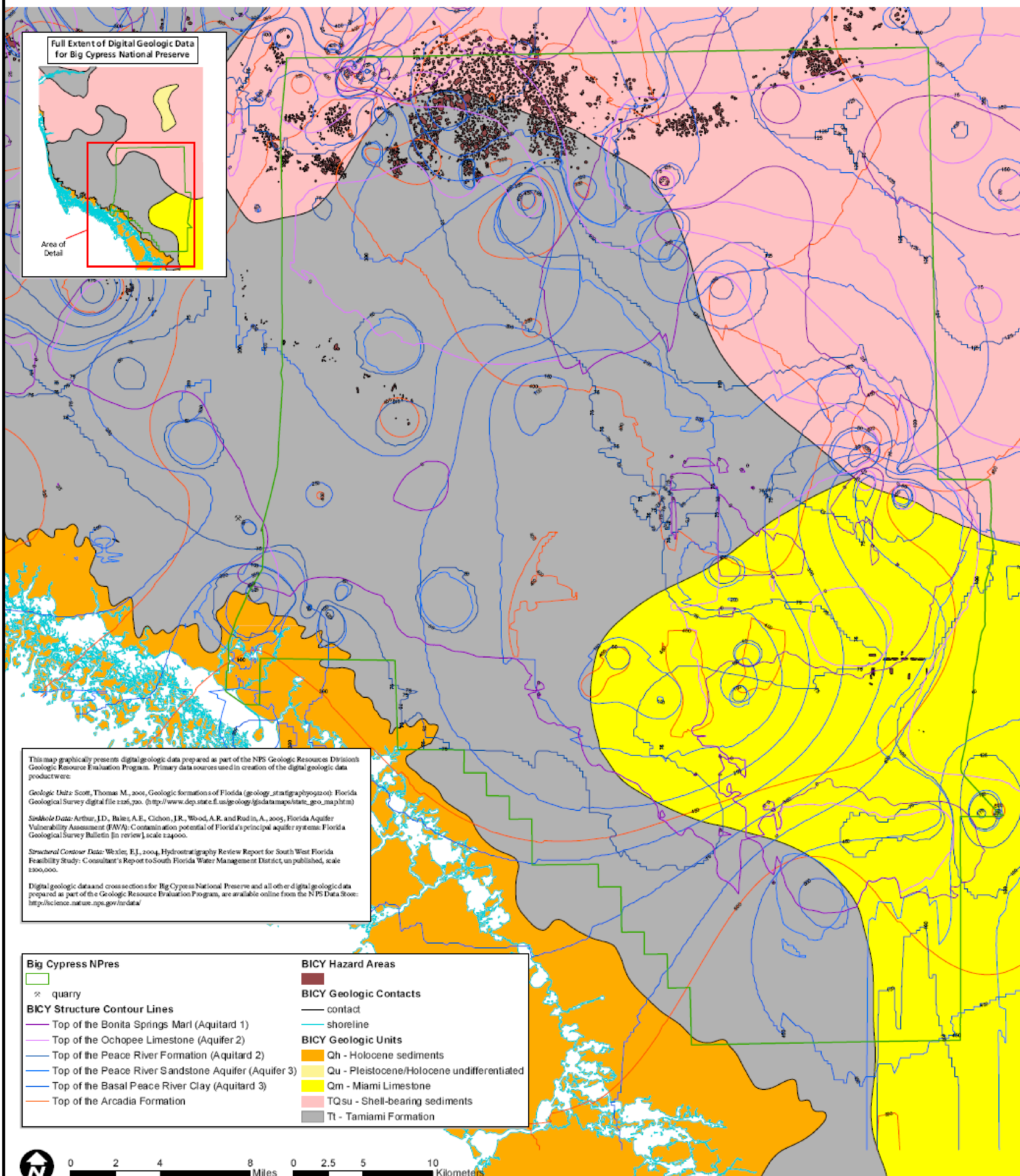
Appendix A: Geologic Map Graphic

The following page is a preview or snapshot of the geologic map for Big Cypress National Preserve. For a poster- size PDF of this map or for digital geologic map data, please see the included CD or visit the Geologic Resource Evaluation publications Web page (http://www2.nature.nps.gov/geology/inventory/gre_publications).

Big Cypress National Preserve
Florida

National Park Service
U.S. Department of the Interior

Geologic Map of Big Cypress N Pres



This map graphically presents digital geologic data prepared as part of the NPS Geologic Resources Division's Geologic Resource Evaluation Program. Primary data sources used in creation of the digital geologic data product were:

Geologic Units: Scott, Thomas M., 2001, Geologic formations of Florida (geology_stratigraphy092001): Florida Geological Survey digital file 1:126,720. (http://www.dep.state.fl.us/geology/gisdatamaps/state_geo_map.htm)

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Structural Contour Data: Wexler, E.J., 2004, Hydrostratigraphy Review Report for South West Florida Feasibility Study: Consultant's Report to South Florida Water Management District, unpublished, scale 1:100,000.

Digital geologic data and cross sections for Big Cypress National Preserve and all other digital geologic data prepared as part of the Geologic Resource Evaluation Program, are available online from the NPS Data Store: http://science.nature.nps.gov/nrdata/

Big Cypress NPres

quarry

BICY Structure Contour Lines

- Top of the Bonita Springs Marl (Aquitard 1)
- Top of the Ochopee Limestone (Aquifer 2)
- Top of the Peace River Formation (Aquitard 2)
- Top of the Peace River Sandstone Aquifer (Aquifer 3)
- Top of the Basal Peace River Clay (Aquitard 3)
- Top of the Arcadia Formation

BICY Hazard Areas

BICY Geologic Contacts

- contact
- shoreline

BICY Geologic Units

- Qh - Holocene sediments
- Qu - Pleistocene/Holocene undifferentiated
- Qm - Miami Limestone
- TQsu - Shell-bearing sediments
- Tt - Tamiami Formation

0 2 4 8 Miles
0 2.5 5 10 Kilometers

Produced by Geologic Resources Division

January 2008

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Big Cypress National Preserve. The scoping meeting occurred on January 27–28, 2005; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact the Geologic Resources Division for current information.

Executive Summary

Followed by a field trip on January 28, 2005, a Geologic Resource Evaluation scoping meeting took place at the preserve headquarters on January 27, 2005. The scoping meeting participants identified the following list of geologic resource management issues.

1. The hydrogeologic system at Big Cypress is a western extension of the Everglades. Surface water flows over the low relief landscape through sloughs and marshes. Roads, canals, and levees at the preserve have altered this flow.
2. Geologic and topographic mapping when combined with flow patterns would help resource management determine which areas to focus on for restoration.
3. Soils and bedrock depth surveys and measurements are needed at the preserve. This in addition to soil recovery research would help resource management deal with ORV damage remediation.
4. Disturbed lands at the preserve include borrow pits and canals dug during the construction of roads and pads for oil and gas drilling. These features disrupt the flow of water and need to be remediated.
5. ORV management is an ongoing process at the park. Implementation of the 2001 ORV Plan is a major management goal. The preserve is trying to designate 644 km (400 miles) of trails to lessen ORV environmental impact.
6. Oil and gas issues include regulating the eight producing wells located within the preserve. Land and mineral ownership rights differ between the surface and subsurface and responsibility for clean up and remediation is often mislaid. Impacts resulting from oil and gas exploration are the responsibility of the operator to clean- up.

Introduction

The National Park Service held a Geologic Resource Evaluation scoping meeting for Big Cypress National Preserve at the park headquarters near Everglades City, Florida on Thursday, January 27, 2005. Following this meeting was a field trip on January 28, 2005. The purpose of the meeting was to discuss the status of geologic mapping in the preserve, the associated bibliography, and the geologic issues in the preserve. The products to be derived from the scoping meeting are: (1) Digitized geologic maps covering the preserve; (2) An updated and verified bibliography; (3) Scoping summary (this report); and (4) A Geologic Resource Evaluation Report which brings together all of these products.

Big Cypress National Preserve was established during Gerald Ford's administration on October 11, 1974. Big Cypress covers 720,567 acres of the southwestern corner of Florida. Big Cypress National Preserve was the first national preserve incorporated into the National Park Service at the same time as Big Thicket National Preserve in Texas. This preserve features incredible biodiversity. The environments protected at the preserve range from sawgrass prairies, mangrove forests, cypress stands and domes, hardwood tree islands, to slow flowing sloughs and marshes. The area covers a large portion of the "western Everglades." The preserve is heavily recreated and contains some of the most productive oil and gas fields in south Florida.

Big Cypress National Preserve identified 37 quadrangles of interest. However, additional coverage of 30 more quadrangles (to the north and west) would add considerably to resource management's understanding of the landscape and watershed at the preserve. The Florida Geological Survey (FGS) has digitized a geologic map covering the state from individual county maps at a small scale (≈ 1:126,720 or larger). This map only displays 5 separate geologic units (Holocene sediments, Pleistocene–Holocene undifferentiated, Miami Limestone, Shell- bearing sediments, Tamiami Formation) for inside the boundaries of the park.

Other geologic maps covering portions of the quadrangles of interest include the FGS MS6/19, MS 6/20, MS 6/21, MS 6/22, MS 6/24, and MS 6/25 (1:24,000, 2000), Geological Society of America (GSA) Memoir 147 (1:79,000, 1977), the FGS OFMS 67 (1:26,720, Dade County), 66/01 (1:126,720, Monroe County), 62 (1:126,720 , Hendry County), 63 and Series 120 (1:126,720, Collier County), 64 (1:126,720, Broward County), 65 (1:126,720, Palm Beach County), USGS 84- 4068 and 86- 4126 (1:134,000 and 1:136,000, 1985 and 1986, respectively). BEM Systems produced a hydrostratigraphy study for Big Cypress National Preserve and a small portion of the Everglades National Park that shows interpolated depth to the tops and bottoms of aquifer and aquitard layers. Additional mapping at a smaller scale will be more helpful for preserve management.

Physiography

South Florida lies within the Atlantic Coastal Plain physiographic province. In the area of Big Cypress National Preserve, it is divided into five physiographic subprovinces. The Big Cypress Swamp subprovince defines the western boundary of the Everglades. This area is slightly higher in elevation than the Everglades basin because it is underlain primarily by the coral- rich limestones of the Pliocene Tamiami Formation (3–4 Ma). This formation is exposed in large areas of Big Cypress. Drainage in the province is primarily to the south and southwest.

The Everglades subprovince forms a south dipping, spoon- shaped low- lying area between the Atlantic Coastal Ridge to the east, the Big Cypress Swamp to the west, and the Sandy Flatlands area to the north. The basin has very low relief. The elevation change is only 3.6–4.3 m (12–14 ft) from the maximum near Lake Okeechobee to sea level. Prior to anthropogenic alteration, this drainage system flowed slowly from north to south.

Bounding the Everglades subprovince on the east is the Atlantic Coastal Ridge. It is comprised of Pleistocene marine limestones covered by thin quartz sand sheets. The subprovince ranges in elevation from 1.5 to 6 m (5 to 20 ft) in the southernmost portions. The width of the ridge ranges from 16 km (10 miles) in southern Miami-Dade County and narrows to 5–8 km (3–5 miles) further north. Periodically breaching the southern portions of the ridge are sloughs (transverse marshes) oriented perpendicular to the trend of the ridge.

The southern reaches of the Everglades and Big Cypress Swamp subprovinces transition into the Coastal Marshes and Mangrove Swamp physiographic subprovince. The subprovince covers an area from the northeastern part of Florida Bay, around the southern Florida peninsula, and west, into the Gulf of Mexico up to the Ten Thousand Island region never Everglades City. Bands of swamps and brackish marshes sitting just above sea level characterize this subprovince. Freshwater runoff and tidal fluxes cause the salinity to change dramatically. This is why the mangrove, capable of enduring such salinity changes, thrives in this area.

Geologic History of South Florida

Sediment cores indicate that South Florida has been predominantly an area of carbonate accumulation since the Mesozoic.

Late Paleozoic Era—During the Mississippian, the landmass that would underlie the grand carbonate platform of Florida today was not attached to the North American Craton. It is speculated that it was attached to the northwest portion of the African continent (Condie and Sloan 1998). However, marine carbonates were being deposited over large portions of the area atop a Paleozoic age crystalline basement high, the Peninsular Arch (Pollastro et al. 2000). In the Pennsylvanian, a collision event, known as the Ouachita orogeny sutured the Florida landmass to the continent as Gondwanaland and North America collided eventually forming the supercontinent Pangaea. The land was still submerged and south Florida was located at the junction of the North American, South American, and African plates. Through the Permian, Pangaea remained intact (Condie and Sloan 1998).

Early Mesozoic Era—At the beginning of the Triassic Period, Pangaea began to break up. During the late Triassic, South and Central America and Africa began to rift away from North America. This established the long-standing passive margin of the eastern seaboard that persists today. The Florida and Cuba blocks detached from northwest Africa and the Gulf of Mexico opened (Condie and Sloan 1998).

Accompanying the rifting of Pangaea was the widespread extrusion of volcanic rocks consistent with mantle plume upwelling due to crustal tension (Heatherington and Mueller 1991). This continental rifting also opened the Atlantic Ocean basin.

Middle Mesozoic Era—Underlying the south Florida basin are igneous rhyolitic - basaltic rocks (Thomas et al. 1989). These rocks were subaerially exposed and eroded during the late Triassic to middle Jurassic. This caused the formation of redbeds locally. As the Atlantic Ocean continued to develop, deltaic and shallow marine sediments were deposited in the late Jurassic. Restriction of marine circulation at this time resulted in periodic accumulations of evaporites and marine carbonates (Cunningham 2005). Deposition of Jurassic and Cretaceous sediments was controlled by the south-southeast plunging axis of the Peninsular Arch. Basal sediments onlap and pinch out against the arch (Pollastro et al. 2000).

Late Mesozoic Era—As marine transgression proceeded during the early Cretaceous, the Florida Platform was the site of more widespread deposition of marine limestones and reefs. Further transgression and global warming during the Late Cretaceous established an open marine accumulation of carbonates over the entire Florida Peninsula.

Cenozoic Era—Cenozoic development of the Florida Platform included additional deposition of marine carbonates and deposition of siliciclastics (grains of silicate minerals such as quartz in lieu of carbonates) from northwestern highlands sources and long shore oceanic currents. Tertiary faulting occurred south of Florida as the Cuban block collided with the Antilles arc and carbonate accumulation continued in Florida (Condie and Sloan 1998). In southern Florida, the open marine setting continued during the Paleocene as more restricted flow to the north resulted in deposits of mixed carbonates and evaporites. Eocene and Oligocene deposition is marked by shallow water carbonates. Intermittent with this deposition were subaerial exposures associated with local oceanic regressions.

Deposition in south Florida during the Miocene changed with the introduction of more widespread siliciclastics from a fluvio- deltaic system prograding down the peninsula. Phosphates and the carbonate ramp of the Arcadia Formation were deposited during the Miocene in south Florida. A Pliocene lowstand caused many of the previous deposits to be reworked and/or eroded. The Tamiami Formation is a Pliocene marine unit comprising a wide range of rock types. These are predominantly fossiliferous sands and clays with limestone.

The Pleistocene era resulted in the conversion from siliciclastic deposition mixed with carbonate accumulation to more widespread carbonate sedimentation (Cunningham 2005). Global sea- level changes during the intermittent ice ages of the Pleistocene controlled the rate and distribution of carbonate units. At 120 ka, the last major sea level fall occurred as the mixed carbonate- siliciclastic sediments formed the Fort Thompson Formation. This unit interfingers with the surficial geologic units, the Miami and Key Largo Limestones, and the Anastasia Formation (≈130 ka) (Cunningham 2005).

At 15–16 ka sea level began to rise rapidly and flood southern Florida around 7 or 6 ka (Shinn et al. 1997). Sea level has continued to rise. Holocene geologic activity in the Big Cypress area consists of the dissolution of carbonate units, the accumulation of carbonate muds, freshwater marls, sand and swamp (organic peat and muck) deposits.

Stratigraphy

Cores drilled in the oil and gas exploration operations help define the stratigraphy underlying the preserve. In the oil producing area of Big Cypress, the sedimentary section is 4,572–5,182 m (15,000 – 17,000 ft) thick. The first 2,134–2,743 m (7,000–9,000 ft) are Late Jurassic through Early Cretaceous rocks, the next 914 m (3,000 ft) are Late Cretaceous age rocks, and the remaining 1,676 m (5,500 ft) are of Tertiary age to the present (Pollastro et al. 2000). These rocks fill the South Florida Basin, the center of which is located northwest of the Florida Keys. The basin is bounded on the east by the Paleozoic Peninsular Arch (trending northwest–southeast), the Florida escarpment to the west, the Tampa- Sarasota Arch (trending northeast–southwest) to the north, and the Pine Key arch to the south.

Jurassic age basaltic- rhyolitic rocks underlie all of south Florida. Since the Jurassic, sedimentation has kept pace with overall basin subsidence. Deposition has included carbonates, clastics and evaporites (Pollastro et al. 2000). The earliest sediments, of the Wood River Formation are continental clastics overlain by salt, limestone, anhydrite and brown dolomite. Between the Wood River and the oil producing Sunniland Formation lie the predominantly carbonate- evaporite Bone Island and Pumpkin Bay Formations, and the Glades Group of shales, dolomites, and anhydrites (Faulkner and Applegate 1986). The Sunniland Formation of Lower Cretaceous age is comprised of anhydrites, thin limestone layers, and dolomites. The Sunniland, along with the anhydrite and limestone of the Lake Trafford Formation and the dolomite, limestone and anhydrite of the Rattlesnake Hammock Formation, comprise the Ocean Reef Group.

The Big Cypress Group and Naples Bay Group overlie the Ocean Reef Group. These are largely dolomites and anhydrites beneath Big Cypress. The Upper Cretaceous Pine Key Formation is composed of chalky limestone and dolomite. It is approximately 914 m (3,000 ft) thick. The Paleocene to present day sedimentary layers lie atop the Pine Key Formation at Big Cypress (Faulkner and Applegate 1986). Relatively uninterrupted Tertiary deposition amassed the grand carbonate platform of South Florida. These sediments reach great thicknesses of approximately 1,676 m (5,500 ft).

Cores drilled in nearby Everglades National Park help determine the upper stratigraphy at Big Cypress. Eocene to late Oligocene deposition consists of marine carbonates of the Avon Park Formation, the Suwannee Limestone and the Ocala Group, and the Arcadia Formation of ramp setting carbonates with scant quartz contents increasing northward (Cunningham 2005). A major disconformity marks the boundary between the Arcadia Formation and the overlying Peace River Formation. In other areas of Florida, the Hawthorn Group (Miocene) is between the Arcadia and Peace River Formations. The Peace River Formation contains two distinct units: a lower diatomaceous mudstone, and an upper fine- grained quartz muddy sandstone (Cunningham et al. 1998). Deposited atop the Peace River Formation is the Tertiary age Tamiami Formation. This unit comprises much of the surface outcrop at Big Cypress.

Shallow water limestone of the Fort Thompson Formation underlies the surficial Miami Limestone. This limestone is probably combined with the capping unit of the Miami Limestone. The Fort Thompson is mostly lagoonal facies carbonate with abundant bivalve fossils and some quartz sand. The Miami Limestone is ≈125–130 ka and represented deposition during an interglacial period. Two facies exist for the Miami Limestone. The western portion of the unit contains predominantly the bryozoan facies, the unit then becomes more oolitic eastward (Hoffmeister et al. 1974; Cunningham 2005).

Overlying the Miami Limestone bedrock are surficial units of freshwater peat and organic muck, freshwater marls, and cyanobacteria mats in the swampy marsh at Big Cypress. The peat and muck typically occurs in low-lying sloughs and solution holes and are dark and fine-grained. During the standing water phase of the wet season, extracellular precipitation of calcium carbonate by cyanobacteria forms fresh limestone marls (Cunningham 2005).

Significant Geologic Resource Management Issues at Big Cypress National Preserve

Hydrogeologic system at Big Cypress

The Big Cypress is really a western extension on the Everglades system. Water is flowing on the surface in marshes and sloughs and below ground in slow flowing aquifers through porous substrate. The present topographic and hydrogeologic information is too coarse and/or inadequate for resource management. More modeling is necessary to understand the true water budget of the preserve.

The flow of water through the preserve has been drastically altered and diverted by the construction of roads, trails, pads, canals, and levees. The state and local pumping policies control a vast portion of water input to Big Cypress. Pumping can control basin dynamics. A major goal of the preserve is the restoration of the original flow ways as best as possible. A focus area is the 9 to 12 m (30 to 40 ft) wide Turner River basin in-channel construction near U.S. Highway 41. Restoration efforts include reconnection flows through canals and roads (building causeways). The Bear Island area is another area to focus restoration efforts. Cooperation is necessary between resource management and local water volume management agencies to coordinate and organize the timing responses of gates and pumps.

Regional models achieve varying degrees of success at Big Cypress. The South Florida Water Management Model (SFWMM) ignores roads and uses an outdated climatic scheme. The Natural Systems Model (NSM) uses vegetation patterns to predict an improved pseudotopography. The Across Trophic- Level System Simulation (ATLSS) correlates species with hydrology, hydroperiod, and vegetation. The Everglades Landscape Model (ELM) covers the hydrology of bounded systems of canals and structural control with rain- driven triggers. The Interim Structural and Operational Model (ISOP), which is 2–3 years from implementation, is probably the closest to the concerted water budget management the preserve needs, but still uses core data from the SFWMM model. Cell size and vertical precision vary on these models from 3.2 km (2 miles) to 30 m (100 ft) and 15 to 3 cm (6 to 1 inches), respectively. Lidar would improve the vertical precision.

Research and monitoring questions and suggestions include:

- Study how rainfall controls the hydrologic system.
- Does the depth to bedrock measurement have a significant control on the system?
- Compare natural and anthropogenic caused hydraulic changes.
- Monitor hydrologic response to storm events.
- Try to get lidar mapping of sloughs for fine- scale topographic changes.
- Obtain more hydrologic sampling and install hydrologic monitoring stations in key locations.
- Determine more stage level measurement points.
- Monitor stage level.
- Attempt to align with the Comprehensive Everglades Restoration Program (CERP) efforts (Big Cypress is largely overlooked in favor of Everglades restoration).
- Cooperate with federal, state, and local agencies to monitor and clean up ground and surface water; examples of pollution include creosote (from Copeland sawmill in the 1960s), agricultural runoff (including pesticides from tomato farms).
- Deep Lake (27 m, or 90 ft, deep) is the southernmost sinkhole in Florida, why?
- Focus geologic studies on processes rather than just features.
- Categorize, describe, and model the near surface, mid- and deep aquifers below Big Cypress National Preserve.

Geologic and topographic mapping

The relief at Big Cypress is approximately 6 cm/km (2 inches/mile) or 4.6 m over 145 km (15 ft over 90 miles). This incredibly low relief is the reason the sloughs, swamps, and marshes thrive at Big Cypress. Water slowly trickles down to the sea from central Florida. High-resolution topographic mapping, when combined with flow patterns would help resource management determine which areas to focus on for restoration.

Research and monitoring questions and suggestions include:

- Relate small- scale topographic differences with the locations of hammocks and pinelands at the preserve.
- Map the locations where the Tamiami Limestone is exposed.
- Focus topography and cross section production on key areas (coordinate with the original flow way restoration efforts).
- Map karst features in addition to canals and rock pits on maps.
- Cooperate with slough mapping project through the Audubon Society.
- Expand upon the Tamiami type section located within the preserve.
- Are strands and paleochannels related?
- Why is the boundary between Big Cypress and the Everglades so dramatic?
- What is the nature of the boundaries between strands?
- Map rock outcrops at different scales and determine if they have a controlling influence on the location of Cypress stands.
- Greg Desmond with the USGS is conducting a High-Accuracy Elevation Project with an Airborne Height Finger (AHF), which creates Digital Elevation Models (DEMs); support him to obtain better data.
- Determine original flow ways with DEMs.
- Suggest more USGS/BLM/NRCS/SFWMD/FLDOT cooperative geologic/mapping projects.

Disturbed lands

Disturbed lands besides areas affected by oil and gas operations, include borrow pits excavated for the construction of the oil and gas pads and roads built to access remote sites.

Research and monitoring questions and suggestions include:

- Quantitatively identify disturbed sites and explore remediation to restore natural water flow.
- Remove Bear Islands closed oilfield roads.
- Work on finding ways to build bridges and reculvert established road areas to improve flow focusing on roads directly perpendicular to flow first.

ORV management

More than 425,145 visitors came to the preserve in 2004. These visitors enjoyed the incredible recreational opportunities at Big Cypress. Activities include camping, kayaking, hiking, bird watching, canoeing, hunting, ORV use, and airboat access. The preserve is attempting to concentrate visitor access to reduce environmental impact.

Raised roadbeds across south Florida have dammed the natural, low relief, slow moving sheet- flow from Lake Okeechobee to Florida Bay. ORV use at Big Cypress has caused major damage to the hydrology and soils. Soil resiliency at the preserve is not well understood. Buggies and other ORVs destroy algae (terraphytes) populations in the soils. The entire ecosystem is based on these microorganisms that lie dormant in dry conditions. When they are churned up and buried, the landscape resembles a soil desert. An ORV management plan, completed in 2001, calls for a designation of 644 km (400 miles) of trails in the preserve. It is estimated that at least 22,000 miles of trails currently exist. For a park the size of the state of Rhode Island, the ranger on duty has difficulty patrolling the ORV activity. Unauthorized airboat use is also a resource management issue affecting water quality, noise levels, and soils.

Research and monitoring questions and suggestions include:

- Determine the best sites for a designated trails system.
- Perform a preserve- wide soils survey to establish baseline conditions for trail planning.
-

Oil and gas issues

Oil and gas exploration began in the Big Cypress area in 1923. Most of the active drilling was in the mid 1970s. The main producing geologic unit is the Sunniland Formation. Approximately 450 wells have been drilled along the northwest–southeast oriented Sunniland Trend. Oil and gas activity in the preserve is rapidly declining. As of September 2004, there are 18 wells producing from only eight fields. Eight of these producing wells are located within the preserve. The oil and gas reservoir rocks are porous (10- 30% porosity). They are composed of carbonate grainstones and dolomites sealed by evaporites and/or nonporous carbonates. Based on 2D seismic surveys, gravity and magnetics data, the overall drilling success rate has been about 3% (Norby 2005).

Most of the oil and gas rights under the preserve are of private ownership, established prior to the designation of the preserve. Ninety- nine percent of the land at the preserve is "split estate" meaning the surface and subsurface ownership is different. The pads and roads left behind when a well is closed leave a large scar on the landscape and affect the hydrologic system at Big Cypress. Roads are built of borrow pit material 1.2 m (4 ft) higher than the surrounding drainage. Culverts are thinly spaced and many are falling into rusty disrepair. The responsibility for monitoring, compliance with regulations, restoration and remediation is often unclear and pipes, wells, and structures are still at abandoned pads.

Research and monitoring questions and suggestions include:

- Explore making a depth to bedrock measurement mandatory per shot hole for oil and gas (seismic) exploration surveys conducted in the Preserve.
- Obtain seismic information per township on a grid pattern.
- Use road and pad fill for trail construction and other remediation work.
- Work with corers to obtain more stratigraphic data.
- Attempt to update the Minerals Management Plan to have stronger surficial protection regulations.

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Big Cypress National Preserve

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/021
NPS D-176, February 2008

National Park Service

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Natural Resource Program Center

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