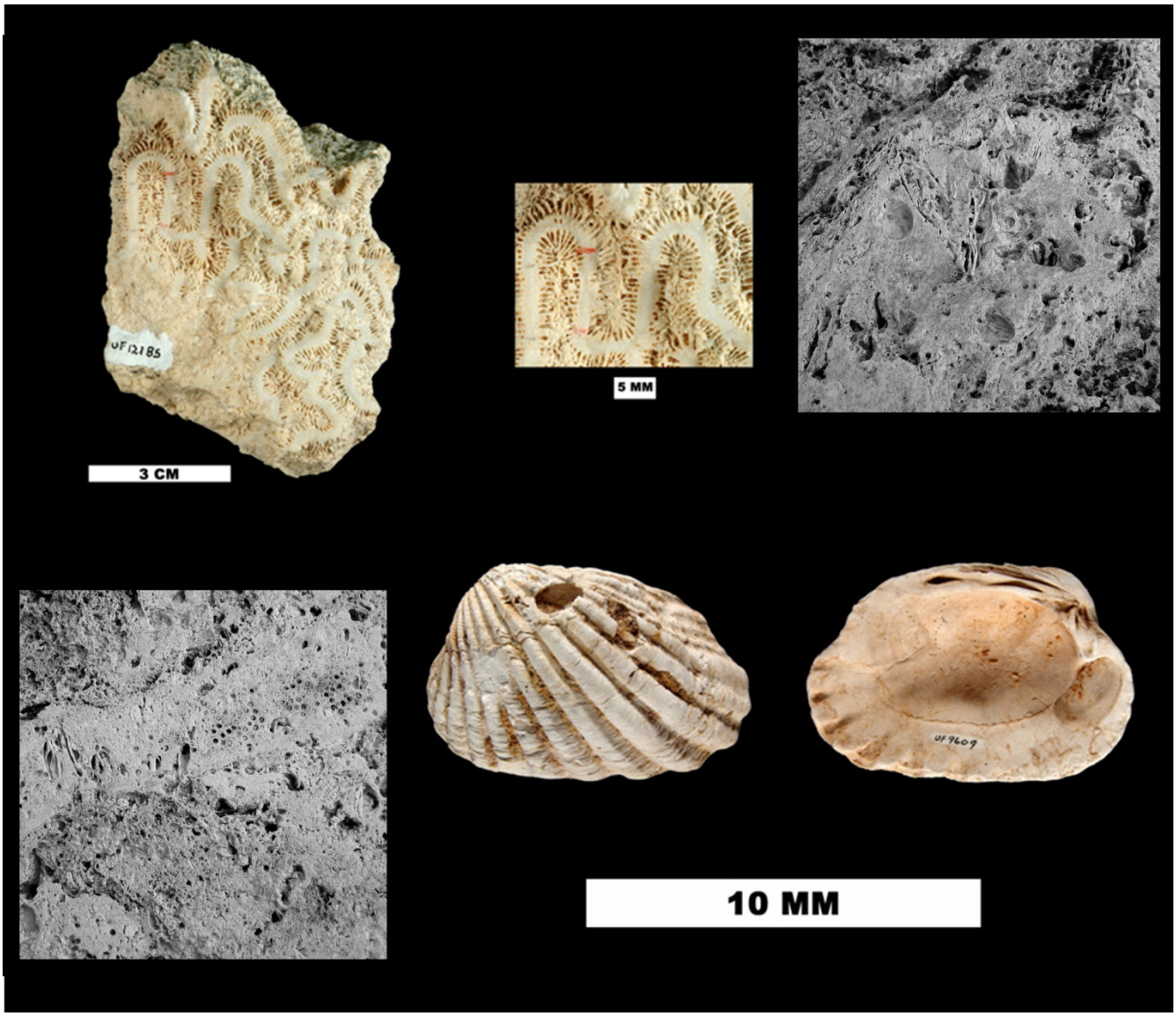
National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Paleontological Resource Inventory and Monitoring

South Florida / Caribbean Network

Natural Resource Technical Report NPS/NRPC/NRTR—2010/335



ON THE COVER
Fossils typical of the South Florida/Caribbean Network. Clockwise from top left: *Diploria strigosa* coral from the Key Largo Limestone of Florida (University of Florida [UF] specimen 12185), detail of *Diplora strigosa* coral (UF 12185); detail of Miami Limestone-Oolite facies used as building stone on Boca Chita Key in Biscayne National Park with visible marine invertebrate fossils; *Carditamera tamiamiensis* bivalve from the Tamiami Formation of Florida (UF 9609); another detail of Miami Limestone on Boca Chita Key in Biscayne National Park.

UF specimen photos courtesy Roger Portell and the Invertebrate Paleontology Division of the Florida Museum of Natural History. Boca Chita Key building stone photos courtesy Elsa Alvear (Biscayne National Park).

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NOTE:
This report provides baseline paleontological resource data to National Park Service administration and resource management staff. The report contains information regarding the location of non-renewable paleontological resources within NPS units.
It is *not* intended for distribution to the general public.

May 2010

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

The National Park Service, Natural Resource Program Center publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report are those of the author(s) and do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service.

This report is available from the South Florida / Caribbean Network intranet (http://www1.nrintra.nps.gov/im/units/SFCN/index.cfm; NPS access only) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/NRPM).

Please cite this publication as:

Toscano, M. A. , J. P. Kenworthy, and V. L. Santucci. 2010. Paleontological resource inventory and monitoring—South Florida / Caribbean Network. Natural Resource Technical Report NPS/NRPC/NRTR—2010/335. National Park Service, Fort Collins, Colorado.

NPS 910/102458, May 2010

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Abstract

Paleontological resources (fossils) are any remains of past life preserved in a geologic context. Paleontological resources are non-renewable resources found in more than 224 National Park Service units. Despite the abundance and diversity of these resources throughout the NPS, until recently few parks have adequate baseline paleontological resource data.

The NPS National Inventory and Monitoring Program and the NPS Geologic Resources Division have developed various strategies to provide parks with the baseline paleontological resource data necessary for greater understanding and appropriate management of these resources. This report presents a paleontological resource summary for the parks of the South Florida / Caribbean Network. The summary was compiled through extensive literature reviews and interviews with park staff and professional geologists and paleontologists. Preliminary paleontological resource management recommendations are also included for each park. Including this report, summaries have been prepared for 30 of 32 NPS Inventory and Monitoring networks. The National Inventory and Monitoring Program has provided funding to complete paleontological resource summaries for each of the remaining networks.

In general, the paleontological resources known from the parks of the South Florida / Caribbean Network (SFCN) come from the late Cenozoic Era, particularly the late Neogene through Quaternary periods. All SFCN parks have fossils typical of marine carbonate environments, including fossil coral reefs, skeletal carbonate shelf sediments and other fossiliferous coastal deposits. Big Cypress National Park (BICY) and Everglades National Park (EVER) share similar modern wetland environments as well as their underlying carbonate geology. Both are underlain by a vast shallow marine bryozoan facies deposited during the peak of the last interglacial period (~125,000 years ago) when sea level was 6 meters above present levels. BICY has manmade exposures of a deeper Neogene marine fauna; EVER's fossil resources extend to Holocene Florida Bay sediments. Dry Tortugas National Park (DRTO) has late Quaternary fossils associated with cultural resources (Civil War fortifications, shipwrecks, and an early 20th century science laboratory). Biscayne National Park (BISC) shares the same Pleistocene fossil reef formation underlying DRTO, but, like all of the middle and upper Florida Keys, has this fossil reef exposed as the surface rock. The late Quaternary fossil corals of BISC and DRTO have been used to document glacial-interglacial sea-level cycles, paleoclimate and comparative mid-late Pleistocene and Holocene coral reef ecology, species changes, and geologic history along the northernmost western Atlantic coral reef system. Both parks presently encompass large subtropical shallow marine areas with ongoing production of skeletal deposits including coral reefs, subsequent taphonomy, and fossilization. The parks of the Virgin Islands, consisting of Buck Island Reef National Monument (BUIS), Salt River Bay National Historical Park and Ecological Preserve (SARI), and Virgin Islands National Park (VIIS), contain recent marine carbonate deposits similar to those of BISC and DRTO, including coral reefs and biogenic shelf sediments. On St. John Island (VIIS) these deposits rest on virtually non-fossiliferous deformed and intruded pre-Cretaceous volcanic rocks. On St. Croix, late Quaternary marine deposits occur on a base of meta-sedimentary and deformed marine formations, in particular the Cretaceous Caledonia Formation. Thus most of the fossil material is of geologically recent age, ranging over the past 130,000 years of geologic time.

Acknowledgments

The authors graciously thank all those individuals, both within and outside of the National Park Service who have contributed valuable information, comments, and suggestions for this report. Reports such as this are impossible without extensive input from those people who know the resources the best.

We wish to thank the National Park Service staff who graciously provided information, comments, suggestions, and/or reviewed their park's section: Elsa Alvear (BISC Resource Management Specialist); Zandy Hillis-Starr (BUIS Chief of Resource Management); Melissa Memory (EVER Chief of Cultural Resources); Nancy Russell (EVER Museum Curator); Meredith Hardy (SEAC Archeologist); and Rafe Boulon (VIIS Chief of Resource Management).

Jim C. Woods of the NPS Geologic Resources Division (GRD) is thankfully acknowledged for his skillful oversight and coordination of the project's budget and personnel. The continued support and information provided by additional GRD staff, including Lindsay McClelland, Bruce Heise, Tim Connors, Lisa Norby, and Jim F. Wood is greatly appreciated.

Thanks to Matt Patterson (SFCN coordinator) for his comments on the project and Judd Patterson (SFCN GIS Specialist) for providing the network map graphic.

This report benefited from the information and suggestions provided by several geologists and paleontologists including: Dennis Hubbard (Oberlin College Department of Geology); Pamela Hallock-Muller (University of South Florida-College of Marine Science); Christopher Reich (U.S. Geological Survey-St. Petersburg); and Frank Rupert (Florida Geological Survey). Doug Rankin (U.S. Geological Survey-Reston) reviewed the Virgin Islands background geology section and the Virgin Islands National Park section. Dennis Hubbard reviewed the Virgin Islands parks' sections.

Finally, this report would not have been possible without the funding from the National Inventory and Monitoring Program and the support of the Geologic Resources Division. The enthusiasm and support of Bert Frost (Associate Director, NPS Natural Resource Stewardship and Science) and Steve Fancy (Chief, Office of Inventory, Monitoring, and Evaluation) is acknowledged. We extend a sincere thanks to Bert and Steve for providing the means upon which this work, and similar work, can be accomplished.



Dedication

This report is dedicated to Beth Johnson, NPS Deputy Associate Director for Natural Resource Stewardship and Science for her avid and continuous support of NPS paleontology.

Introduction

Paleontological resources, or fossils, are any remains of past life preserved in geologic context. There are two main types of fossils: body fossils and trace fossils. Body fossils are the physical remains or imprints of an actual organism (shells, bones, teeth, plant leaves, etc.) while trace fossils (burrows, coprolites, footprints, trackways, etc.) preserve evidence of an organism's activity or behavior. Fossils are non-renewable natural resources that possess great scientific, educational, and interpretive value.

To most non-scientists, it may seem difficult to determine what material would be considered "fossil" and what would be considered "modern." The National Park Service defines a fossil as any remains of life preserved in a geologic context. While the "geologic context" is intended to imply some level of antiquity, this definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. This is especially relevant in South Florida / Caribbean Network parks such as Biscayne National Park (BISC), Dry Tortugas National Park (DRTO), Buck Island Reef National Monument (BUIS), Salt River Bay National Historical Park and Ecological Preserve (SARI), and Virgin Islands National Park (VIIS). These parks present geologically very young sediments and reef deposits on the seabed and along the coasts. Generally, specimens dating back to the late Pleistocene are considered fossils, as are the early-late Holocene foundations of the modern coral reef and shallow marine systems at BISC, DRTO, BUIS, SARI and VIIS. Surface and subsurface specimens collected and analyzed at BISC, DRTO, BUIS and SARI are known to span this range from Pleistocene and Holocene. In addition, because the marine geologic systems of these parks have been developing continuously over the past 8,000-10,000 years with the same resident species, there is no easy way to distinguish fossil vs. modern material unless the animal (coral, snail, clam, etc.) is still alive.

The process of fossilization begins when the animal has died and its hard parts are no longer occupied. They enter the fossil record via the sedimentary system where their hard and soft parts are subjected to taphonomic (post-mortem deterioration) processes including erosion, encrustation, chemical alteration and predation. Burial of hard parts and remineralization are usually essential for preservation and fossilization over the long term, but many true fossils of Pleistocene to Holocene age in the coastal realm have not yet been permanently entombed or mineralogically altered. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Much of the late Pleistocene coral in the Key Largo Limestone of BISC and DRTO has been altered by recrystallization of the original biogenic aragonite to calcite, but many subsurface samples have not been altered and may appear to be modern if dislodged and washed onshore in the dynamic marine environment. Shells found on the beach may be thousands of years old, likely having been disturbed from burial by storm waves and washed onshore where they mix with younger specimens. The islands of DRTO in particular are constructed of a storm-deposited mixture of time-averaged biogenic sediments. With no definitive or practical means of placing an age on a shell found on the beach, unless it has a living animal resident, all shells, coral fragments, and even the biogenic sediment itself should be considered "fossil" for conservation and preservation purposes. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.

The establishment of baseline paleontological resource data is essential for the appropriate management of fossils found within National Park Service (NPS) areas. Although more than 224 NPS areas have been identified with paleontological resources, few parks have adequate baseline paleontological resource data. In conjunction with the NPS Geologic Resources Division and the NPS Inventory and Monitoring (I&M) Program, paleontological resource inventories have been initiated in dozens of parks Servicewide and are further described in the Methodology and Inventory Strategies section of this report. This report presents paleontological resource inventory and monitoring data compiled for the parks of the South Florida / Caribbean I&M Network (SFCN).

The South Florida / Caribbean Network includes seven National Park Service areas as shown in Figure 1, four in southern Florida and three in Caribbean islands: Big Cypress National Preserve (BICY), Biscayne National Park (BISC), Buck Island Reef National Monument (BUIS), Dry Tortugas National Park

(DRTO), Everglades National Park (EVER), Salt River Bay National Historical Site and Ecological Preserve (SARI), and Virgin Islands National Park (VIIS). The parks that comprise the South Florida / Caribbean Network vary in size from 397 ha (982 acres) at SARI to 610,483 ha (more than 1.5 million acres) at EVER. The parks of the network together hosted more than 2.9 million visitors during FY2008.

These parks are found across an area that changes in geographic setting from the southern portion of peninsular Florida, Florida Bay and the Florida reef tract in the north, westward into the Gulf of Mexico and southeastward across the Straits of Florida into the Caribbean Sea and the Antillean Islands. The vast continental wetland or slough of BICY and EVER originates from the Kissimmee watershed, through Lake Okeechobee, and propagates southward as sheet flow. This unique system ends southward in Florida Bay, where subtropical carbonates accumulate behind the Florida Keys. Several major geographic and geologic elements of the SFCN, the Florida Keys, reef tract and mainland coastal area, were built over the course of several major sea-level fluctuations, particularly during "highstands" resulting from the interglacial (warm) portions of climate cycles of the Pleistocene epoch. This area is therefore the setting for multiple, superimposed coral reef deposits separated in time by intervening glaciations and low sea levels. The last interglacial highstand 125,000 years ago established the paleoenvironment for the accretion of the vast reef tract and associated shallow marine carbonate facies (analogous to the modern reef tract) which forms the Florida Keys and extends from BISC in the north to DRTO some 285 km (180 miles) to the southwest.

Across the Straits of Florida, the SFCN extends into the Caribbean Sea to the U. S. Virgin Islands, which lie between the Greater Antillean Islands of Cuba, Hispaniola, and Puerto Rico, and the Lesser Antillean Island arc chain. Virgin Islands National Park (VIIS on St. John) and parks on St. Croix (SARI, BUIS) contain additional carbonate deposits, both geologically recent or modern, as well as extending into the Cretaceous Period . The deformed, metamorphosed rocks of St. John and St. Croix provide very few paleontological resources. However, extensive Paleogene and Neogene (together referred to as the "Tertiary") though Quaternary sedimentary facies containing both deep and shallow-water fossils occur in St. Croix and border the the land areas of SARI. VIIS, SARI and BUIS all contain modern coral reef and carbonate shelf environments, while in north-central St. Croix late Pleistocene reef deposits have been cored beneath Holocene reefs in areas adjacent to SARI.

South Florida Geology

In pre-Jurassic time, the Florida-Bahama Platform was attached to West Africa as part of the Pangaea supercontinent. Paleozoic rocks in the subsurface of Florida contain sparse fossils, all of them pre-Late Devonian, after which marine deposition ceased due to the continental collision (Winston 1991). After North America broke from Africa in the Triassic, Lower Jurassic igneous rocks were extruded over north Florida. These rocks are not exposed at the surface. The Atlantic Ocean, Caribbean Sea and Gulf of Mexico began to form; south Florida and the Bahamas existed as a shallow marine area. The Southeastern Sedimentary Province in Florida was separated from the Northwestern Province by the Sarasota/Peninsular arch (a feature of the basement rock), which ran southwest-northeast across Charlotte County, to the northwest of EVER and west of BICY.

The underlying structure in South Florida, the South Florida Basin, formed during the Early Cretaceous (Comanchean) and since then has undergone relatively minor subsidence (Missimer 1984). The South Florida Basin is bounded updip by the Sarasota/Peninsular Arch and the Ocala Uplift. It extends downdip to Cuba and the Straits of Florida; this southern boundary formed by the end of the Cretaceous. Petroleum exploratory wells, some drilled to depths of 6,166 m (18,670 ft) (Applegate et al. 1981) have reached the volcanic basement, the basal transgressive clastic sequence, and the thick Cretaceous and later marine carbonate sequences which range in thickness from about 4,300 m (~13,000 ft) near the south end of Lake Okeechobee, to more than 6,600 m (20,000 ft) downdip to the southwest. Microfossils (e.g. stratigraphically significant foraminifera) in these ancient rocks are rare (Winston 1991). The Jurassic to Lower Cretaceous (Coahuilan to Comanchean) marine carbonate-evaporite sequence (varying percentages of dolomites, anhydrites and limestones/black limestones) was deposited in a slowly

subsiding setting (Missimer 1984). Upper Cretaceous deepwater carbonate sequences have decreasing amounts of anhydrite and absence of black limestones, signifying shallowing of the basin and slowing subsidence. These non-fossiliferous depositional sequences deeply underlie EVER and BICY.

During the Upper Cretaceous until the end of the Paleocene, the Florida Peninsula was ringed by the Rebecca Shoal Barrier Reef (Winston 1991), which survived the K-T (Cretaceous-Tertiary) boundary with no apparent hiatus. Inside this atoll, shallow-water white chalk, chalky limestone and dolomite interbedded with anhydrite were deposited through the Eocene, at the end of the topographic expression of the Sarasota Arch, which was subdued as a result of sedimentation in the basin (Winston 1991).

Paleogene sedimentation in South Florida began in the Paleocene with cyclic dolomite and evaporite deposits containing characteristic and common microfossils (foraminifera *Borelis gunteri* and *Borelis floridanus*; Missimer 1984). The Eocene section consists of fossiliferous and/or biostratigraphic units with *Dictyoconus*, *Lituonella*, *Fabularia* and other fossils (Applin and Applin 1944; Cole and Applin 1964, Chen 1965). The Ocala Limestone in South Florida is characterized by a lower white/light gray limestone and an upper white fossiliferous coquinoid limestone with numerous large foraminifera (Applin and Applin 1944; Chen 1965; Scott 2001).

The Oligocene Suwannee Limestone contains soft calcarenites consisting of tests of foraminifera, as well as some clastic sediment in the northern Everglades area. Upper Oligocene and Miocene sedimentary units in South Florida belong to the Hawthorn Group (Scott 1988, 2001), considered the most lithologically complex stratigraphic unit in Florida (Missimer 1984). These transgressive–regressive cycles of limestone-carbonate/clastic and upper deltaic deposits contain diatoms and foraminifera (Peck et al. 1979) and in southeast Florida, mixed sandy phosphatic limestones and dolomites overlain by mixed green dolosilts, lime muds, and quartz sands.

Pliocene sediments include the upper part of the Hawthorn Group (Peace River Formation), the Tamiami Formation (Mansfield 1939; Hunter 1968; DuBar 1974; Waldrop and Wilson 1990; Lyons 1991; Missimer 1992; Scott 2001; Petuch and Roberts 2007), and the Caloosahatchee Formation (DuBar 1974). The late Pliocene Caloosahatchee Formation is absent from the surface in BICY and western EVER areas but present several meters below the surface (Petuch and Roberts 2007). Dewatered sections of the Caloosahatchee were visible in northeastern parts of the Everglades and near Lake Okeechobee due to dredging, draining and canalization in the 1960s. The Caloosahatchee was redefined as a thin discontinuous unit with diagnostic fossils (*Cypraea problematica*, *Strombus leidyi*, *Liochlamys bulbosa*), "numerous corals" (Pliocene) from north Lee County, and Pleistocene-aged vertebrate fossils and a molluscan assemblage.

According to the Geologic Map of the State of Florida (Scott et al. 2001), surficial stratigraphic units in South Florida are all of Pliocene-Quaternary age. This general grouping includes highly fossiliferous Pliocene ("Tertiary")-Quaternary sands and carbonates (TQsu – Tertiary-Quaternary Shell Units) of latest Pliocene - early Pleistocene age. Pleistocene deposits originating in warm shallow seas represent at least five stratigraphic units (Q1-Q5 from oldest to youngest; Perkins 1977) which date minimally from the past ~400,000 years (Q3) to the Late Pleistocene last interglacial highstand of the sea at ~125,000 years ago (Q5). Q5 deposits have been subdivided into substages of the last interglacial period where possible through radiometric dating (Q5e-Q5a; Multer et al. 2002). Formations forming the bedrock of southern Florida within EVER, BICY, BISC and DRTO include the widespread bryozoan and oolitic facies of the Miami Limestone (Qm) and the extensive fossil coral reef system of the Key Largo Limestone (Qk). Last interglacial coastal marine deposits (sandy limestones, calcareous sandstone, sand, shells, and coquina) of the Anastasia Formation occur along the east coast of Florida, starting in Palm Beach County, north of and interfingering with the Miami Limestone, and span Q1 to Q5 time (Perkins 1977). The Anastasia does not underlie or crop out in any of the SFCN parks.

Along the northeastern side and northern border of BICY, undifferentiated Tertiary-Quaternary shell units (TQsu) have been mapped outcropping at the surface adjacent to Miami Limestone and the Tamiami Formation (Thornberry-Ehrlich 2008). These fossiliferous units may include the

Caloosahatchee formation below the surface but are most likely to be represented by the Fort Thompson Formation at the surface.

Lidz et al. (2003) determined that the Florida Platform is tectonically stable (citing Davis et al. 1992), thus despite higher elevations to the west there is no evidence of platform tilting as per Parker and Cooke (1944), Parker et al (1955) and Perkins (1977). Higher elevations are constructional rather than of tectonic origin.

Virgin Islands Geology – St. John and St. Croix

The Virgin Islands are located along the northeastern edge of the Caribbean plate south of the Puerto Rico Trench. They lie between the Greater Antilles (Cuba, Jamaica, Hispaniola and Puerto Rico) to the west and the Paleogene through modern Lesser Antillean volcanic island arc curving to the east and south. Numerous seafloor and subsurface investigations document Quaternary sedimentary deposits consisting of reef and nearshore shallow-water carbonate environments.

To the north of the Virgin Islands along the Puerto Rico Trench, faults separate the eastward moving Caribbean plate and the westward moving North American plate. Research is ongoing, but one of these faults may separate St. Croix from the Virgin Islands-Puerto Rico platform (D. Hubbard, Oberlin College, pers. comm., February 2010). Movement along the faults cause frequent earthquakes that are usually too small in magnitude to cause tsunamis. An exception was the high-magnitude Virgin Islands Earthquake and subsequent tsunami of 1867. Tsunamis are known to occur throughout the Lesser Antilles due to a variety of causes, including subsea slope failures/slumps, volcanic activity, etc. (Lander et al. 2002; Morton et al. 2006). Teletsunamis (e.g. generated across the Atlantic in the vicinity of Lisbon, Portugal; Lander et al. 2002) have also affected the Caribbean region. Along the eastern Caribbean island arc of the Lesser Antilles, convergent, subduction tectonics produce earthquakes, volcanic activity, submarine landslides and flank failures, and pyroclastic flows that generate well documented local tsunamis which affect one or a few islands, attenuate rapidly and thus do not have widespread impacts (Pararas-Carayannis 2004; Morton et al. 2006; Mattioli et al. 2007).

The northern Virgin Islands, west to east, include St. Thomas, St. John, and the British Virgin Islands, all east of Puerto Rico. St. Croix lies 60 km (37 mi) to the south across the Virgin Island Basin. St. John consists of volcanic, volcaniclastic, and intrusive rocks of Cretaceous and Paleogene or Neogene age, surrounded by modern coral reefs. Refer to the appendix for a geologic time scale. As summarized by Rankin (2002), the oldest rocks on St. John are Early Cretacoues igneous rocks such as keratophyre, basalt, basaltic andesite, their colcaniclastic and hypabyssal intrusive equivalents, and minor chert emplaced in an extensional (pulling apart) oceanic plateau environment. These were followed by Early to Late Cretaceous island arc volcanic rocks, their volcaniclastic equivalents, and minor calcareous rocks that were part of an early sudbuction cycle common to all the Gretaer Antilles. Paleogene and Neogene mafic (low-silica) dikes and tonalitic plutons (bodies of molten rock solidifying beneath the surface) intrude all rocks. Later, compression, likely due to eastward movement of the Caribbean plate as the Cayman Trough began spreading, caused folding. Rankin (2002) indicates that St. John has not exhibited recent tectonic movement.

The island of St. Croix is located to the south of the other Virgin Islands and to the east of the Greater Antilles. Because it is predominantly composed of meta-sedimentary and volcaniclastic rocks, St. Croix is geologically more similar to Puerto Rico, Cuba, and Hispaniola (Dominican Republic/Haiti) than to the volcanic Lesser Antillean islands. St. Croix consists of deformed Upper Cretaceous sedimentary rocks intruded by igneous rocks older than late Oligocene in age. These rocks from horsts (areas of relative “up” between down-dropped valleys) at the eastern and western ends of the island. These are unconformably overlain by upper Oligocene to lower Miocene mudstones and limestones that accumulated in a northeastward-oriented graben (down-dropped valley) in the central part of the island (Lewis and Draper 1990). Tectonic extension (pulling apart) formed faults along which the grabens were down-dropped. The island has a complex structural and tectonic history, with units segmented by major fault zones as

part of a deformed collisional plate boundary with "initial compression followed by transcurrent tectonics and extension" (Nagle and Hubbard 1989; Whetten 1966, 1974; Ratte 1974; Stanley 1987a, 1987b, 1988, 1989; Speed 1989; Holmes and Kindinger 1985). Case et al. (1984) categorized St. Croix and its platform as one of several moderately to strongly deformed basins of the Anegada Province. Speed and Joyce (1989) reinterpreted the geology of St. Croix as representing a tectonic complex of six fault-bounded, stacked nappes formed in a forearc system with a north-dipping subduction zone during the Late Cretaceous, which later changed to southward subduction in the Paleogene. Gill et al. (1989) and McLaughlin et al. (1995) documented and interpreted the subsurface and outcropping Neogene geologic history and biostratigraphy of the Kingshill Basin (the graben), which runs northeast-southwest across central St. Croix. Salt River Bay is located on the north coast of St. Croix, within the central graben or Kingshill Basin which contains the Neogene geologic section, in particular the Miocene Kingshill Limestone. Much of the Paleogene and Neogene section in the central Kingshill basin is of deeper marine origin, dated through foraminiferal and ostracode biostratigraphic interpretations and zonations.

Collectively, the paleontological resources of the SFCN Network contribute to a greater understanding of the history of life on earth. Continued paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the National Park Service. Although more than 224 parks have already been identified as containing paleontological resources, much of what is to be known about the history of life on earth recorded in the NPS remains to be discovered.

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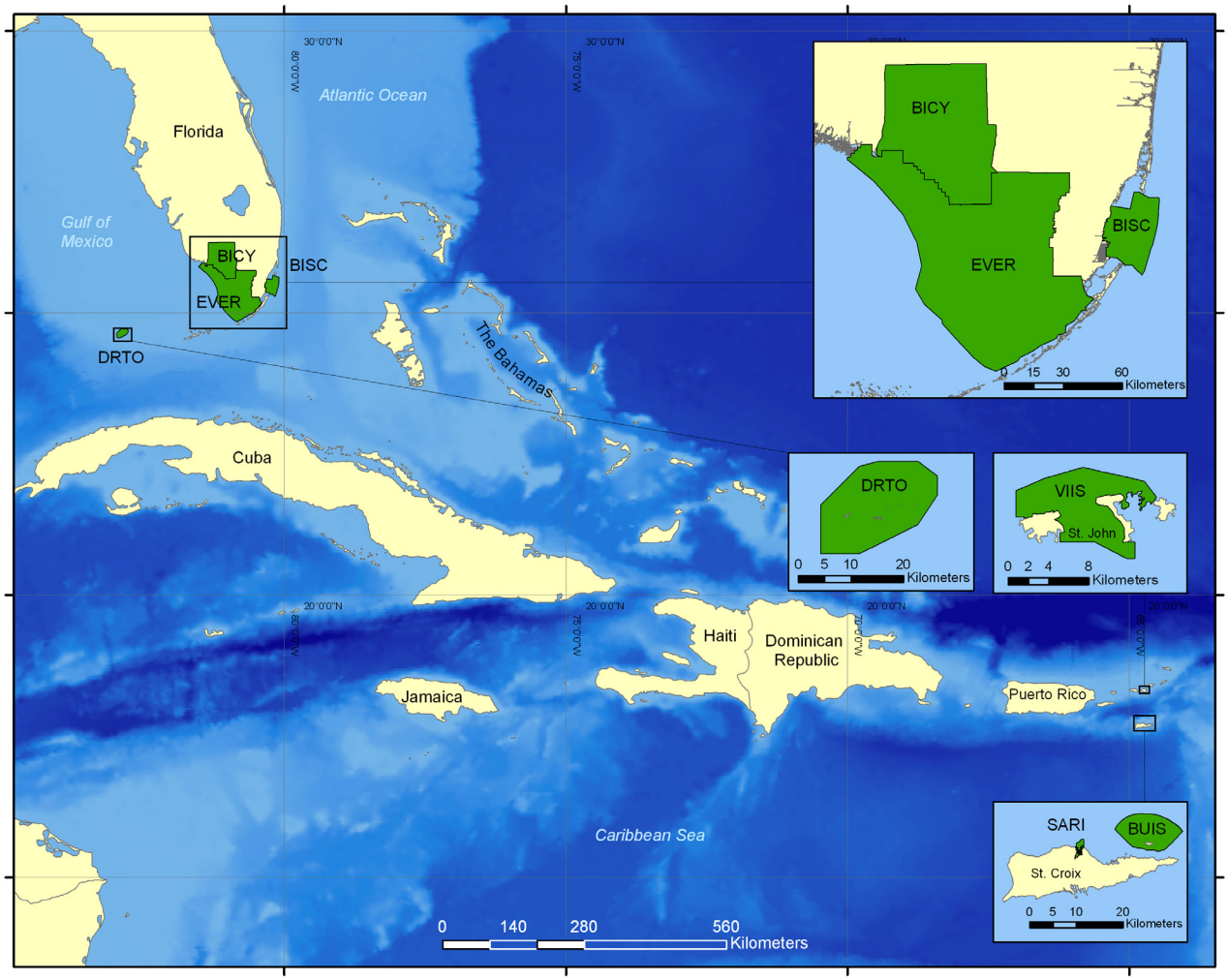


Figure 1. Map of South Florida / Caribbean Network parks. Courtesy Judd Peterson (SFCN).

Paleontological Resource Inventory Strategies and Methodology

To better document fossil occurrences and provide baseline paleontological resource data to National Park Service areas, the NPS Geologic Resources Division (GRD) and the NPS Inventory and Monitoring Program (I&M) have established three paleontological resource inventory strategies, each with its own goals and objectives. These strategies include: comprehensive park-specific paleontological resource inventories, Servicewide thematic paleontological resource inventories, and Inventory & Monitoring Network-based baseline paleontological resource inventories. Santucci and Koch (2003) outline basic paleontological resource monitoring strategies and potential threats to fossil resources.

Comprehensive Park-Specific Paleontological Resource Inventories

Comprehensive park inventories are designed to identify all known paleontological resources within a single park unit. A team of specialists from within the NPS and from educational institutions and cooperators work with the targeted park to identify and address all aspects of its paleontological resources, including resource management, museum curation, law enforcement, and interpretation. Paleontology-specific training for park staff is an important component of many comprehensive paleontological inventories. Park-specific comprehensive paleontological resource inventories have been completed at Yellowstone NP (first park to have inventory completed), Amistad NRA, Arches NP, Bighorn Canyon NRA, Death Valley NP, Grand Teton NP, Santa Monica Mountains NRA, Walnut Canyon NM, and Zion NP.

Servicewide Thematic Paleontological Resource Inventories

Servicewide thematic paleontological resource inventories compile data regarding specific types of paleontological resources that occur in parks throughout the NPS. The first thematic paleontological resource inventory identified 19 NPS units that preserve fossil vertebrate tracks (Santucci et al. 1998). Subsequent discoveries have increased the number of parks identified with fossil vertebrate tracks to 25 and warranted an updated publication (Santucci et al. 2006). Another thematic inventory identified paleontological resources associated with NPS caves in 35 parks (Santucci et al. 2001). Cave fossils occur in two contexts: first, fossils can be preserved in the marine limestones in which caves develop; second, the remains of Pleistocene/Holocene animals and plants that lived, died or were transported into caves after death are common types of cave fossils. Servicewide thematic inventories have also been initiated for fossil fish (Hunt et al. 2006) and fossils found in cultural resource contexts (Kenworthy and Santucci 2006).

Inventory and Monitoring Network Paleontological Resource Inventories

Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular network. Network-based inventories have been completed for 30 of the 32 I&M networks including: Appalachian Highlands, Arctic, Chihuahuan Desert, Cumberland Piedmont, Eastern Rivers and Mountains, Great Lakes, Greater Yellowstone, Gulf Coast, Heartland, Klamath, Mediterranean Coast, Mid-Atlantic, Mojave Desert, National Capital Region, North Coast and Cascades, Northeast Coastal and Barrier, Northeast Temperate, Northern Colorado Plateau, Pacific Island, Rocky Mountain, San Francisco Bay Area, Sierra Nevada, Sonoran Desert, Southeast Coast, Southeastern Alaska, Southern Colorado Plateau, Southern Plains, South Florida / Caribbean (this report), Southwestern Alaska, and Upper Columbia Basin networks. Research for summaries of the Central Alaska, and Northern Great Plains networks are currently underway. NPS I&M Program funding is targeted to complete paleontological resource summaries for the remaining networks in FY2010. Citations for the completed reports are in the Additional References section.

I&M Network Paleontological Resource Inventory Methodology

Network-based paleontological inventories were funded directly by the individual networks from 2002 to 2006. In FY2006, the National I&M Program provided funds to complete reports for the remaining networks between FY2006-2009. These funds provide stipends or salary for contractors, interns, paleontological technicians, or NPS employees who perform data mining activities. A brief summary outlining the basic techniques used to assemble an I&M Network-based inventory follows below.

The most valuable component of any paleontological resource inventory is an intensive literature search. Various databases contain citations for geology or paleontology themed publications. The American Geological Institute's GeoRef is the primary database for geology references and contains "millions" of references from the middle 1700s through today. GeoRef, available in both online or CD-ROM versions, is accessible at many major university libraries. The NPS NatureBib (which supersedes PaleoBib) is an internet-based database for scientific citations presented as bibliographic references but does not yet contain a comprehensive paleontology bibliography. The U.S. Geological Survey (USGS) Library (main branches in Reston, Virginia; Denver, Colorado; and Menlo Park, California) is a premier repository for geologic publications, and houses most of the publications obtained for the network-based paleontological resource inventories. Many USGS publications are available for free download online at the USGS Publications Warehouse (http://pubs.usgs.gov). Additionally, museum libraries such as at the Smithsonian Institution's National Museum of Natural History, and university libraries provide access to a wide range of geological and paleontological publications. Individual state geological surveys are also excellent sources of information, as are geologists familiar with local geology and paleontology.

The literature search also includes unpublished material (i.e. gray literature) from park files, museum archives, local newspapers, field notes, etc. These are often excellent sources of anecdotal information about park resources. In addition to literature searches, interviews with park staff, university faculty, geologists from the USGS and state geological surveys, and even local amateur geologists or paleontologists can yield information regarding park paleontological resources. These interviews frequently result in capturing data that might otherwise be undocumented and potentially lost or unrecognized.

Bibliographic searches include a search for geologic maps associated with each park. The NPS Geologic Resources Division maintains a database of geological map coverage for many parks (current contact is Tim Connors). A digital geologic map for each park is one product of the NPS GRD Geologic Resource Inventory program. In addition, the USGS National Geologic Map Database (NGMDB; http://ngmdb.usgs.gov) lists maps for a given geographic area or place name and provides information on how to obtain maps. Geologic maps show the types of rocks and the associated geological formations within a park area. These maps, alone, can often indicate the potential for paleontological resources to occur within a park.

Fossils are most commonly found in sedimentary rocks such as sandstones, shales, and limestones. Fossils, with few exceptions, are not found within igneous rocks (volcanic or intrusive origin) or metamorphic rocks (altered by heat, pressure, and/or chemical change) due to the extreme heat and/or pressure associated with their origin and history. The nomenclature for geologic formations can be confusing, but the NGMDB includes a searchable lexicon of valid geologic formation names that can be very useful in clearing up nomenclatural confusion. This lexicon provides a basic summary for each formation, summarizes current and past usage of the various formation names found in the literature, and provides an annotated bibliography for each formation.

Organization of the Reports

Information from these various sources is compiled into a narrative report for each park. Each park report includes an executive summary of the park's significance and a brief description of the geologic background. Geologic formations mapped within the park that are known to preserve fossils within the park are described in the "Sources of Paleontological Resources" section. Geologic formations mapped within the park that potentially preserve fossils (based on fossil discoveries outside the park) are listed in

the section "Potential Sources of Paleontological Resources." Field investigations could determine whether these "Potential Sources" do preserve fossils within the park. The park narratives also include a summary of paleontology specimens in park museum collections and, where applicable, highlight fossils that occur in cultural resource contexts (see Kenworthy and Santucci 2006).

In addition to this geologic and paleontologic content information, the authors suggest preliminary recommendations for each park regarding that park's management of the paleontological resources based on discussion with park staff and other geologists or paleontologists. A comprehensive list of publications related to paleontological research associated with the park is also included. The reports include all bibliographies that may be associated with a park's paleontological resources. However, bibliographic data are subdivided in the report into those cited in the narrative (Literature Cited) and other associated publications (Additional References). Finally, a list of datasets relative to the park's paleontological resources is developed. These data sets include museum collections where fossils from the park are reposited and locations of archives or other files and information relative to the park.

The reports undergo peer review by professional geologists, paleontologists, and staff from each park for accuracy before being submitted to the network. These reports are designed to consolidate baseline paleontological resource data for each park to support management operations and decision-making. Therefore, the reports are written in NPS language and in addition to the scientific information, the reports address issues of resource management, protection, and interpretation.

Within the "Sources of Paleontological Resources" or "Potential Sources" sections, information is synthesized regarding the scope and significance of fossils documented from geologic formations mapped within the park. Fossils are assessed and organized based upon taxonomy, stratigraphy, and paleoecology. Paleontological resources can be divided into six taxonomic groups: protists (unicellular plants and animals – typically plankton), microbes (fossil bacteria – typically found in stromatolites or as coatings on fossils), paleobotany (fossil plants), invertebrates (multicellular animals without backbones), vertebrates (animals with backbones), and trace fossils (evidence of biological activity such as tracks, traces, burrows, etc.). Fossils typically have a finite stratigraphic range and occurrence in geologic time (a geologic time scale is included as an appendix). The period between the first and final occurrences of a fossil species is referred to as the stratigraphic range zone. Thus specific groups of fossils may be identified directly with a particular stratigraphic unit or stratigraphic range. Likewise, rock units often represent specific ancient sedimentary depositional environments. Paleoecologically, fossil groups may occur primarily, or in some instances only, in specific environmental conditions (temperature, aquatic, terrestrial, etc.). Thus many fossils may be useful as indicators of past environmental conditions.

The "Sources" and "Potential Sources" sections are organized stratigraphically presenting the geologic and paleontologic information chronologically from oldest to youngest. Important fossils documented from localities outside a park are often reported in the park inventory, as these data may indicate the potential for fossils in similar stratigraphic units exposed within park boundaries.

Given the tremendous diversity of past life, the existence of life for over a billion years, and the range of environments to which life has adapted, there is a broad spectrum of research interests in paleontology. It is not surprising that most of what is to be learned about the history of life remains to be discovered. Through research, more than 219 NPS areas have been identified as containing paleontological resources. However, the paleontological research for a particular park may vary widely from an incidental fossil discovery, to over a century of intensive paleontological investigations. Therefore, the inventory reports include information on the history of paleontological research, identification of any museums or universities serving as repositories for park fossils, and a complete bibliography.

Paleontological Resource Management Legislation and Guidance

I&M Network reports such as this are meant to provide network parks with sound baseline paleontological resource data that can stimulate future research, interpretation, education, or resource

management projects. The proper management of resources identified through these inventories is mandated by many NPS policies including the newly enacted Paleontological Resource Preservation Act.

The Paleontological Resource Preservation Act (PRPA) (P.L. 111-11), signed into law on March 30, 2009, will serve as explicit authority for the management, protection and interpretation of paleontological resources in parks, in addition to the NPS Organic Act of 1916. The PRPA specifically provides the NPS with the following mandates to enhance paleontological resources stewardship:

> §6302 calls for the management and protection of paleontological resources using scientific principles and expertise. The NPS should develop plans for inventory, monitoring, and the scientific and educational use of paleontological resources. Planning should emphasize interagency coordination and collaboration and where possible include non-federal partners, the scientific community and the public.
>
> §6303 calls for the establishment of education programs to increase public awareness about the significance of paleontological resources.
>
> §6304 calls for the development of a specific permit for the collection of NPS paleontological resources. The new legislation and other existing authorities clarify and reaffirm issues of property ownership, accountability, access and confidentiality of locality information associated with the management of NPS paleontological resources.
>
> §6305 calls for the curation of NPS paleontological resources, along with any associated data or records, in approved repositories.
>
> §6306 provides clarity regarding prohibited acts involving paleontological resources and specifies criminal penalties associated with these prohibited acts.
>
> §6307, along with other existing authorities, enables the NPS to seek civil penalties and restitution for the violation of any prohibited activities involving paleontological resources.
>
> §6308 provides the NPS a confidentiality provision with an exemption from the disclosure of any information associated with the nature and specific location of NPS paleontological resources.
>
> §6310 directs the Secretaries of the Interior and Agriculture to issue regulations appropriate to carry out the Act

In addition to the PRPA, several other authorities influence the management of NPS paleontological resources. The 2006 National Park Service Management Policies (§1.4.6) stipulates that paleontological resources are considered park resources and values that are subject to the "no impairment" standard set forth by the NPS Organic Act in 1916. Basic guidelines for management of paleontological resources are found in sections 4.8.2 and 4.8.2.1 of the 2006 NPS Management Policies.

Paleontological resource management issues were the subject of a Report of the Secretary of the Interior in May 2000, prepared in response to a Congressional request for an assessment of the need for a unified federal policy on the collection, storage and preservation of fossils and for standards that would maximize the availability of fossils for scientific study. That report, an "Assessment of Fossil Management on Federal and Indian Lands," summarized a number of principles relating to paleontological resources and their management. The Paleontological Resources Management section of Natural Resource Management Reference Manual 77 provides guidance and additional information regarding the implementation and continuation of paleontological resource management programs. Links to the above documents are listed in the "Additional References" section.

The Geologic Resources Division and Geological Society of America assembled a geologic resource monitoring manual that includes chapters on various geologic resources, including in situ paleontological resources (Santucci et al. 2009), and a set of monitoring vital signs that may be applicable to a variety of

parks. Monitoring represents the next phase in paleontological resource management, following the initial research inventory (represented by this report) of potential fossils and any subsequent field work to identify fossils within a park. Contact the Geologic Resources Division for more information or to obtain a copy of the report.

Our knowledge of the fossil record is only as good as our previous field season. The potential for new paleontological discoveries is proportionally related to our understanding as managers and stewards of this non-renewable evidence of life from the past. We believe that the baseline information provided in these reports and the resulting increased understanding of paleontological resources will inevitably result in future fossil discoveries in NPS areas.

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NPS 1998 Omnibus Management Act (paleontological resource summary): http://www.nature.nps.gov/geology/paleontology/paleo_5_1/index.htm

NPS Natural Resource Management Reference Manual #77 (paleontology section): http://www.nature.nps.gov/rm77/paleo.cfm

Assessment of Fossil Management on Federal & Indian Lands: http:/www.fs.fed.us/geology/fossil.pdf

National Park Service Paleontology Program Sites

NPS Geologic Resources Division: http://www.nature.nps.gov/geology/

NPS GRD Geologic Resource Inventory products (scoping summaries, GRI reports, digital geologic maps): http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

NPS Paleontology Program: http://www.nature.nps.gov/geology/paleontology/

NPS Park Paleontology Newsletter (published 1999-2004): http://www.nature.nps.gov/geology/paleontology/newsletter.cfm

I&M Network paleontological resource summary project website and PDFs of all reports (InsideNPS): http://inside.nps.gov/waso/custommenu.cfm?lv=4&prg=753&id=4518

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Paleobiology Database (search for fossil taxonomy, localities, or geologic formations): http://paleodb.org/cgi-bin/bridge.pl

Paleontology Portal (general fossil info based on geographic location or geologic time): http://www.paleoportal.org/

University of California-Berkeley Museum of Paleontology online paleontology exhibits: http://www.ucmp.berkeley.edu/

U.S. Geological Survey Paleontological Terms Glossary: http://geology.er.usgs.gov/paleo/glossary.shtml

U.S. Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/

U.S. Geological Survey Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features, and plot them on topographic maps or aerial photos): http://gnis.usgs.gov/

U.S. Geological Survey GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator").

U.S. Geological Survey Publications Warehouse (many USGS publications are available online): http://pubs.usgs.gov

U.S. Geological Survey, description of physiographic provinces: http://tapestry.usgs.gov/Default.html

Big Cypress National Preserve

Big Cypress National Preserve (BICY), created in 1974, is the northward continuance of the vast Everglades (EVER) National Park and currently protects 813,790 ha (720,567 acres) of Everglades wetlands in the southwestern corner of Florida. BICY was established as part of the National Park System "in order to assure the preservation, conservation, and protection of the natural, scenic, hydrologic, floral and faunal, and recreational values of the Big Cypress Watershed in the State of Florida and to provide for the enhancement and public enjoyment thereof…" The park consists of an interconnected ecosystem of wetlands and waterways of the Kissimmee-Okeechobee-Everglades and adjacent Big Cypress watersheds.

Geologic Background

The Big Cypress Swamp subprovince (Brooks 1981) constitutes the western extension of the Everglades. Elevation in the Big Cypress Swamp is slightly higher than in the Everglades basin, ranging from 3.6 to 12 m (12 to 39 ft) above mean sea level to the north to just above sea level along the Coastal Marsh and Mangrove portion of EVER to the west and south (Thornberry-Ehrlich 2008). The introduction to this report contains a brief summary of the geologic history of South Florida. Fossiliferous geologic units exposed within BICY, or found within cores are further described below. The late Pliocene Tamiami Formation (approximately 3- 4 million years old), and the late Pleistocene Miami Limestone (bryozoan facies) are the primary fossiliferous units, exposed in, and underlying, large areas of BICY. Overlying the Miami Limestone are relatively undifferentiated Pleistocene and Holocene unconsolidated surficial sands, muds, freshwater peats and organic muck, freshwater marl, and cyanobacterial mats being produced in the marshes, strands, and pinelands in BICY (Scott et al. 2001). Much older (Late Jurassic-Early Cretaceous) deposits produce the hydrocarbons extracted within the park. As these sediments are located at great depth (thousands of meters) and were accessed during oil and gas exploration within the park, they are not described here (see Thornberry-Ehrlich 2008 for additional information and references).

The late Pliocene Tamiami Formation was originally described by Mansfield (1939) as the hard, sandy, leached limestone exposed by trenching along the 55 km (34 mile) Tamiami Trail (US 41) road bed in Collier and Monroe counties. These limited exposures only revealed what is now defined as the quartz-containing Ochopee limestone member (Hunter 1968; Petuch and Roberts 2007). There are no natural exposures of the Tamiami Formation in southern Florida; however, NPS Geologic Resource Inventory documents (Thornberry-Ehrlich 2005; 2008) indicate that it is exposed at the surface, presumably in canals, along roadways and along the Tamiami Trail, which crosses the southern portion of BICY. The type section of the Ochopee member is seen in borrow pits at the intersection of US 41 and state highway 29 just west of the town of Ochopee within BICY's boundaries. The Tamiami Formation underlies all of Big Cypress and the Everglades and is overlain to the east and south by the surficially-exposed Pleistocene Miami Limestone, with its oolitic facies to the east towards the Atlantic Coastal Ridge, and the bryozoan facies to the west in BICY and southward towards EVER and Florida Bay (Hoffmeister et al. 1967; Petuch and Roberts 2007). To the northeast and along the northern border of the park, undifferentiated Tertiary-Quaternary shell-bearing units (labeled "TQsu" on geologic maps and including the Fort Thompson Formation) have been mapped (Thornberry-Ehrlich 2008). The Miami Limestone is overlain by Holocene sediments along the western coastal margin of BICY (bordering EVER's western arm), and the freshwater muck, freshwater peat, and freshwater marls precipitated by cyanobacterial mats; all characteristic of BICY-EVER swamps, tree islands and hammocks (Thornberry-Ehrlich 2005, 2008). Soils are approximately 0.6 m (2 ft) thick, combining freshwater marl and sand, while muck and peat accumulate in the karst depressions formed in the surface of the underlying Miami Limestone (McPherson 1974).

The National Park Service Geologic Resources Division (GRD) conducted a Geologic Resources Inventory scoping session meeting for BICY on January 27-28, 2005. A scoping summary report

(Thornberry-Ehrlich 2005) was produced. The final Geologic Resources Inventory report and associated digital geologic map was recently completed (Thornberry-Ehrlich 2008).

Sources of Paleontological Resources

Mapped, fossil-bearing rock units exposed at the surface at BICY are limited to the Tamiami Formation, undifferentiated Plio-Pleistocene shell-bearing sediments, the Miami Limestone, undifferentiated Holocene and Pleistocene deposits, and Holocene sediments (Scott et al. 2001). These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research.

Tamiami Formation (Upper Pliocene)

The Tamiami Formation along 55 km (34 miles) of the Tamiami Trail (US 41) is a white to grey, hard, porous non-oolitic sandy limestone with only calcitic fossil shells (pectens, oysters, barnacles, corals, foraminifers, calcareous nannoplankton and echinoids) preserved; aragonitic species are represented only by calcite-spar filled molds. Mansfield (1939) named the Tamiami, assigned it to the Pliocene, and defined its type section, having previously described the fossils found in spoil from ditches along the Tamiami Trail (Mansfield 1931). In later studies (Parker and Cooke 1944; Puri and Vernon 1955; Parker et al. 1955; DuBar 1964; Olsson and Petit 1964) these beds were assigned to the Pliocene in some cases and the Miocene in others. Fossils from the Tamiami (in its entirety) have been described by all of the above-mentioned studies; only the Ochopee Limestone Member fossils are accessible near the surface in BICY. The older Tamiami units are not exposed in the park. Puri and Vernon (1955) described the Tamiami Formation as having been deposited in a shallow open sea near an estuary due to the presence of oyster reefs and large barnacles. They assigned the Tamiami to the Miocene, and provided a list of oysters, pectens, other bivalves, and echinoids from the type locality. Parker et al. (1955) likewise placed the Tamiami in the Miocene and provided a section from quarries at the type locality within the park consisting of the thin Bed 2 (1.3 m [4 ft] thick, presumably the Ochopee member), underlain by the much thicker Bed 1 (8m [25 ft] thick) deposited prior to the Ochopee). They provide a listing of ostracodes in Bed 2, and a long list of fossils for the entire section, not differentiating between Beds 1 and 2. This list includes many aragonitic mollusks which probably come from Bed 1.

Hunter (1968) proposed three concurrent range zones for fossils in the Tamiami Formation and defined the Ochopee member as the uppermost Tamiami unit at the type locality (essentially Mansfield's [1939] Tamiami). She determined from fossil evidence that the correlative Pinecrest, Ochopee and Buckingham Limestone members belonged to the *Pecten tamiamiensis* concurrent range zone of the Pliocene, based on regional correlations with known Pliocene formations in Florida and the Carolinas. The Ochopee member is about 10 m (30 ft) thick in wells at the type locality and contains abundant mollusk molds, and well preserved calcitic pectens, oysters, echinoids and barnacles. The most important Ochopee index fossils are listed by Petuch and Roberts (2007); several appear to be updated nomenclature from the classic studies, however, the full listing of fossils and molds is not given in that publication. Petuch and Roberts (2007) list a variety of the calcitic pectin genera defining the marine fauna of the formation, including *Argopecten*, *Carolinapecten*, *Christinapecten*, *Chesapecten*, *Lindapecten*, *Nodipecten*, *Euvola* and *Amusium*, but do not specify the *Pecten* (*Lyropecten*) *tamiamiensis* range zone of Hunter (1968). It is assumed that *Christinapecten tamiamiensis* is the new designation for *P. tamiamiensis*.

Undifferentiated Shell-Bearing Sediments (Pliocene–Pleistocene)

Along the northeast corner and north border of BICY, an undifferentiated highly fossiliferous shell-bearing sediment unit (labeled TQsu) is mapped at the surface (see geologic map compilation in Thornberry-Ehrlich 2008). Undifferentiated Tertiary through Quaternary shell-bearing sediments underlie the Miami Limestone to the east and south or are its lateral equivalents to the north and west. Paleontological resources from these beds may include an "incredible fossil array" but the unit is not paleontologically well defined. Although not differentiated on the geologic map, theTQsu unit could be subdivided into the latest Pliocene-early Pleistocene Caloosahatchee Formation (DuBar 1974) with

diagnostic fossils (*Cypraea problematica*, *Strombus leidyi*, *Liochlamys bulbosa*), the early Pleistocene Bermont formation (informal; subsurface), and late Pleistocene Fort Thompson Formation.

The assumption for this report is that the TQsu unit exposed at the surface in this area of the park is likely represented by the uppermost Coffee Mill Hammock member of the Fort Thompson Formation, which grades into the oolitic facies of the Miami Limestone to the east and south. The Coffee Mill Hammock member has been described by Sellards (1919), Cooke (1945), DuBar (1974), Petuch (1974) and Petuch and Roberts (2007) as a "thin shell marl" in a matrix of 80% fine quartz sand and 20% molluscan fossils. Index fossils include four bivalves (particularly *Chione elevata*; formerly called *Chione cancellata*), one of which is endemic and restricted to the member—*Anomalocardia hendryana*. Thirty-three gastropods include two (*Cerithidea scalariformis palmbeachensis* and *Pyrazisinus ultimus*) which are endemic as well as restricted to the Coffee Mill Hammock Member. The full list of index fossils is provided by Petuch and Roberts (2007).

Miami Limestone (upper Pleistocene)

The Miami Limestone occurs at or near the surface in the southeastern corner of BICY (see geologic map compilation in Thornberry-Ehrlich 2008). In adjacent Dade and Broward counties to the east, it attains elevations of up to 7 m (23 ft) above mean sea level (Sanford 1909; Cooke and Mossom 1929; Hoffmeister et al. 1967; DuBar 1974; Halley et al. 1977). Underlain by the Fort Thompson Formation, the Miami Limestone consists of an upper oolitic facies, dunes of which form the Atlantic Coastal Ridge along the east coast of Florida, and a bryozoan facies to the west. The oolitic facies has been dated via Uranium-Thorium isotope ratios (based on radioactive decay of ^{234}U to ^{230}Th) to a range of 120,000 to 90,000 years old (Broecker and Thurber 1965; Osmond et al. 1965). While fossils are more common in the bryozoan facies, the oolitic facies contains scattered small mollusk fossils, some *Halimeda* (calcareous algae), and some bryozoans (Hoffmeister et al. 1967).

The correlative (similarly-aged) bryozoan facies of the Miami Limestone was described by Hoffmeister et al. (1967) as "made largely of bryozoan zoaria" or zoaria (the 'skeleton' of a bryozoan colony) composing at least 70% of the rock. The vast majority (80%) of the bryozoans are *Schizoporella floridana*. Bryozoans typically encrust other organisms, whose forms might be identified by the shape of the encrusting zoaria. In the case of the bryozoan facies, it is believed that they encrusted marine vegetation such as *Thalassia*, or possibly gorgonians (sea fans), which decayed, leaving hollow tubes of rhizomes or grass blades. No evidence of hard parts of encrusted calcareous organisms has been identified. Hard to identify calcareous worm tubes are present (up to 10-20% of the rock), as is a "poorly preserved" and unidentified species of *Strombus* (gastropod; Hoffmeister et al. 1967).

Index fossils from the bryozoan facies include the large queen conch *Eustrombus gigas* and the bivalve mollusk *Codakia orbicularis* (Petuch and Roberts 2007). Puri and Vernon (1964) add several other nearshore mollusks to the limited list of fossils in this formation. The bryozoan facies directly underlies the surficial Everglades ecosystem and extends westward into the southeastern corner of BICY. It grades southward into correlative units including the Key Largo Limestone (Pleistocene coral reef) to the east and south (forming the Keys in Biscayne National Park), and the Anastasia Limestone (nearshore coastal marine facies) to the north in Palm Beach County.

Sedimentary deposits (Holocene)

Muck and marl overlying the Tamiami Formation and Miami Limestone have not been investigated paleontologically; however, biologic elements of the marl may preserve fossils at some point in the future. Holocene coastal sediments are mapped in small areas along the western boundary of the park where BICY's border extends into the coastal zone along its western border with EVER (see geologic map compilation in Thornberry-Ehrlich 2008). In mangrove swamps, fossil peat deposits of Holocene age have been preserved. Sedimentary deposits in Florida Bay constitute the modern analogue of Neogene and Quaternary formations underlying the Everglades.

Park Collections

According to Nancy Russell (EVER Museum Curator, pers. comm., April 2009) there are no specimens catalogued as "paleontology" within BICY museum collections, although the scope of collections does allow for such items.

Cultural Resource Contexts

Thornberry-Ehrlich (2008) suggests that the paleontological resources of the Tamiami Formation and undifferentiated shell-bearing sediments ("TQsu") may have historically provided trade items for American Indians in the area. Such occurrences have not yet been documented, but present an opportunity for future research. Fossils occur in a number of cultural contexts throughout that National Park Service, Kenworthy and Santucci (2006) present an overview and cite selected examples.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for Big Cypress National Preserve in January 2005 and developed a series of recommendations for future work. Although fossils were noted in the scoping summary (Thornberry-Ehrlich 2005), no specific paleontological resource recommendations were made. A geologic resources inventory report (Thornberry-Ehrlich 2008) was recently completed.
- The low relief and pervasive muck and marl within the park limit exposures of subsurface units and associated paleontological resources. Nevertheless the Tamiami Formation may be exposed along the Tamiami Trail. The park may want to consider future field investigations and paleontological resource monitoring as this is the type locality for the Tamiami Formation. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring (Santucci et al. 2009).
- The location of the Mansfield specimens is currently unknown and should be further investigated; they may be curated at the Florida Museum of Natural History (Gainesville).
- Further investigation may reveal a connection between American Indians and fossil material in the area, which may have provided trade items.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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Data Sets

Big Cypress National Preserve Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Big Cypress National Preserve Museum Collections
1974-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by BICY staff; status: Active.

Big Cypress National Preserve Digital Geologic Map
2006-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
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Biscayne National Park

Biscayne National Park (BISC) preserves a rare combination of terrestrial, marine, and amphibious life in a tropical setting of great natural beauty. The park is situated on several islands in the upper Florida Keys (Boca Chita, Sands, Elliot, Adams, Old Rhodes, Swan, Porgy, Reid and the Rubicon Keys), formed by the extensive late Pleistocene fossil coral reef system (Key Largo Limestone) situated near the modern reef tract in Biscayne Bay. Thus, BISC contains ancient, Holocene and living coral reefs, shallow carbonate environments with high percentages of biogenic sediments (recent fossils), coastal facies including Holocene mangrove peat deposits, and modern fauna, all within sight of Miami. The park was originally authorized as Biscayne National Monument on October 18, 1968 and, following a boundary change in 1974, was re-designated and enlarged on June 28, 1980. Biscayne National Park now encompasses 69,980 ha (172,924 acres), only 1,799 ha (4,446 acres) of which is land area.

Geologic Background

The marine focus of the park is appropriate given its location along the Florida Reef Tract and the fact that marine invertebrate animals played a dominant role in the "construction" of the park's underlying geology, which has been dominated by coral reef ecosystems since the Pleistocene. Geologically, the surface rock forming the islands of BISC is very young. This late Pleistocene limestone has been dated to approximately 125,000 years ago and is the remains of the ancient coral reef that formed during the last interglacial period (approximately 140,000–78,000 years ago) during which sea levels peaked approximately 6 m (20 ft) higher than they are today. This highstand of the sea approximately 125,000 years ago was followed by a period of slightly lower, but near-present sea levels (from 115,000–78,000 years ago) until sea level fell again during the most recent glacial period (from about 70,000 to 20,000 years ago). The glacial lowstand fell to 120 m (394 ft) below present sea levels and the Florida shelf and continental slope were subaerially exposed. When these most recent glaciers melted starting at approximately 20,000 years ago, sea level rose at initially rapid rates, then at decreasing rates until reaching the edge of the shelf just seaward of the present Florida Reef tract during the early Holocene (Toscano and Lundberg 1998). BISC has therefore been the location of more than one episode of reef building, with the addition of early Holocene to recent coral reef and shallow marine carbonate deposits dating from when the shelf was flooded about 8,000 years ago to the present. Much of the surficial coral and sediment is less than 500 years old. The introduction to this report contains a discussion of these geologically very young paleontological resources and provides a more detailed geologic history for South Florida.

The late Pleistocene Key Largo Limestone (Sanford 1909; Stanley 1966; Hoffmeister and Multer 1968) is the main fossiliferous unit mapped within the park. The Key Largo Limestone forms the surface rock for all islands in BISC and forms all of the upper Keys above Key Largo to Soldier Key, north of which it trends under Key Biscayne, Virginia Key and Miami Beach (Hoffmeister and Multer 1968). To the southwest, the Key Largo Limestone forms the middle Keys, then is overlain by the late Pleistocene oolitic facies of the Miami Limestone in the lower Florida Keys. Holocene coral reef and lagoonal deposits underlying the modern reef tract and lagoon throughout the park, and the carbonate sediments in Biscayne Bay are also a source of fossil resources. The fossils of BISC contribute to paleoecological studies and provide a record of past changes that can be compared with modern ecological issues (e.g. Carnahan et al. 2008; Downs et al. 2006; Dupont et al. 2008). The South Florida / Caribbean Network initiated a modern reef monitoring program began in 2004 at two sites with a total of 40 transects in the Ball Buoy Reef and Amanda's Reef areas of BISC.

Sources of Paleontological Resources

Fossils have been observed within the Key Largo Limestone of BISC and are also visible within the building stones of the Honeywell Complex on Boca Chita Key (see Cultural Contexts section, below). These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research.

Key Largo Limestone (late Pleistocene)

The late Pleistocene-aged Key Largo Limestone is a widespread unit throughout the Florida Keys. It is a white to light gray, moderately- to well-cemented, fossiliferous coralline limestone composed of coral heads encased in a calcarenite matrix with a significant component of lime mud infilling (Hoffmeister and Multer 1968; Stanley 1966). Pleistocene paleontological resources of BISC and the northernmost Florida Keys located therein are contained with this formation. An exceptional exposure of the Key Largo Limestone exhibiting large coral heads occurs in the Windley Key Quarry State Geological Site in the upper Florida Keys at Islamorada, south of BISC. The Key Largo Limestone was an important building stone (called "Keystone") in the area during the early 20th century. Many larger buildings in Key West, for example, are faced with Keystone and exhibit cross sections of large coral heads, small corals and limestone matrix over their exteriors.

Numerous investigations have been conducted on the ancient reef and ooid (see below) shoals forming the Florida Keys (e.g. Agassiz 1883, 1895, 1896; Brooks 1963; Vaughn 1910, 1914, 1919; Ginsburg 1995—containing Vaughn's paleoecological research). These deposits were first named the Key Largo Limestone by Sanford (1909). From its southernmost surficial exposure at Big Pine Key (Coniglio and Harrison 1983) northward through the middle and upper Keys and Hawk Channel, the Pleistocene Key Largo Limestone underlies Holocene and recent reefs and lagoonal sediments. The Key Largo Limestone also occurs inland along southeastern Florida's Atlantic coast (Stanley 1966; Multer et al. 2002). Ooids are distinctive small (1-2 mm [~0.06 in]), spherical, generally concentrically layered carbonate grains likely formed around a nucleus such as a shell fragment or sand grain. They are currently only known from the vicinity of Joulter's Cay in the Bahamas. Their mode of formation has been hypothesized but not observed in the modern marine system of Florida.

The Key Largo Limestone occurs from the Miami area (Biscayne Bay and upper Florida Keys) through the middle Keys (Parker et al. 1955) and underlies (and is laterally equivalent to) the oolitic facies of the Miami Limestone in the lower Keys (Harrison and Coniglio 1985). A deeper unit with a Fort Thompson Formation mollusk assemblage is also included in the Key Largo Limestone (Stanley 1966). Fossils present within the Key Largo Limestone include corals, mollusks and bryozoans. The Key Largo Limestone consists of 30% large corals (*Diploria* sp., *Porites* sp., *Siderastrea* sp., *M. annularis* (an overwhelming preponderance), *Acropora cervicornis*, and very little *A. palmata*) in a calcarenite matrix of skeletal fragments (coral, coralline algae, *Halimeda*, mollusks and foraminifera) and lime mud.

Broecker and Thurber (1965) and Osmond et al. (1965) dated the coralline limestone forming the Keys using Uranium-Thorium isotope ratios (based on radioactive decay of ^{234}U to ^{230}Th) to 130,000–120,000 years ago. Mitterer (1975) provided similar ages based on amino acid racemization techniques using organic material from the shells of the common bivalve genera *Mercenaria*. Amino acid racemization ages ranged from 180,000 years in a deeper unit to 125,000 years in the uppermost Pleistocene reef limestone forming the Keys. As accuracy and precision in radiometric dating increased, improved ages for the Key Largo Limestone were attempted. Muhs et al. (1992) dated one sample of the coral *Montastraea annularis* from a core at Long Key and obtained a date of 144,000 years before present. Because this pre-dated the well-established sea-level highstand 125,000 years ago in which the fossil coral reef forming the Keys was built, Muhs et al. (1992) attributed the older age to a proposed earlier highstand within the last interglacial period. Using higher precision U-Th methods, Fruijtier et al. (2000) dated Key Largo Limestone and Miami Limestone material outside of the park at Windley Key and Flagler quarries on Key Largo from outcrops at about 5.3 m (17 ft) above mean sea level (minimum sea level during the late Pleistocene was about 6 m, or 20 ft, above mean sea level). Most samples ranged from 138,000 to 125,000 years old. Using

higher-precision U-Th techniques, Toscano (1996), Ludwig et al. (1996), and Toscano and Lundberg (1998,1999) dated corals from younger relict Pleistocene reefs offshore of the Florida Keys and just seaward of the modern Florida reefs. Ages ranged from 112,000 to 78,000 years old. These studies also identified a wide variety of fossil scleractinian corals and associated fauna and flora from two drilling transects across these "outlier reefs" (Lidz et al. 1991) at Carysfort (upper Keys near BISC) and Sand Key (Key West/lower Keys area). Multer et al. (2002) continued the work of Toscano (1996) and Toscano and Lundberg (1999), completing a comprehensive stratigraphic analysis and high-precision U-Th dating of deeper/older units of the Key Largo Limestone, as well as of younger fossil reef and lagoonal material deposited after the Florida Keys were formed. Older corals from deeper portions of cores along the Florida shelf edge and reef tract and in Hawk Channel produced ages from 370,200 to 366,800 years before present. Approximately contemporaneous with formation of the Keys, late Pleistocene corals gave dates of 128,100 and 124,200 years. Latest Pleistocene ages, post dating the formation of the Keys, ranged from 112,400 to 77,800 years before present. In addition to U-Th ages Multer et al. (2002) provided minimal paleontologic information and a paleo-facies analysis of the region.

There have been several interpretations of the paleoecology and geologic development of the Key Largo Limestone. Stanley (1966) interpreted the Key Largo Limestone as a broad homogenous shelf reef system, with no seaward barrier reef, due in part to the lack of *Acropora palmata* in the formation and the importance of the massive coral *Montastraea annularis*. This reef system would have formed inside an open shelf margin, in water depths of 6–12 m (20–39 ft). Hoffmeister and Multer (1968) favored a shallow water, linear series of coalescing patch reefs growing behind a shelf-edge barrier reef (since eroded). Existence of such a barrier was an interpretation based on finding two *A. palmata* fragments (vestiges of a barrier reef near the shelf edge?) in Unit Q5 near Looe Key. Perkins (1977) envisioned a shallow-water, patch reef-sand shoal complex initiated at a topographic break in slope nearer the outer shelf margin; this complex migrated landward due to rising sea level. A drop in sea level could have left the leading edge as an arcuate linear high.

Biscayne Bay coral reef and marine carbonate deposits (Holocene–modern)

Holocene and modern reef and marine carbonate sediments first occurred on the southeast Florida continental shelf about 8,000 years ago, when the Holocene rise in sea level reached the shelf edge, allowing first mangroves, then coral reefs and lagoonal sediments to accumulate (e.g., Robbin 1984; Toscano and Lundberg 1998; Toscano and Macintyre 2003; Shinn 1980). Mangrove peat—dating to late Holocene age (1,000-2,000 years before present)—has been documented outside the park (Hoffmeister and Multer 1965) on the northeast corner of Key Biscayne, and is likely to be found within the park (Harris and Tuttle 1990). Modern reefs and shelf sediments contain coral and invertebrate macro/microfossil assemblages, coralline algae, etc. similar to their Pleistocene counterparts, but in different proportions. Coral age data come from nearby areas outside the park (e.g., Toscano and Lundberg 1998).

Stubbs (1939) listed numerous shallow water benthic foraminifera in Biscayne Bay. Stone et al. (2000) reconstructed a paleoecological history of the past 550 years of Featherbed Bank, Biscayne Bay from changes in ostracode, mollusk and foraminiferal assemblages in a 2.26 m sediment core. Carnahan et al. (2008) reported 61 genera of benthic foraminifera from 110 Biscayne Bay cores during their analysis of heavy metal contamination of sediment samples in Biscayne Bay (see Carnahan 2005 for full list). Rice et al. (2007) provide a herpetological inventory of BISC. These animals are not fossil forms but might provide insight as to possible Holocene vertebrate fossils.

Park Collections

There are no specimens cataloged as "paleontology" in the park's museum collections, which are housed at EVER (N. Russell, EVER Museum Curator, pers. comm., April 2009). However, according to Russell, the park's scope of collections includes the possibility for such items. There are a number of coral specimens and the sediment cores and coral-head cores studied by the U.S. Geological Survey accessioned into the park's collections.

The USGS Center for Coastal and Watershed Studies in St. Petersburg maintains a collection of cores obtained within BISC. According to the USGS database (C. Reich, USGS Geologist, pers. comm., August 2009), there are at least 56 cores from various localities within the park including Air Force, Coconut Grove, Mowry Canal, Cutler, Billy's Point and Pacific Reef areas. These localities were sampled using a rotary core with an age range of approximately 125,000-3,000 years. The USGS collections also include up to 300 year old coral cores from specimens of *Siderastrea siderea*, *Montastraea faveolata*, *Diploria strigosa*, *Montastraea annularis*, among others, that were obtained within the park. For more information, refer to Multer et al. (2003), Reich et al. (2006, 2009).

The University of South Florida College of Marine Science maintains a collection of sediment and foraminifera from BISC associated with various publications and theses, although some of the thesis material (e.g. Ramirez 2008) will be returned to BISC collections (at EVER) following publication (P. Hallock-Muller, USF College of Marine Science, pers. comm., August 2009).

Cultural Resource Contexts

While the Key Largo Limestone provides potential for in situ fossils, the Honeywell Complex on Boca Chita Key offers the potential for fossils in an atypical "exposure" within the park. Leynes and Cullison (1998) describe the architectural and historic significance of the complex and the historic structures. As documented in Leynes and Cullison (1998), all of the structures' exterior walls were constructed of Miami Limestone (oolitic facies), commonly called "Miami Oolite." The building stone is common throughout South Florida and further described in the BICY and EVER sections of this report. The original quarry site of the stones used on Boca Chita Key is unknown. Although the distinctive spherical ooids may form around a small shell fragment, they are not fossils. Fossils found in the oolitic facies of the Miami Limestone include mollusks, *Halimeda* algae, and bryozoans (Hoffmeister et al. 1967). Photos provided by Elsa Alvear (BISC Chief of Resource Management, November 2009) (see front cover) confirmed the presence of fragmentary fossil material in some of the building stones. In particular, the lighthouse building stone displays a variety of coral, mollusk (gastropod?), and other marine invertebrates. Further investigation of the building stone on Boca Chita Key may reveal additional fossil resources or more detailed identifications. Building stones with fossils are a common cultural context for paleontological resources in the National Park Service. Kenworthy and Santucci (2006) present an overview and cite selected examples throughout the NPS.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping session for BISC during January 2005. The participants of the BISC Geologic Scoping meeting developed a series of recommendations for future work regarding paleontological resources: inventory the Pleistocene fossil corals at Biscayne National Park; attempt to locate and catalogue specimens previously removed from the park for public/private collections; and create an interpretive exhibit for the fossil resources on Windley Key.
- Several formations are represented by publications and geologic maps as being fossiliferous in BISC, but have not had detailed study.
- Biscayne National Park is formed by the fossil remnants of a great late Pleistocene reef that forms the foundation for the Florida Keys. These fossil reefs of the Key Largo Limestone are ancient analogues for the modern Florida reef tract and surrounding marine environments. While many geologic investigations have described the Key Largo Limestone and its fossil corals and marine invertebrates, the areas in BISC could be independently inventoried, mapped, and described.
- Interpretation and public education could include information that the keys are built upon a fossil framework, that contains valuable information for scientific research. A paleontological resource protection message could be included in enforcement of non-destructive diving and fishing practices. Close inspection may reveal additional fossil material within the "Miami Oolite"

building stones of the Honeywell Complex on Boca Chita Key, and an "accessible" exposure of a Pleistocene geologic unit that underlies various SFCN parks.

- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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1992-present. (sediment and coral cores; associated data, maps, and publications). Originated by USGS staff, contact Chris Reich; status: Active

University of South Florida College of Marine Science
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Biscayne National Park Digital Geologic Map
2009-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
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Buck Island Reef National Monument

Buck Island Reef National Monument (BUIS) was established by Presidential proclamation in 1961, and significantly expanded on January 17, 2001, by proclamation of President Clinton under the Antiquities Act, in order to preserve "one of the finest marine gardens in the Caribbean Sea." The proclamation added 7,254 ha (18,135 acres) of submerged lands to the monument, bringing the total acreage to just over 7,600 ha (19,000 acres) (to the shelf edge and including Buck Island Bar), all of which consist of submerged lands except for the 71 ha (176 acre) Buck Island. Located 2.4 km (1.5 miles) north of St. Croix, Buck Island Reef National Monument is now one of only a few fully marine protected areas in the National Park System. The island and surrounding coral reef ecosystem support a large variety of native flora and fauna, including several endangered and threatened species such as hawksbill turtles and brown pelicans. The Elkhorn coral barrier reef that surrounds two-thirds of the island has extraordinary coral accumulations, deep grottoes, abundant reef fishes, sea fans and gorgonians. Although mainly known for its coral reef and nesting sites for turtles and birds, Buck Island has a rich cultural history as well.

Geologic Background

Buck Island Reef National Monument surrounds Buck Island, situated 2.4 km (1.5 miles) offshore of the northeastern coast of St. Croix. The island proper is underlain by the Caledonia Formation, which was deposited in a deep basinal setting during the Late Cretaceous (refer to the appendix for a geologic time scale). A complex history followed the Late Cretaceous sedimentation. The introduction to this report contains a brief summary of the geologic history of and tectonic forces shaping the Virgin Islands. The primary natural resources of the park include the shelf edge feature Buck Island Bar, an early Holocene (approximately 8,000–7,000 years old) reef (Macintyre and Adey 1990; Hubbard et al. 2005; Macintyre et al. 2008).

Buck Island Reef and Buck Island Bar consist of Holocene coral reef structures and shallow water carbonate facies built or accumulating on a Pleistocene carbonate platform surrounding Buck Island (Adey et al. 1977; Suchanek 1989; Macintyre and Adey 1990; Hubbard 1991; Hubbard et al. 2005; Macintyre et al. 2008). Uppermost Pleistocene carbonate and reef deposits have been detected via core drilling (Toscano et al. in prep.; Hubbard 1991; Hubbard et al. 2005) and date to the last interglacial period in the age range of 135,000–125,000 years ago beneath the Holocene reefs (Macintyre et al. 2008). Macintyre and Adey (1990) drilled a reef-crest core consisting of early Holocene reef framework, mixed coral heads and other corals, *Millepora* sp., crustose coralline algae, evidence of boring activity and high energy conditions. Hubbard et al. (2005) reported a reef crest dominated by *Acropora palmata* that started on a Pleistocene surface 15 m (49 ft) below present sea level. Hubbard (1991), in a report to the National Park Service, reported on the geologic development of the reefs through two core transects at the northeast and southeast sides of the fringing reef around Buck Island and one through Buck Island Bar. This was further detailed by Hubbard et al. (2005). Isolated “haystack” reefs were also sampled. Holocene and Pleistocene reef corals consist of the same species which construct the modern reefs around Buck Island. The South Florida / Caribbean Network initiated a modern reef monitoring program began in 2000 at two sites with a total of 40 transects in the South Fore Reef and Western Spur and Groove Reef areas of BUIS.

The National Park Service Geologic Resources Division (GRD) conducted a Geologic Resources Inventory scoping session meeting for BUIS in April, 2004 and produced a summary report (Hall 2005). A geologic map is available for St. Croix Island (Whetten 1966). A benthic habitat map has also been produced (Pittman et al. 2008). Fossils are known from both the Late Cretaceous rocks as well as the Pleistocene-Holocene coral reefs, although fossils within BUIS are only known from the Pleistocene-Holocene reefs.

Sources of Paleontological Resources

Fossils have been observed within BUIS as part of the coral reef deposits. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research.

Coral Reef Deposits (Pleistocene–Holocene)

Within BUIS, Pleistocene corals and other reef dwelling species have been identified from cores (Macintyre and Adey 1990; Hubbard et al. 2005; Macintyre et al. 2008) and include *Porites* sp., *Montastraea annularis*, *Diploria* sp. and *Acropora palmata*, among others. Modern coral species include *Acropora palmata* (elkhorn coral), *Porites* sp., *Diploria* sp., *Montastraea* sp., etc. Numerous mollusks are reported from nearby Smugglers Cove by Miller (1998), and Ferguson and Miller (2007). *Homotrema* sp., a common encrusting foraminifer, trace fossils (e.g. *Lithophaga* borings seen in cored corals; Macintyre et al. 2008; Toscano et al. in prep.) and *Callianassa* mounds/valleys are also common (Miller 1988). Coralline algae are also common in the reef environments.

Modern echinoderms include *Diadema antillarum*, *Tripneustes ventricosus*, *Echinometra lucunter*, and *Echinometra viridis* at Buck Island, Salt River Bay and sites around St. Croix (Miller et al. 2003). Regular echinoids *Diadema antillarum*, *Tripneustes ventricosus*, *Echinometra lucunter*, and *E. viridis* have been noted at Buck Island, Salt River Bay and sites around St. Croix. Greenstein (1991, 1993) studied echinoid taphonomy at nearby Smugglers Cove and Rod Bay, and reported low (living) numbers of the above regular echinoids as well as *Eucidaris tribuloides*, and no irregular echinoids (sand dollars), which prefer unconsolidated sediment substrates. His work indicated that regular echinoids decay rapidly and disarticulate into discrete skeletal components (spines, corona, plates, Aristotle's lantern) within a varying number of days of death. Fossils of the local echinoid species will most likely consist of spines and coronas (*Eucidaris*, *Diadema*), or mainly coronas and rare spines (*Tripneustes*, *Echinometra*). Adey et al. (1977) produced a field guide which lists all known living shallow marine carbonate and reef-associated species. The fossil record is not known for some types in this area.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations within BUIS, most of which are below the land surface. However, these units are known to preserve fossils elsewhere, and future field investigations within the park may recover fossils from one or more (or none) of them.

Caledonia Formation (Upper Cretaceous)

Buck Island itself is formed of the oldest portions of the Upper (Late) Caledonia Formation, a weakly-metamorphosed thick basal Cretaceous sedimentary unit consisting mainly of mudstones, followed in abundance by sandstones, limestones, cherts and conglomerates (Whetten 1966; Nagle and Hubbard 1989; Adey 1973). According to a comprehensive sedimentological study of the Caledonia Formation by Stanley (1987a, 1987b, 1988, 1989) these deposits record a depositional regime of downslope gravity flows and intermediate sandy strata emplaced by turbidity currents (underwater sediment-carrying currents moving downslope), and deposits reworked along bathymetric contours by bottom currents flowing toward the west in a deep basinal setting. The Caledonia Formation consists of thin (10–50 cm) medium volcaniclastic sandstone layers (30% of the formation) alternating with slate/siltstone/mudstone layers derived from volcanic rocks (70%), with rare biogenic remains.

Fossils from the Caledonia Formation are limited to invertebrates and trace fossils. Whetten (1966) collected invertebrates—marine foraminifera, rudists and corals—of Campanian (Late Cretaceous) age. Speed et al. (1979) discovered an ammonite (*Tarrantoceras*?) in rock fragments on the north side of St. Croix along Tague Bay about 3.5 km (2.2 miles) southeast of Buck Island. If in situ, this ammonite would indicate that the Caledonia sediments on the east end of the island of St. Croix are 90-100 million years old (pre-Campanian). The ammonite is in the collections of the Smithsonian National Museum of Natural History (D. Hubbard, Oberlin College, pers. comm., July 2009). Stanley (1988) mentions trace fossils in

deep basinal settings. The presence of bioturbated sediment (disturbed through biological processes, such as burrowing) suggests the bottom waters were not anoxic and the bottom water circulation was not restricted even if the early Atlantic Ocean was much narrower (Stanley 1988). Similar fossils have not yet been described from the park but could be present (D. Hubbard, pers. comm., July 2009).

Park Collections

National Park Service museum collections for BUIS do not contain materials catalogued as "paleontology" (Z. Hillis-Starr, BUIS/CHRI/SARI Chief of Resource Management, pers. comm., April 2009). The coral reef cores and associated documentation collected within BUIS by Dennis Hubbard (Oberlin College, Ohio) are maintained in the Department of Geology at Oberlin College (D. Hubbard, pers. comm., July 2009). Additional cores from Buck Island Bar, Tague Bay (due south of BUIS on St. Croix), Long Reef and other areas within and near St. Croix or Buck Island are maintained in the collections of the Smithsonian Institution National Museum of Natural History (Washington, D.C.).

Cultural Resource Contexts

Like the other Virgin Islands NPS units, BUIS interprets a rich cultural history associated with indigenous people. Meredith Hardy (SEAC archeologist, pers. comm., April 2009) also suggested that many of the ancient societies that lived on the islands collected various natural history items of interest. Some were fashioned into various tools, ornaments, beads, or religious items. The Andersen collection (made by an amateur archeologist) contains a number of these items from the Virgin Islands (M. Hardy, pers. comm., April 2009). Further investigation may yield additional information regarding the provenance and context of these items as well as their relationship to NPS areas in the Virgin Islands. Fossils occur in a number of cultural contexts throughout that National Park Service, Kenworthy and Santucci (2006) present an overview and cite selected examples.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division (GRD) sponsored a Geologic Resources Inventory (GRI) scoping meeting for BUIS on April 5, 2004. This scoping session did not include any specific paleontology recommendations (Hall 2005).
- The geologically young age of much of the coral material within the park encompasses the Pleistocene-Holocene transition, as described in the introduction to this report, this includes material commonly considered fossil as well as more modern material. Regardless, such resources contain important information for continuing research into paleoecological change through time and the development of the modern ecosystem.
- Park staff should be encouraged to observe exposed gullies, other erosional bedrock, and streams for fossil material, particularly where the Caledonia Formation is exposed, while conducting their usual duties. Given the fossiliferous nature of the rock unit, exposures might yield paleontological resources similar to those on St. Croix Island.
- A field-based inventory of paleontological resources may yield more information regarding the scope and significance of fossils within the park. Significant localities should be documented using NPS fossil locality and condition assessment forms that meet GRPA goal 1a9A. The park may want to consider long term paleontological resource monitoring of documented sites. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring (Santucci et al. 2009).
- Staff should photodocument and potentially monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding

rock) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.

- Because cores and other materials used to describe the paleoecology of the park are located in repositories outside of the park (e.g. Smithsonian Institution and Oberlin College), one potential project would be to submit funding requests for assistance in the development of a guide (perhaps online) to these materials. The guide could include logs, photographs, and other matierals (D. Hubbard, Oberlin College, pers. comm., February 2010).
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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Buck Island Reef National Monument Collections
1961-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by BUIS staff; status: Active.

Buck Island Reef National Monument Digital Geologic Map
2008-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
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Smithsonian Institution National Museum of Natural History Collections
1970s-present. (museum specimens; sediment cores; associated specimen notes; collection records; maps; etc.). Originated by NMNH researchers; status: Active.

Dry Tortugas National Park

Fort Jefferson National Monument (established January 4, 1935) was renamed and re-designated Dry Tortugas National Park (DRTO) on October 26, 1992 "in order to preserve and protect for the education, inspiration, and enjoyment of present and future generations nationally significant natural, historic, scenic, marine, and scientific values in South Florida…" The park includes Garden Key and Fort Jefferson, Bush Key, Long Key, Loggerhead Key, smaller islands, shoals, reefs, and marine protected areas. In addition, a 119 sq km (46 sq mile) Research Natural Area (RNA) adjacent to the Tortugas Ecological Reserve of the Florida Keys National Marine Sanctuary (FKNMS) was established in 2007 to "restore ecological integrity and capacity for self-renewal by minimizing human disturbance." The park is managed "to protect and interpret a pristine subtropical marine ecosystem, including an intact coral reef community; to protect populations of fish and wildlife, including (but not limited to) loggerhead and green sea turtles, sooty terns, frigate birds, and numerous migratory bird species; to protect the pristine natural environment of the Dry Tortugas group of islands; to protect, stabilize, restore, and interpret Fort Jefferson, an outstanding example of nineteenth century masonry fortification; and to preserve and protect submerged cultural resources." The park encompasses 26,184 ha (64,701 acres) but only a very small fraction—16 ha (39 acres)—is land. DRTO is administered by Everglades National Park.

Geologic Background

The National Park Service Geologic Resources Division (GRD) conducted a Geologic Resources Inventory scoping session meeting for DRTO in January, 2005 and produced a summary report (Thornberry-Ehrlich 2005). The introduction to this report contains a summary of the geologic history of south Florida, including DRTO. The fossiliferous Pleistocene Key Largo Limestone forms the foundation of the modern reef deposits within the park. The main body of fossiliferous material immediately accessible for preservation and management in the Dry Tortugas is found within the Holocene/modern carbonate environment forming the substrate of the islands and shallow marine areas of the park. The islands are formed of unconsolidated carbonate reef rubble and sediment of Holocene-modern age, with the exception of modern carbonate beachrock forming on Long Key (Multer et al. 2002). Coral/algal reefs, carbonate shoals, banks, seagrass beds and deeper facies all contain a mixture of modern and older skeletal material accumulating since the early Holocene (~10,000 years ago; see the appendix for a geologic time scale). Holocene and modern carbonate environments occupy areas and surfaces of analogous late Pleistocene coral reefs and shallow marine facies which formed during the last interglacial period (when sea level was 6 m [20 ft] higher than today) approximately 125,000 years ago, then were exposed during the most recent glacial stage due to a 120 m (390 ft) drop in sea level as continental ice sheets advanced. As sea level rose during the last de-glaciation (beginning approximately 20,000 years ago), carbonate environments and reefs re-established themselves on this open shallow shelf. The South Florida / Caribbean Network initiated a modern reef monitoring program began in 2004 at Bird Key with a total of 20 transects in DRTO.

Sources of Paleontological Resources

All sedimentary carbonate units forming the substrate of the islands and all modern and Holocene reef and shallow-marine sediments contain paleontological resources, including corals, mollusks, and a variety of invertebrates, microfauna and calcareous algal remains. The fossils of DRTO present opportunities for education, interpretation, and continued or future scientific research in the park.

Key Largo Limestone (Upper Pleistocene)

The foundations of DRTO's Holocene-modern reefs and carbonate shelf sediments are Upper (Late) Pleistocene fossil reefs of the Key Largo Limestone, which is extensively exposed within Biscayne National Park (see BISC section of this report). It occurs from the Miami area, forming the Keys' surface rock from Biscayne Bay and the upper Florida Keys (including BISC) through the middle Keys (Parker et

al. 1955). The Key Largo Limestone, a fossil coral reef, is correlative with the Miami Limestone oolitic facies forming the lower Florida Keys (Harrison and Coniglio 1985).

Hoffmeister and Multer (1968) reported that the Key Largo Limestone underlies the Miami Limestone of the lower Florida Keys, and also extends to the subsurface of the westernmost Dry Tortugas Keys, where it was encountered 10 m (33 ft) below sea level in a borehole. The Miami Limestone (oolitic facies) apparently does not extend to this location 113 km (70 miles) west of Key West and the Lower Keys.

The Late Pleistocene Key Largo Limestone is a white to light gray, moderately to well indurated (cemented), fossiliferous, coralline limestone composed of coral heads encased in a calcarenite matrix (Hoffmeister and Multer 1968; Stanley 1966) with little to no siliclastic sediment. Fossils present include corals, mollusks and bryozoans. The Key Largo Limestone consists of 30% large corals including *Diploria* sp., *Porites* sp., *Siderastrea* sp., *Montastraea annularis* (an overwhelming preponderance), *Acropora cervicornis*, and little *Acropora palmata* in a calcarenite matrix of skeletal fragments (coral, coralline algae, *Halimeda*, mollusks and foraminifera). Radiometric dating of corals (e.g. *Montastraea annularis*) and mollusks (e.g. *Mercenaria*) from the Key Largo Limestone (Broecker and Thurber 1965; Osmond et al. 1965; Mitterer 1975; Muhs et al. 1992; Fruijtier et al. 2000) has consistently confirmed the age range of the coralline limestone forming the Florida Keys to be within 144,000–120,000 years ago, and the ages of later (offshore, relict) reefs formed near the end of the last interglacial period to 112,000–78,000 years ago (Toscano 1996; Ludwig et al. 1996; Toscano and Lundberg 1998, 1999; Multer et al. 2002).

In 1967, a 31 m (103 ft) deep borehole was drilled to bedrock at 0.6 m (2 ft) above mean sea level in the center of Fort Jefferson on Garden Key (Hoffmeister and Multer 1968; Multer et al. 2002). The upper 9 m (29.5 ft) section of unconsolidated skeletal sand is underlain by coralline limestone (boundstone) to 13.8 m (45.3 ft) below mean sea level, then by a unit of molluscan packstone/wackestone and coralline boundstone to 24 m (79 ft) below mean sea level in the borehole. Multer et al. (2003) provided a corrected chronology and stratigraphy for the core. New high-precision radiometric dates utilizing Uranium-Thorium isotope ratios (based on radioactive decay of ^{234}U to ^{230}Th) indicate that the unconsolidated Holocene sediment section (dated to 9,330 years before present) extends down to 16 m (52 ft) beneath Garden Key. The subaerially-exposed and soilstone-crusted top of the Pleistocene Key Largo Limestone actually occurs at 16 to 17 m (52 to 56 ft) below mean sea level, not at 9 m (29.5 ft) depth as previously interpreted by Hoffmeister and Multer 1968). Paleontological data include the same corals and invertebrate species mentioned above and in the BISC section of this report. An additional date of 107,000 years old is available for the top of the Key Largo Limestone at Dry Tortugas (Mallinson et al. 2003). The BISC section of this report contains detailed information regarding the history of investigation, age, and paleoecological interpretations of the Key Largo Limestone from a regional perspective.

Reef and carbonate sediments (Holocene–Modern)

Holocene reef and carbonate shelf accumulations contain an assemblage of *Acropora cervicornis*, head corals, mollusks and other skeletal material including coralline algal remains in loose shelf sediments that are similar to the assemblages found in the older Key Largo Limestone. Holocene reef and carbonate skeletal sediments accumulated above subaerial exposure surfaces (caliche and soil horizons) of the Key Largo Limestone. These accumulations have been cored and dated from approximately 10,000 years ago to the present (Multer et al. 2002; Mallinson et al. 2003; Shinn et al. 1977). Shinn et al. (1977) cored Southeast Reef, Pulaski Reef, a site off Loggerhead Key and another north of Fort Jefferson (Garden Key) within DRTO. Southeast Reef contains a 13 m (43 ft) accumulation of head corals identical to those forming the modern reefs in the Keys, topped by several meters of carbonate sands to the surface. The absence of *Acropora palmata* and the prevalence of sediment and reef rubble near the surface suggested to Shinn et al. (1977) that these reefs accumulated both biologically (with mostly slow-growing, deeper-water head corals) as well as mechanically (through deposition of sediment and reef debris). This biological and mechanical accumulation of a reef feature differs from the rapid growth of branching corals as per the standard *Acropora palmata* interlocking reef-crest framework model of Holocene reef development.

Park Collections

According to Nancy Russell (EVER Museum Curator, pers. comm., April 2009) there are no specimens catalogued as "paleontology" within DRTO museum collections, although the scope of collections does allow for such items. Cores through some of the largest head corals, obtained during the 1980s, are curated within park collections housed at EVER as part of the South Florida Natural Resource Center (N. Russell, pers. comm., July 2009).

The USGS Center for Coastal and Watershed Studies in St. Petersburg maintains a collection of cores obtained within DRTO in 1998, 2004, and 2008. According to the USGS database (C. Reich, USGS Geologist, pers. comm., August 2009), there are at least 20 cores from Pulaski Shoal, Middle Key, East Key, North Key Harbor, the Tortugas Bank, and various wells near swim beaches and the Fort Jefferson moat. The Pulaski Shoal and Middle Key samples are coral cores from specimens of *Diploria strigosa*, *Siderastrea siderea*, and *Montastraea faveolata* that were obtained within the park. These corals are modern in age, perhaps as old as 300 years. The remaining samples are rotary cores and date back to the late Holocene (perhaps as old as 10,000 years or as young as 3,000). For more information, refer to Multer et al. (2002), Reich et al. (2006, 2009).

Cultural Resource Contexts

Fossis in cultural resource contexts have not yet been identified within DRTO.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division sponsored a GRI scoping session for DRTO on January 23-24, 2005 (Thornberry-Ehrlich 2005). While none of the recommendations in that report specifically address paleontological resources, recreational activities that impact the Pleistocene reef framework were indentified in the report and their management could also impact paleontological resources.
- The geologically young age of much of the coral material within the park encompasses the Pleistocene-Holocene transition, as described in the introduction to this report, this includes material commonly considered fossil as well as more modern material. Regardless, such resources contain important information for continuing research into paleoecological change through time and the development of the modern ecosystem.
- Interpretation and public education could include information that the keys are built upon a fossil framework that contains valuable information for scientific research. A paleontological resource protection message could be included in enforcement of non-destructive diving and fishing practices.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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Data Sets

Dry Tortugas National Park Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Dry Tortugas National Park Museum Collections (housed at EVER)
1980s-present. (core samples, coral samples, associated notes; collection records; maps; etc.). Originated by DRTO staff; status: Active.

U.S. Geological Survey Center for Coastal and Watershed Studies St. Petersburg
1992-present. (sediment and coral cores; associated data, maps, and publications). Originated by USGS staff, contact Chris Reich; status: Active

Everglades National Park

Everglades National Park (EVER) is the largest designated wilderness in the southeast and the only subtropical preserve on the North American continent. The Park was authorized in 1934 and established in 1947, when it was dedicated by President Harry S Truman at Everglades City. Everglades was designated a Biosphere Reserve and World Heritage Site in 1976, a Wetland of International Importance in 1987, and was expanded in 1989 and again in 1991. As described on the park website, Everglades "is almost exclusively a biological park dedicated to the preservation of a complex and precisely ordered living mechanism. It lies at the interface between temperate and sub-tropical America, giving a rich diversity of species, many at the limit of their ranges."

Geologic Background

The Everglades is essentially a river system and figures prominently in the water budget of South Florida. The Everglades can be both a discharge and, sometimes a recharge area to the underlying surficial and Biscayne aquifer systems. The Everglades ecological and hydrological system is not contained by park boundaries but flows from its northern neighbors Big Cypress National Preserve (BICY) and Lake Okeechobee. Along its southern and western shorelines, Everglades contains the largest mangrove ecosystem in the western hemisphere and the nationally significant estuarine complex of Florida Bay. Total land and water area amounts to 1,509,000 acres (610,684 hectares, 2,358 square miles), in Dade, Monroe, and Collier counties. Land elevations are low, ranging from 0 to 2.4 m (8 ft), averaging 1.8 m (6 ft) above mean sea level; there is little topography. Water crosses the park to the sea essentially as a "broad sheet" flowing slowly over, as well as through, the limestone bedrock. There are no geological outcrops in the park, but the underlying geology has been studied to crystalline bedrock through deep drillholes and geophysical methods, and the recent muck deposits have been cored extensively to determine assemblages of benthic organisms, pollen and the vegetation record. The fossiliferous units at EVER include the Miocene Tamiami Formation (see BICY section of this report); the Pleistocene Fort Thompson Formation (subsurface), and the Pleistocene Miami Limestone (including oolitic and bryozoan facies; see BICY section). Several recent paleoenvironmental studies have been undertaken in the late Holocene and modern sediments within the Florida Bay portion of the park (Brewster-Wingard et al. 1998a, 1998b; Ishman et al. 1998), providing listings of micropaleontological resources obtained in these cores.

A Geologic Resources Inventory scoping session, coordinated by the NPS Geologic Resources Division, was held for Everglades in January 2005. The scoping summary was published in February 2005 (Thornberry-Ehrlich 2005). The Florida Geologic Survey (FGS) geologic map displays four separate geologic units (Holocene sediments, Key Largo Limestone, Miami Limestone, Tamiami Formation) inside the boundaries of the park (Scott et al. 2001). The compilation map in Thornberry-Ehrlich (2005) has included 11 additional geologic map units from the surrounding area. Petuch and Roberts (2007) published a general audience book on the geology of the Everglades region.

Sources of Paleontological Resources

While there are no outcrops in the park, the geologic units that underlie EVER are known to preserve fossils. The fossils of EVER present opportunities for education, interpretation, and continued or future scientific research in the park.

Tamiami Formation (Pliocene)

The Tamiami underlies (at or near the surface) most of western EVER in Collier and Monroe counties in particular, but also in Lee County and the western edge of Hendry County (BICY). Members recognized within the Tamiami Formation include: the Buckingham Limestone Member; an unnamed tan clay and sand; an oyster (*Hyotissa*) facies, a sand facies, the Ochopee Limestone Member, the Bonita Springs Marl Member; an unnamed limestone facies; the Golden Gate Reef Member; and the highly fossiliferous

Pinecrest Sand Member, a facies occurring well to the north of the park (Missimer 1992; Allmon 1992; Ketcher 1992; Ketcher and Allmon 1993; Allmon 1993). Numerous fossils occur, particularly in the Pinecrest Sand Member. Fossil molds, casts and original shell material include barnacles, mollusks, corals, echinoids, foraminifers, ostracodes and calcareous nannoplankton. The BICY section of this report contains additional information regarding the Tamiami Formation.

Cypresshead Formation (Pliocene)

According to the Geologic Map of Florida (Scott et al. 2001), this nearshore siliclastic deposit does not crop out in the park or perhaps not in a large enough area to be mapped. It may occur in the shallow subsurface, based on the mention of reworking in the stratigraphic chart. Mollusk molds and casts, burrows and marine trace fossils occur but no original organic fossil material is preserved.

Undifferentiated sediments (Pliocene–Pleistocene)

Undifferentiated Pliocene/Quaternary sediments include the Caloosahatchee Formation (DuBar 1974) with its diagnostic fossils (*Cypraea problematica*, *Strombus leidyi*, *Liochlamys bulbosa*), and the Bermont formation (informal) and Fort Thompson Formation. The Fort Thompson does not crop out in the Everglades. For a description of fossils from the Fort Thompson, see Puri and Vernon (1964), DuBar (1974), and Olsen and Petit (1964). Also mentioned are dunes, shell-bearing sediments, and reworked Cypresshead Formation. Paleontological resources for these undifferentiated units are supposed to include an "incredible fossil array" but the unit is not paleontologically well defined.

Miami Limestone—bryozoan and oolitic facies (Upper Pleistocene)

The Miami Limestone (consisting of bryozoan and oolitic facies), occurs at or near the surface in Dade and Broward counties up to elevations of 7 m (23 ft) above mean sea level (Sanford 1909; Cooke and Mossom 1929; Hoffmeister et al. 1967; DuBar 1974; Halley et al. 1977; Johnson 1992). Underlain by the Fort Thompson Formation, the Miami Limestone consists of an upper oolitic facies, dunes of which form part of the Atlantic Coastal Ridge along the southeastern coast of Florida. This portion grades into correlative units including the Key Largo Limestone to the east and south (see BISC) and the Anastasia Limestone (nearshore coastal marine facies) to the north in Palm Beach County. The Oolitic facies extends westward into EVER, containing scattered small mollusk fossils, some *Halimeda* and bryozoans (Hoffmeister et al. 1967) and has been dated via Uranium-Thorium isotope ratios (based on radioactive decay of ^{234}U to ^{230}Th) to a range of 120,000 ± 1000 years old to 90,000 ± 900 years old (Broecker and Thurber 1965; Osmond et al. 1965). Ooids are distinctive small(1-2 mm [~0.06 in]), spherical, generally concentrically layered carbonate grains likely formed around a nucleus such as a shell fragment or sand grain. They are currently only known from the vicinity of Joulter's Cay in the Bahamas. Their mode of formation has been hypothesized but not observed in the modern marine system of Florida.

The lower bryozoan facies (Hoffmeister et al. 1967) extends westward across EVER, forming the bedrock directly underlying the muck and sediments of the Everglades and Florida Bay. It is the main surficial unit underlying Everglades muck east of the Atlantic Coastal Ridge. The bryozoan facies contains mollusks, bryozoans (80% of which are *Schizoporella floridana*), corals, molds and casts. Index fossils also include the large queen conch *Eustrombus gigas* and the bivalve *Codakia orbicularis* (Petuch and Roberts 2007). Johnson (1992) adds lithologic details and names various fossils within the formation. Puri and Vernon (1964) added several other nearshore mollusks to the limited list of fossils in this formation.

Surficial Deposits (Holocene)

Surficial Holocene deposits consist of thin soil over the Miami Limestone, peat with marl, marl, marl underlain by peat, muck, and carbonate mud forming islands and embankments (see map compilation in Thornberry-Ehrlich 2008). As yet undocumented paleontological resources may include plant matter, pollen, microfossils, and freshwater mollusks. Sediment types include quartz sands, carbonate sands and muds containing freshwater mollusks. Pleistocene and Holocene beach ridge and dune deposits have been noted in floodplains and on terraces and ridges.

Geologic studies of coastal mangrove and vermetid gastropod reef deposits from the Ten Thousand Islands area (northwestern arm of EVER) and nearshore salt marshes in Whitewater Bay (southwestern EVER behind Cape Sable; Scholle 1964a, 1964b) have revealed the Holocene history of sea-level rise and peat deposition on top of the pre-Holocene limestone or siliclastic sedimentary surfaces. In the Ten Thousand Islands area, the transgressive (sea-level rise) sequence overlying the Tamiami Formation consists of a basal unit of freshwater sediment overlain by a transgressive unit of fibrous peat (virtually devoid of shells), then overlain by a quartz-rich sedimentary unit (Scholle 1964a, 1964b). Shier (1969) studied reefs composed of the vermetid gastropod *Vermetus* (*Thylaeodus*) *nigricans* Dall, some of which were up to 3 m (9 ft) thick. Shier (1969) also documented the microfauna (foraminifera) and macrofauna (mollusks) of the sedimentary facies surrounding the reefs and the adjacent paleoenvironments. Parkinson (1989) studied the Ten Thousand Islands region in the vicinity of Everglades City and described the low-relief mangrove-capped oyster bars and vermetid gastropod reefs constructed respectively of *Crassostrea virginica* and *Vermetus nigricans*, as well as four coast-parallel sedimentary zones, in particular the mainland shoreline zone with its fringe of red mangrove (*Rhizophora mangle*) grading landward into EVER freshwater environments. The *R. mangle* peat directly overlies Pleistocene sediments along the mainland shoreline.

In the case of Whitewater Bay in southwest EVER, the Miami Limestone underlies a transgressive sequence of basal freshwater peat with freshwater gastropods (*Helisoma* sp., *Physa* sp., and *Planorbis* sp.) and some marine and brackish water mollusks, overlain by "peaty marine and brackish-water muddy shell debris" (Scholle 1964a, 1964b). In Whitewater Bay, this older peat is in turn overlain by nearshore carbonate sediments (marine and brackish-water mollusks) and landward by the peat of modern mangroves. Scholle (1964a, 1964b), Scholle and Stuiver (1967) and Scholle et al. (1969) constructed a submergence curve from dated material at both locations for the past 4,000 years. Parkinson (1989) utilized the Scholle et al. (1969) curve to interpret a transgressive-regressive (sea-level rise and fall) sequence in the Ten Thousand Islands area where vermetid gastropod reefs became established approximately 3,400 years before present and kept pace with slowing rates of sea-level rise. This, combined with sediment accumulation, caused the reefs to achieve sea level in elevation and become colonized by *R. mangle* and capped by beach deposits, creating a progradational (outward-building) coastal zone.

Benthic Habitat Deposits (Holocene)

Benthic habitats range from marine nearshore seagrass beds, tidal channels and reef/hardbottom communities, to freshwater streams, swamps and dredged/canalized areas (indicated on the compiled map in Thornberry-Ehrlich 2008).

Florida Bay, the southernmost part of EVER, contains a Holocene biogenic marine sedimentary record and is effectively a modern analogue of previous epicontinental sea depositional episodes which built the Florida peninsula (Petuch and Roberts 2007). Modern studies of biogenic carbonate production and their sedimentary records include carbonate production by epibionts on *Thalassia* (Nelsen and Ginsburg 1986), production of lime mud by algae (Stockman et al. 1967), foraminiferal assemblages (Lidz and Rose 1989) and several USGS reports on a variety of biotic assemblages (benthic foraminifera, mollusks, ostracodes, diatoms, pollen, dynocysts) in cores in Florida Bay (Wingard et al. 1995, 2005; Brewster-Wingard et al. 1996, 1997, 1998, 2001; Pyle et al. 1998; Trappe and Brewster-Wingard 2001; Cronin et al. 2001). Many of these records cover historic timeframes and are dated both with radioactive isotopes of lead (^{210}Pb) and carbon (^{14}C) or using known historic pollen horizons or other environmental events which may be correlative with other records in the region.

Park Collections

According to Nancy Russell (EVER Museum Curator, pers. comm., April 2009) there are no specimens catalogued as "paleontology" within EVER museum collections, although the scope of collections does allow for such items.

The USGS Center for Coastal and Watershed Studies in St. Petersburg maintains a collection of cores obtained within EVER from 1978 through 1998; most were collected in the mid 1990s. According to the USGS database (C. Reich, USGS Geologist, pers. comm., August 2009), there are at least 33 cores from 23 locations in Florida Bay. An additional 13 cores were obtained from Cane Patch, Rookery Branch, Shark River-Harney River, Grossman's Hammock, Rock Reef Pass, and Taylor Slough. These samples are rotary cores and date back to the Pleistocene (perhaps as old as 120,000 years). For more information, refer to Multer et al. (2002), Reich et al. (2006, 2009).

Cultural Resource Contexts

Thornberry-Ehrlich (2008) suggests that the paleontological resources of the Tamiami Formation may have historically provided trade items for American Indians in the area. Such occurrences have not yet been documented, but present an opportunity for future research. Fossils occur in a number of cultural contexts throughout that National Park Service, Kenworthy and Santucci (2006) present an overview and cite selected examples. Melissa Memory (EVER Chief of Cultural Resources, pers. comm., September 2009) indicated that the Ten Thousand Island area of the park contains numerous mounds, plazas, water courts, and other structures constructed of shell material. In addition whelk shells (likely modern) formed a significant part of the economy for Mississippian cultures (approximately 800 to 1500 C.E. [common era]).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for Everglades National Park in January 2005 and developed a series of recommendations for future work. Although fossils were noted in the scoping summary (Thornberry-Ehrlich 2005), no specific paleontological resource recommendations were made although the importance of continued coring operations for understanding paleoclimates was noted. A geologic resources inventory report (Thornberry-Ehrlich 2008) was recently completed.
- The geologically young age of much of the surficial material within the park encompasses the Pleistocene-Holocene transition, as described in the introduction to this report. This includes material commonly considered fossil as well as more modern material. Regardless, such resources contain important information for continuing research into paleoecological change through time and the development of the modern ecosystem. The pollen and core record (see data sets) of the Everglades are particularly important for this research.
- Interpretation and public education could include information that south Florida is built upon a fossil framework, that contains valuable information for scientific research and provides clues to understand the effects of sea-level changes.
- The low relief and pervasive muck and marl within the park limit exposures of subsurface units and associated paleontological resources.
- Further investigation may reveal a connection between American Indians and fossil material in the area, which may have provided trade items.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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Data Sets

Everglades National Park Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Everglades National Park Museum Collections
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Everglades National Park Pollen Atlas(U.S. Geological Survey)
unknown-present. (electronic data, summary information, reports, publications). Compiled by USGS staff; status: Active. Online. http://sofia.usgs.gov/publications/papers/pollen_atlas/intro.html

U.S. Geological Survey Center for Coastal and Watershed Studies St. Petersburg
1978-present. (sediment and coral cores; associated data, maps, and publications). Originated by USGS staff, contact Chris Reich; status: Active

Everglades National Park Digital Geologic Map
2008-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
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Salt River Bay National Historical Park and Ecological Preserve

Salt River Bay National Historical Park and Ecological Preserve (SARI) was created in 1992 as part of the National Park System and managed jointly by the National Park Service and the Government of the United States Virgin Islands. The park consists of 411 ha (1,015 acres) representing an interconnected ecosystem of mangroves, estuary, coral reefs, and submarine canyon. The park was established "to protect and preserve an astounding array of natural and cultural resources. The park includes fragile coral reefs, a submarine canyon, and the largest remaining mangrove forest found in the Virgin Islands."

Geologic Background

The island of St. Croix, south of the Greater Antillean island arc, is predominantly composed of weakly metamorphosed sedimentary and volcaniclastic rocks. These rocks originated from sedimentary facies believed to have formed in a late Cretaceous sedimentary basin (Nagle and Hubbard 1989; Gill et al. 1998, 1999), and later by tuffaceous deposition. Salt River Bay is located on the north coast of St. Croix, within the central graben or Kingshill Basin which contains the Neogene (Miocene–Pliocene; see the appendix for a geologic time scale) geologic section, in particular the Miocene Kingshill Limestone. A conglomerate of the Kingshill Limestone outcrops in the Salt River Bay area and is described below. Refer to the introduction of this report for a summary of the geologic history of the Virgin Islands.

During the Cretaceous, the basin sediments making up the island may have been deposited below the carbonate compensation depth (CCD) (D. Hubbard, pers. comm., February 2010). Carbonate shells dissolve below this depth and would make fossil preservation unlikely. Any fossils that may have been preserved above the CCD might have subsequently been destroyed by metamorphism. Much of the Paleogene and Neogene ("Tertiary") section in the central Kingshill Basin is of deeper marine origin, dated through foraminiferal and ostracode biostratigraphic interpretations and zonations. Some of these Cretaceous rocks (the Judith Fancy Formation) are exposed immediately east of the park. Numerous seafloor and subsurface investigations document Quaternary sedimentary deposits consisting of reef and nearshore shallow-water carbonate environments. Living, subfossil, Holocene and Late Pleistocene invertebrate faunal and floral assemblages have been described from sediments and cores. Aside from scleractinian corals and a variety of mollusks, the preservation potential of many components is limited, and time averaging in unconsolidated sediments may represent thousands of years. Yet these are the primary paleontological resources along the northeastern coast of St. Croix.

Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, have not yet been held for Salt River Bay. Paleontological scoping sessions have likewise not been held for the park and there have been no formal paleontological resource surveys or inventories. Nevertheless, paleontological resources are known from SARI and there is good potential for continued discovery.

Sources of Paleontological Resources

The Miocene Kingshill Limestone and much younger Holocene deposits within the park preserve paleontological resources. Many are microfossils such as foraminifera. Holocene and more recent material provide information regarding fossil preservation potential and interpreting the fossil record. The fossils of SARI present opportunities for education, interpretation, and continued or future scientific research in the park.

Kingshill Limestone (Lower Miocene)

The Lower Miocene Kingshill Limestone outcropping near the mouth of the Salt River Bay contains benthic foraminifera indicative of deposition in upper bathyal depths of 600–800 m (2,000–2,600 ft) within the former Kingshill basin. Foraminifera are described by Gill (1989) and Gill et al. (1998, 1999). Other shallow water fauna and lagoonal sediments described by Lidz (1982, 1984) and Gerhard et al. (1978) may have been transported into these pelagic (open ocean) carbonates (Gill et al. 1989). McLaughlin et al.

(1995) described foraminifera and ostracode faunas from cores and outcrops of Miocene rocks near the park in St. Croix, in particular the lowest exposed strata of the La Reine Member of the Kingshill Limestone outcropping in the Salt River Valley. A conglomerate bed representing shelf-derived debris flow deposits within the middle bathyal environments of the La Reine Member contains a nearshore (probably reefal) ostracode fauna in clay clasts. These gravity-flow deposits outcrop specifically in the Salt River Valley. Ostracodes and foraminifera (*Archaias* sp., *Amphistegina* sp., milliolids) in these samples are much like those in modern shallow water carbonate/reef environments. Faunal assemblages restrict the age range of the conglomerate to around the lower Miocene-middle Miocene boundary, or between the *Globigerinatella insueta* and *Globorotalia fohsi peripheroronda* zones (McLaughlin et al.1995 referencing van den Bold 1970).

Salt River Bay, Sugar Bay, and peat deposits (Holocene)

Along the undeveloped portions of the wetland margins of Sugar and Triton embayments, Hubbard (1989) reported healthy stands of red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia nitida*), white mangrove (*Laguncularia racemosa*) and buttonwood (*Conocarpus erecta*). Mangrove peat deposits can become meters (yards) thick and migrate landward with sea-level rise; however, the stratigraphy of these mangroves, if studied, has not been published and their record has not been radiocarbon dated as far as is known from the literature.

Gerhard and Petta (1974) studied sedimentary environments of Sugar Bay, the head of the Salt River estuary, where clastic sedimentation via the ephemeral Salt River transitions into autochthonous restricted marine carbonate sedimentation in Salt River Bay itself. Carbonate sediments in Sugar Bay are produced in situ by unspecified mollusks (both bivalve and gastropod), foraminifera, echinoids, calcareous green algae (*Halimeda* sp. and *Penecillus* sp.) and calcareous rhodophytes. Hubbard (1989) reported that seagrasses (*Thalassia*, *Syringodium*), macroalgae (dense stands of *Halimeda* sp; *Penecillus* sp.) and "various" infauna (unspecified mollusks and crustaceans) dominate the bay floor. Gerhard and Petta (1974) mention numerous burrows and living infauna (unspecified), suggestive of trace fossils of the same origin in older, deeper sediments in Salt River Bay. Miller et al. (1992) compared pre- and post-hurricane molluscan skeletal (death) assemblages composed of 17 species collected along the central axis of Salt River Bay before and after Hurricane Hugo in 1989. While death assemblages generally reflect the composition of the local life assemblage, there is inherent time-averaging of non-contemporaneous death assemblages spanning up to several thousand years (Ferguson and Miller 2007) and a range of possible environmental conditions.

Salt River Barrier Reef (Holocene)

A barrier reef separates Salt River Bay from Salt River Submarine Canyon. The *Acropora palmata* reef started to develop approximately 4,000 years ago according to Hubbard (1989) and gradually shifted to the sediment-tolerant head corals (*Montastraea*, *Siderastrea*), and *Agaricia* sp. common today.

Salt River Submarine Canyon (Holocene)

Adey et al.'s (1977) field trip guidebook describes the Salt River Submarine Canyon walls and fauna as primarily of coral reef origin and lists a variety of corals and invertebrates. The west wall hosts a diversity of corals, gorgonians and sponges. The east wall held more sponges than the west. Hubbard et al. (1986) studied differential patterns of reef accretion along the sides of the Salt River submarine canyon, which starts at a depth of 5m (16 ft) offshore of the Holocene barrier reef fronting Salt River Bay and ends at 100 m (330 ft) depths offshore. Surficial corals include *Montastraea annularis*, *Agaricia* and *Siderastrea*, as well as sponges, gorgonians and algae. Seven horizontal cores (dated from approximately 10,000 to 800 years before present), recording 24 m (79 ft) of lateral Holocene accretion of the canyon walls, indicate that more recently the major framework corals were similar to modern assemblages and include *M. annularis* (64%), and *Siderastrea* sp (18%), encrusting and boring sponges (*Cliona* sp.), mollusks (*Lithophaga* sp.), polychaete and serpulid worms and coralline algae. *Acropora palmata* occurred in the lower portions of one vertical core, indicating that it was the initial primary reef builder until at least 6,000 years before present.

Hubbard (1989) further specifies the fauna on the shelf and along the walls of the canyon. Shelf fauna include widely scattered *Acropora palmata* and *A. cervicornis* colonies and the encrusting form of the hydrozoan *Millepora* sp. as well as head corals and gorgonians. The steep west wall is inhabited by anthozoans, antipatharians, scleractinian corals (most abundantly *M. annularis*, *Siderastrea* sp. and *Agaricia* sp.), gorgoniids and plexaurids. The eastern wall is cobble-covered and contains sponges, gorgonians, plexaurids and colonies of sediment-tolerant corals. Coral and rock cobbles (rhodoliths) are covered with *Porolithon* sp. (calcareous algae), *Gypsina* and *Homotrema* (encrusting foraminifers), and other red algae that are not preserved due to herbivory. *Callianassa* sp. (burrowing shrimp) inhabits the canyon floor and may leave trace fossils. *Acropora palmata* was initially the main reef framework builder from approximately 10,000 to 6,000 years before present along the west wall.

Suchanek (1989) specifically mentions the occurrence of *Mycetophyllia lamarckiana* (fungus coral) as uncommon on St. Croix but found in the canyon. Fifty-six distinct cryptic taxa (largely soft bodied invertebrates that live under corals, shells, sponges, and rocks) were observed by Rasmussen and Brett (1985) on caves ceilings and under ledges at various depths in Salt River Submarine Canyon. These included unspecified green and coralline algae, foraminifera, demosponges, sclerosponges, corals, hydrocorals, bryozoans, brachiopods, ascidians, serpulid and sabellid worms and bivalves. At least 62% of these cryptic organisms would not be preserved in the geologic record; these were primarily green algae, demosponges, sabellid worms and ascidians (tunicates). Aronson et al. (1993) assessed the impact of Hurricane Hugo (September 1989) on biota of Salt River submarine canyon and found a 90% decline in echinoderm abundance (mostly ophiuroids/brittle stars) as well as significant declines in hard coral cover.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic unit within SARI. However, future field investigations within the park may yield fossils from the Judith Fancy Formation. Fossils are documented from the Judith Fancy Formation outside of the park.

Judith Fancy Formation (Upper Cretaceous)

The Upper Cretaceous Judith Fancy Formation is named for exposures at Estate Judith Fancy immediately east of SARI boundaries. Additional outcrops are not common on the island but can be found in stream valleys, roadcuts, and along the coast (Whetten 1966). As described by Whetten (1966), the formation includes three members: the Clairmont member (limestone and volcanic pebble conglomerate), Recovery Hill Member (mudstone and volcanic ash-rich sandstone) and the Blue Mountain Member (hard sandstone with interbeds of ash-rich sedimentary rocks).

Fragmental fossils are found in some of the limestone layers and include foraminifera and rudist corals (Whetten 1966, 1974; Lidz 1988). These fossils suggest a Late Cretaceous (Campanian) age, approximately 83.5 to 70.6 million years old. It is unclear if fossil material outcrops within the boundaries of SARI, although future field research may indicate their presence within the park.

Park Collections

Meredith Hardy (SEAC, pers. comm., April 2009) noted that fossils are present in collections at the NPS headquarters facility at Christiansted National Historic Site on St. Croix. However, the details of the fossil material and its provenance is unknown. Some were likely associated with cultural resource contexts, as described below.

Cultural Resource Contexts

Like the other Virgin Islands NPS units, SARI interprets a rich cultural history associated with indigenous people. Meredith Hardy (SEAC archeologist, pers. comm., April 2009) also suggested that many of the ancient societies that lived on the islands collected various natural history items of interest. Some were fashioned into various tools, ornaments, beads, or religious items. The Andersen collection (made by an

amateur archeologist) contains a number of these items from the Virgin Islands (M. Hardy, pers. comm., April 2009). Further investigation may yield additional information regarding the provenance and context of these items as well as their relationship to NPS areas in the Virgin Islands. Fossils occur in a number of cultural contexts throughout that National Park Service, Kenworthy and Santucci (2006) present an overview and cite selected examples.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division sponsored a GRI scoping session for SARI on April 6, 2004. Participants developed a series of recommendations for future work (Hall 2005). However, none of the recommendations in that report specifically address paleontological resources.
- The geologically young age of much of the coral material within the park encompasses the Pleistocene-Holocene transition, as described in the introduction this includes material commonly considered fossil as well as more modern material. Regardless, such resources contain important information for continuing research into paleoecological change through time and the development of the modern ecosystem.
- The park may want to consider future field investigations and paleontological resource monitoring of the Kingshill Limestone and Judith Fancy Formation if exposed within the park. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring (Santucci et al. 2009).
- Further research into trade items and other cultural resources of the Taino Indians may reveal paleontological resources, although none are currently known.
- Because cores and other materials used to describe the paleoecology of the park are located in repositories outside of the park (e.g. Smithsonian Institution and Oberlin College), one potential project would be to submit funding requests for assistance in the development of a guide (perhaps online) to these materials. The guide could include logs, photographs, and other matierals (D. Hubbard, Oberlin College, pers. comm., February 2010).
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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Data Sets

Salt River Bay National Historical Park and Ecological Preserve Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Salt River Bay National Historical Park and Ecological Preserve Museum Collections
1992-present. (museum specimen; associated specimen notes; collection records; maps; etc.). Originated by SARI staff; status: Active.

Smithsonian Institution National Museum of Natural History Sedimentology Lab
1990s-present. (core samples, publications, hard copy, and electronic data). Originated by NMNH staff and Macintyre, Adey, and Toscano. Status: Active.

Oberlin College
1998-present. (core and/or sediment samples, publications, hard copy and electronic data). Originated by Hubbard, Dennis K. Status: Active.

Virgin Islands National Park

Virgin Islands National Park (VIIS) was authorized on August 2, 1956. Spanning more than 2,800 ha (approximately 7,500 acres; more than half of the island) of St. John Island, the park preserves the dramatic forested hills, white sandy beaches, and extraordinary coral reefs and seascapes of the island and surrounding waters. The park also interprets three thousand years of cultural resources ranging from an 800 BCE archeological site, to petroglyphs that may be from the Taino people and the ruins of European sugar plantations. In 1962, the park was expanded to include 2,290 ha (5,650 acres) of waters around St. John. In 1976, the park was declared a United Nations Biosphere Reserve. After an expansion in 1978, the park also encompasses nearly all of Hassel Island and includes the Wintberg Estate on St. Thomas Island as well as some land in Red Hook, also on St. Thomas Island. Virgin Islands Coral Reef National Monument, established in January 2001, is administered by VIIS and preserves approximately 5,140 ha (12,710 acres) federally owned submerged lands (including Hurricane Hole) within the 5 km (3 mile) belt surrounding St. John Island. The park currently encompasses at total of nearly 5,900 ha (14,700 acres), some 2,290 ha (5,650 acres) of which is water. Research within, and conducted by, the park aims to develop policies and practices to protect the fragile coral reef ecosystems.

Geologic Background

The geology of St. John Island was described and mapped by Donnelly (1966) with revised and updated mapping and geologic history by Rankin (2002). The National Park Service Geologic Resources Division conducted a Geologic Resources Inventory Scoping Meeting on April 7-9, 2004. Hall (2005) presents a summary of this meeting and geologic resources identified within the park. Refer to the introduction of this report and Hall (2005) for a summary of the geologic history of the Virgin Islands.

The Cretaceous-aged (see the appendix for a geologic time scale) igneous, metamorphosed and deformed core of the island of St. John does not offer abundant fossil resources (Donnelly 1966; Rankin 2002). However, rare fossils are documented from the park in the Water Island and Louisehoj formations as described below.

While Cretaceous-aged paleontological resources may be rare within the park, modern fossil-forming ecosystems in the park include nearshore marine mangrove areas, shallow seagrass beds and coral reefs. The NPS has been monitoring coral reef sites annually at VIIS since 1988 (e.g. Rogers 1990, 1998; Rogers et al. 1991). The SFCN now monitors 100 transects at five coral monitoring sites in and around VIIS (Mennebeck Reef, Haulover Reef, Newfound Reef, Tektite Reef, and Yawzi Reef). These shallow tropical marine environments have been forming since the Holocene transgression flooded the nearshore shelf, creating depositional environments for coral, mollusks, echinoderms and other invertebrates, and calcareous algae, which contribute to the recent fossil-forming assemblage of the area. Modern degradation of this resource that has taken thousands of years to form is a concern of resource managers. Coral reef cover has been declining throughout the Caribbean over the past 30 to 40 years. Gardner et al. (2003) estimate a 6 to 10 percent decline in coral cover for the Virgin Islands as a whole. In 2005-2006 the Virgin Islands lost at least an additional 50% of live coral cover due to a severe bleaching event followed by a significant increase in coral disease (Miller et al. 2009). The Elkhorn coral *Acropora palmata*, a once-common primary reef builder throughout the Caribbean, has severely declined throughout the region and around St. John as a result of two decades of storm and disease damage (Devine et al. 2003).

Brooks et al. (2007) established the Holocene sedimentary sequence in Coral Bay, St. John, from vibracores, sedimentary petrology and radiometric dating. A blue-green clay facies representing the basal pre-transgression surface of soils and "weathering residua" (indicative of subaerial exposure) with some marine material, is overlain by an organic-mud marginal marine facies containing roots, burrows and fibrous organic material likely remaining from an intertidal mangrove environment. A radiocarbon calendar age of 5,040 calendar years before present at 6 m (20 ft) below mean sea level is consistent with the Caribbean sea level model of Toscano and Macintyre (2003), indicating this was a transgressive (rising

sea level) deposit of the mid-Holocene. This initial transgressive facies is in turn overlain by a muddy, shelly, sand/gravel facies with more than 80% carbonate. The facies is composed of biogenic components (echinoderm test fragments, benthic foram tests, molluscan debris, *Halimeda* flakes, etc.) typical of a naturally-evolving shallow tropical carbonate marine environment. Terrestrial material is rarely present. The top facies in contrast is dominated by terrigenous sediment, increasing toward the surface. Lead isotope dating indicates the rapid deposition of this uppermost facies, within the last 50 years. This "impacted marine" facies can be correlated to the increase in sediment runoff from anthropogenic activities including land clearing, construction and the creation and maintenance of unpaved roads along the high-relief mainland (Hubbard 1987; Nemeth and Nowlis 2001; MacDonald et al. 1997, 2001; Ramos-Scharron and MacDonald 2005,2007).

Sources of Paleontological Resources

Fossils are known from the Cretaceous rocks of the island as well as the Holocene coral reefs and sedimentary deposits of the park. The fossils of VIIS present opportunities for education, interpretation, and continued or future scientific research in the park.

Water Island Formation (Lower Cretaceous)

The oldest rocks on the island are from the Lower Cretaceous Water Island Formation. As revised by Rankin (2002), the Water Island Formation no longer includes intrusive igneous rocks as in Donnelly (1966). The formation is primarily composed of an extrusive volcanic rock called keratophyre and weathered, eroded, and transported fragments of the keratophyre. Basaltic lava and breccia is also present as is a very minor chert component. The Water Island Formation is mapped by Rankin (2002) throughout the central and eastern portion of St. John. Fossils are not known from the volcanic rocks of the Water Island Formation, but the chert is known to preserve radiolarians (microfossils useful for age-dating and correlation).

Radiolarian chert is found in small areas near Kiddel Point (within the park) and Contant Point (outside the park, north shore of Great Cruz Bay). Rankin (2002) reported particularly well preserved radiolarians from the Kiddel Point locality, where the unit is exposed along Saltpond Bay. Because they are microfossils, however, they are not visible in hand sample. Rankin discovered the radiolarians during subsequent investigation of thin sections taken of the rocks. Rankin (2002) does not offer further identifications. Rankin (2002) also reports a rudist or solitary coral fossil in the limestone matrix of basalt breccias of the Water Island Formation on the west side of Contant Point.

Louisenhoj Formation (Cretaceous)

The Upper Cretaceous Louisenhoj Formation is characterized by well cemented volcanic conglomerate, breccias, volcanic wacke, shale, chert, andesite, basalt, tuff, and "rare" limestone (Rankin 2002). Rankin maps the formation over much of the northern and western portion of St. John and considers its age to be Cretaceous (Albian-Santonian; approximately 112–83.5 million years old). As with the older Water Island Formation, the volcanic clasts are not fossiliferous. However, rare limestone clasts locally preserve fossils.

Limestone clasts of the Louisenhoj Formation observed on Rata and Ramgoat cays (within the park) are known to be fossiliferous (Rankin 2002). Rankin made a collection of these clasts, and noted that some of the fossils may be identifiable, but does not offer further identifications. Fossils in the clasts are also preserved as "fossil hash" layers, made up of broken fossil fragments.

Coral Reefs and Sedimentary Deposits (Holocene)

Fossil mollusks, foraminifera, coralline/calcareous algae, echinoderms and other invertebrate remains, coral debris and plant matter are likely to be found within the nearshore lagoons and marginal marine mangrove areas of the island, the coral reefs and the sedimentary sequence documented by Brooks et al. (2007). Named species may be found in marine monitoring studies and publications such as those by Rogers (1990,1998), Rogers et al. (1991), Devine et al. (2003), Hubbard (1987) and Nemeth and Nowlis (2001).

Potential Sources of Paleontological Resources

Fossils have not been documented in VIIS from the following geologic unit. However, future field investigations within the park may yield fossils from the Outer Brass Limestone, as microfossils are documented from the unit outside of the park.

Outer Brass Limestone (Upper Cretaceous)

The Outer Brass Limestone is characterized by thin bedded and metamorphosed blue-gray calcite marble and a conglomerate in a carbonate matrix. Abundant fossils would not be expected in a metamorphosed unit such as the Outer Brass Limestone. Indeed, Rankin (2002) does not mention any from St. John. However, Rankin mentions that planktonic Foraminifera (microfossils) have been observed in the thin sections of the Outer Brass Limestone on the island of St. Thomas.

Park Collections

The Virgin Islands National Park Collections Management Plan recorded 73 classified catalogue cards pertaining to geology specimens collected by Dr. Thomas Donnelly. The report also mentions a "small series of hand specimens of rocks" which had not been catalogued but had labels for future identification.

The Collections Management Report (under Scope of Collections) suggests that the "geology" collection should consist of one expertly identified hand specimen of each of the rock formations (and soil types) occurring on the island (St. John), rock and fossil specimens from submerged formations in the park, one expertly identified specimen of each mineral found in the park, and thin sections from the aforementioned rocks and specimens. While specimens specifically meant to show "the actions of geologic forces at work in the island" are suitable for the collection, they "should not be duplicated". The report does not list the geologic samples.

Douglas Rankin's (USGS emeritus scientist) thin sections illustrating radiolarians from the chert of the Water Island Formation as well as the fossiliferous limestone clasts collected from the Louisenhoj Formation are currently in Rankin's working collections at the U.S. Geological Survey in Reston, Virginia (D. Rankin, USGS Emeritus, pers. comm., January 2010).

Cultural Resource Contexts

Like the other Virgin Islands NPS units, VIIS interprets a rich cultural history associated with indigenous people. Meredith Hardy (SEAC archeologist, pers. comm., April 2009) also suggested that many of the ancient societies that lived on the islands collected various natural history items of interest. Some were fashioned into various tools, ornaments, beads, or religious items. The Andersen collection (made by an amateur archeologist) contains a number of these items from the Virgin Islands (M. Hardy, pers. comm., April 2009). Marble trading beads associated with the Taino culture are known from VIIS (e.g. Hall 2005). The source of this marble is unclear. The marble beads do not contain fossil material, however, trade items are known to contain fossil resources in a number of National Park Service units (see Kenworthy and Santucci 2006 for a summary and selected examples). Further investigation may yield additional information regarding the provenance and context of these items as well as their relationship to NPS areas in the Virgin Islands.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division sponsored a Geologic Resources Inventory (GRI) scoping session for VIIS on April 7-9, 2004. Participants developed a series of recommendations for future work (Hall 2005). However, none of the recommendations in that report specifically address paleontological resources.

- The geologically young age of much of the coral material within the park encompasses the Pleistocene-Holocene transition, as described in the introduction to this report, this includes material commonly considered fossil as well as more modern material. Regardless, such resources contain important information for continuing research into paleoecological change through time and the development of the modern ecosystem.
- The park may want to consider future field investigations and paleontological resource monitoring of the limestone clasts on Rata and Ramgoat Cays. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring (Santucci et al. 2009).
- Further research into trade items and other cultural resources of the Taino Indians may reveal paleontological resources, although none are currently known.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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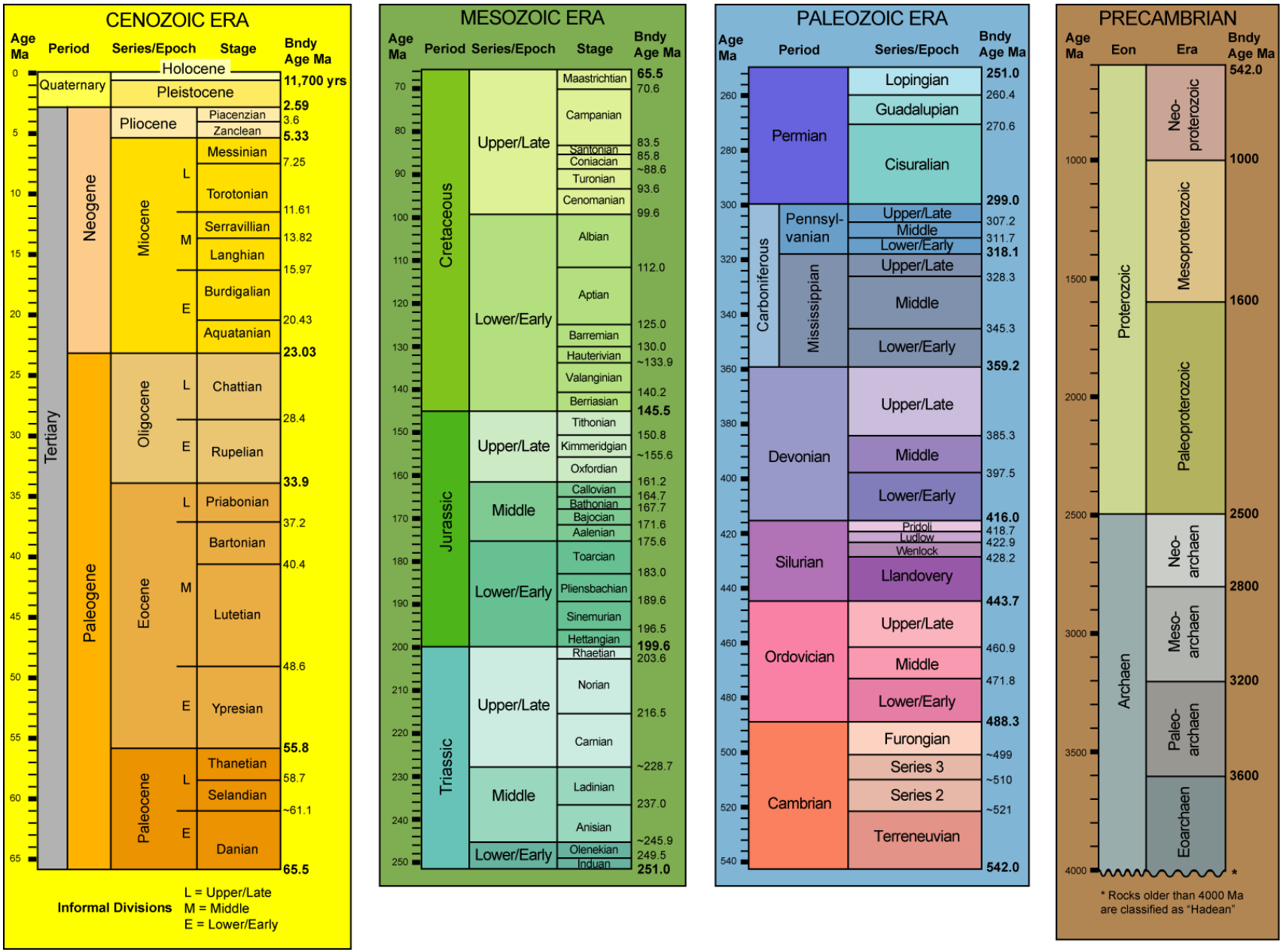
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Data Sets

Virgin Islands National Park Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Virgin Islands National Park Museum Collections
1956-present. (museum specimen; associated specimen notes; collection records; maps; etc.). Originated by VIIS staff; status: Active.



Appendix: Geologic Time Scale. *Ma = Millions of years old. Bndy Age = Boundary Age*. Colors are standard USGS colors for geologic maps. Modified from 2009 Geological Society of America Timescale (www.geosociety.org/science/timescale/timescl.pdf). Dates and additional information from 2004 International Commission on Stratigraphy (www.stratigraphy.org/gssp.htm) and USGS Fact Sheet 2007-3015 (http://pubs.usgs.gov/fs/2007/3015/).

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 910/102458, May 2010

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